Lab Manual

BUILDING AND CONSTRUCTION MATERIALS

Testing and Quality Control

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PREFACE

Introduction

Materials play an important role in the construction all types of structures. Right selection of quality materials adds to the economy and service life of a structure. The design of structures is usually based on the presumption that each of the materials to be used in construction of a typical structure has certain characteristics; this presumption makes it mandatory to verify that the materials used in construction have the assumed characteristics. This can only be ensured by regular testing of materials according to certain National and International standard procedures which will provide a clear picture of material characteristics.

The past practice of exercising quality control only during construction is irrelevant in modern quality control concept; quality control is exercised at all the three stages of construction activity, i.e., at preconstruction stage specifying and controlling the quality of materials, during the construction phase and acceptance quality checks after completion of each stage of construction, which is termed as "stage passing".

As in the manual, references has been made to numerous codes and specifications which are frequently amended and updated, users should use the latest edition of the referenced specifications/code. Moreover, the codes are the source of more complete and error-free information. Readers are cautioned to exercise independent professional judgment while using the information set forth in this manual; it is not aimed to render engineering or other consultancy services.

It is earnestly hoped that the manual will also provide enough guidance to the concrete/material testing/construction materials/building material laboratories to provide testing services to builders and the construction industry. It will prove to be a helpful guide to the field engineers for day-to-day reference and the contractors engaged in construction work.

Salient Features of the Book

- Tests relevant to various construction activity described in a systematic and logical style, enabling readers to first get acquainted with the basics of the material and then move on to the test procedures
- Test procedures to be followed for conducting various tests, along with the equipment required for each test are in accordance with the National and International Standards
- List of relevant National Standards (IS codes) and references given at the end of each section
- Pedagogical features include
  98 Experiments
  973 Viva-voce questions
  155 Figures
  225 Tables

Book Organisation

The manual covers the curriculum requirements of civil engineering and architecture students at both degree and diploma level programs of most of the institutions, and is intended to develop in the reader the ability to conduct material test systematically. The test procedures have been divided into 16 sections, namely concept of quality control, cement, building limes, aggregates, water, conventional fresh concrete, self-compacting concrete, hardened concrete, non-destructive tests, concrete mix design, pavement aggregates, bitumen, bricks, steel and investigative tests.

The test procedures to be followed for conducting various tests, along with the equipment required for each test are in accordance with the methods given in the relevant National and International Standards. The objective and scope of the test with its significance has also been given for each test. List of relevant National

Standards (IS codes) and references are given at the end of each section, and a set of searching questions based on the test procedure are given at the end of each test.

The test procedures relevant to three stages of construction activity are described in a systematic and logical style that will enable the readers to first get acquainted with the basics of the material before moving on to the test procedures. The manual also provides detailed information on current thinking on the subject matter in the discussion part of the procedure.

Besides presenting adequate relevant information, the manual has been made users friendly by including a large number of coloured images (photographs) of equipment in each section to enhance comprehension.

Acknowledgements

We are indebted to numerous sources for the information presented in the manual some of them are listed in the references at the end of each section. Dr Gambhir is grateful to the Bureau of Indian Standards for their published material to which references are made at numerous places in the manual.

We wish to acknowledge the contributions made by many individuals and organizations that provided valuable assistance in bringing out the manual. It gives us immense pleasure in acknowledging the assistance rendered by Dr Puneet Gambhir, Er Mohit Gambhir and Er Atul Jamwal CE MBA. The task could be completed because of their wholehearted inputs. We would also like to express our deepest gratitude to Mrs Saroj Gambhir, wife of Dr Gambhir for her personal sacrifices, unwavering cooperation and encouragement in bringing out this text.

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M L Gambhir
Neha Jamwal

Feedback

The manual of this nature cannot remain static; it has to be dynamic with continuous upgradation of technology; in process, the users play very important role in pointing out the deficiencies. Feedback/suggestions will greatly help in improving and making the manual more useful in future reprints and editions.

The publisher regrets to inform the sad and untimely demise of Dr M.L. Gambhir on 4th January 2013. This work is dedicated to the untiring spirit of an academician par excellence who always dreamt of a seamless dissemination of knowledge and strove incessantly towards the same.

Publisher's Note

We look forward to receiving valuable views, comments and suggestions for improvements from teachers and students, all of which can be sent to *tmh.civilfeedback@gmail.com***,** mentioning the title and author's name on the subject line.

Piracy related issues can also be reported.

CONCEPT OF QUALITY CONTROL

Chapter 1

This section describes the concept of quality control as applicable to construction materials. The understanding of these principals is crucial for ensuring quality structures that are safe, durable and economical.

1.1 CONCEPT OF QUALITY CONTROL

The quality of a product is determined by its users and not by the society or any organisation. It is not same as 'expensive' or 'high quality'. Low priced products can be considered as having high quality if the product or services meet or exceed users' expectations which are generally based on performance characteristics, economics and aesthetics of the product.

Thus, quality is user's perception; whereas, quality assurance (QA) is the process of verifying or determining whether products or services meet or exceed users' expectations. This process-driven approach consists of systematic monitoring, testing and evaluation of the various aspects of a product, service or facility to maximise the probability that minimum standards of quality, i.e., high level of acceptance of the product is being attained by the production process. It includes two basic principles namely, 'Fit for purpose', the product should be suitable for the intended purpose; and 'Right first time', mistakes should be eliminated. In addition, QA considers design, regulation of the quality of raw materials, development, production and services related to production and monitoring or inspection processes.

The quality of products is dependent upon that of the participating constituents, some of which are sustainable and effectively controlled while others are not. The quality assurance consists of four steps; **(i) Planning** which consists of establishing objectives and processes required to deliver the desired results; **(ii) Design,** i.e., the implementation the developed process; **(iii) Checking** which includes monitoring and evaluation of the implemented process by testing the results against the predetermined objectives and **(iv) Action,** i.e., to take actions necessary for improvement if the results require changes. These four quality assurance steps are commonly abbreviated as PDCA.

PDCA is an effective tool for monitoring quality assurance as it analyses existing conditions and methods used to provide products to clients. The goal is to ensure that excellence is inherent in every component of the process. This aspect of QA requires formulation of specification defining the quality requirements. If the specification does not reflect the true quality requirements, the product's quality cannot be guaranteed. For instance, the parameters for concrete should cover not only the materials and structure but also the environmental, safety, reliability and maintainability or serviceability requirements.

1.2 QUALITY CONTROL THROUGH TESTING

The testing is a process of determining certain facts or qualities of a material. Each material that is to be used in construction must have certain given qualities in order to play its part in the structure. Laboratory and field

tests have been devised to determine these qualities in a comparatively short interval of time. When the test results lie within a certain range, the engineer is confident that in most of the cases the material behaviour will be satisfactory. The results of the tests vary with the method of doing the tests. In order to prevent such deviation, specifications have been prepared by National Standards for testing the materials. A number of tests on construction materials have been devised to acquaint the reader with some of the factors affecting performance, to furnish data that can be used as the basis for making calculations and preparing curves that are more commonly used in construction works and to give the reader some idea how the *quality control* can be achieved.

The quality control generally has two purposes. One to ensure that the workmanship does not fall below certain specified standard and the other is to limit the overall variation in quality of material. Specifications generally stipulate a limit to the minimum performance characteristics of material, but no upper limit of performance is specified. In the best interest of economy, however, it is preferred to keep the greatest values down to as low as possible provided the lowest performance parameter under consideration still complies with requirements of the specifications. In certain materials, typically concrete, the variations in concrete quality are due to a large number of factors. Proper control of concrete quality can only be done by organising an adequate system of testing and inspection.

In this manual, testing procedures for construction materials like concrete, structural steel, bitumen, etc., are given in details. However, the statistical concepts dealing with the variation in quality are explained in terms of concrete performance as concrete is the most important construction material which is manufactured at the site and is likely to have variability of strength from batch to batch and also within the batch due to large numbers of factors contributing to variation in strength as discussed in Section 1.3.

1.3 QUALITY OF CONCRETE

The above-mentioned variations are inevitable during production to varying degrees. For example, the cements from different batches or sources may exhibit different strengths. The grading and shape of aggregates even from the same source vary widely. Considerable variation occur partly due to quality of plant available and partly due to efficiency of operation. Some of the variations in test results are due to variations in sampling, making, curing and testing the specimen even when carried out in terms of relevant standard specifications. There are no unique attributes to define the quality of concrete in its entirety. Under such a situation, the concrete is generally referred to as being of *good, fair* or *poor quality.* This interpretation is subjective. It is, therefore, necessary to define the quality in terms of desired performance characteristics, economics, aesthetics, safety and other factors. Due to large number of variables influencing the performance *of concrete, the* quality control is an involved task. However, it should be appreciated that the concrete has mainly to serve the dual needs of safety (under ultimate loads) and serviceability (under working loads) including durability. These needs vary from one situation one type of construction to another.

It should be noted that the usual 28-day cube tests are not the quality control measures in the strict sense; they are in fact the acceptance tests. In situations of site production and placing, the quality of the concrete is to be controlled way ahead of the stage of testing cubes at 28 days. Moreover; the compressive strength, although taken as an index of quality of concrete does not satisfy the requirements of durability where impermeability and homogeneity are more important parameters.

The aim of the quality control is to reduce the above variations and to produce uniform material which provides the characteristics desirable for the job envisaged. Thus the quality control is a corporate, dynamic programme to assure that all the aspects of materials, equipment and workmanship are well looked after. The tasks and goals in these areas are properly set and defined in the specifications and control requirements. The specifications have to state clearly and explicitly the steps and requirements, adherence to which would result in a construction of acceptable quality. Except for compressive strength and appearance, there is no early measure of construction performance. Each step in construction procedure is therefore to be specified. The probability-based specification containing allowable tolerances on its attributes is more rational and is preferred.

Quality control is thus conformity to the specifications, neither more nor less. The most practical method of effective quality control is to check what is done in totality to conform to the specifications. An owner will have no right to expect performance anything more than what is in the specifications. The builder, on the other hand, knows that anything less than what is in the specification will not be acceptable to the owner.

1.4 DISTRIBUTION OF RESULTS

The compressive strength test results of cubes from random sampling of a mix although exhibit variations, when plotted on a histogram are found to follow a *bell-shaped curve termed normal or Gaussian distribution curve*. The results are said to follow a normal distribution as shown in Fig. 1.1 if they are equally spaced about the *mean value*. However, some divergence from the smooth curve is only to be expected, particularly if the number of results available is relatively small. The normal distribution curve can be used to ascertain the *variation of strength from the mean*. The area beneath the curve represents the total number of test results. The proportion of results less than the specified value is represented by the area beneath the curve to the left-hand side of the vertical line drawn through the specified value.

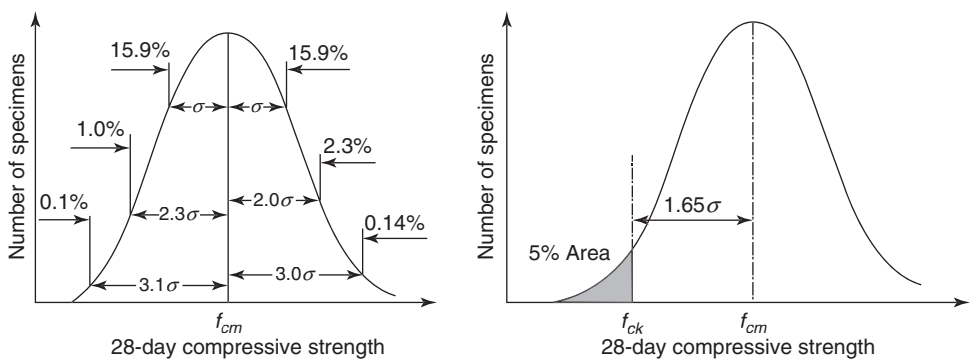

Fig. 1.1 *Idealised normal distribution of compressive strength results*

A *normal distribution* curve can be defined by two parameters, namely, the mean strength and the standard deviation. The mean strength is defined as the arithmetic mean of the set of actual test results. The standard deviation S is a measure of the spread of the results and the formula for computing the standard deviation is given in IS: 456-2000 as explained below.

1.5 STANDARD DEVIATION

The *root mean square* (rms) deviation of the whole consignment is termed as the *standard deviation* and is defined numerically as

$$S = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

S = standard deviation of the set of observations,
x = any value in the set of observations,
$\bar{x}$ = arithmetic mean of the values and
n = total number of observations.

The *standard deviation* increases with the increasing variability. It may be appreciated that the value of S is minimum for very good control and progressively increases as the level of control decreases as indicated by Table 1.1. The validity of the important property of standard deviation relating it to the proportion of all

the results falling within or outside certain limits can generally be assumed in case of concrete work without serious loss *of* accuracy as long as techniques of random sampling are followed.

Table 1.1 *Standard deviation for different types of controls (According to Himsworth)*

Types of control	Excellent	Very good	Good	Fair	Poor	Uncontrolled
Standard Deviation, MPa	2.8	3.5	4.2	5.6	7.0	8.4
Coefficient of Variation, per cent	5	12	15	18	20	25

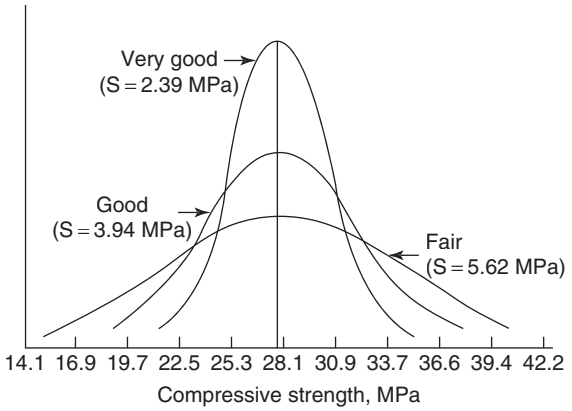

Fig. 1.2 *Typical normal distribution curves for different degree of control*

The spread of normal distribution curve along the horizontal scale shown in Fig. 1.2 is governed by the standard deviation, while the position of the curve along the vertical scale is fixed by the average value, the limit below or above which the proportion of the results can be expected to fall are set out as $(x \pm k\,S)$, where k is the probability factor. For different value of k, the percentage of results falling above and below a particular value is illustrated in Fig. 1.2, in relation to the area bounded by the normal probability curve. The values of k are given in Table 1.2.

Alternatively, the variation of results about the mean can be expressed by *coefficient of variation* which is non-dimensional measure of variation obtained by dividing the standard deviation by the average value and is expressed as

$$v = \frac{S}{\bar{x}} \times 100$$

With constant coefficient of variation, the standard deviation increases with strength and is larger for high strength concrete. The values of coefficients of variation suggested by Stanton Walker for different degrees of control are given in Table 1.1.

1.6 APPLICATIONS

The standard deviation and the coefficient of variation are useful in the design and quality control of concrete. As the strength test results follow normal distribution, there is always the probability that some results may fall below the specified strength. Recognising this fact, IS: 456-2000 has brought in the concept of characteristic strength. The term *characteristic strength* indicates that value of the strength of material below which not more than five per cent of the test results are expected to fall. In the design of concrete mixes, the average

strength to be aimed, i.e., the *target mean strength,* should be appreciably higher than the minimum or characteristic strength if quality of concrete is to comply with the requirements of the specifications. If from previous experience, the expected variation in compressive strength is represented by a certain *standard deviation* or *coefficient of variation,* it is possible to compute the target mean strength of the mix, which would carry with it a predetermined chance of results falling below a specified minimum strength. The characteristic strength is obtained by using the following relation:

$$f_t = f_{ck} + kS$$

where f_t = target mean strength,
f_{ck} = characteristic strength,
k = probability factor and
S = standard deviation.

The value of k where not more than five per cent (1 in 20) of test results are expected to fall below characteristic strength is 1.65 as obtained from Table 1.2 and the above relation reduces to

$$f_t = f_{tk} + 1.65\,\mathrm{S}$$

However, it should be noted that for a given degree of control, the standard deviation method yields higher target mean strengths than the coefficient of variation method for low and medium strength concretes. For high strength concrete, the coefficients of variation method yields higher value of target mean strength. The cost of production being dependent on the target mean strength of concrete, the method of evaluation should be consistent with the observed trend of results for different range of strengths. However, the use of coefficient of variation is not envisaged in IS: 456-2000.

Table 1.2 *Probability factor for various tolerances*

Percentage of results below characteristic strength	50 (1 in 2)	16 (1 in 6)	10 (1 in 10)	6.5 (1 in 15)	5 (1 in 20)	2.5 (1 in 40)	1.0 (1 in 100)	0.5 (1 in 200)
Probability factor, k	0	1.0	1.28	1.5	1.65	1.96	2.33	2.58

To keep a control on the quality of concrete produced it is required to cast a number of specimens from random samples and to test them at suitable intervals to obtain results as quickly as possible to enable the level of control to be established with reasonable accuracy in a short time. IS: 456-2000 stipulates that *random samples* from fresh concrete shall be taken as specified in IS: 1199-1959 and the cubes shall be made, cured and tested as described in IS: 516-1959.

The *random sampling* procedure is adopted to ensure that each concrete batch shall have a reasonable chance of being tested, i.e., the sampling should be spread over the entire period of concreting and cover all mixing units. The code prescribes minimum *frequency of sampling* of 1, 2, 3 and 4 samples, respectively, for 1–5, 6–15, 16–30 and 31–50 m^3 of concrete being used in the job. For concrete quantity of 51 m^3 and above, the number of samples shall be four plus one additional sample for every 50 m^3 of concrete or part thereof. At least one sample should be taken from each shift. In case of continuous production unit, e.g., *ready mixed concrete plant,* the frequency of sampling may be as per agreement. Additional samples may be required for various purposes, e.g., for determination of seven-day strength, accelerated strength, time of striking the formwork, etc.

As far as the requirements of specifications with regard to the acceptance criteria for concrete is concerned, IS: 456-2000 stipulates that the concrete shall be deemed to satisfy the compressive and flexural strength requirements as follows.

1. **Compressive strength** The mean strength determined from any group of four consecutive test results and that of any individual test result comply with the strength requirements of Table 1.3.
2. **Flexural strength** When both the following conditions are met, the concrete deemed to comply with the flexural strength requirements:

(a) The mean strength determined from any group of four consecutive test results exceeds the specified characteristic strength by at least 3 MPa.
(b) The strength determined from any test result is not less than the specified characteristic strength minus 3 MPa.

Table 1.3 *Acceptance criteria for concrete is concerned as per IS: 456-2000*

Specified grade	Mean of the group of four non-overlapping consecutive test results, MPa	Individual test results, MPa
M15	$\geq f_{ck} + 0.825 \times$ established standard deviation or $f_{ck} + 3$ MPa whichever is greater	$\geq f_{ck} - 3$ MPa
M20 or above	$\geq f_{ck} + 0.825 \times$ established standard deviation or $f_{ck} + 4$ MPa whichever is greater	$\geq f_{ck} - 4$ MPa

Value of standard deviation should be established from results of 30 test or more samples at the earliest and rounded to 0.5 MPa. In the absence of established values of standard deviation, values of 3.5 MPa, 4.0 MPa and 5.0 MPa may be assumed for M15; M20–M25; and M30–M50 grade concretes, respectively, for very good quality control. For good quality control, these values are increased by 1.0 MPa. Concrete of each grade shall be assessed separately.

As all the main variations of a job as in batching, proportions of ingredients, characteristics of aggregates, etc., are reflected in the fluctuations of the *water-cement ratio* and this ratio is in itself closely related to compressive strength, a *control ratio* can be applied to reduce the water-cement ratio to take into account the observed variations in the strength. The control ratio is defined as

$$\text{Control ratio} = \frac{\text{Water – cement ratio required to produce average strength}}{\text{Water – cement ratio required to produce minimum strength}}$$

Table 1.4 gives suggested values of control ratio for various probabilities of results falling below minimum with four different degrees of control.

Table 1.4 *Control ratios for different degrees of control*

Degree of control	Control ratio for probabilities of			Remarks
	1 in 25	1 in 40	1 in 100	
A	0.82	0.80	0.76	Weigh batching of cement and aggregates by servo-operation
B	0.79	0.76	0.72	Weigh batching of cement and aggregates by manual operation

(*Continued*)

Table 1.4 *Contd.*

Degree of control	Control ratio for probabilities of			Remarks
	1 in 25	1 in 40	1 in 100	
C	0.77	0.74	0.69	Weigh batching of cement and volume batching of aggregate
D	0.75	0.72	0.67	Volume batching for both cement and aggregate

1.7 ADVANTAGES OF QUALITY CONTROL

The general feeling that quality control means extra cost is not correct; the advantages due to quality control offset the extra cost. Some of the advantages of quality concrete are:

1. Quality control means a rational use of the available resources after testing their characteristics and reduction in the materials costs.
2. In the absence of quality control there is no guarantee that overspending in one area will compensate for the weakness in another, e.g., an extra bag of cement will not compensate for incomplete compaction or inadequate curing. Proper control at all the stages is the only guarantee.
3. In the absence of quality control at the site, the designer is tempted to overdesign, so as to minimise the risks. This adds to the overall costs.
4. Checks at every stage of production of concrete and rectification of the faults at the right time expedite completion and reduces delay.
5. Quality control reduces the maintenance costs.

It should be understood that if good quality concrete is made with cement, aggregates and water; then the ingredients of bad concrete are exactly the same. The difference lies in the few *essential steps collectively called quality control.*

NATIONAL STANDARDS

1. IS 456-2000 (reaffirmed 2011): *Code of Practice for Plain and Reinforced Concrete* (4th revision)

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CEMENT

Chapter 2

This section describes the tests generally performed on cement. The cement tests covered are for specific gravity, fineness, specific surface, setting times, soundness, compressive strength and effect of curing conditions. The physical characteristics of cement as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

2.1 INTRODUCTION

The ingredients of the concrete can be classified into two groups namely active and inactive. The active group consists of cement and water whereas inactive group comprises of fine and coarse aggregates. The inactive group is also sometimes called *inert matrix.*

Although all materials that go into concrete mixture are essential, the cement is very often the most important because it is usually the delicate link in the chain. The function of the cement is first of all to bind the sand and stone together and second to fill up the *voids* in between sand and stone particles to form a compact mass. Although, the cement constitutes about 20 per cent of the volume of the concrete mix, it is active portion of the binding medium and it is the only scientifically controlled ingredient of concrete. The cement most widely used as binding material for construction works is the Portland cement. Cement has, thus, occupied an indispensable place in the construction works.

There are a variety of cements available in the market and each type is used under certain conditions due to its special properties. The cements in general can be classified into two categories namely, (i) the general-purpose Portland cements and (ii) the special-purpose cements.

2.2 GENERAL-PURPOSE PORTLAND CEMENTS

This is the most commonly used form of cement. It essentially consists of a mixture of various *aluminates* and *silicates* of calcium produced by the interaction of various oxides during fusion. The raw materials for its manufacture are clay and chalk or limestone. First they are taken in proper proportions, crushed and then ground to a fine powder. Secondly, the resulting mass is heated to about 1450°C in a *kiln* where lime (obtained from the limestone) and alumina and silica (constituents of clay) fuse to form a mixture of *calcium silicate* and *calcium aluminate* called *clinker.*

Finally, the clinker is cooled and mixed with about 3 to 4 per cent of gypsum, by mass, which is subsequently ground to an exceedingly fine powder. This powder is the cement in the final form. The gypsum acts as a retarder to prevent immediate setting and also improves the *soundness of the cement*. The fineness of grinding and the raw materials influence the reactivity of the cement, fine cement hardens more quickly than coarse cement of the same composition.

High lime content generally increases the *setting time* and results in high early strengths. High silica content prolongs the setting time and gives more strength. The presence of excess unburnt lime is harmful since the hydration takes place slowly and causes expansion (*unsoundness*) in later stages. The iron oxide is not a very active constituent of cement; it generally acts as a catalyst and helps the burning process. Due to the presence of iron oxide, the cement derives the characteristic grey colour. Magnesia, if present, in larger quantities causes unsoundness.

As mentioned above, the constituents of cement are not simple oxides but are in the form of more *complex compounds* having definite molecular structure. The major compounds in the ordinary Portland cement are tricalcium silicate, dicalcium silicate, tricalcium aluminate and tetracalcium aluminoferrites, symbolically represented as C_3S, C_2S, C_3A and C_4AF, respectively. C_3S and C_2S constitute about 70 to 80 per cent of the Portland cement and contribute to its *strength.* They enhance the *durability* by making the cement resistant to acid and alkali attack, C_3S hydrates rapidly and hence contributes to the early and ultimate strength of cement. On the other hand, C_2S hydrates slowly and contributes to later age strength. C_3A hydrates rapidly contributing to early strength but reducing ultimate strength. This compound is liable to be attacked by salts and alkalies. C_4AF is the most undesirable compound and does not contribute to the strength.

The commonly used Portland cement in India is branded as 33-grade (IS: 269–1989), 43-grade (IS: 8112–1989) and 53-grade (IS: 12269–1987) having 28-day mean compressive strengths exceeding 33 MPa, 43 MPa and 53 MPa, respectively. All the three grades of ordinary Portland cement are produced from the same materials.

The conventional OPC, i.e., 33-grade cement has virtually disappeared and has been displaced by high strength 43-grade cement. The minimum compressive strengths of the 43-grade cement are 23 MPa and 33 MPa at the end of three days and seven days, respectively. Greater fineness of 43 and 53 grade cements increase workability due to reduction of friction between aggregates. Moreover, due to shorter setting time and faster development of strength, the stripping time is shorter. However, to make high strength concrete a high performance concrete, will require extremely careful batching, mixing, transportation, placing, compaction and curing.

2.3 SPECIAL-PURPOSE CEMENTS

The special-purpose cements are manufactured for the specific performance requirements. They are classified as: (i) OPC-based cements and (ii) Non-OPC cements.

2.3.1 OPC-based Cements

OPC-based cements have some further classifications, which are described below.

1. **Rapid hardening Portland cement** This cement is similar to OPC but with higher C_3S content and finer grinding. A higher fineness of cement particles provides greater surface area (not less than 325 000 mm^2/g) for action with water. It gains strength more quickly than OPC, though the final strength is only slightly higher. The one-day strength of this cement is equal to the three-day strength of 33-grade OPC with the same water–cement ratio. This cement is used where a rapid strength development is required. The rapid gain of strength is accompanied by a higher rate of heat development during the hydration of cement. The composition, fineness and other properties are governed by IS: 8041–1990. It is only about 10 per cent costlier than OPC.

2. **Low heat Portland cement** This cement is less reactive than OPC and is obtained by increasing the proportion of C_2S and reducing C_3S and C_3A. This reduction in the content of more rapidly hydrating compounds C_3S and C_3A results in a slow development of strength but the ultimate strength is the same. In any case, to ensure a sufficient rate of development of strength, the specific surface of cement must not be less than 320 000 mm^2/g. The initial setting time is greater than OPC. The properties and composition are governed by IS: 12600–1989. This cement is recommended for the use in mass concrete construction such as dams where temperature rise by heat of hydration can become excessive.

3. **Sulphate resisting cement** A Portland cement having high silicate content and low C_3A (less than five per cent) and C_4AF contents is very effective against sulphate attack; whereas the ordinary Portland cement is susceptible to attack of sulphates in solution which permeate in the hardened concrete and react with free $Ca(OH)_2$, hydrate of calcium aluminate and even hydrated silicates to form calcium sulphoaluminate having a volume of approximately 227 per cent of the volume of original aluminates. This expansion within the hardened structure of cement paste results in cracks and subsequent disruption. This phenomenon is called *sulphate attack*, which is greatly accelerated if accompanied by an alternate wetting and drying as in the case of marine environment.

4. **Portland slag cement** This type of cement is made by inter-grinding not less than 35 per cent of ordinary Portland cement clinker and granulated *blast-furnace slag* (a waste product consisting of a mixture of lime, silica and alumina obtained in the manufacture of pig iron). Generally, small percentage of gypsum is added to the clinker to be ground with slag to regulate setting time. The slag can also be used together with lime stone as a raw material for conventional manufacture of Portland cement resulting in clinker which when ground gives *Portland slag cement.* This cement is less reactive than OPC and gains strength little more slowly during first 28 days and adequate curing is essential. It has the advantages in generating heat less quickly than ordinary Portland cement. It is suitable for mass concreting but is unsuitable in cold weather. Because of its fairly high sulphate resistance it is used in sea-water construction. The composition and properties are governed by IS: 455-1989.

5. **Portland-pozzolana cement** Portland-pozzolana cement can be produced either by grinding together Portland cement clinker and pozzolana with addition of gypsum or calcium sulphate, or by intimately and uniformly blending Portland cement and fine pozzolana. While grinding of two materials together present no difficulty, the mixing of dry powders intimately is extremely difficult.

   Portland-pozzolana cement produces less heat of hydration and offers greater resistance to the sulphate attack and chloride-ion penetration due to impurities in water, than normal Portland cement. It is particularly useful in marine and hydraulic constructions, and other mass concrete structures. The Portland-pozzolana cement can generally be used wherever ordinary Portland cement is usable under normal conditions. However, all the pozzolanas need not necessarily contribute to the strength at early ages. IS:1489 (Part-1)-1991 gives the specifications for the production of Portland-pozzolana cement equivalent to ordinary Portland cement on the basis of 7-day compressive strength. The compressive strength of Portland-pozzolana cement at 28 days also has been specified to enable the Portland-pozzolana cement be used as substitute for ordinary Portland cement in plain and reinforced concrete works. The Portland-pozzolana cement should conform to the requirements specified in IS: 1489-(Parts-1 and 2)-1991.

6. **Super sulphate cement** This cement is manufactured from well granulated slag (80 to 85 per cent) and calcium sulphate (10 to 15 per cent) together with one to two per cent of Portland cement. Its *specific surface* is between 350 000 and 500 000 mm^2/g. It has an *initial setting* time between 2½ to 4 hours and *final setting* between 4½ to 7 hours. The total *heat of hydration* is very low; it is about 38 cal/g at the seventh day and 42 cal/g at the 28th day, which make it suitable for mass concreting but requires great care while concreting in cold weather.

2.4 STORAGE OF CEMENT

It is often necessary to store cement for a long period, particularly when the deliveries are irregular. Although, cement will retain its quality almost indefinitely if moisture is kept away from it, but the cement exposed to air will absorb moisture slowly which will cause its deterioration. Absorption of one or two per cent of water has no appreciable effect, but a further amount of absorption retards the hardening of cement. The more finely

cement is ground, the more reactive it is, and consequently the more rapidly it absorbs moisture from damp surroundings. Once the cement has been properly stored, it should not be disturbed until it is to be used. The practise of moving and restacking the bags to reduce warehouse peak only exposes fresh cement to air.

2.4.1 Rejection

The current trend is to accept certification by the cement manufacturer that the cement complies with specifications. Verification tests are taken by the BIS to continually monitor specification compliance. The cement producer has a variety of information available from production records and quality control records that may permit certification of conformance without much, if any, additional testing of the product as it is shipped.

However, due to defective storage for long periods, the cement is adversely affected. The cement remaining in bulk storage with manufacturers for more than six months or cement in jute or paper bags or in local storage in the hands of suppliers for more than three months after completion of tests may be retested before use and rejected if it fails to conform to any of requirements of IS: 269-1989.

2.5 TESTS FOR PHYSICAL PROPERTIES OF PORTLAND CEMENT

The cement to be used in construction must have certain given qualities in order to play its part effectively in the structure. When these properties lie within a certain range, the engineer is confident that in most of the cases the cement performance will be satisfactory. Also, based on these properties, it is possible to compare the quality of cement from different sources. The tests for important physical properties of cement are:

2.5.1 Fineness (IS: 269-1989 and Other Relevant Codes)

The fineness of cement is a measure of the size of particles of cement and is expressed in terms of *specific surface of cement.* It can be calculated from the particle size distribution or determined by one of *air* permeability methods. It is an important factor in determining the *rate of gain of strength* and *uniformity* of quality. For a given mass of cement, the surface area is more for finer cement than for coarser cement. Finer the cement, higher is the *rate of hydration,* as more surface area is available for chemical reaction. This results in an early development of strength. If the cement is ground beyond a certain limit its cementing properties may be adversely affected due to pre-hydration by atmospheric moisture.

The residue when sieved on a 90 micron IS sieve should not exceed 10 per cent for ordinary Portland cement and 5 per cent for rapid hardening Portland cement.

2.5.2 Setting time

Cement when mixed with water forms slurry which gradually becomes lesser and lesser plastic, and finally a hard mass is obtained. In this process of setting, a stage is obtained when the cement paste is sufficiently rigid to withstand a definite amount of pressure. The time to reach this stage is called *setting time.* The time is reckoned from the instant when water is added to the cement. The setting time is divided into two parts, namely, the *initial* and the *final setting time.* The time at which the cement paste loses its plasticity is termed *initial setting time.* The time taken to reach the stage when the paste becomes a hard mass is known as *final setting time.*

It is essential for proper concreting that the initial setting time should not be too less to allow time for mixing, transporting and placing the concrete. The setting process is accompanied by the temperature changes. The temperature rises rapidly from the initial setting to a peak value at the final setting. The setting time decreases with rise in temperature up to 30°C and vice versa. The setting times specified for various types of cements are given in Table 2.l. For an ordinary Portland cement, the initial setting time should not be less than 30 minutes and final setting time should not be more than 600 minutes. A phenomenon of abnormal premature hardening within a few minutes of mixing the water is termed *false set.* However, not much heat is involved and remixing the paste without water restores the plasticity and the cement sets in the normal manner with no appreciable loss of strength.

2.5.3 Soundness

The *unsoundness of cement* is caused by undesirable expansion of some of its constituents, sometimes, after setting. The large change in volume accompanying expansion results in disintegration and severe cracking. The unsoundness is due to the presence of free lime and magnesia in the cement. The free lime hydrates very slowly because it is covered by the thin film of cement particles which prevents direct contact between lime and water. After the setting of cement, the moisture penetrates into the free lime resulting in its hydration. Since the slaked lime occupies larger volume, the expansion takes place resulting in severe cracking. The unsoundness due to the presence of magnesia is similar to that of lime.

The main test for soundness is the *Le-Chatelier test.* The expansion carried out in the manner described in IS: 269-1989 should not be more than 10 mm.

2.5.4 Compressive Strength

Compressive strength is one of the important properties of cement which provides an indication of ability of the cement to make concrete strong in *compression.* Compressive strength is determined by the *mortar cube crushing tests* and *concrete compression tests.* These are conducted on standardised aggregates under carefully controlled conditions and therefore give a good indication on strength qualities of cement. Cement mortar cubes having an area of 5000 mm^2 composed of one part of cement, three parts of standard sand (conforming to IS: 650-1991) by mass and (p/4 + 3.0) per cent (of combined mass of cement and sand) water obtained in the manner described in IS: 4031-1968 are prepared and tested in compression testing machine. Here p is the percentage of water to produce a paste of standard consistency. Physical properties of various types of cements are listed in Table 2.1.

2.5.5 Hydration of Cement

The silicates and aluminates of cement react with water to form a binding medium which solidifies into a hardened mass. This reaction by virtue of which the Portland cement becomes a bonding medium is termed *hydration.* The hydration of cement is exothermic with approximately 120 cal/g being liberated. In the interior of a large concrete mass, the hydration can result in a large rise in temperature. At the same time, the exterior of the concrete mass loses some heat so that a steep temperature gradient may be established and during subsequent cooling of interior, severe cracking may occur.

The *heat of hydration* is defined as the quantity of heat, in calories per gram of hydrated cement, evolved upon complete hydration at a given temperature. It is determined by measuring the heats of evolution of unhydrated and hydrated cement in a mixture of nitric and hydrofluoric acids; the difference between the two values represents the heat of hydration. The rate of hydration and the heat evolved increases with the fineness of cement but the total amount of heat liberated is unaffected by fineness.

Table 2.1 *Physical properties of various types of cements*

Type of cement and controlling standard	Fineness	Setting times		Compressive strengths				Soundness	
	(m^2/kg) min.	Initial (mts.) min.	Final (mts.) max.	1 day (MPa) min.	3 days (MPa) min.	7 days (MPa) min.	28–Days (MPa) min.	Le-Chatelier (mm) max.	Autoclave per cent max.
1. 33 Grade OPC IS: 269 -1 989	225	30	600	–	16	22	33	10(5)*	0.8
2. 43 Grade OPC IS: 8112 -1989	225	30	600	–	23	33	43	10(5)	0.8

(*Continued*)

Table 2.1 *Contd.*

Type of cement and controlling standard	Fineness	Setting times		Compressive strengths				Soundness	
	(m^2/kg) min.	Initial (mts.) min.	Final (mts.) max.	1 day (MPa) min.	3 days (MPa) min.	7 days (MPa) min.	28–Days (MPa) min.	Le-Chatelier (mm) max.	Autoclave per cent max.
3. 53 Grade OPC IS: 12269 -1987	225	30	600	–	27	37	53	10(5)	0.8
4. Rapid hardening cement IS: 8041 -1990	325	30	600	16	27	–	–	10(5)	0.8
5. Low heat cement IS: 12600 -1989	320	60	600	–	10	16	35	10(5)	0.8
6. Sulphate resisting cement IS: 12330 -1988	225	30	600	–	10	16	33	10(5)	0.8
7. Portland slag cement IS: 445 - 1989	225	30	600	–	16	22	33	10(5)	0.8
8. Portland-pozzolana cement IS: 1489(Part 1)-1991	300	30	600	–	16	22	33	10(5)	0.8
9. Super Sulphate Cement IS: 6909 - 1990	400	30	600	–	15	22	30	5	–
10. High Alumina Cement IS: 6452 -1989	225	30	600	30	35	–	–	5	–

Note: *Maximum unaerated (aerated) expansion

2.6 PREPARATION OF CEMENT SAMPLE

Sampling is the process of selecting small representative quantities of a given material for the purpose of testing. Since the quality of large amount of material is to be determined on the basis of samples selected hence it is very essential that samples for testing must be truly representative. To ensure the true representation, the main sample should be made up from a number of smaller samples taken from various parts of the moisture proof container and thoroughly mixed in order that the sample may be uniform throughout the test. The smaller sample taken from the thoroughly mixed main sample shall be passed through a 90 μm IS sieve and all lumps shall be rejected.

EXPERIMENT NO. 1: Specific Gravity of Cement

Objective

To determine the specific gravity of cement.

Theory and Scope

Specific gravity is normally defined as the ratio between the mass of a given volume of material and mass of an equal volume of water. One of the methods of determining the specific gravity of cement is by the use of a liquid such as water-free kerosene which does not react with cement. A specific gravity bottle may be employed or a standard Le Chatelier specific gravity flask may be used.

In addition to hydraulic cement, the Le Chatelier specific gravity flask can also be used to obtain specific gravity of dust, sand, and other fine materials.

Apparatus

Weighing balance; Le Chatelier specific gravity flask with a ground glass stopper, Specific gravity bottle; Kerosene free from water; Constant temperature water bath.

Description of Apparatus

The Le Chatelier flask shown in Fig. 2.1(b) is made of thin glass having a bulb at the bottom. The capacity of the bulb is nearly 250 ml. The bulb is 78 mm in mean diameter. The stem is graduated in millilitres; small oval bulb in neck holds 17 ml, below this bulb are graduations from 0–1ml; above the bulb, the neck is graduated from 18–24 ml. The portion above 24 ml mark is in the form of a funnel having top diameter as 50 mm. Thus the total capacity of the stem of bulb is 24 ml. A glass stopper or nipple is fitted in the stem to cover the flask.

Procedure

Step 1: With specific gravity bottle

(a) Weigh the specific gravity bottle dry. Let the mass of empty bottle be W_1.
(b) Fill the bottle with distilled water and weigh. Let the mass be W_2.
(c) Wipe dry the specific gravity bottle and fill it with kerosene and weigh. Let this mass be W_3.
(d) Pour some of the kerosene out and introduce a weighed quantity of cement, W_5 (about 50 g) into the bottle. Roll the bottle gently in inclined position until no further air bubbles rise to surface. Fill the bottle to the top with kerosene and weigh it. Let this mass be W_4.
(e) From these data calculate the specific gravity of the cement, S.

Specific gravity of kerosene, $s = \dfrac{W_3 - W_1}{W_2 - W_1}$

Volume of bottle $= W_2 - W_1$

Volume of cement $= W_5/S$

Volume of kerosene after cement has been added $= (W_2 - W_1) - W_5/S$

wherefrom mass of kerosene after cement has been added $= [(W_2 - W_1) - W_5/S]\, s$

Therefore, $[(W_2 - W_1) - W_5/S]\, s + W_5 + W_1 = W_4$

Substituting the value of s and on simplification,

$$\frac{W_5}{S} = (W_5 + W_3 - W_4) \times \frac{[(W)_2 - W_1]}{(W_3 - W_1)}$$

Therefore, specific gravity of cement, $S = \dfrac{[W_5(W_3 - W_1)]}{(W_5 + W_3 - W_4)(W_2 - W_1)}$

Observations and Calculations

Mass of empty bottle ,	W_1, g		
Mass of bottle + water ,	W_2, g		
Mass of bottle + kerosene,	W_3, g		
Mass of cement,	W_5, g		
Mass of bottle + cement + kerosene,	W_4, g		
Specific gravity of kerosene,	$s = \dfrac{W_3 - W_1}{W_2 - W_1}$		
Sp. gr. Of cement,	$S = \dfrac{[W_5(W_3 - W_1)]}{(W_5 + W_3 - W_4)(W_2 - W_1)}$		

Step 2: With Le Chatelier flask

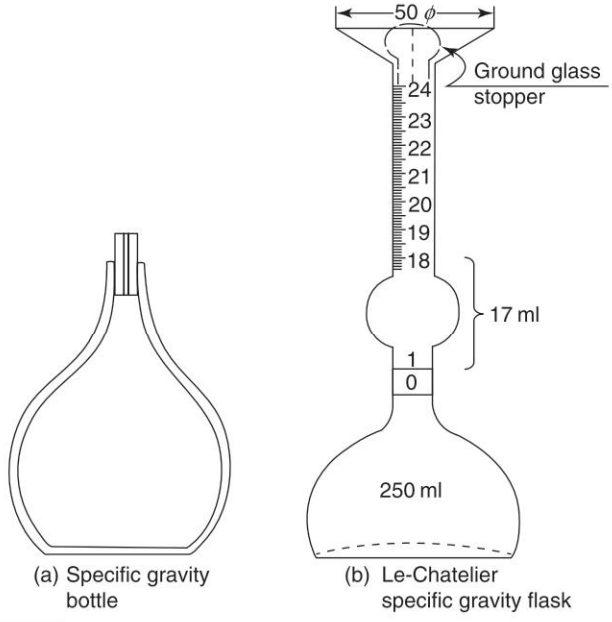


Fig. 2.1 *Apparatus for determining the specific gravity of cement*

(a) Dry the flask carefully and fill with kerosene or Naphtha to a point on the stem between zero and 1 ml.
(b) Dry the inside of the flask above the level of the liquid.
(c) Immerse the flask in a constant temperature water bath maintained at room temperature, for sufficient period before taking any reading so as to avoid variation greater than 0.2°C in the temperature of the liquid in the flask.
(d) Record the level of the liquid in the flask as initial reading, V_1.
(e) Place a weighed quantity of cement, W_1 (about 60 g) into flask so that level of kerosene rises to about say 22 ml mark. Care being taken to avoid splashing and to see that cement does not adhere to the sides of the flask above the liquid.
(f) After putting all the cement into flask, insert the nipple and roll the flask gently in an inclined position to free the cement from air until no further air bubble rises to the surface of the liquid.
(g) Keep the flask back in constant temperature water bath and note down the new liquid level as final reading, V_2.
(h) Calculate the specific gravity, S.

Observations and Calculations

Air temperature,	°C		
Mass of cement used, W_1	g		
Initial reading of flask, V_1	ml		
Final reading of flask, V_2	ml		
Volume of cement particles, $V_2 - V_1$	ml		
Mass of equal volume of water, $W_2 = (V_2 - V_1) \times$ specific weight of water	g		
Specific gravity, $S = W_1/W_2$			

Precautions

1. The kerosene or Naphtha used should be free from water.
2. The specific gravity bottle and the Le Chatelier flask should be held in a constant temperature water bath sufficiently long to ensure same temperature before each weighing is made.
3. Duplicate determination of specific gravity should agree within 0.01.
4. While introducing cement, care should be taken to avoid splashing and cement should not adhere to the inside of the flask above the liquid.

Discussion

In case specific gravity bottle shown in Fig. 2.1(a) is used, it is necessary to determine the specific gravity of kerosene or other liquid used and all the measurements are made entirely by mass. If Le Chatelier flask is used, some of the measurements are made by volume and it is not necessary to know the specific gravity of kerosene. The relative density of kerosene is 0.8. The specific gravity of ordinary Portland cements is in the range of 2.15.

Viva-Voce Questions

1. Define specific gravity. Is it permissible to use water in this experiment, if not, why?
2. What liquid do you think would suit the requirement of the experiment?
3. If some of the test sample be lost after weighing, what is the effect on the specific gravity value obtained?
4. If some of the liquid be lost from the flask after the initial reading is taken, what is the effect on specific gravity value?
5. What is the fundamental difference in determination of specific gravity by these two methods? Which one is better? What are the sources of error in the experiment?
6. Do kerosene and naphtha have higher or lower coefficient of expansion than water?
7. In determination of specific gravity by Le Chatelier flask, if the temperature of the liquid be higher at the time of the second reading than it was at the time of the first reading, what is the effect on the specific gravity value?
8. If the air bubbles were not completely removed before taking reading, what is the effect on the specific gravity values? Where do you need the value of specific gravity of cement?

Notes and Comments

EXPERIMENT NO. 2: Fineness of a Cement Sample by Sieving

Objective

To determine the fineness of hydraulic cement by means of the 90 µm IS sieve as per IS: 4031 (Part 1) – 1996

Theory and Scope

This test method covers the determination of the fineness of hydraulic cement by means of the 90 µm sieve; test assesses quality of grinding of cement in terms of amount of grit retained on the standard sieve. During the manufacture cement must be properly ground to be uniformly fine, otherwise the concrete made of it will be of poor workability and will require large amount of mixing water. In such cases, the solids settle down even before initial setting of concrete, and water will appear on the top surface; this is called *bleeding.*

As all sieves are not exactly alike and there may be difference in performing tests, the specifications provide that a *correction factor* shall be obtained by sieving the cement standardised by Bureau of Indian Standards in the manner provided for testing the cement. The difference between the *percentage residue* on the sieve and that assigned to the standard sample, is the amount of correction and shall be added or subtracted as necessary.

Apparatus

90 micron IS Sieve (mesh openings of 0.087 mm); Plate; Weighing balance (sensitive to 0.1 g); Bristle brush (25 or 40 mm brush with 250 mm handle).

Procedure

Step 1: Weigh accurately 100 g of cement in a plate and transfer it to a clean dry IS test sieve and break down any air set lumps.

Step 2: While holding the sieve and pan in both hands, sieve with gentle wrist motion until most of the fine material has passed through and the residue looks fairly clean. This usually requires three to four minutes.

Step 3: Place the cover on the sieve and remove the pan. With sieve and cover held firmly in one hand, the other side of the sieve is tapped with the handle of the brush which is used for cleaning the sieve. Sweep clean the underside of the sieve.

Step 4: Empty the pan and wipe it clean with a cloth. Replace the sieve in the pan and remove the cover carefully. Return any coarse material that had been caught in the cover during tapping the sieve.

Step 5: The sieving is continued as described above for 15 minutes, rotating the sieve continuously throughout the sieving operation, involving no danger of spilling the cement.

Step 6: Weigh the residue.

Observations and Calculations

Correction factor,	C		
Mass of cement taken on IS sieve,	g		
Mass of residue after sieving,	g	100	100
$\text{Fineness} = \frac{\text{mass of residue in gms} \pm C}{100}$	per cent		

Note: C is correction factor.

Result

Residue of cement is……per cent.

Precautions

1. Any air set lump in the sample should be broken with fingers, but do not rub on the sieve.
2. The sieve must be cleaned thoroughly before starting the experiment.
3. Care should be taken to ensure that no cement is spilled. After sieving all residues must be taken out carefully and weighed.

Discussion

The method only indicates the amount of grit retained on the sieve. To have a thorough idea of particle sizes, it is more common to specify the surface area of cement particles in one gram of cement. Finer the cement more is the surface area. The Bureau of Indian Standards has laid down two methods for finding the surface area: (i) *Air permeability method,* and (ii) *Wagner's Turbidimeter method.* The first one is more commonly used.

The standard cement should comply with the following conditions of fineness as given by IS: 269-1989 and IS: 8041-1990:

1. For ordinary Portland cement, the residue by mass on IS test sieve should not exceed 10 per cent.
2. For rapid hardening Portland cement, the residue by mass on IS test sieve should not exceed 5 per cent.

Viva-Voce Questions

1. How is the fineness expressed when using the 90 micron IS sieve? What is the field application, i.e., utility of this test? What is the correction factor?
2. What is the maximum value of fineness of cement? What effect does additional fineness of grinding have upon the strength of concrete and on the rate of development of strength?
3. What precautions do you take while performing the experiment?
4. What precautions will you take in transporting and storing the cement?
5. Elaborate the statement in relation to the arrival of cement at the construction site "First arrived first used". How many openings are there per square centimeter in the 90-micron IS Sieve*?*

Notes and Comments

EXPERIMENT NO. 3: Specific Surface of Cement

Objective

To determine the specific surface of cement, pozzolanas, etc., using Blaine air permeability apparatus.

Theory and Scope

The degree of fineness of cement is a measure of the mean size of the grains in the cement. The rate of hydration and consequent development of strength depends upon the fineness of cement. To have the same rate of hardening in different brands of cement, the fineness has been standardised. The finer cement has quicker action with water and gains early strength though its ultimate strength remains unaffected. However, the shrinkage and cracking of cement will increase with fineness of cement.

This test method covers determination of the fineness of hydraulic cement, using the Blaine air-permeability apparatus, in terms of the specific surface expressed as total surface area in square centimetres per gram, or square metre per kilogram of cement. The test method uses the manually operated standard Blaine apparatus. It should be understood that, in general, relative rather than absolute fineness values are obtained.

The Blaine air permeability apparatus is essentially a means of drawing a definite quantity of air through a prepared bed of cement of definite porosity. The number and size of pores in a prepared bed of definite porosity is a function of the particles and determines the rate of air flow though the bed.

Apparatus

The Blaine's variable flow air permeability apparatus; Analytical balance: Weight box; Stop watch; Mercury and Crucible.

Description of Apparatus

The Blaine's variable flow air permeability apparatus conforming to IS: 5516-1996 shown in Fig. 2.2 consists of a permeability cell, perforated disc, plunger, filter paper, and manometer. The *Permeability cell* is a rigid cylinder of 12.5 ±1 mm inside diameter, made of glass or non-corroding metal (like brass or stainless steel), the top of the cell should be at right angles to the principal axis of the cell. The bottom of the cell shall form an airtight connection with the top of manometer. The internal walls of the cell shall be smooth, true and vertical. A *ledge* 0.5 to 1 mm in width shall be an integral part of the cell located at a depth of 50 ± 15 mm from the top of the cell for supporting the *perforated disc.*

The bottom end of the permeability cell is *flared* downward from the ledge portion to a length of 35 ±1 mm along the axis; if the cell is a female type then the wall of the cell is flared downward from the ledge level to a distance of 45 ±1 mm. The flaring shall be about 5^{o} from the axis of the cell. The flaring ensures an airtight connection with the corresponding part of manometer limb.

The *perforated disc* is constructed of non-corroding metal and is 0.9 ± 0.1 mm in thickness, perforated with 30 to 40 circular holes each of one millimetre in diameter equally distributed over its area and finished smooth. The disc fits the inside of the cell snugly and is supported on the *ledge.*

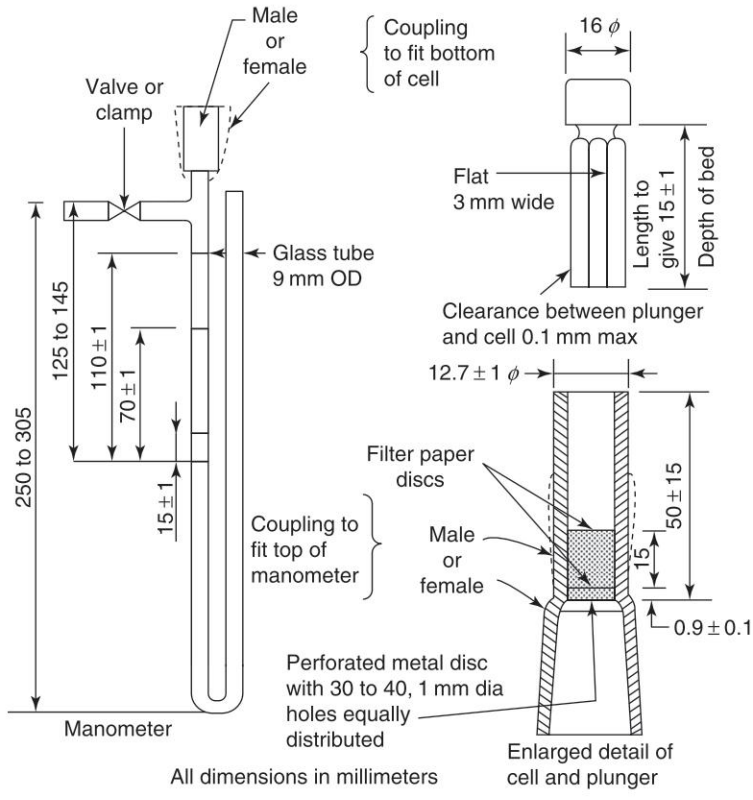


Fig. 2.2 *Blain air permeability apparatus*

The *plunger* is of the same material as the cell and fits into the cell with a clearance of not more than 0.1 mm. The bottom of plunger has square edges right angles to the principal axis. An air vent is provided either in the centre or on one side of the plunger. The top of the plunger is provided with a collar such that when plunger is placed in the cell and the collar brought in contact with the top of the cell, the distance between the bottom of the plunger and the top of the perforated disc is 15.0 ±1.0 mm.

The *filter paper* corresponds to No. 40 Whatman and is circular with smooth edges with the same diameter as the inside of the cell.

The U-tube *manometer* with arms vertical and mounted firmly on a well-seasoned hardwood is made up of a standard glass tubing of high clarity having nominal 9 mm outside diameter. The top of one arm of the manometer has coupling suitable to receive the cell and to ensure an airtight connection with cell. The manometer is filled to the midpoint with a non-volatile, non-hydroscopic liquid of low viscosity and density such as dibutyphthalate.

The manometer arm to be connected to the cell has a line etched around the tube at 125 to 145 mm below the top of the side outlet and also others at distances of 15, 70 and 110 mm above that line. A side outlet is provided at 250 to 305 mm above the bottom of the manometer for use in evacuation, of the manometer arm connected to the permeability cell. A positive airtight-valve (petcock) or clamp is provided on the side outlet at not more than 50 mm from the manometer arm.

Procedure

Part 1: Calibration of the Blaine apparatus

Step 1: Calculate the bulk volume of the compacted bed of cement v by the following formula:

$$v = (W_A - W_B)/\rho$$

where W_A = mass of the mercury required to fill the permeability cell,
W_B = mass of the mercury to fill the portion of the cell not occupied by the bed of cement formed by 2.8 g of the standard cement sample and
ρ = density of mercury at the temperature of test.

The masses W_A and W_B are obtained by weighing the mercury in the crucible.

Step 2: Determine the mass sample, w required for the cement bed having porosity of 0.500 (= e) as follows:

$$w = 3.15\ v\ (1 - e)$$

Step 3: Evacuate the air until the fluid moves above the upper line without pulling it over the top of the side outlet. Close the valve and note the time T_s taken by manometer liquid to fall from second mark (from top) to the third mark on the manometer when the air is allowed to permeate though the compacted bed of standard cement sample. Note the air temperature.

Part 2: Specific surface determination

Step 4: Weigh an amount of cement sample equal to that determined in Step 2, during the calibration process.

Step 5: Place the perforated disc in the permeability cell, and then add a filter paper, followed by the sample and another filter paper. Compress the specimen with plunger, remove the plunger and couple the permeability cell with the manometer.

Step 6: Evacuate the air until the fluid moves above the upper line without pulling it over the top of side tube. Close the valve of manometer and note the time T taken by the fluid to drop from the second mark to the third mark on the manometer when the air is allowed to permeate through the compacted bed of cement obtained in Step 5 above. Note the air temperature.

Step 7: Calculate the specific surface S in square centimetres per gram of the tested cement by using the following formula, if the temperatures at calibration and at the time of test are within ± 3 per cent of each other

$$S = \frac{S_s\sqrt{T}}{\sqrt{T_s}}$$

where S_s = specific surface of standard cement used in calibration in cm^2/g,
T_s = measured time in seconds required for the fluid to fall the middle interval for standard sample and
T = measured time in seconds required for the fluid to drop over the middle interval.

Step 8: Compare the test values with the specified values of the cement sample used.

Observations and Calculations

1. Calibration data		
Apparatus identification		
Mass of empty crucible,	g	
Mass of crucible + mercury required to fill the cell,	g	
Mass of mercury required to fill the cell W_A,	g	
Mass of crucible + mercury required to fill the portion of cell above the cement bed,	g	
Mass of mercury required to fill the portion of cell above the cement bed W_B,	g	
Bulk volume of compacted bed of cement v,	cm^3	
Mass of sample w,	g	
Average time taken by manometer liquid to fall from second to third line T_s,	sec.	
Air temperature,	°C	
Specific surface of standard cement S_s,	cm^2/g	
2. Fineness determination		
Material identification		
Mass of sample w.	g	
Air temperature,	°C	
Time for liquid to fall through middle interval:		
First run,	sec.	
Second run,	sec.	
Third run,	sec.	
Average time T',	sec.	
Specific surface,	cm^2/g	

Precautions

1. The weighing should be done to an accuracy of 1 in 1000.
2. While evacuating the air from the manometer by moving the fluid above the upper line, care should be taken not to pull the liquid above the side outlet.

Discussion

The method gives a thorough idea of particle sizes present in the cement. The fineness is expressed in terms of surface area of cement particles in one gram of cement (cm^2/g). Finer the cement more is the surface area. The Bureau of Indian Standards has laid down two methods for finding the surface area (i) Air permeability method, (ii) Wagner's Turbidimeter method. The first method used is commonly recommended.

Viva-Voce Questions

1. What does the fineness of cement indicate? What is the maximum or minimum value of fineness of cement?
2. What effect does additional fineness of grinding have upon the strength of concrete and on the rate of development of strength?
3. Define specific surface of cement. Name the commonly used methods to determine the specific surface.
4. Explain the basic theory behind the air permeability method for determining the fineness. Why is fineness an important characteristic of cement?
5. Is the Blaine's apparatus suitable for measuring the fineness of all types of particles? Give several other possible methods for getting particle size and its distribution. What precautions do you take while performing the experiment? What precautions do you take in transporting and storing the cement?
6. Elaborate the statement in relation to the arrival of cement at the construction site "First arrived first used". Correct the statements: (a) Finer the cement, lesser the surface area, (b) Finer the cement lesser the strength it will attain.
7. What does the test of sieving the cement through 90 micron IS sieve indicate? Does it give any idea of the particles sizes present in the sample? What is the objective of this test?

Notes and Comments

EXPERIMENT NO. 4: Standard Consistency and Setting Time

Objective

To determine (a) the standard consistency and (b) the initial and final setting times of a given cement sample by Vicat apparatus.

Theory and Scope

1. **Standard consistency** The objective of conducting this test is to find out the amount of water to be added to the cement to get a paste of normal consistency, i.e., the paste of a certain standard solidity, which is used to fix the quantity of water to be mixed in cement before performing tests for setting time, soundness and compressive strength.
2. **Setting time** In order that the concrete may be placed in position conveniently, it is necessary that the initial setting time of cement is not too quick and after it has been laid, hardening should be rapid so that the structure can be made use of as early as possible. The initial set is a stage in the process of hardening after which any crack that may appear will not reunite. The concrete is said to be finally set when it has obtained sufficient strength and hardness.

Therefore, certain limits for initial and final setting times have to be specified.

Apparatus

Vicat apparatus; Vicat mould; Gauging trowel; Measuring jar (100 to 200 ml capacity); Weighing balance (accuracy 0.05 per cent of w); Weight box; Stop watch, Plates; Glass plates and Rubber gloves.

Description of Apparatus

The Vicat apparatus shown in Fig. 2.3 consists of a frame bearing a movable rod with a cap at one end and detachable needle or plunger at the other. The movable rod carries an indicator which moves over a graduated scale having graduations in mm from zero to 40 on either direction to measure the vertical movement of the plunger. The scale is attached to the frame. The movable part with all attachments, i.e., the cap and rod with needle or plunger, weighs 300 g.

The plunger A, required for determining the consistency, is of polished brass 10 mm in diameter and 50 mm long with the lower end flat and small projection at upper end for insertion into movable rod. The needle B required for determining the initial setting time is 1 mm square or 1.13 mm in diameter with the lower end being flat.

The needle C, required for determining the final setting time, is the same as B but with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter, the end of the needle projects by 0.50 mm.

The Vicat mould for cement paste consists of a split ring 80 mm in diameter and 40 mm in height and rests on a non-porous plate.

The gauging trowel weighs about 210 g.

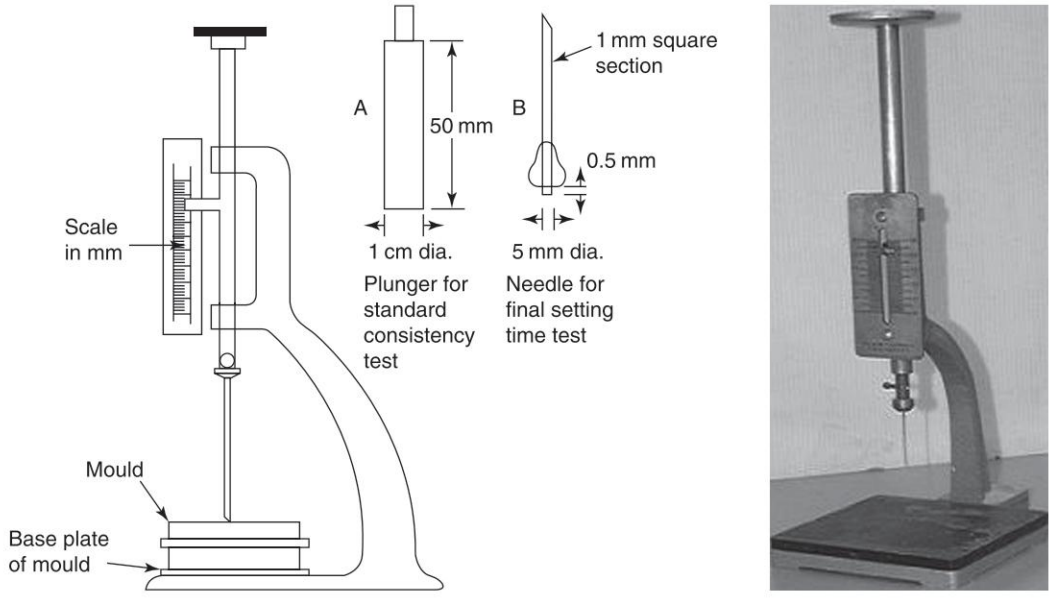


Fig. 2.3 *Vicat apparatus*

Procedure

Part 1: Standard consistency

The standard consistency of a cement paste (the amount of water expressed as percentage by mass of the dry cement) which permits the Vicat plunger A to penetrate to a height 5 to 7 mm from the bottom of the Vicat mould when the cement paste is tested as described below.

Step 1: For preparing one mould take 400 g of cement passing 850 micron IS sieve and prepare a paste of cement with a weighed quantity of water (100 ml) taking care that the time of gauging is between three to five minutes. The gauging time is counted from the time of adding water to the dry cement until commencing to fill the mould.

Step 2: Fill the Vicat mould placed upon non-porous plate with this paste. After completely filling the mould, smooth off the surface of the paste by single movement of palm making it level with the top of the mould. The mould may be slightly shaken to expel air.

Step 3: Place the test block in mould with the non- porous resting plate under the rod attached with the plunger A. Lower the plunger gently to touch the surface of the test block and release it quickly, allowing it to sink into the paste.

Step 4: Prepare the trial pastes with varying percentage of water (firstly at an interval of 4%, that is of 24%, 28% and 32% and then at an interval of 1 % and 0.25% between the percentage range determined by the previous test) and test as described above until the amount of water necessary for the standard consistency as defined is obtained.

Part 2: Setting time of cement

Step 1: Prepare a neat cement paste by gauging the cement with $0.85P$ water, where P is the standard consistency as determined above. The gauging time is again kept between 3 to 5 minutes. Start the stop watch at the instant when the water is added to the cement.

Step 2: Fill the Vicat mould and smooth off the surface of the paste making it level with the top of the mould. The cement block thus prepared is known as *test block*.

Step 3: For the determination of initial setting time, place the test block confined in the mould and resting on non-porous plates under the rod attached with the needle B, lower the needle gently in contact with the surface of the test block and release quickly, allowing it to penetrate into the test block.

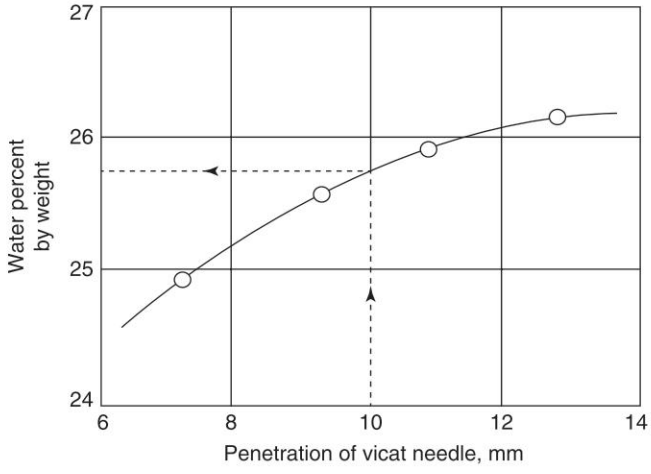


Fig. 2.4 *Typical graph for determining the normal consistency of cement*

Step 4: Repeat this procedure until the needle fails to pierce the block for about 5 mm measured from the bottom of the mould. The period elapsed between the time when water is added to the cement and the time at which the needle fails to pierce the test block by about 5 mm is the initial setting time.

Step 5: For the determination of final setting time replace the needle B of the Vicat apparatus by the needle with an annular attachment C. The cement is considered finally set when, upon applying the needle C gently to the surface of the test block, the needle makes an impression thereon, while the attachment fails to do so. In the event of scum forming on the surface of the test block, use the underside of the block for the determination of final setting time.

Step 6: Draw a graph between percentage of water and penetration in millimetres.

Observations and Calculations

1. For standard consistency Mass of cement taken for one mould = 400 g.					
Percentage of water					
Initial reading					
Final reading					
Height not penetrated, mm					

Note: Initial reading is the indicator reading when the lower end of plunger touches the bottom non-porous surface of the mould.

2. For setting times Mass of cement taken = 400 g Mass of water taken = 0.85 P × 400 g						
Time in minutes						
Initial reading						
Final reading						
Height not penetrated, mm						

Results

1. Standard consistency of cement = ...per cent
2. Initial setting time of cement = ...minutes
3. Final setting time of cement = ...minutes.

Precautions

1. The experiment should be conducted at a room temperature of 27 ± 2°C and at a relative humidity of 90 per cent.
2. After a half minute from the instant of adding water, it should be thoroughly mixed with fingers for at least one minute. A ball of this paste is prepared and then it is pressed into the test mould, mounted on the non-porous plate.
3. The plunger should be released quickly without pressure or jerk, after the rod is brought down to touch the surface of the test block.
4. For each repetition of the experiment fresh cement is to be taken.
5. Plunger should be cleaned during every repetition and make sure that it moves freely and that there are no vibrations.

Discussion

For Portland cement, the initial setting time should not be less than 30 minutes and final setting time should not be more than 600 minutes. For quick setting cement, initial setting time should not be less than 5 minutes and final setting time should not exceed 30 minutes. The *setting time* is influenced by *temperature, humidity of air* and *quantity of gypsum in the cement.*

Viva-Voce Questions

1. What is normal or standard consistency of a cement paste? What is the purpose of making this determination? How is the standard consistency expressed?
2. What is the range of values for most Portland cements?
3. What factors in the test procedure will affect the results of the normal consistency determination?
4. What is the significance of time of set? Physically what do you understand by initial and final setting times?
5. What is the weight of the moving part of the Vicat apparatus and what are the dimensions of the plunger and initial setting time needle?
6. For finding the initial setting time of cement, what is the amount of water mixed with cement and what is the gauging time?
7. How do you carry out the experiment of finding the final setting time?

8. What should be the minimum initial setting time and maximum final setting time of cement according to IS Specifications?
9. What precautions should be taken while performing the experiment?
10. On what factors does this time of set depend?
11. How is the rate of setting of Portland cement controlled in the manufacturing process? Or how does fine grinding affect the time of set?
12. Why is gypsum added to the clinker in the production of cement? What is the effect of adding substances like coal to cement?
13. What is the difference in the meaning of two words, "setting" and "hardening"?
14. What percentage of water (by mass) of dry materials should be added to the cement in preparation of 1:3 standard sand mortars for compressive strength tests?

Notes and Comments

EXPERIMENT NO. 5: Soundness of Cement

Objective

To determine soundness and to decide the suitability of given cement sample using

1. *Le Chatelier method*
2. *Autoclave test*

Theory and Scope

Excess of *free lime* and *magnesia* present in cement slakes very slowly and cause appreciable change in volume after setting resulting in cracks, distortion and disintegration; thereby giving passage to water and atmospheric gases which may have injurious effect on concrete and reinforcement. This defect is known as *unsoundness.* The expansion is prevented by limiting the quantities of free lime and magnesia in the cement.

The test is designed to accelerate this slaking process by application of heat and to measure the extent of expansion and to see if this expansion is less than the specified limit. Indirectly, this test gives the extent of free lime and magnesia present in cement.

1. Le-Chatelier method

Apparatus

'Le Chatelier' apparatus, two glass plates, temperature controlled water-bath, scale, china dish to mix the paste, counter balance, weight box, graduated cylinder, trowel and 850 micron IS sieve.

The apparatus consists of a small split cylinder of spring brass or some other suitable metal of 0.5 mm thickness, 30 mm internal diameter and 30 mm height. On either side of the split are attached two indicators with pointed ends, the distance from these ends to centre of the cylinder is 165 mm. The mould is kept in good condition with the jaws not more than 0.5 mm apart.

Procedure

Step 1: Gauge 100 gm of cement with 0.78 times the water required to make a paste of standard consistency (approximately 30 per cent) in the manner explained in Experiment No. 4.

Step 2: Place the Le Chatelier apparatus on a glass plate and fill it with the paste, and level the top surface.

Step 3: Cover the mould with another piece of glass sheet and place a small weight on this covering glass-sheet; and immediately submerge the whole assembly in water at a temperature of 29 ± 2°C for 24 hours.

Step 4: Measure the distance D_1 between the indicator points after 24 hours and again submerge the mould in water at the temperature prescribed above.

Step 5: Bring the water to boiling point in 25 to 30 minutes and keep it boiling for 3 hours.

Step 6: Remove the mould from the water, allow it to cool and measure the distance D_2 between indicator points.

The difference $(D_2–D_1)$ between the two measurements gives the expansion of cement and it should not be more than 10 mm according to IS specifications (IS: 269-1989).

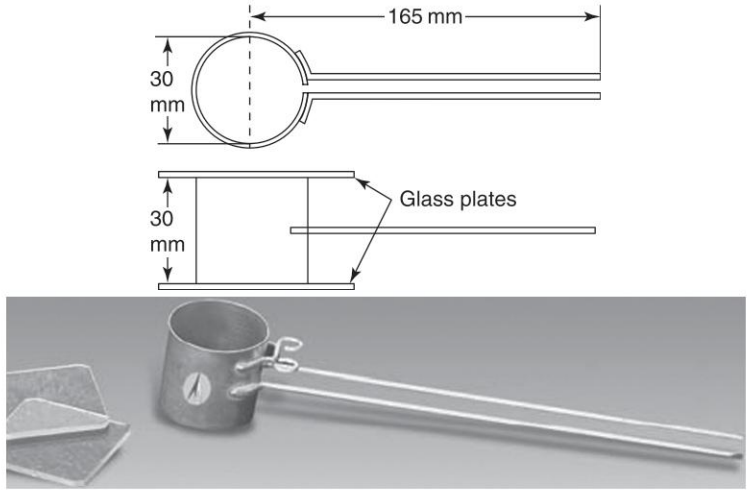


Fig. 2.5 *Le Chatelier test apparatus*

Observations and Calculations

Types and brand of cement				
Grade of cement				
Mass of cement sample w_c,	g			
Standard consistency p,	per cent			
Water added to the cement sample = $0.78 \times p \times w_c$,	ml			
Initial distance between indicator ends D_1,	mm			
Final distance between indicator ends D_2,	mm			
Cement expansion (D_2–D_1),	mm			

Since the average expansion of cement is……... mm, hence cement sample is……(sound / unsound.)

Precautions

1. The cement should be thoroughly mixed with fingers for at least one minute.
2. After filling the mould with cement paste and covering it with another glass plate, the mould with glass plates should be immediately placed in a water bath whose temperature is between 29 ± 2°C.
3. The distance between the tips of pointers should be measured, after cooling it completely.
4. During boiling, water level should not fall below the height of mould.

Discussion

The objective of this test is to determine the extent of free uncombined lime present in the cement. Hydration of this lime is accelerated by boiling, causing expansion. It is this expansion which is one of the causes of

cracking of cement concrete and hence the importance of this test. The shrinkage of this cement is kept to a minimum by immersing the paste in water.

When tested by this method, the unaerated ordinary, rapid-hardening, and low-heat Portland cements shall not have an expansion of more than 10 mm.

In the event of cement failing to comply with above requirements, a further test shall be made in the manner described above on another portion of the same sample. After aeration (done by spreading out to a depth of 75 mm at a relative humidity of 80 to 90 per cent for total period of 7 days) the cement is tested and the expansion of each of the three types of cement mentioned above shall not be more than 5 mm.

2. *Autoclave test*

Theory and Scope

Le Chatelier method detects *unsoundness* due to free lime only. The unsoundness due to magnesia present in the raw materials from which the cement is manufactured can be determined by *autoclave test.* This test is sensitive to both free magnesia and the free lime. In this test, high pressure steam accelerates the hydration of both magnesia and lime. The results of the autoclave test are affected by, in addition to the compounds causing expansion, the tricalcium aluminate (C_3A) content. The test thus gives no more than a broad indication of the long term expansion expected in service.

Apparatus

Weighing balance; Weights; Graduated glass cylinder; Trowel; Length comparator: Moulds of size $25 \times 25 \times 250$ mm

Procedure

Step 1: Oil the mould lightly with a layer of mineral oil. Set the reference points which are clean and free from oil.

Step 2: Take 500 g of cement and gauge it with a weighed quantity of water just sufficient to give a paste of standard consistency (approximately 30 per cent).

Step 3: Fill the mould in one or two layers by pressing the paste into corners by thumb. Smooth the top surface with the flat side of trowel.

Step 4: Immediately upon completion of moulding, place the mould in a moist room (humidity chamber). After 24 hours, remove the specimens from the moulds.

Step 5: At 24 + ½ hours after moulding, remove the specimen from the moist atmosphere and measure the length L_1.

Step 6: Place the specimen in an autoclave at room temperature in a rack so that the four sides of each specimen shall be exposed to the air. Turn on the heat and allow the air to escape from the autoclave during the early portion of the heating period; the air vent valve shall be kept open until steam begins to escape. Close the valve and raise the temperature of autoclave at such a rate as will bring the gauge pressure of the steam to 2.1 MPa in 1 to 1½ hours from the time the heat is turned on. Maintain a pressure of 2.0 ± 0.1 MPa.

Step 7: Switch off the autoclave after three hours and cool it at such a rate so as to lower the pressure to 0.1 MPa in an hour and open the air vent valve to bring it to atmospheric pressure.

Step 8: Remove the specimen immediately from the autoclave and place it in the water of temperature above 90°C. Then cool the water to 27 ± 2°C in 15 minutes.

Step 9: Calculate the unsoundness as the percentage of the effective gauge length.

Observations and Calculations

Type of cement tested					
Gauge length,		mm			
Initial length of the specimen	L_1,	mm			
Final length of the specimen	L_2,	mm			
Expansion of the specimen	$(L_2 - L_1)$,	mm			
Unsoundness,		per cent			

Precautions

1. The moulds should be oiled before use.
2. The specimen should be so placed in the autoclave that its four sides are exposed to the saturated steam.
3. The autoclave should contain enough water to maintain an environment of saturated steam vapour during the entire period of test. Ordinarily 7 to 10 per cent of the volume of the autoclave shall be occupied by the water.
4. The temperature and pressure should be accurately controlled.

Viva-Voce Questions

1. What is meant by unsoundness?
2. What is likely the cause of unsound cement?
3. Of what importance is the soundness of cement?
4. How is the slaking process, i.e., hydration accelerated in this experiment?
5. Why is it necessary to keep the cement paste moist in the test while it is setting?
6. How may unsoundness can be determined?
7. What is the maximum expansion for ordinary Portland cement?
8. What precaution should be taken while performing the test?
9. Distinguish between expansion and shrinkage of cement paste.
10. What is the requirement in the specifications for the cement which fails to pass the soundness test as received?
11. What is the cause of free lime in cement?
12. What precautions do manufacturers take to prevent unsound cement?

Notes and Comments

EXPERIMENT NO. 6: Compressive Strength of Cement

Objective

To determine the compressive strength of 1:3 cement-sand mortar cubes after three days and seven days curing.

Theory and Scope

The compressive strength of cement mortar is determined in order to verify whether the cement conforms to IS specification (IS: 269-1989) and whether it will be able to develop the required compressive strength of concrete. According to IS: 269-1989, the ultimate compressive strength of cubes of cement sand mortar of the ratio 1: 3, containing (P/4+3.0) per cent of water should be as given in Table 2.1.

Apparatus

Universal testing machine or compression testing machine; Cube moulds; Vibrating Machine (12000 ± 400 rpm; amplitude of vibration 0.055 mm; 3 phase motor with automatic cut off); Crucible for mixing cement and sand; Measuring cylinder; Trowels; Non-porous plate and Balance with weight box.

Description of Apparatus

Typical vibrating machine shown in Fig. 2.6 consists of a heavy frame, on one side of which is fixed an electric motor and on the other side, there is a set of four springs. Above these springs is fixed a mould on another frame and this mould is removable. With the frame carrying mould, a pulley is attached and the belt runs on the pulley and the motor. The mould is fitted with a detachable hopper at the top. Through the hopper mortar or concrete can be put into the mould without any loss of sample. A weight is attached to the frame to keep the mould in balance. When motor is started, it vibrates the mould at the rate of 12000±400 cycles/minute. These vibrations are simple harmonic at 90° out of phase. The normal running speed of electric motor is 12000 ± 400 rpm. Due to the load attached to the frame, the C.G. of machine falls near the weight.

Moulds The cube mould for compression test has 70.5 mm side (5000 mm^2 face). It is constructed in such a way that it can be split up in parts in order to take out the cube without any damage. The base plate is non-porous and of such a size that there should be no leakage of water from the bottom. Multiple moulds containing three moulds in a line are also available, but they require different vibrating platform.

The side of the cube mould is 70.5 ± 1.27 mm and angle between adjacent interfaces should be 90 ±0.5 degrees.

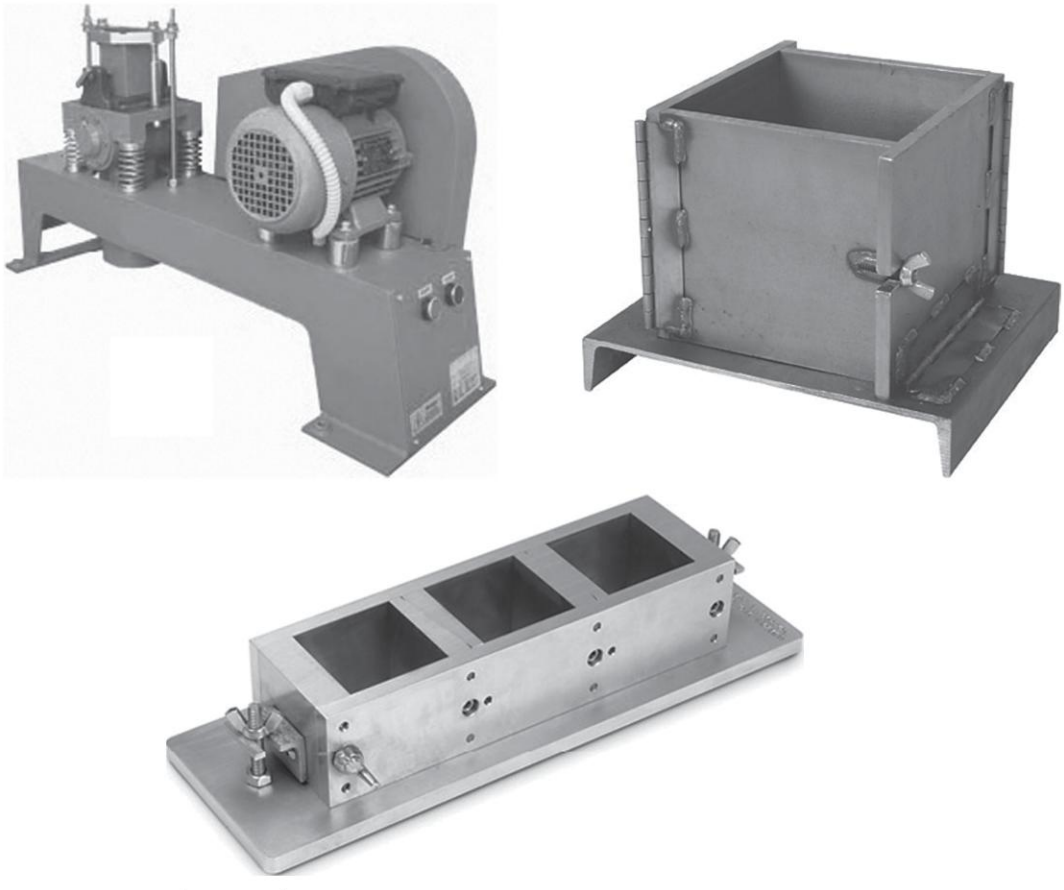


Fig. 2.6 *Apparatus for compressive strength of cement*

Procedure

Step 1: Calculate the material required; the quantities of cement and standard sand for each cube shall be as follows and mixed separately:

Cement = 200 g

Standard sand = 600 g

Water $= \left(\frac{P}{4} + 3.0\right)$ per cent = 84 g

where P is percentage of water for standard consistency.

Step 2: Place the mixture of cement and standard sand in the proportions of 1:3 by mass on a non-porous plate or china dish and mix it dry with a trowel for 1 minute and then with water until the mixture is of uniform colour. The percentage of water to be used shall be $\left(\frac{P}{4} + 3.0\right)$ per cent of dry mass of cement and sand. The time of mixing (gauging) shall not be less than 3 minutes and if the time taken to obtain a uniform colour exceeds 4 minutes, the mixture shall be rejected and the operation is repeated with a fresh quantity of cement, sand and water.

Step 3: Place the assembled mould on the table of the vibrating machine and firmly hold it in position by means of suitable clamps. Securely attach the hopper at the top of the mould to facilitate filling and this hopper shall not be removed until completion of the vibration period.

Step 4: Immediately after mixing the mortar as explained above, fill the entire quantity of mortar in the hopper of the cube mould and compact by vibration. The period of vibration shall be 2 minutes at the specified speed of 12000 ± 400 cycles per minute.

Step 5: Remove the mould from the machine and keep it at a temperature of 27 ± 2°C in an environment of at least 90 per cent relative humidity for 24 hours after completion of vibrations.

Step 6: At the end of this period, remove the cube from the mould and immediately submerge it in clean and fresh water and keep there until taken out just prior to breaking. The water in which the cubes are submerged shall be renewed after every 7 days and be maintained at a temperature of 27 ± 2°C. Keep the cubes wet till they are placed in machine for testing.

Step 7: Test the specimens at the required periods.

Test three cubes at the periods mentioned below, the periods being reckoned from the completion of vibration. The compressive strength shall be the average of the strengths of the three cubes for each period:

(a) Ordinary Portland cement: 3 and 7 days.
(b) Rapid hardening Portland cement: 1 and 3 days.
(c) Low heat Portland cement: 3, 7 and 28 days.

The cubes shall be tested on their sides, the load being applied at the rate of 35 MPa/minute.

Observations and Calculations

1. Ordinary Portland cement				
Sl. No.	**3-day strength**		**7-day strength**	
	Load, kN	Strength, MPa	Load, kN	Strength, MPa
1. 2. 3.				
Average				

2. Rapid hardening Portland cement				
Specimen No.	**1-day strength**		**2-day strength**	
	Load, kN	Strength, MPa	Load, kN	Strength, MPa
1. 2. 3.				
Average				

3. **Low heat Portland cement**				
Specimen No.	**7-day strength**		**28-day strength**	
	Load, kN	Strength, MPa	Load, kN	Strength, MPa
1. 2. 3.				
Average				

Precautions

1. The mortar shall not be compressed into the moulds with hand.
2. Neglect the results which fall outside by 15 per cent of the average results on either side.
3. The cubes should be tested on their sides and not on their faces.
4. The inside of the cube mould should be oiled to prevent the mortar from adhering to the sides of the mould.
5. The size of sand particles should be such that not more than 10 per cent by mass shall pass a 60 micron IS sieve and shall completely pass through a 85 micron IS sieve.
6. The time of wet mixing shall not be less than 3 minutes. If the time of mixing exceeds 4 minutes to bring a uniform colour, the mixture shall be rejected and fresh mortar should be prepared.
7. The cubes shall not be allowed to dry until they are broken.

Discussion

The crushing strength test for cement has established itself as superior to the tensile strength test. Results are less variable between different laboratories. In addition there is good correlation between the strength of cement-sand mortar cubes and strength of concrete made with same cement. The strength of such a mortar is nearly equal to that of concrete having a water-cement ratio of 0.45 by mass. The relation between compressive strength of cement mortar and concrete is shown in Fig. 2.7.

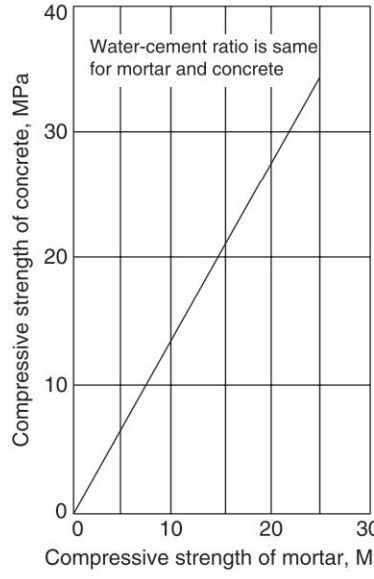


Fig. 2.7 *Relationship between compressive strength of cement-mortar and concrete*

Viva-Voce Questions

1. What is the significance of this test?
2. What are ultimate strengths of cement-sand mortar cubes after 3 days and 7 days?
3. What is the percentage of water (by mass of dry materials) added in preparation of 1:3 cement standard sand mortar for compressive strength tests? How can it be ensured that the cement and sand are thoroughly mixed?
4. What is the rule for mixing water to the sand cement mix for preparing test specimens for compressive strength of cement?
5. What are the requirements for the moulds, including base and cover plates?
6. What is the minimum number of specimens of a kind to be made for each age at testing?
7. What are the requirements concerning the removal of the cubes from the moulds?
8. How is the curing of test specimen done? Why should the specimen not be allowed to dry until they are tested?
9. What is the rate of loading?
10. How is the age of specimen reckoned?
11. What difference in compressive strength can occur by varying the rate of application of load from the slowest to fastest rates?
12. What precautions should be taken during the determination of compressive strength?

Notes and Comments

EXPERIMENT NO. 7: Effect of Curing on Compressive Strength

Objective

To determine the effect of curing conditions upon compressive strength of (1: 3) Portland cement mortars.

Scope

This test is designed to show the effect of various temperature and moisture conditions during curing period upon the compressive strength of Portland cement mortars. The effect of moisture will be shown by curing some specimens moist while others will be stored in dry air.

Apparatus

Compression testing machine; Balance with a set of weights; Moulds; Crucible for mixing cement and sand; Measuring cylinder; Trowels; Non-porous plate and Vibrating machine.

Procedure

Step 1: Calculate the materials required for each cube specimen.

Cement = 200 g

Sand = 600 g

Water $= \left(\frac{P}{4} + 3.0\right)$ per cent of the weight of aggregate = 84 g

where P is percentage of water for standard consistency.

Step 2: Place in the mixing crucible the mixture of cement and sand (which is washed, surface dried and sieved through the standard sieve) in the proportion of 1:3 and mix it dry with a trowel for one minute and make a crater in the centre. Water measuring 84.0 ml is added to this crater. The material at outer edge is turned into the crater within 30 seconds. After allowing an additional 30 seconds for the absorption of the water; mixing is completed by vigorous and continuous turning and stirring for 2 minutes. If this time taken to obtain a uniform colour exceeds 4 minutes, the mixture shall be rejected and operation is repeated for fresh quantity of cement.

Step 3: Place the assembled, lightly oiled (inside) mould on the table of the vibrating machine and firmly hold it in position.

Step 4: Immediately after mixing the mortar; place the entire quantity of mortar in hopper of the cube and compact it by vibrations for two minutes at the specified speed of 12000 ± 400 cycles per minute. In case of compaction by hand fill the cube mould in three equal layers tamping each layer 25 times.

Step 5: Mark the specimen giving group and specimen identification, date, etc., and cover the specimens in moulds with moist gunny bags.

Step 6: Remove the specimens from the moulds after 24 hours.

Step 7: Keep three specimens in sun; three in shade and three in water for effecting different conditions of curing.

Step 8: Test all the specimens at the age of 21 days after measuring lateral dimensions of each specimen to the nearest 0.1 mm.

Precautions

1. The mortar should not be compressed into the mould with hand.
2. Neglect the results which fall outside by 15 per cent of the average results on either side.
3. Cubes should be tested on their sides; not on their faces.
4. The inside of the cube moulds should be oiled to prevent the mortar from adhering to the sides of the moulds.

Observations and Calculations

Curing condition	Specimen No.	Load, kN	Strength, MPa	Average strength, MPa	Time of breaking, seconds	Rate of loading	Remarks
Sun dried at temperature of (say 40°C)	1 2 3						
Air dried in shade (say at 35°C)	4 5 6						
Water cured at temperature of (say at 30°C)	7 8 9						

Discussion

The curing conditions with relation to moisture and temperature influence the strength of the concrete by affecting the hydration of the cement. The longer is the period of moist storage the greater is the strength. Exposure to air with constant drying arrests the hydration. The rate and extent of drying depends on the mass of concrete relative to the area of exposed surface as well as humidity of surrounding air. It will be seen that the strength of specimen air dried in shade is 1½ times the strength of specimen dried under direct sun. Similarly the specimens cured under water have 3 to 4 times the strength of those dried under sun.

1. **Effect of temperature** The temperature of the specimen at the time of test has marked influence on *indicated strength.* Higher the temperature lower is the indicated strength. An average variation of 2 to 4°C in testing temperature results in a difference in strength of 1 per cent. The standard tests are made under temperature of 27 ± 2°C.
2. **Effect of rate of loading** The more rapid the static loading of concrete the higher will be the *observed strength.* The loading in hydraulic machine is to be applied at a constant rate within the range 0.15 to 0.35 MPa/sec; normally 0.25 MPa/sec is employed.

Viva-Voce Questions

1. What is meant by curing?
2. What is the scope of this experiment?
3. How do the curing conditions with relation to moisture and temperature influence the strength of cement-sand mortars?
4. Why does wet curing produce a concrete superior to that kept dry?
5. Discuss the influence of temperature and moisture conditions while curing on the strength of cement mortars.
6. Would you expect that compressive strength of concrete in road slabs and building slabs to be effected by the similar curing conditions about the same degree as for your mortar specimens? Explain.
7. Discuss the effect of moisture condition of specimen at the time of test.
8. What should be the routine precautions taken in transferring specimens from the job to the laboratory for test or for storage and test?
9. What precautions should be taken during the test?

Notes and Comments

NATIONAL STANDARDS

1. IS 650-1991 (2nd revision, reaffirmed 2008): *Specification for Standard Sand for Testing of Cement*
2. IS 3535-1986 (1st revision, reaffirmed 2008): *Methods of Sampling Hydraulic Cement*
3. IS 4031(Part 1) -1996 (2nd revision, reaffirmed 2011): *Methods of Physical Tests for Hydraulic Cement:* Part 1: *Determination of Fineness by Dry Sieving*
4. IS 4031(Part 2) -1999 (2nd revision, reaffirmed 2008): *Methods of physical tests for hydraulic cemen*t: Part 2: *Determination of Fineness by Specific Surface by Blaine air Permeability Method*
5. IS 4031(Part 3-13) -1988 (1st revision, reaffirmed 2009): *Methods of Physical Tests for Hydraulic Cement*
6. Part 3: *Determination of Soundness*
7. Part 4: *Determination of Consistency of Standard Cement Paste*
8. Part 5: *Determination of Initial and Final Setting Times*
9. Part 6: *Determination of Compressive Strength of Hydraulic Cement* (*other than masonry cement*)
10. Part 7: *Determination of Compressive Strength of Masonry Cement*
11. Part 8: *Determination of Transverse and Compressive Strength of Plastic Mortar Using Prism*
12. Part 9: *Determination of Heat of Hydration*
13. Part 10: *Determination of Drying Shrinkage*
14. Part 11: *Determination of Density*
15. Part 12: *Determination of Air Content of Hydraulic Cement Mortar*
16. Part 13: *Measurement of Water Retentivity of Masonry Cement*
17. IS 4031(Part 15) -1991 (reaffirmed 2009): *Methods of Physical Tests for Hydraulic Cement: Part 15: Determination of Fineness by Wet Sieving*
18. IS 5513-1996 (2nd revision, reaffirmed 2011): *Specification for Vicat Apparatu*s
19. IS 5514-1996 (1st revision, reaffirmed 2011): *Specification for Apparatus used in Le Chatelier Tes*t
20. IS 5516-1996 (1st revision, reaffirmed 2011): *Specification for Variable Flow-type Air-Permeability Apparatus* (*Blaine type*)
21. IS 5536-1969 (reaffirmed 2009): *Specification for Constant Flow-type Air-Permeability Apparatus* (*Lea and Nurse type*)

REFERENCES

1. Gambhir, M. L., *Concrete Technology,* 4th Edition, McGraw-Hill Education, 2009.
2. Gambhir, M. L. and Neha Jamwal, *Building Materials*: *Products, Properties and Systems*, McGraw-Hill Education, 2011.

BUILDING LIMES

Chapter 3

This section covers procedures for the tests generally performed on building limes. The tests include lime reactivity, soundness of lime, strengths of building limes, lime reactivity of pozzolanic material, available lime content or purity of lime. The physical characteristics of limes as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

3.1 INTRODUCTION

Lime is an important basic material used in building construction mainly in *mortars*. There are two forms of lime: quicklime and hydraulic lime. Quicklime is produced by burning stone containing calcium carbonate at temperatures above 900°C for several hours. In this process known as calcining, the carbon dioxide in the calcium carbonate is driven off and the remaining solid product is *quicklime*.

Quicklime is an unstable and hazardous product and is therefore normally slaked or hydrated with water to produce *hydrated lime*. When (a limited amount of) water is added to quicklime it reacts with water and liberates heat. After hydration ceases to evolve heat, the resulting product is a fine, dry white powder. This white powder is *calcium hydroxide* or *slaked lime*. The process is called *slaking of lime*. The form into which lime is slaked depends on the intended use. In the case of lime for use in plasters and mortars, this could be either in the form of putty or a dry powder.

When quicklime is mixed with larger amount of water from two to three times its weight, chemical reaction takes place which evolves sufficient heat to bring the entire mass to a boil. On cooling, the semi-fluid mass stiffens to *putty*. This slaked quicklime putty, when cooled and preferably screened, is the material used in construction.

Hydraulic lime is always a factory-made product, whereas quicklime putty is almost always a job-slaked product.

3.1.1 Cementing Action of Lime

The *cementing action* of lime is based on the property of *carbonation* of calcium hydroxide wherein it combines with carbon dioxide from the atmosphere to form calcium carbonate which has cementing properties. Sand is added in lime mortar not only to add bulk (for economy) to it, but also to make mortar porous so that air can circulate freely through the mortar mass to assist carbonation. The minerals like pozzolanas which have reactive silica can combine with lime and produce cementing compounds in the presence of moisture and do not require air for reaction. Thus, the lime in which the reactive silica (Pozzolanas) are naturally present or are added in it, can set even under water, and hence may be called *hydraulic lime*.

3.1.2 Synergy with Pozzolana

Pozzolana, an essentially silicious material which while in itself possess little or no cementitious properties will, in finely divided form and in the presence of water, react with calcium hydroxide at ambient temperature to form compounds possessing cementitious properties. The term *Pozzolana* includes natural volcanic mate-

rial having pozzolanic properties as also other natural and artificial materials, such as diatomaceous earth, calcined clay, fly ash, etc. Pozzolanas conforming to relevant standards are generally used in the manufacture of Portland pozzolana cement (PPC) either by blending with finished Portland cement or inter-grinding with Portland cement clinker.

Fineness and average compressive strength of pozzolana that is to be blended with finished Portland cement to produce Portland Pozzolana cement, when tested in accordance with the procedure specified by IS 1727: 1967 shall not be less than 320 m^2/kg or 4.0 MPa. Average compressive strength in lime reactivity test of such pozzolana shall be carried out at the fineness at which pozzolana has been ground for blending.

3.2 PROPERTIES OF LIME

Slaked lime which is a white powder can be used in a wide range of applications. The basic useful characteristics of lime are: (i) It re-carbonates by reacting with CO_2; thus, provides cementing capability to lime; (ii) It is alkaline in nature; thus increases acid resistance; (iii) Calcium hydroxide undergoes pozzolanic reaction with reactive silicates, resulting in calcium silicates which are the cementing materials and (iv) Calcium carbonate precipitates when carbon dioxide passes through lime mortar thus sealing the minor cracks. The hydrated lime is only slightly soluble in water and the solubility is inversely proportional with temperature.

The physical and chemical properties of various classes of limes are specified by IS: 4031-1968 and IS: 6932-1973 Parts (3 to 10). The physical properties of various classes and types of limes are listed in Table 3.1 for reference.

Table 3.1 *Physical requirements of building limes [IS 6932-1973 (Parts 1 to 11, RA 2009)]*

Characteristics of lime	Class and type of building Limes										Test method or test reference
	A	B		C		D		E	F		
	Hyd	Quick	Hyd	Quick	Hyd	Quick	Hyd	Hyd	Quick	Hyd	
1. Fineness:											
(a) Residue on 2.36 mm IS sieve, per cent, max	Nil	-	Nil	-	Nil	-	Nil	Nil	-	Nil	IS 6932-1973 (Part 4)
(b) Residue on 300 μ IS sieve, per cent, max	5	-	5	-	Nil	-	Nil	5	-	5	
(c) Residue on 212 μ IS sieve, per cent, max	-	-	-	-	10	-	10	-	-	-	
2. Residue on slaking:											
(a) Residue on 850 μ IS sieve, per cent, max	-	10	-	5	-	5	-	-	10	-	IS 6932-1973 (Part 3)
(b) Residue on 300 μ IS sieve, per cent, max	-	-	-	5	-	5	-	-	-	-	

Table 3.1 *Contd.*

Characteristics of lime	Class and type of building Limes										Test method or test reference
	A	B		C		D		E	F		
	Hyd	Quick	Hyd	Quick	Hyd	Quick	Hyd	Hyd	Quick	Hyd	
3. Setting time:											
(a) Initial set, min, hour	2	-	-	-	-	-	-	2	-	-	IS 6932-1983 (Part 11)
(b) Final set, min, hour	48	-	-	-	-	-	-	48	-	-	
4. Compressive strength, minimum, MPa											
(a) at 14 days	1.75	1.25	1.25	-	-	-	-	1.0	1.25	1.25	IS 6932-1973 (Part 7)
(b) at 28 days	2.8	1.75	1.75	-	-	-	-	1.75	1.75	1.75	
5. Transverse strength, minimum, MPa											
(a) at 28 days	1.0	0.7	0.7	-	-	-	-	0.7	0.7	0.7	
6. Workability bumps, max	-	-	-	12	10	12	10	-	-	-	IS 6932-1973 (Part 8)
7. Volume yield ml/g, min	-	-	-	1.7	-	1.4	-	-	-	-	IS 6932-1973 (Part 6)
8. Soundness, Le-Chaterlier expansion	5	-	5	-	-	-	-	10	-	10	IS 6932-1973 (Part 9)
9. Popping and pitting	Free	-	Free	-	Free	-	Free	-	-	Free	IS 6932-1973 (Part 10)

3.3 CLASSIFICATION OF LIME

Limes are broadly classified as: (i) fat lime and (ii) hydraulic lime. The hydraulic lime differs from fat lime in the process of hardening. IS: 712-1973 has classified lime in to six classes, Class A to Class F. The lime containing more than 30 per cent impurities like clay is called *poor lime*. The compressive strength of standard A class lime and cement mortars at 14 and 28 days are 1.75 and 2.8 MPa, respectively; whereas the corresponding strengths of lowest grade cement (33 grade) are 22.0 and 33.0 MPa, respectively.

3.4 TESTS FOR BUILDING LIMES

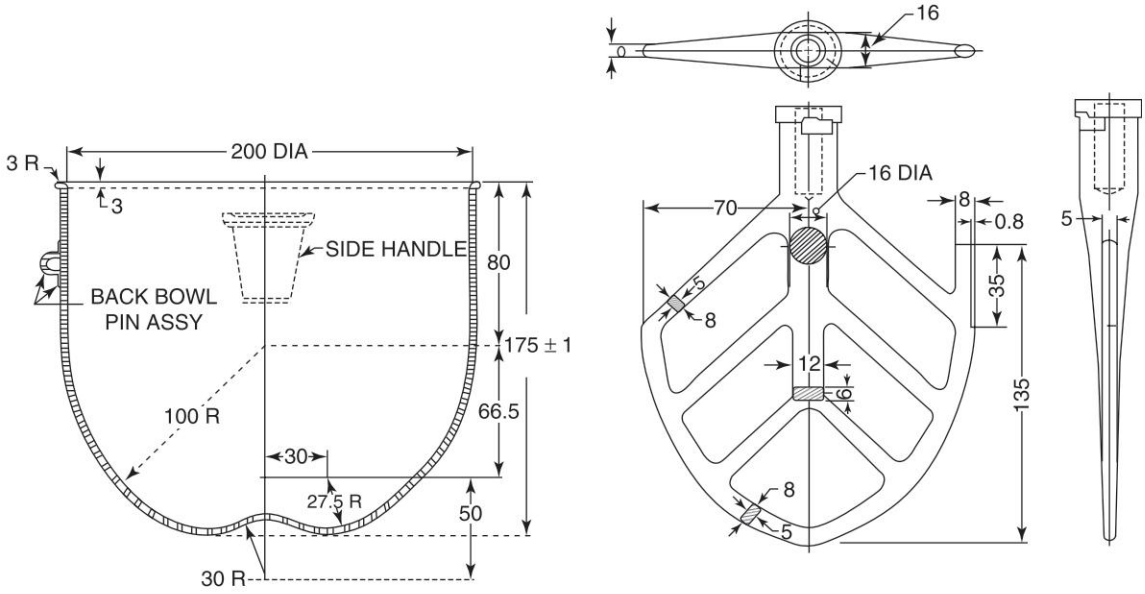
The tests generally performed on lime can be classified as: laboratory tests and field tests. IS 6932-1973 has specified eleven laboratory tests for limes.

3.4.1 Test Samples for Physical Tests

Test samples of lime should be collected as quickly as possible so that the material does not deteriorate. From each lot, three test samples are taken for quick lime as well as for hydraulic lime. The sample size for quick lime is given in Table 3.2 and that for hydraulic lime should not be less than 5 kg.

Table 3.2 *Test sample size of quicklime*

Lot size, tonne	Gross sample size for quicklime, kg	
	Lump quicklime	*Powdered quicklime*
Up to 100	500	250
101 to 300	1000	500
301 to 500	1500	750
501 to 1000	2000	1000



(a) Mixing bowl (b) Mixer blade

Fig. 3.1 *Details of mortar mixer*

3.4.2 Standard Equipment for Laboratory Tests

Following standard equipment is commonly required for testing lime:

1. **Mortar mixer** The mixer is an electrically driven mechanical device of the epicyclical type which consists essentially of a stainless steel mixing bowl with a nominal capacity of five litres of the shape and dimensions as shown in Fig. 3.1(a) and provided with means by which it can be securely fixed to the mixing frame during mixing process, and a mixer blade of the form and dimensions shown in Fig. 3.1(b) revolving about its axis as it is driven in a planetary movement around the bowl by an electric motor. The first or slow speed shall revolve the paddle or blade at a rate of 140 ± 5 rpm, with a planetary motion of approximately 62 ± 5 rpm. The second speed shall revolve the paddle or blade at a rate of 285 ± 10 rpm, with a planetary motion of approximately 125 rpm. The electric motor shall have a power of about 150 W. Generally, the mixing is done at first or slow speed. The mixer is capable of adjustment so that when the bowl is in the mixing position the clearance between the lower end of the blade and the bottom of the bowl is approximately 2.5 mm; but not less than the approximate diameter of a grain of the standard sand.

2. **Standard flow table** The flow table used to determine the workability or consistency of mortars and building limes is illustrated in Fig. 3.2. These are available in two models, i.e., manual and motor operated. Motor operated models are driven by a motor speed reducer and the number of drops are preset on the counter, which stops automatically with the machine at the end of the cycle. These are supplied complete with flow mould and tamping rods. Some flow tables also include the filling hopper.

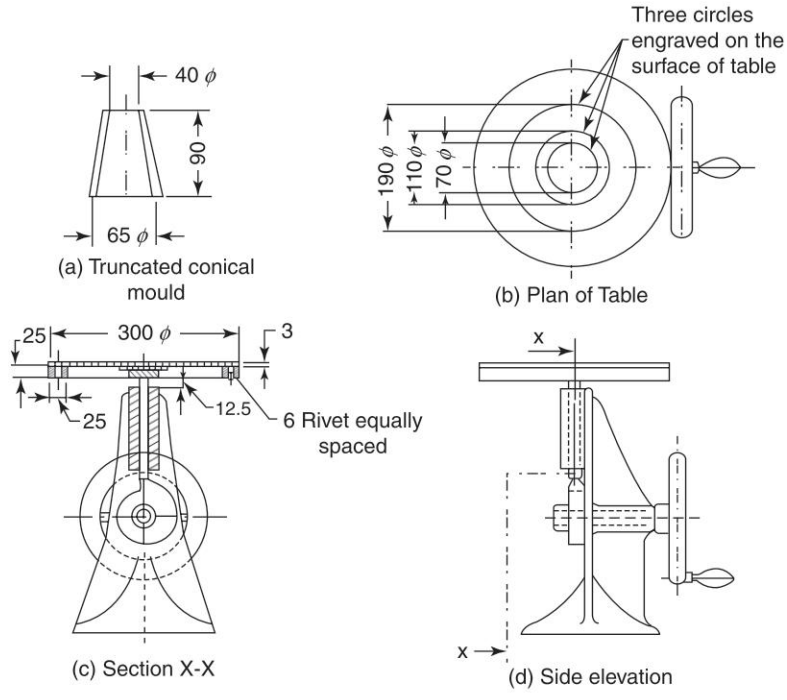


Fig. 3.2 *Standard flow table and truncated conical flow mould*

3.4.3 Tests for Building Limes

The tests conducted on building limes can be divided in two categories:

1. Routine tests and
2. Special tests

1. Routine tests The commonly used routine tests are:

(a) Determination of residue on slaking of quick lime [*IS: 6932* (*Part 3*)] Sample of quick lime is sieved through 2.36 mm IS sieve and the residue, if any, is broken and sieved again until the whole quantity passes through the sieve. The quantity of water required for slaking is usually four times the mass of quick lime, however, for certain high calcium limes it may be as high as eight times.

Two separate samples of quicklime each weighing 5 kg are slaked by adding them in small quantities, in requisite amount of water with temperature maintained at 50°C and 100 ± 2°C within 5 minutes. With the temperature maintained at this level, the mix is stirred continuously for one hour. The product is allowed to stand for 24 hours from the time the quicklime was added to water and is allowed to cool gradually to room temperature. The product is stirred at least twice during this period; the last stirring is done within one hour before the expiration of 24 hours. The supernatant liquid is sieved through 850 micron IS sieve and subsequently through 300 micron IS sieve; this is followed by sieving the remainder

product after stirring it thoroughly. A temporary filter cloth is fitted to the vessel. The contents of the slaking vessels are transferred on to the sieves by washing the vessel with a jet of water. The residues are washed with a jet of water and then dried at 100 ± 10°C to constant mass. The residues on the two sieves are weighed separately and are reported as per cent of the mass of quicklime test sample.

(b) *Fineness test* [*IS: 6932* (*Part 4*)] The sieves are arranged one above the other with the coarser sieves at the top and the finer sieves at the bottom. Sieving is done with a gentle wrist motion. A sample of 100 g of the hydrated lime is placed on the top sieve and is washed through the sieves with a moderate jet of water for not more than 30 minutes. The residue on each sieve is dried at 100 ± 10°C to constant mass and weighed. The result is expressed as a per cent of the mass of hydrated lime sample.

(c) *Workability test* [*IS: 6932* (*Part 8*)] The test is conducted on a standard flow table and a truncated conical mould shown in Fig. 3.2. For testing hydrated lime, the lime putty is prepared by thoroughly mixing 500 g of hydrated lime with an equal mass of water at a temperature of 27 ± 2°C and kept for 24 hours. The soaked material is then thoroughly mixed and knocked up to produce plastic putty, by passing the material twice through the mixer.

The lime putty is adjusted to standard plastering consistency, which is indicated by an average spread of the lower part of lime putty to 110 mm with a permissible deviation of not more than 1 mm, when subjected to one bump on the standard flow table. If consistency is too stiff, more water is added, and if too wet, a small portion of water is withdrawn by placing the material for a short period on a clean absorbent surface.

The putty is filled in moulds in such a way that no air bubbles or voids are trapped inside. The temperature during the test is maintained at 27 ± 2°C. The top of the table is cleaned and dried. The cone of the material is applied to the centre of the table and the mould is withdrawn. The handle of the flow table is turned steadily and evenly at the rate of one turn per second. The average spread of material is determined by measuring three diameters of approximately 60° apart and taking the average. The number of bumps required to attain an average spread of 190 mm.

(d) *Soundness test* [*IS: 6932* (*Part 9*)] The test is performed to determine the quality, i.e., the unsoundness or disintegration property of lime using the Le Chatelier apparatus. Small cores of overburnt material may be present in the lime hydrate. They will slake very slowly. If a lime containing such cores is used in a plaster, at some future time the core will slake in the wall causing the material around it to pop out, hence the commonly known defect the popping. To avoid this defect, the lime hydrate supplied must be completely slaked, without any core of over burnt material.

The test consists of mixing in dry state the cement, hydrated lime and standard sand in the ratio 1:3:12; The mix is then gauged and mixed with 12 per cent by mass of water calculated on the dry mixture.

Three test moulds lightly greased internally are placed on a small non-porous plate and filled with the mortar under test. The moulds are then covered with non-porous plates and small weights are placed over them. All the three moulds are left undisturbed for one hour. At the end of this period, the distance between the indicator pointers is measured. The apparatus is then kept in damp air for 48 hours and is thereafter subjected to steam at atmospheric pressure for three hours. The sample is cooled to room temperature and the distance between the pointers is measured again. The difference in the two measurements after deduction of 1 mm, to allow for expansion of added cement, is the net expansion due to lime. This should not be more than 10 mm.

The test determines how effectively the quicklime slakes and is used to control the quality of lime produced during the course of production.

(e) *Setting time test* [*IS: 6932* (*Part 11*)] The initial and final setting times of hydrated lime are determined using Vicat's apparatus in the same way as that for Portland cement. Here in this test, lime putty is used instead of cement mortar.

(f) *Strength tests* [*IS: 6932* (*Part 7*)] The standard strengths of the types of hydraulic lime and natural hydraulic lime are the compressive strengths determined in accordance with IS: 6932 (Part 7) after 14 and 28 days and shall have the values given in Table 3.3.

i. Compressive strength test The method consists of preparing twelve 50-mm side cube specimens using 1: 3 standard lime-sand mortar and keeping them undisturbed for 72 hours in an atmosphere of at least 90 per cent relative humidity and at a temperature of 27 ± 2°C. At the end of this period, the specimens are taken out of the mould and kept in the air for four days. Six of the 12 specimens are cured in water for 7 days and tested in a compression testing machine for 14-day compressive strength with the load increasing uniformly from zero to a rate of 150 ± 15 N per minute till specimen crushes. The remaining six cubes are cured for 21 days and tested for the compressive strength at 28 days. The average strength of six specimens obtained by dividing the crushing load by the area of the cube provides the 14 and 28-day compressive strengths of mortar.

ii. Transverse strength test The method consists of preparing six test specimens of size 25 × 25 × 100 mm using mortar obtained by mixing standard sand and lime sample (quick or hydrated lime) in the ratio 1:3. The filled mould together with its base plate are covered on to with a similar plate are cured for 28 days in a suitable container in an atmosphere of at least 90 per cent relative humidity and at a temperature of 27 ± 2°C. At the end of this period, the specimens are taken out of the mould and immersed in water for 30 minutes. Then the specimen is supported on two rollers of transverse testing machine for limes spaced at 80 mm and a concentrated load is applied at the midpoint by means of another roller of same size. The load is applied steadily and uniformly at a rate of 150 ± 15 N per minute till the specimen breaks.

Transverse strength or modulus of rupture at 28 days,

$$\sigma_\tau = \frac{M}{Z} = \frac{WL}{4} \times \frac{6}{bh^2} = \frac{3WL}{2bh^2} \text{ MPa}$$

where

W = breaking load in N,

L = spacing between the rollers in mm and

b, h = width and depth of specimen, respectively.

For L = 80 mm; b = 25 mm; h =25 mm. $\sigma_\tau = 0.00768$ W MPa

(g) *P*opping and pitting test [IS: 6932 (Part 10)] To determine the soundness of fat lime, lime pats are prepared by mixing 70 g of hydrated lime with 70 ml of clean water at a temperature of 27 ± 3°C and kept for two hours. The lime putty so obtained is thoroughly mixed and knocked up with a trowel. The putty is then spread over a non-porous surface and 10 g of Plaster of Paris is spread evenly over it and the whole mass mixed rapidly and thoroughly for two minutes. The gauged material is then pressed in small quantities with the aid of a broad palette knife or spatula into a ring mould 100 mm in diameter and 5 mm deep. A flat pat of putty is formed by smoothening off the top surface with not more than 12 strokes of knife. This entire process should be completed within 5 minutes from the time of adding Plaster of Paris.

Four such pats are formed and left for 30 minutes. These are then transferred to a drying oven maintained at a temperature between 40 ± 5°C and are kept for 16 hours. Any test pat showing cracks is rejected. The test pats are then placed horizontally in a steam boiler and subjected to the action of saturated steam for three hours. The pats are then examined for disintegration popping or pitting. If any of these phenomena occurs the lime is considered to be unsound.

2. Special tests The special tests generally conducted are:

(a) Loss on ignition test (LOI) The loss on ignition test can be conducted to monitor the relative degree of calcination. It consists in strongly heating a sample of the material at a specified temperature, allowing volatile substances to escape, until its mass ceases to change. The simple test typically consists of placing a few grams of the material in a tare, pre-ignited crucible and

determining its mass, placing it in a temperature-controlled furnace for a set time, cooling it in a controlled (e.g., water-free, CO_2-free) atmosphere, and determining the mass. The process may be repeated to show that mass change is complete.

(b) *Reactivity assessment of quicklime* Addition of water to quicklime to produce a lime hydrate results in the evolution of heat. Lightly burnt quicklime reacts at a faster rate than the hard over burnt quicklime. This phenomenon is used in this test to monitor the reactivity and hence the degree of burning of the quicklime.

(c) *Determination of available lime by the rapid sugar test* Method consists in taking 500 mg sieved hydrated lime sample in a flask containing 20 ml distilled water. The corked flask is swirled and heated for two minutes. To this is added 150 ml water and 15g granulated sugar and flask re-corked and shaken at intervals for five minutes. The solution is allowed to stand for 30 minutes to one hour. The solution in the flask is titrated with the standard hydrochloric acid (HCl) solution with 2 drops phenolphthalein using standard procedure. The reading is noted; 1 ml of acid solution is equivalent to one per cent available lime expressed as CaO.

(d) *Volume yield of quicklime [IS: 6932 (Part 6)]* When quicklime is mixed with three to four times its mass of water, a chemical reaction takes place. The calcium oxide combines with water to form calcium hydroxide, and sufficient heat is evolved to bring the entire mass to a boil. The resulting product is a suspension of finely divided calcium hydroxide (and magnesium hydroxide or oxide if dolomitic lime is used) in water. This slaked quicklime putty, when cooled and preferably screened, is the material used in construction. On cooling, the semi-fluid mass stiffens to a putty of such consistency that it may be shoveled or carried by the desired mode.

The yield of putty varies depending on the type of quicklime, its degree of burning, and slaking conditions, and usually amounts 70 to 100 ft^3 of putty per ton of quicklime. The principal use of the putty is in masonry mortars, where it is particularly valuable because of the high degree of plasticity or workability it imparts to the mortar.

The Southard Viscometer is used for adjusting the consistency of the putty. This instrument consists of a 50 mm internal diameter metal cylinder mounted on a wooden platform. A close fitting piston moves up and down without turning in this cylinder. Working stroke is 65 mm. A metal bridge is provided to measure the degree to which ejected cylinder of putty has slumped. The instrument is usually supplied complete with lime putty density vessel.

Sufficient putty is put in the filter cloth, which is folded in the form of bag. It is then suspended by cord above the vessel to allow the putty to drain. The process can be accelerated by applying moderate pressure by hand on the bag. The consistency of the putty is adjusted to give a slump of 13 mm. The density of putty is determined by weighing a known volume of this putty, using the density vessel.

Volume in ml/g of quicklime = $0.70 /(d - 1)$

where d is the density of lime putty.

3.4.4 Field Tests

IS 1624-1974 has specified a number of simple field tests for the limes. They can be readily performed at site.

1. **Visual examination** Class-C lime should be pure white in colour.
2. **Hydrochloric acid test** The test is carried to obtain an idea of the class and the carbonate content of lime. The method consists in pouring ½N hydrochloric acid to lime sample measuring full levelled tablespoon, placed in a test tube till effervescence ceases (about 100 ml acid would be required). The sample is left standing for 24 hours. High effervescence or bubbling action will indicate presence of

lime, and the volume of insoluble residue at the bottom of the tube the unwanted inert material (adulteration) in the lime. The following observations would be helpful:

(a) Formation of good thick gel which does not flow when test tube is inverted indicates class-A lime.
(b) Formation of flowing gel indicates class-B lime.
(c) No gel formation indicates class-C lime.

3. **Ball test** A ball, about the size of an egg made of the lime sample with just enough water (stiff lime paste), is stored for six hours and then placed in a basin of water. The following inferences can be drawn:

   (a) Expansion and disintegration of ball in a few minutes of its placement in water indicates class-C lime.
   (b) Little expansion with numerous cracks in the ball indicates class-B lime.
   (c) No adverse effect indicates that lime belongs to class-A category.

4. **Impurity test** A known weight of lime sample is mixed with water in a beaker and the solution is decanted. The residue is dried well in hot sun for eight hours and then weighed. If the residue is less than 10 per cent then the lime is good; 10 to 20 per cent it is fair and above 20 per cent it is poor.
5. **Plasticity test** Lime sample is mixed with water to a thick paste and left over night. It is then spread on a blotting paper like butter with a knife to test its plasticity. Good lime is plastic in nature.
6. **Workability test** To judge the workability of lime sample 1:3 lime-sand mortar is prepared and thrown on the surface on which it is to be used by a trowel; if it sticks well its workability is good. The area covered by the mortar and its quantity is recorded which indicate the workability of the lime mortar. It is a very crude field test performed with the actual mortar.

3.5 PRECAUTIONS WHILE HANDLING LIME

Lime can cause skin burns particularly when the skin is moist. The problem would be serious in humid and warm weather when there would be much perspiration. The skin protecting cream may be helpful. Usually workers, oil theirs skins to avoid skin problems. Hydrated lime dust can cause health hazards when breathed in. The workers handling lime must wear goggles, respirators, face masks, hand gloves, boots, etc.

3.6 PREPARATION OF LIME MORTARS

3.6.1 Slaking of Lime

If lime is supplied in the form of quick lime, it shall be slaked and converted into putty, if necessary, in accordance with IS: 1635-1992.

3.6.2 Mixing of Lime Mortars

1. **Putty and sand** Putty and sand in the specified proportions shall be mixed with or without addition of water on a dry waterproof platform or in mixer. The mix shall then be fed into a mortar mill with the required addition of water. The mortar shall be raked continuously during grinding. Water may be added during grinding as required, but care shall be taken not to add more water than to bring the material to the working consistency. The mixing shall be done till every particle of the aggregate is coated uniformly with the cementitious material.
2. **Dry hydrated lime and sand** Dry hydrated lime and sand in specified proportions shall be mixed dry first and shall then be fed into a mortar mill with required additions of water. The mixing shall be done as described above in point 1.

3. **Lime-pozzolana mixtures** Mortars using lime-pozzolana mixtures shall be prepared in the same manner as described in point 1.

   Mortars with lime-pozzolana mixture of type LP 20 and LP 40 as binder shall be used within 4 hours from the time of mixing of the mortar, whereas mortars which have hydraulic lime (Class B) or fat lime (Class C) and pozzolana or lime-pozzolana mixture of type LP 7 as ingredients, but do not have either Portland cement or eminently hydraulic lime (Class A), shall be used within 12 to 24 hours from the time of mixing of the mortar

   When factory made dry hydrated lime conforming to IS: 712-1973 is used, grinding of the lime and sand in the mortar mill is not necessary.

3.7 GRADES OF MORTARS

Grades of commonly used masonry mortars based on their compressive strength are listed in the Table 3.3.

Table 3.3 *Compressive strength of masonry mortars (IS: 2250- 1965)*

Sl. no.	Mortar mix by loose volume					Type of lime-pozzolana mixture in accordance with IS: 4098 –1967	Mortar grade	Compressive strength at 28 days, MPa
	Cement	*Lime Grade*	*Pozzolana*	*Lime-pozzolana mixture*	*Sand*			
1.	0	1B† or E†	0	0	3	-		
2.	0	0	0	1	1.25	LP – 7	MM 0.5	0.5 to 0.7
3.	0	1C†or D†	1‡	0	2	-		
4.	0	0	0	1	1.5	LP – 20		
5.	0	0	0	1	2.25	LP – 40	MM 0.7	0.7 to 1.5
6.	1	3C† or D†	0	0	12	-		
7.	0	0	0	1	2	LP – 40	MM 1.5	1.5 to 2.0
8.	0	1A†	0	0	3	-		
9.	0	1C† or D†	3§	0	0	-		
10.	1	2C† or D†	0	0	9	-	MM2.0	2.0 to 3.0
11.	0	0	0	1	1	LP – 20		
12.	0	0	0	1	1.75	LP – 40		
13.	0	1C† or D†	2	0	0	-		
14.	1	1C† or D†	0	0	0	-		
15.	1	0	0	0	6	-	MM 3.0	3.0 to 5.0
16.	1§	0	0.21§	0	4.2	-		
17.	0	0	0	1	1.5	LP – 40		
18.	0	0	0	1	1	LP – 40		
19.	1	0	0.4	0	5	-	MM 5.0	5.0 to 7.5

(continued)

Table 3.3 *Contd.*

Sl. no.	Mortar mix by loose volume					Type of lime-pozzolana mixture in accordance with IS: 4098 –1967	Mortar grade	Compressive strength at 28 days, MPa
	Cement	*Lime Grade*	*Pozzolana*	*Lime-pozzolana mixture*	*Sand*			
20.	1	¼ C† or D†	0	0	3	-		
21.	1	½ C† or D†	0	0	4.5	-	MM 7.5	7.5 and above
22.	1	0	0.4	0	3.75	-		

† A, B and C denote the class of limes to be used [IS: 712- 1973 Specification for building limes (revised)].

‡ Pozzolana of minimum lime-reactivity of 4.0 MPa.

§ This radio by volume corresponds approximately to cement pozzolana ratio of 0.8: 0.2 by mass. In this case, only ordinary Portland cement [IS: 269- 1967; Specification for ordinary, rapid hardening and low heat Portland cement (3rd revision)]

* The strength values of lime mortars given in the Table are after wet grinding of mortar ingredients.

EXPERIMENT NO. 1: Lime Reactivity

Objective

1. *To determine the reactivity or slaking rate of pulverised quicklime (unslaked lime).*
2. *To determine the residue on slaking of pulverised quicklime.*

Theory and Scope

This test covers the procedure to assess the performance of pulverised quicklime in terms of its slaking characteristics. The test method is based on the exothermic reaction of unslaked lime with water and the presumption that high reactivity lime reacts fast and slakes well in water. The test method can serve as a useful quality control tool.

The method is one of the two tests which are normally conducted on unslaked lime to ensure its compliance with specifications, namely the available *lime content determination* and the *reactivity test*. The test is conducted as described in a German DIN procedure and adopted in the EN 12485:2010 (E). The first test mentioned above measures the acid neutralisation capacity of the unslaked lime, while the second one describes the kinetics of how fast the material will react with water to produce a specific RDIN value or reactivity value. This latter test indicates degree of reactivity of the unslaked lime. The DIN classification of lime's reactivity is as follows:

RDIN value > 30:	highly reactive lime
10 < RDIN value < 30:	reactive lime
RDIN value < 10:	unreactive lime

This test is used to determine temperature rise in 3 minutes as well as total temperature rise to complete slaking reaction which provides a measure of the available lime content of the sample. This test is also used to determine total slaking period which provides a measure of the overall degree of reactivity of the material.

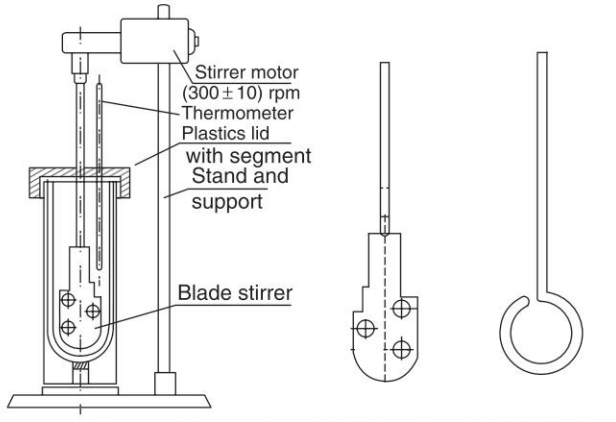
Apparatus

Oven at 1000°C; 0.5 mm pore size sieve; Calcinator with temperature maintainable at 950°C; Mechanical mixer with a stainless steel or plastic stirrer capable of 300 ± 10 rpm (400 ± 50 rpm ASTM) with stand and support; Thermostatically isolated container or flask; Ordinary thermometer of 0 to 100°C range in 0.5°C increments; Stopwatch or suitable timing device; Balance with weights; Stainless steel weighing and feeding device; Paintbrush; Graduated cylinder; Face mask; Rubber hand gloves

Description of Apparatus

The apparatus consists of a thermostatically isolated vacuum reaction container or flask of 1000 ml capacity with internal diameter about 77 mm, internal height about 235 mm. It is fitted with a mechanical stirrer and thermometer. The quicklime charge is stirred with a mechanical stirrer with its blade made of suitable plastics with diameter about 60 mm and thickness about 4 mm. The shape of the blade stirrer follows the contour of the reaction container. The reaction container is provided with plastics lid with segment which can be opened, feed opening and bore for the thermometer. The test apparatus shall have a water equivalent of 200 J/K to 300 J/K.

Appropriate rod type (ASTM) stirrers shown in Fig. 3.3(c) may also be used for reactivity test.



(a) Vacuum reaction container or flask (b) Blade stirrer (c) ASTM stirrer

Fig. 3.3 *Apparatus for testing reactivity*

Thermometer Calibrated thermometer 0°C to 100°C with an accuracy of 0.5°C and a high rate of response (adjustment time from 20°C to 60°C in less than 10 sec.). The penetration depth shall be about 160 mm from a suitable hole on the top edge of the lid. A recorder for the temperature measurement is recommended.

Test sample The sample is crushed and passed through 2.36 mm IS sieve as rapidly as possible to prevent its deterioration; about 0.5 kg sample shall be stored in an airtight container to ensure that the sample corresponds to the product to be tested. The sample is allowed to come to room temperature before testing. Absorption of even small amounts of moisture influences the pattern of the wet slaking process.

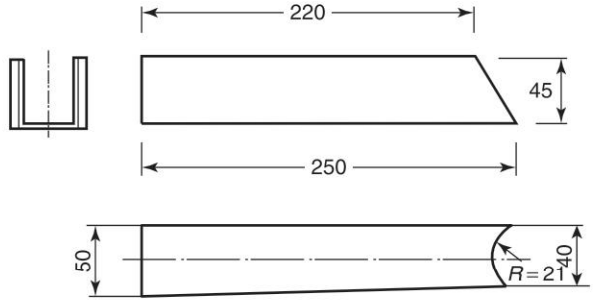


Fig. 3.4 *Weighing and feeding vessel*

Procedure

Part 1: Reactivity or slaking rate test

Step 1: Adjust the temperature of about two litres of distilled water to 20° C (25 ± 0.5° C ASTM). Add 600 ± 1 ml (400 ml ASTM) of this water to the reactivity container or flask.

Step 2: Set the mechanical stirrer with the stirring blade or stirring rod in the flask revolving at 300±10 rpm (400±50 rpm ASTM). Insert the thermometer; the temperature of the water in the flask must remain at 20 ± 0.5° C (25 ± 0.5° C ASTM).

Step 3: Weigh 150 ± 0.5 g (100 g ASTM) of the prepared sample for the individual test. With the stirrer running, immediately introduce the weighed quantity of sample into the water by means of the feeding vessel. Start timer. This moment marks the start of the lime slaking period.

Step 4: Record the slaking temperatures at 30 second intervals. Continue readings until less than 0.5° C temperature change is noted in each of three consecutive readings. The time at which the first of three consecutive readings was taken marks the end of the lime slaking period. If the period of slaking exceeds 10 minutes record the temperature at one or two intervals after this period till the maximum temperature T_{max} is reached.

Step 5: Draw the wet slaking curve by plotting the measured slaking temperature in °C as a function of time in minutes. Determine the time t necessary to reach the required slaking temperature T.

Step 6: Calculate RDIN values in each case by dividing 2400 (40°C temperature rise × 60 sec/min) by the time in seconds in which the temperature rise occurred.

Step 7: Conduct at least three repetitions of each test run to obtain reasonably repeatable values.

Part 2: Residue on slaking test

Step 1: After the reactivity test transfer the limewater mixture from the reaction container on to a 300μ IS sieve for screening.

Step 2: Dry the residue collected on the sieve in an oven for three hours at 100°C and then cool it at room temperature.

Step 3: After cooling, gently brush the residue with a paintbrush until all the fine powder is removed and only the coarser and hard solid particles are left on the sieve.

Step 4: Weigh the residue to calculate the grit as per cent of the original mass of lime used in the test.

Observations and Calculations

1. The total slaking period is the difference between the time at which the first of three consecutive readings were taken and the time of the start of the slaking test (= 0.0 minutes).
2. The final temperature is the one noted at the time at which the first of three consecutive readings were taken.
3. The total temperature rise is the final temperature minus the initial temperature, i.e., presumably 20 ± 0.5° C (25 ± 0.5° C ASTM).
4. The temperature rise in 3 minutes is the temperature at 3 minutes minus the initial temperature, i.e., presumably 20 ± 0.5° C (25 ± 0.5° C ASTM).
5. The time taken for 40°C rise in temperature is the difference between the time at which the temperature was 40°C + initial temperature, i.e., presumably 20 ± 0.5° C (25 ± 0.5° C ASTM) and the time of the start of the slaking test (= 0.0 minutes).

1. Lime slaking rate											
Time, minute	0.0	0.5	1.0	1.5	2.0	2.5	3.0*	3.5	4.0	4.5	5.0
Temperature, °C											
Time, minute	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
Temperature, °C											

2. Other details				
Sample number		1	2	3
The initial temperature,	°C			
Time taken for 40°C rise in temperature t_{40},	minutes			
Total slaking period,	minutes			
Temperature rise in three minutes,	°C			
Total temperature rise	°C			
Mass of the sample M_1,	g			
Mass of the dried residue M_2,	g			
Residue on slaking or grit $= \frac{M_2}{M_1}$	per cent			

Precautions

1. Since the quicklime is very corrosive in contact with moisture breathing the dust when crushing and sieving quicklime should be avoided by wearing a face mask and the hands should be protected by rubber gloves.
2. Commercial unslaked lime sample to be tested should be crushed and sieved in various size fractions, ranging from 75 μm to 4.75 mm and stored in air tight containers.
3. The temperature in the reactivity container shall not deviate from 20°C by more than ± 0.5°C.
4. It should be ensured that the contents of the reactivity vessel are thoroughly mixed throughout the entire duration of the test. For limes which thicken severely, the speed of the motor should be increased after a reaction temperature of about 60°C has been reached.

Informative Comments

Reactivity results are test method specific and hence standardised procedures are used. The standard DIN procedure calls for an amount of 150 g of unslaked lime with a particle size of between 1.0 mm and 4.75 mm to be added to 600 grams of water at 20°C in a thermostatically isolated container; the time is measured that took the water's temperature to rise to 60°C as a result of the exothermic slaking reaction between the water and the lime. With highly reactive limes, the temperature should be measured at shorter intervals, since the reaction may be completed after a few minutes.

The required RDIN value is then calculated by dividing 2400 (40°C temperature rise × 60 sec/min) by the time in seconds in which the temperature rise occurred. Some standards express the reactivity of lime as the time t_u required for the reaction to be 80 per cent complete. The temperature T_u is defined as the temperature in °C at which reaction is 80 per cent complete.

To determine the residue on slaking the limewater reaction mixture is screened through a standard sieve after the reactivity test. The rationale behind this test is that any slaked lime would form very fine calcium

hydroxide particles that would easily pass through the used sieve size, while the coarser, unhydrated parts and impurities would be trapped by this sieve size. The residue retained on the sieve is dried and cooled under specified conditions. After cooling, the coarser and hard solid particles left on the sieve after removing all the fine powder is weighed to calculate the grit as a per cent of the original mass of lime used in the test.

Residue on slaking test can be used to distinguish between qualities of different limes as it determines the amount of grit produced during the slaking procedure. The amount of grit produced in each case is to an extent independent of the reactivity values measured. Thus, the amount of grit produced is a not a good measure of the reactivity of the lime.

The particle size has an influence on the slaking rate and thus on the measured reactivity of lime. In the size range of 1.0 to 4.75 mm, however, the measured reactivity stays more or less constant. Therefore, for the particle size range in the test procedure, the reactivity should not be influenced by a small variation in particle size distribution between the various samples evaluated.

Since the commercial lime slakers in industry normally operate by using three to four parts of water for one part of unslaked lime, in the test procedure a 4:1 ratio of water to lime is recommended. There is a direct relationship in the decrease of the reactivity values with an increase in the amount of water used in the test. The tests using 150 g of lime and 300 ml of water results in inefficient slaking of the lime and may even produce an explosive and violent reaction. The difficulty in measuring the reactivity in such cases is reflected in the large standard deviation obtained. Thus, when insufficient material is available for test purposes the tendency to reduce the required quantities of reagents by pro-rata amounts leads to unreliable results.

The acceptance criterion according to ASTM is given below.

Lime reactivity	Criteria	Recommendation
High	Temperature increase of 40°C in three minutes and total slaking period is less than 10 minutes.	The material is deemed acceptable.
Medium	Temperature increase of 40°C in three to six minutes. Total slaking period is between 10−20 minutes	Chemical analysis of sample may be required.
Low	Temperature increase of 40°C in 6 minutes or more. Total slaking period is more than 20 minutes	Chemical analysis of sample is required.

Viva-Voce Questions

1. What is unslaked or quick lime?
2. What is the significance of reactivity tests of building limes?
3. What is the basis of the reactivity test of unslaked lime?
4. Is there a well-established relationship between purity and reactivity of lime?
5. How is the lime reactivity classified?
6. What is wet slaking curve?
7. How are the results of reactivity test expressed?
8. How is the RDIN value calculated?
9. What are the acceptance criteria according to DIN and ASTM standards?
10. Why is the 4:1 ratio of water to lime recommended in the reactivity test?
11. What is the particle size range generally recommended for the reactivity test?
12. What is the significance of amount of residue (grit) on slaking test?
13. What is the basis of the amount of grit test?
14. What are the applications of this test?

15. Is the amount of grit produced a good measure of the reactivity of the lime?
16. What precautions need to be taken while performing the test?
17. What are the sources of error in this test?
18. What precautions need to be taken in handling the lime?

Notes and Comments

EXPERIMENT NO. 2: Soundness of Lime

Objective

To determine soundness and to decide the suitability of given lime sample using: LE-CHATELIER method.

Theory and Scope

The test is performed to determine the quality of lime in terms of its unsoundness or disintegration property. It determines how effectively the quicklime slakes and method is used to control the quality of lime during the course of its production.

The test is designed to accelerate the slaking process by application of heat and to measure the extent of expansion and to check whether this expansion is within the specified limit. Indirectly, this test gives the extent of over burnt lime cores present in lime hydrate; it is indicative of the potential of appearance of surface defects in plastering applications.

The test consists in mixing in dry state the cement, hydrated lime and standard sand in the ratio 1:3:12; The mix is then gauged and mixed with 12 per cent by mass of water calculated on the dry mixture. After accelerated slaking the extent of expansion is measured.

Apparatus

'LE-CHATELIER' apparatus; Two Glass plates; Temperature controlled water-bath; Scale; China dish to mix the paste; Counter balance; Weight box; Graduated cylinder; Trowel and 850-micron IS sieve.

Description of Apparatus

The apparatus shown in Fig. 3.5 consists of a small split cylinder of spring brass or some other suitable metal of 0.5 mm thickness, 30 mm internal diameter and 30 mm height. On either side of the split are attached two indicators with pointed ends, the distance from these ends to centre of the cylinder is 65 mm. The mould is kept in good condition with the jaws not more than 0.5 mm apart.

Fig. 3.5 *Le-Chatelier test apparatus*

Procedure

Step 1: Mix 75 g of lime with 1/3 of its mass of Portland cement and four times its mass of standard sand.

Step 2: To this mixture add 12 per cent of water by mass of total dry mix and gauge.

Step 3: Place three well-greased moulds on separate non-porous glass plates and fill them with the mortar, care being taken to keep the edges visibly open. Cover each mould with another plate and place small weights on them.

Step 4: After one hour, measure the distance D_1 between the indicator points and transfer the moulds to a damp air cupboard for a period of 48 hours.

Step 5: Remove moulds from cupboard and keep the same in a suitable steam-boiler, in which water is already boiling vigorously, for three hours, but the moulds must not be immersed in water.

Step 6: Allow the moulds to cool and measure the distance D_2 between the indicator points.

The increase over the former measurement after deducting 1 mm for the expansion of added cement is the net expansion due to lime and it should not be more than 10 mm as per IS specifications.

Observations and Calculations

Initial distance between indicator ends D_1,	mm			
Final distance between indicator ends D_2,	mm			
Expansion of lime (D_2-D_1-1),	mm			

Since the average expansion of lime is……... mm, hence lime sample is…… (Sound / unsound)

Precautions

1. As the quicklime and hydrated lime have a high affinity for moisture and carbon dioxide, care should be taken to protect the material during sampling, storage, and testing.
2. The materials should be thoroughly mixed with fingers for at least one minute.

Informative Comments

The objective of this test is to determine the extent of unburned lime cores present in the hydrated lime. Hydration of this lime is accelerated by boiling, causing expansion. It is this expansion which is one of the causes of popping and pitting in the surface in plastering applications and hence the importance of this test.

Viva-Voce Questions

1. What is meant by unsoundness?
2. What is likely the cause of unsound lime?
3. Of what importance is the soundness of lime?
4. How is the slaking process, i.e., hydration accelerated in this experiment?
5. What is the maximum permissible expansion for common lime?
6. What precautions are taken while performing the test?
7. What are the field tests that can be performed to judge the quality of lime?
8. What are the various laboratory tests recommended for determining the suitability of a lime for construction?

Notes and Comments

EXPERIMENT NO. 3: Strengths of Building Limes by Sieving

Objective

To determine compressive and transverse strengths of building lime by testing 1:3 lime-standard sand mortar specimens.

Theory and Scope

The compressive and transverse strengths of building lime are computed by using the principles of mechanics as follows.

1. Compressive strength, $\sigma_c = \frac{W}{2500}$ MPa .
2. Transverse strength after 28 days $= \frac{M}{Z} = \frac{WL}{4} \times \frac{6}{bh^2} = \frac{3WL}{2bh^2}$

   where $L = 80$ mm; $b = 25$ mm; $h = 25$ mm.

Apparatus

Compression and transverse testing machine for lime of 100 kN capacity; Mortar mixer; Cube moulds 50 mm side; Prism moulds 25 × 25 × 100 mm in size; Balance with weights; Non-absorbent bowl; Graduated cylinder; Rice plates; Trowel; Rubber hand gloves

Procedure

Part 1: Preparation of test specimens

Step 1: Calculate the materials required for preparing 1:3 lime and standards sand mortar specimens. For 12 cubes and six prism specimens take 1250 g sample of hydrated lime and 3750 g of standard sand conforming to IS: 650-1991 and 815 ml of water (65 per cent of the mass of lime). The material may be mixed in a mechanical mortar mixer or by hand in two batches as explained below.

Step 2: Pour required water for the batch into the bowl which has been previously wiped clean with a damp cloth.

Step 3: Add 625 g lime sample into water stirring it with fingers of one hand protected by rubber gloves until all of the hydrated lime is melted. Mix it thoroughly by hand-rod mixer for five minutes and prepare the lime putty.

Step 4: Add approximately 1000 g of sand; and lime putty in a plate and the stirring is continued for approximately half a minute.

Step 5: Add the remainder of 875 g of sand and mix it by vigorous and continued stirring; squeezing and kneading with one hand.

Step 6: Allow the mortar to stand for about one minute and then mix for another minute. During the mixing operation the hands are protected by rubber gloves.

Step 7: For preparing the specimens take six cube moulds and three prism moulds; and oil them lightly with a medium viscosity oil or grease.

Step 8: Fill the moulds half with mortar puddled into place with finger tips of the glove hand and then fill to over-flow and again puddle with the finger tips.

Step 9: Cut off the mortar flush with the top of the moulds by drawing the straight edge of the trowel with sawing motion at right angles to the length.

Repeat the process with the second batch of materials for preparing balance of six cube specimens and three prism specimens.

Part 2: Curing

Step 1: Store the filled prism moulds covered at the top and bottom undisturbed for 28 days in a suitable container in an atmosphere of at least 90 per cent relative humidity and at a temperature of 27 ± 2°C. Before testing at the end of 28 days, the specimens are immersed in water for 30 minutes.

Step 2: Store the filled cube moulds undisturbed in a suitable container for a period of 72 hours, i.e., three days in an environment of at least 90 per cent relative humidity and at a temperature of 27 ± 2°C. After three days, remove the specimens from the moulds and place in the air in the laboratory for four days. Immerse the seven days old specimens in clean water and leave them until just prior to testing.

Part 3: Testing

Step 1: Test the prism specimens; after 28 days on the transverse testing machine for limes. The specimen is supported on two rollers spaced at 80 mm and a concentrated load is applied at the midpoint by means of another roller of the same size. The load is applied steadily and uniformly at a rate of 150 ± 15 N per minute.

Step 2: The cube specimens are tested on 100 kN universal testing machine with 10 or 20 kN dial at an age of 28 days. The load is applied along the sides of the specimen and not along the direction of casting;

Step 3: Record the total load at the time of failure of each specimen and also note the mode of failure.

Observations and Calculations

Type of material							
Date of casting specimen and time		Date at 14 days curing			Date at 28 days curing		
Temperature of air,	°C						
Mass of lime used,	g						
Mass of graded standard sand used,	g						
(a) Cube specimen with 14 days curing		1	2	3	4	5	6
Crushing load *W*,	kN						
Compressive stress, $\sigma_c = 0.4\ W$	MPa						
Average 14 days compressive strength,	MPa						
(b) Cube specimen with 28 days curing		1	2	3	4	5	6
Crushing load *W*,	kN						
Compressive stress, $\sigma_c = 0.4\ W$	MPa						
Average 28 days compressive strength,	MPa						

(continued)

(Contd.)

(c) *Prism specimen with 28 days curing*		1	2	3	4	5	6
Failure load W,	kN						
Bending stress, $\sigma_t = 7.68\ W$	MPa						
Average 28 days transverse strength,	MPa						

***Note:** While calculating the average of loads; if any individual value differs from the average value by more than 15 per cent it is rejected and the average of remaining is taken.

Compressive strength of lime is……MPa.
Transverse strength of lime is …… MPa.

Precautions

1. As the quicklime and hydrated lime have a high affinity for moisture and carbon dioxide, care should be taken to protect the material during sampling, storage, and testing.
2. During mixing operation the hands should be protected by rubber gloves.
3. The moulds should be oiled with a medium viscosity oil to prevent the mortar from adhering to the sides.
4. The load should be applied uniformly and without shock.
   (a) In case of prism testing; the rate of loading should be 150 ± 15 N per minute.
   (b) In case of cube testing; the travel of moving head is adjusted at the rate of approximately 1.25 mm/minute when the machine is running idle.
5. Testing of cube specimens should be carried out immediately after their removal from moist closet.
6. The storage water should be kept clean by frequent changing.
7. Wipe dry the surface of cube and remove any loose sand grains from the faces that will be in contact with bearing blocks.

Informative Comments

Reliable strength results depend upon careful observance of all the specified requirements and procedures. Improper centering of cubes results in oblique fracture or lateral movement of one of the heads of testing machine during loading and will cause lower strength results. Hence, the principal factors which may cause variation of test results are:

1. Eccentric loading due to a misalignment of various parts of the testing machine.
2. Tilting of platens due to lack of lateral rigidity of the structure of the testing machine.
3. Inability to maintain a uniform rate of loading right up to the point at which the cube fails.
4. Lack of planeness of platens.

It is extremely difficult to maintain a constant rate of application of load right up to failure point because as the cube nears the failure point in compression; the rate of yield increases considerably requiring the movement of platens to be speeded up to maintain constant rate of loading. Hence rate of loading decreases as the failure point is reached and this results in a reduction of load at which failure takes place.

Viva-Voce Questions

1. What is the significance of compressive and transverse strength tests of building limes?
2. What are the sizes for compression test and flexure test specimens?

3. What is the percentage of water (by mass of lime) added in preparation of (1: 3) lime standard sand mortar specimens?
4. What are the requirements concerning mixing of ingredients?
5. What are the requirements for moulding the test specimens?
6. How is the curing of test specimens done?
7. What type of loading is used in flexure tests?
8. How is flexure results expressed?
9. Is there a well-established relationship between compressive and transverse (i.e., flexure) strengths?
10. What is the rate of loading for this test?
11. What precautions need to be taken while performing the test?
12. What are the sources of error in this test?
13. What other factors may be responsible for any difference between laboratory results and the standard strength requirements?
14. What is the lever ratio of transverse lime testing machine?
15. What is hydraulic lime?
16. What are the field tests that can be performed to judge the quality of lime?
17. What are the various laboratory tests recommended for determining the suitability of a lime for construction?
18. What precautions need to be taken in handling the lime?

Notes and Comments

EXPERIMENT NO. 4: Lime Reactivity of Pozzolanic Material

Objective

To determine the reactivity of a pozzolanic material with hydrated lime.

Theory and Scope

This method of test covers the procedure for determining the reactivity of the pozzolanic material with hydrated lime in terms of compressive strength of standard mortar test cubes prepared and tested under specific conditions.

This test is used to determine the suitability of pozzolana to be used in production of Portland Pozzolana cement. The average compressive strength in lime reactivity of pozzolana test that is to be blended with finished Portland cement to produce Portland Pozzolana cement, when tested in accordance with the procedure specified in IS 1727: 1967 shall not be less 4.0 MPa. However, the average compressive strength in lime reactivity test of such pozzolana shall be carried out at the fineness at which pozzolana has been ground for blending or at the fineness in as received; condition, whichever is greater.

Size and Number of Test Specimens: The tests specimen shall be 50 mm cubes. At least three specimens shall be made for each period of test specified.

Apparatus

100 kN Compression testing machine for lime; Mortar mixer with non-absorbent mixing bowl; Mortar flowtable; Incubator for curing: Balance with weights; Cube moulds 50 mm side of metal not attacked by cement-pozzolana or lime-pozzolana mortar; Base plates for moulds made of non-absorbent and non-corrodible material; A plastic scraper; Graduated cylinder; Trowel; Tamping rod; Rice plates; Rubber hand gloves.

Description of Apparatus

Compression testing machine The standard compression testing machine.

Mortar mixer The standard mortar mixer conforming to IS: 2250-1981 is shown in Fig. 3.1.

Flow table The standard flow table shall be as given in IS: 5512-1969 and shown in Fig. 3.6.

Cube moulds The moulds shall be rigidly constructed in such a manner as to facilitate the removal of the moulded specimen without damage. The moulds shall be machined so that when assembled ready for use the internal dimensions shall be accurate to 50 ± 0.1 mm for new moulds, and 50 ± 0.5 mm for moulds in use; and the angle between adjacent interior faces and between interior faces and top and bottom planes of the mould shall be 90 ± 0.5 degrees.

Base plate The base plate provided with mould shall be of such dimensions as to support the mould during the filling without leakage and surface machined to a tolerance of 0.1 mm.

Scraper The scraper consist of a semi-rigid rubber blade about 75 mm long, 50 mm wide, and tapered to a thin edge about 1.5 mm thick. The blade is attached to a handle about 150 mm long.

Tamping rod The tamping rod is made of a non-absorptive, non-abrasive, non-brittle material such as a rubber compound with sufficient hardness or seasoned teak wood rendered non-absorptive by immersion for 15 minutes in paraffin at approximately 200°C. The tamping rod is of a cross section of 12 × 25 mm and a length of 125–150 mm.

Trowel This shall have a steel blade 100 to 150 mm in length with straight edges.

Fig. 3.6 *Typical flow table, flow mould and tamper*

Procedure

Step 1: Calculate the proportions of dry materials for the standard test mortar for preparing the test specimens with lime: pozzolana: standard sand in proportion 1: 2 m: 9 by weight.

where $$m = \frac{\text{Specific gravity of pozzolana}}{\text{Specific gravity of lime}}$$

Step 2: Determine the amount of water for gauging the mortar which is equal to that required to give a flow of 70 ± 5 per cent with 10 drops in 6 sec as measured for the trial mixes. With dry material in the proportions

given above, prepare trial mixes with different percentages of water until specified flow is obtained. Make each trial with fresh mortar. The mixing shall be done mechanically by means of mixing apparatus.

For first trial take water amounting to 60 per cent by mass of lime and pozzolanic material; for subsequent trials water quantity may be selected based on the flow value of preceding trial. For each trial mix following procedure shall be adopted:

(a) Place the dry paddle or blade and the dry clean bowl in the mixing position in the mixer. Then introduce the materials for trial batch into the bowl and mix in the following manner:

i. Place the mixing water in the cleaned bowl.
ii. Add the lime and pozzolana mixture to the water, and then start the mixer and mix at a slow speed of (140 $\pm$ 5 rpm) for 30 sec.
iii. Add the entire quantity of sand slowly over a period of 30 sec, while mixing at slow speed.
iv. Stop the mixer, change to medium speed of (285 $\pm$ 10 rpm), and mix for 30 sec.
v. Stop the mixer, and let the mortar stand for one and a half minute. During the first 15 sec of this interval, quickly scrape down into the batch with the scraper any mortar that may have collected on the side of the bowl, then for the remainder of this interval, cover that bowl with the lid.
vi. Finish by final mixing for one minute at medium speed (285 $\pm$ 10 rpm).
vii. Upon the completion of mixing, shake the mixing paddle to remove excess mortar into the mixing bowl.

(b) Determine the flow of the trial mixes as follows:

i. Carefully wipe the flow table top clean and dry, and place the mould at the centre.
ii. Place a layer of trial mortar mix obtained in Step 2(a) about 25 mm in thickness in the mould and tamp 20 times with the tamping rod. The tamping pressure shall be just sufficient to ensure uniform filling of the mould. Then fill the mould to overflow with mortar and tamp as specified for the first layer. Cut off the mortar to a plane surface flush with the top of the mould by drawing the straight edge of a trowel (held nearly perpendicular to the mould) with a sawing motion across the top of the mould.
iii. Wipe the table top clean and dry, particularly taking care to remove any water from around the edge of the flow mould.
iv. Lift up the mould from the mortar one minute after completing the mixing operation.
v. Immediately drop the table through a height of 12.5 mm ten times in 6 sec.
vi. Measure the resulting increase in average base diameter of the mortar mass, i.e., the flow. Take at least four diameters measurements at approximately equispaced intervals and express the increase as a per cent of the original base diameter.
vii. Repeat the above procedure, with the materials for each batch mixed separately using the quantities of dry materials in the specified proportions and the predefined quantity of water.
viii. Determine the amount of water to give a flow of 70 $\pm$ 5 per cent with 10 drops in 6 sec from measured flow values of the trial mixes. This provides the amount of water required for gauging the mortar.

Step 3: Calculate the quantities of the materials required for casting six test cube specimens for reactivity test; mix the ingredients in the manner described in Step 2(a). The following quantities of materials may be used for preparation of mortar:

150 g Hydrated lime; 300m g Pozzolana and 1350 g Standard sand; the per cent water for gauging the mortar shall be as obtained in Step 2; where m is the ratio of specific gravity of pozzolana to that of lime obtained in Step 1.

Step 4: Take six cube moulds and thinly cover the interior faces of the test moulds and base plates with a medium viscosity mineral oil or light cup grease. Moulds shall then be set on plane, non-absorbent base plates that have been thinly coated with mineral oil, or light cup grease.

Step 5: Mould the test specimen by immediately placing the mixed mortar in a 50 mm cube mould in a layer of about 25 mm thickness and tamp 25 times with the tamping rod. The tamping shall be just sufficient to ensure uniform filling of the mould. Then fill the mould to overflow and tamp as specified for the first layer. On the completion of the tamping, the tops of all cubes shall overflow slightly above the tops of the moulds. Cut off the mortar to a plane surface flush with the top of the mould by drawing the straight edge of a trowel (held nearly perpendicular to the mould) with a sawing motion across the top of the mould.

Step 6: Store and cure the specimens in the following manner:

Cover the surface of the specimen in the mould with a smooth and lightly greased glass plate. Keep the specimens within the moulds along with the cover plates under wet gunny bags for 48 hour. Then remove the specimens from the moulds and cure at 90 to 100 per cent relative humidity at 50°C ± 2°C for a period of eight days in the incubator. Samples shall not be cured under water.

Step 7: Remove the specimens after curing for eight days from the incubator and cool them to room temperature.

Step 8: Test the specimen immediately for compressive strength after they reach the room temperature in the following manner:

(a) Remove any loose material from the sides of the specimen; record the dimensions of the specimen.

(b) Wipe clean the bearing surfaces of the testing machine and place the specimen in the machine in such a manner that the load shall be applied to opposite sides of the cube as cast, i.e., not to the top and bottom.

(c) Align the axis of the cube specimen carefully with the centre of thrust of steel bearing plates of the testing machine without any packing between the cube and steel platens of the testing machine

(d) Apply the load on the specimen without shock at a rate uniformly increasing from zero to a rate of 3.5 MPa/min until failure occurs.

Step 9: Record the maximum load at failure. At least three cubes shall be tested.

Step 10: Calculate the compressive strength from the crushing load and the average area over which the load is applied. The individual results shall be calculated to the nearest 0.05 MPa.

Observations and Calculations

1. Water for gauging the mortar measured for the trial mixes								
Mass of lime / batch,	g							
Mass of pozzolana/ batch,	g							
Mass of sand/ batch,	g							
Amount of water,	per cent							
Flow of trial mortar,	per cent							

Water required for gauging the mortar is…….per cent.

2. Compressive strength of mortar cubes							
Temperature of air,	°C						
Mass of lime,	g						
Mass of pozzolana,	g						
Mass of graded standard sand,	g						
Volume of water for gauging,	ml						
Specimen No.		1	2	3	4	5	6
Crushing load W,	kN						
Crushing stress,	MPa						
Average stress or strength*	MPa						

*Cubes that give strength differing by more than 15 per cent from the average value of all test specimens, made from the same sample and tested at the same period shall not be considered in determining the compressive strength. After discarding such cubes, if less than two strength test values are left for determining the compressive strength at any given period, a retest shall be made.

Compressive strength of lime, pozzolana and standard sand mortar is……MPa.

Precautions

1. The mixing of the ingredients shall be carried out at a temperature of 27 ± 2°C and all ingredients before mixing shall be brought to the same temperature.
2. The interior faces and the top and bottom surfaces of each mould should be coated with a medium viscosity oil to prevent the mortar from adhering to the sides.
3. Clean appliances shall be used for mixing. The temperature of the water and that of the test room at the time when the mixing operation is being performed shall be from 27°C + 2°C.
4. As the quicklime and hydrated lime have a high affinity for moisture and carbon dioxide, care should be taken to protect the material during sampling, storage and testing.
5. Wipe dry the surface of specimens and remove any loose sand grains from the faces that will be in contact with bearing blocks.
6. During mixing operation the hands should be protected by rubber gloves.
7. In the case requiring a remixing, any mortar adhering to the side of the bowl shall be quickly scraped down into a batch with the scraper prior to remixing.

Informative Comments

A pozzolana is defined as a material that is capable of reacting with lime in the presence of water at ordinary temperatures to produce cementitious compounds. The pozzolanic reaction products and the compounds produced on ageing differ and depend on the calcium to silica ratio in solution; whereas, modern hydraulic hydrates derive their hydraulic properties from the subsequent hydration of compounds of principally calcium and silica produced by solid state reaction in the kiln. The chemistry is of the same chemical nature, but it is not the same.

As the water content of the sample cannot be fixed due to variations in materials being used; the workability or consistency of the mortar mix is a more useful working parameter. To quantify the workability the 'flow' of the mortar is measured. A flow of between 65 and 75 per cent is recommended.

Fineness and average compressive strength in lime reactivity of pozzolana that is to be blended with finished Portland cement to produce Portland Pozzolana cement, when tested in accordance with the procedure

specified in IS 1727:1967 shall not be less than 320 m^2/kg and 4.0 MPa respectively. Average compressive strength in lime reactivity test of such pozzolana shall be carried out at the fineness at which pozzolana has been ground for blending.

The addition of ten per cent pozzolana in lime improves durability and strength and slightly reduces porosity and permeability. The pozzolana reacts with the lime and does not set in isolation as occurs when hydraulic lime or cement is added. Pozzolans are generally added to lime putty mortars where there is doubt about durability and the reduced porosity is advantageous. Correctly proportioned pozzolanic lime mortars are durable.

Reliable strength results depend upon careful observance of all the stipulated requirements for test procedures. Improper centering of cubes resulting in oblique fracture or lateral movement of one of the heads of testing machine during loading will cause lower strength results. Hence, the principal factors which may cause variation of test results are:

1. Eccentric loading due to a misalignment of various parts of the testing machine.
2. Tilting of platens due to lack of lateral rigidity of the structure of the testing machine.
3. Inability to maintain a uniform rate of loading right up to the point at which specimen fails.
4. Lack of planeness of platens.

It is extremely difficult to maintain a constant rate of application of load right up to failure point because as the specimen nears the failure point in compression; the rate of yield increases considerably requiring the movement of platens to be speeded up to maintain constant rate of loading. Hence rate of loading decreases as the failure point is reached and this results in a reduction of load at which failure takes place.

Viva-Voce Questions

1. What are pozzolana and pozzolanic action?
2. What is the significance of lime reactivity of pozzolana test?
3. What are advantages of addition of pozzolana in lime mortars?
4. How is the lime reactivity of pozzolana expressed?
5. What is the size of compression test specimens?
6. How is the amount of gauging water (per cent by mass of lime and pozzolana) is estimated for lime reactivity of pozzolana test specimens?
7. What are the requirements concerning mixing of ingredients?
8. What are the requirements for moulding the test specimens?
9. How is the curing of test specimens done?
10. Is there a well-established relationship between compressive strength and lime reactivity of pozzolana?
11. What is the rate of loading for this test?
12. Why is it difficult to maintain a constant rate of application of load right up to failure point?
13. What precautions need to be taken while performing the test?
14. What are the sources of error in this test?

Notes and Comments

EXPERIMENT NO. 5: Available Lime Content or Purity of Lime

Objective

Determine available calcium oxide or calcium hydroxide per cent in the lime sample.

Theory and Scope

This test method sets out the procedure for determining the available calcium hydroxide [$Ca(OH)_2$] or calcium oxide (CaO) in hydrated lime and quicklime, respectively. It provides a measure of the purity of lime.

The purpose of the test is to determine the non-lime or unburnt components of lime that is produced from quarried limestone and is frequently referred to as "grit". The purity of the lime is determined in terms of available (unbound) lime that is in the form of calcium oxide and calcium hydroxide as opposed to be being in the form of calcium carbonate. Available lime per cent represents the lime that is chemically available for most applications/reactions.

The test requires a specified sample mass and specified acid normality. This makes it convenient for laboratory personnel since they can simply read the number of millilitres (ml) of acid used from the burette, which is then equal to the available lime percentage (CaO per cent). However, in the case of any deviation with regard to the sample size and acid normality, the available lime per cent is determined by simple calculations. The lime should have a purity or availability of at least 70 per cent by mass of CaO.

Apparatus

Laboratory glassware: Pipettes, 500 mL and 100 mL burettes, Borosilicate type glass beaker; 400 mL volumetric flasks, Wide-bottom type low-form platinum crucible; Filter paper, etc.

Oven maintained at 105 ± 2°C; Electric muffle furnace; Tongs for use with muffle furnace, 500 mm length; Hard-surfaced temperature resistant board or Hot Plate; Vacuum desiccator; Analytical balance of suitable capacity capable of weighing to an accuracy of 0.005 g.

Stopwatch to record up to 30 minutes; 300μm IS sieve; Magnetic type stirrer.

Reagents

Hydrochloric acid; Nitric acid; Sulphuric acid; Ammonium hydroxide; Aluminium hydroxide; Indicator: Potassium permanganate.

Preparation of sample: In the case of quicklime, take a representative sample and crush as rapidly as possible to a size passing a 300 μm IS sieve and place in a sealed container until required for testing. Testing should be carried out as soon as possible.

Procedure

Step 1: Weigh one gram of powdered lime on an analytical balance in a platinum crucible. Place it in an oven maintained at 105 ± 2°C until on cooling and weighing, constant mass is obtained.

Step 2: Heat the crucible first gently and then ignite in an electric muffle furnace at 1000°C. Cool the crucible in a vacuum desiccator and weigh to a constant mass.

Step 3: Transfer the ignited lime to a borosilicate type glass beaker, add 50 ml of cold CO_2 - free distilled water and mix well, add 10 to 15 ml of concentrated hydrochloric acid, and boil for 15 minute. Filter, wash with distilled hot water, ignite and weigh to constant mass.

Step 4: To the filtrate, add concentrated hydrochloric acid, if necessary, in sufficient amount to make the total amount equivalent to 10 to 15 ml of concentrated hydrochloric acid. Add a few drops of nitric acid and boil. Dilute to 200–250 ml. Add slight excess of ammonium hydroxide and keep just below the boiling point until the odour of ammonia is barely perceptible. Filter off the iron and aluminium hydroxide while hot, collecting the filtrate in a 250 ml volumetric flask. Wash with hot CO_2 - free distilled water. Ignite the residue in a platinum crucible, blast, cool in a desiccators and weigh as aluminium oxide and ferric oxide. Make up the filtrate to 250 ml.

Step 5: Take 50 ml of the filtrate in a beaker with pipette and dilute to 100 ml. Heat to boil and add slowly about 35 ml of boiling ammonium oxalate solution. Continue boiling for 2 or 3 minute and allow the precipitated calcium oxalate to settle for half an hour.

Step 6: Filter the precipitated calcium oxalate through filter paper. Wash thoroughly with small portions of dilute ammonium hydroxide (1 N) and then with hot water until the washing do not decolourise a hot dilute potassium permanganate solution in the presence of dilute sulphuric acid.

Step 7: Puncture the filter paper and transfer the precipitate to the beaker already used for precipitation with a fine jet of hot water. Add about 50 ml of dilute sulphuric acid, heat to 60°C and titrate with standard potassium permanganate solution with constant stirring. Towards the end of the titration, introduce the filter paper which was used for filtration into the titration vessel and carry out the titration till the end point is reached.

Step 8: Carry out a blank with all reagents following the procedure outlined in the previous steps. In the case of magnesium limes, decant through a filter paper, dissolve the calcium oxalate in the beaker and in the filter paper with dilute hydrochloric acid and wash the filter paper four times with hot CO_2 - free distilled water and finally with dilute ammonium hydroxide (5 N) in a slight excess and proceed as before. For the second filtration, use the same filter paper as was used earlier.

Step 9: If it is desired to complete the analysis in as short a time as possible, a portion of 50 ml of the filtrate from the ferric and aluminium oxide determination should be precipitated in the usual way with excess of ammonium oxalate. Boil for about 5 minute and let the calcium oxalate settle clear. Decant through a qualitative filter paper and cool the filtrate (with ice water if possible).

Add di-ammonium hydrogen phosphate solution in large excess and 5 to 10 ml of ammonium hydroxide solution. Stir rapidly with rubber 'policeman'. From the amount of precipitate thus formed, one can judge whether the lime contains sufficient magnesium oxide to require a double precipitate or not. For accurate work, if there is more than a slight amount of magnesium oxide, a double precipitation should be carried out, using a fresh 50 ml aliquot.

Calculate the available calcium oxide or calcium hydroxide to the first decimal place and take the mean of the two determinations. Total calcium oxide (CaO), per cent by mass is given by

$$\text{Total calcium oxide} = \frac{14.02(V_1 - V_2)N}{W} \text{ per cent}$$

where

V_1 = volume, in ml, of standard potassium permanganate solution used for titration;
V_2 = volume, in ml of standard potassium permanganate solution used for the blank test;
N = normality of standard potassium permanganate solution; and
W = mass, in g, of the material taken for the test

Observations and Calculations

Mass of sample taken for the test, W	g	
Volume of reagent used for titration of the sample, V_1	ml	
Volume of reagent used for blank titration, V_2	ml	
Normality of standard potassium permanganate solution,	N	
Amount of calcium oxide = $\frac{14.02(V_1 - V_2)N}{W}$	per cent	

Since the total amount of calcium oxide is……per cent, hence lime sample is…… (suitable/ unsuitable) for use.

Precautions

1. Since the test for available CaO per cent is quantitative test and lime has a high affinity for moisture and carbon dioxide, care should be taken to protect the material during sampling, storage, and testing procedures.
2. Standard solution should be prepared carefully to ensure that it is as accurate as possible since an incorrect acid normality will result in inaccurate CaO per cent determinations.
3. Hydrochloric acid is corrosive, handle it with care. Always add acid to water, NEVER the reverse. Safety glasses must be worn.
4. Distilled CO_2-free water should be used in the test.
5. Before titrating the sample, the inside walls of the flask should be rinsed to insure that none of the sample is on the walls.
6. The persons handling lime must wear goggles, respirators, gloves, boots, etc.
7. As the test procedure involves use of acids which is hazardous, sufficient care should be taken.

Informative Comments

Lime is produced from quarried limestone, a naturally occurring material which is never 100 per cent pure calcium carbonate; thus, non-lime and un burnt components are a normal part of lime referred to as "grit". In determining the purity of the lime produced there are two chemical concepts. One is *total lime* and the other is *available lime*. Any unburned limestone that is in the grit will also react with the acid solution used in the titration process to determine the amount of lime in a sample; however, all of this lime would not be readily available in most application processes. The term "Available Lime" refers to the lime that is in the form of calcium oxide/CaO, as opposed to be being in the form of calcium carbonate.

Reporting

1. For quicklime, available lime expressed as calcium oxide rounded off to the nearest whole number. Values of 0.5 are to be rounded up.
2. For hydrated lime, available lime expressed as calcium hydroxide rounded off to the nearest whole number. Values of 0.5 are to be rounded up.

Since lime has a very low solubility in water, simply titrating the 'slurry' of lime with an acid solution can lead to inaccurate results. The addition of sugar to the lime solution results in an enormous increase in the

solubility of lime through the formation of an intermediate product, calcium succrate. Titrating lime, using one of the types of standard "Rapid Sugar" tests (ASTM C-25 or AWWA B-202) produces a calcium oxide percentage that more accurately reflects the lime that is "available" to react as calcium hydroxide. Typically, the "Available Lime" percent is always less than the "Total Lime". Most users of lime generally prefer to use the "Available Lime" per cent, since this represents the lime that is chemically available to them for most reactions.

Viva-Voce Questions

1. What is the significance of purity of lime test?
2. What does the calcium oxide equivalent in hydrated lime means?
3. What is the difference between total lime and available lime?
4. What is there in the test procedure which indicated that lime is a very strong base?
5. What are the reasons for the result indicating low available lime per cent?

Notes and Comments

NATIONAL STANDARDS

1. IS 712-984 (3rd revision, RA 2009): *Specification for Building Limes*
2. IS 1514-1990 (1st revision, RA 2003): *Methods of Sampling and Test for Quick Lime and Hydrated Lime (Available lime content test)*
3. IS 1624-986 (2nd revision, reaffirmed 2009): *Method of Field Testing of Building Lime*
4. IS 1635:1992 (2nd revision, reaffirmed 2009): *Code of Practice for Field Slaking of Building Lime and Preparation of Putty*
5. IS 1727: 1967(1st revision, reaffirmed 2008): *Methods of Test for Pozzolanic Materials*
6. IS 2250:1981(1st revision, RA 2010): *Code of Practice for Preparation and Use of Masonry Mortars*
7. IS 4098 : 1983(1st revision, reaffirmed 2009): *Specification for Lime-Pozzolana Mixture*
8. IS 5512:1983 (1st revision, RA 2008): S*pecification for Flow Table for Use in Tests of Hydraulic Cements and Pozzolanic Materials*
9. IS 6508-1988 (1st revision, reaffirmed 2009): *Glossary of Terms Relating to Building Lime*
10. IS 6932-1973 (Parts 1 to 11, RA 2009): *Methods of Tests for Building Limes*
11. IS 6932-1973 (RA 2009): Part 1: *Determination of Insoluble Residue, Loss on Ignition, Insoluble Matter, Silicone Dioxide, Ferric and Aluminium Oxide, Calcium Oxide and Magnesium Oxide*
12. IS 6932-1973 (RA 2009): Part 1: *Determination of Carbon Dioxide Content*
13. IS 6932-1973 (RA 2009): Part 3: *Determination of Residue on Slaking of Quicklime*
14. IS 6932-1973 (RA 2009): Part 4: *Determination of Fineness of Hydrated Lime*
15. IS 6932-1973 (RA 2009): Part 5: *Determination of Unhydrated Oxide*
16. IS 6932-1973 (RA 2009): Part 6: *Determination of Volume Yield of Quicklime*
17. IS 6932-1973 (RA 2009): Part 7: *Determination of Compressive and Transverse Strength*
18. IS 6932-1973 (RA 2009): Part 8: *Determination of Workability*
19. IS 6932-1973 (RA 2009): Part 9: *Determination of Soundness*
20. IS 6932-1973 (RA 2009): Part 10: *Determination of Popping and Pitting of Hydrated Lime*
21. IS 6932-1983 (RA 2009): Part 11: *Determination of Setting Time of Hydrated Lime*

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1. ASTM C110–11: *Standard Test Methods for Physical Testing of Quicklime, Hydrated Lime, and Limestone*.
2. ASTM C311–77: *Standard Methods of Sampling and Testing Fly Ash or Natural Pozzolanas For Use as a Mineral Admixture in Portland Cement Concrete*.
3. BS EN 196-5:1996; *Methods of Testing Cement, Pozzolanicity test for pozzolanic cements*,
4. BS EN 459-2: 2010; *Building Lime Test Methods*.
5. EN 12485:2010 (E): *Chemicals Used For Treatment of Water Intended For Human Consumption - Calcium Carbonate, High-Calcium Lime, Half-Burnt Dolomite, Magnesium Oxide and Calcium Magnesium Carbonate -Test Methods*
6. Gambhir, M. L. and Neha Jamwal, *Building Materials: Products, Properties and Systems*, McGraw-Hill Education (India), 2011.

AGGREGATES

Section 4

This section covers procedures for the tests generally performed on fine and coarse aggregates. The tests include impurities in aggregates; specific gravity, bulk density, voids, water absorption, moisture content of aggregates; fineness modulus and grain size distribution of aggregates; amount of fine silt and clay and bulking of fine aggregates. The physical characteristics as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

4.1 INTRODUCTION

Aggregate is a collective term for the relatively inert mineral materials such as sand, gravel and crushed stone that are used with a binding medium such as water, Portland cement, lime, bitumen, etc., to form composite materials such as Portland cement concrete and bituminous concrete. In case of Portland cement concrete, the aggregate is the principal constituent consisting fine and coarse materials. The coarse aggregate is used primarily for the purpose of providing bulk to the concrete. To increase the density of resulting mix, the coarse aggregate is frequently used in two or more sizes. The most important function of the *fine aggregate* is to assist is producing *workability* and *uniformity* in mixture. The fine aggregate also assists the cement paste to hold the coarse aggregate particles in suspension. This action promotes plasticity in the mixture and prevents the *segregation* of the paste and coarse aggregate, particularly when it is necessary to transport the concrete some distance from the mixing plant to point of placement.

The aggregate provides about 75 per cent of the body of concrete and hence its influence is extremely important. The physical, thermal and also sometimes chemical properties of aggregate greatly affect the performance of the concrete. The properties influenced are workability, strength, durability and economy. As the aggregates are cheaper than cement, it is economical to add into concrete as much of the aggregate as possible.

For producing good quality concrete the aggregate particles of different sizes are used; the particle size distribution is called the *grading of the aggregate*. The aggregate particles are generally classified in two size groups: (i) Fine aggregate and (ii) Coarse aggregate.

4.2 FINE AGGREGATE

IS: 383-1970 defines the *fine aggregate* as the aggregate most of which passes the 4.75 mm IS sieve and contains only as much coarser material as permitted is termed as fine aggregate.. The fine aggregate is often termed as *sand-size aggregate*. It may be classified as:

1. **Natural sand** Fine aggregates resulting from natural disintegration of rock and which have been deposited by the streams or glacial agencies.
2. **Crushed stone sand** Fine aggregate produced by crushing hard stone.
3. **Crushed gravel sand** Fine aggregate produced by crushing natural gravels.

The sand is generally considered to have a lower size limit of 0.07 mm. The material between 0.06 mm and 0.002 mm is classified as *silt,* and still smaller particles are termed as *clay*. *Loam* is a soft deposit consisting of sand, silt and clay in about equal proportions.

4.2.1 Physical Properties of Fine Aggregate

1. **Fineness modulus (IS 460-1978)** Fineness modulus of fine aggregate is defined as total cumulative percentage of materials retained on 4.75 mm, 2.4 mm, 1.2 mm, 600 μm, 300 μm and 150 μm IS Sieves conforming to IS: 460-1978, divided by 100. The recommended fineness modulus is 2.75 with variation of 0.2 on either side.

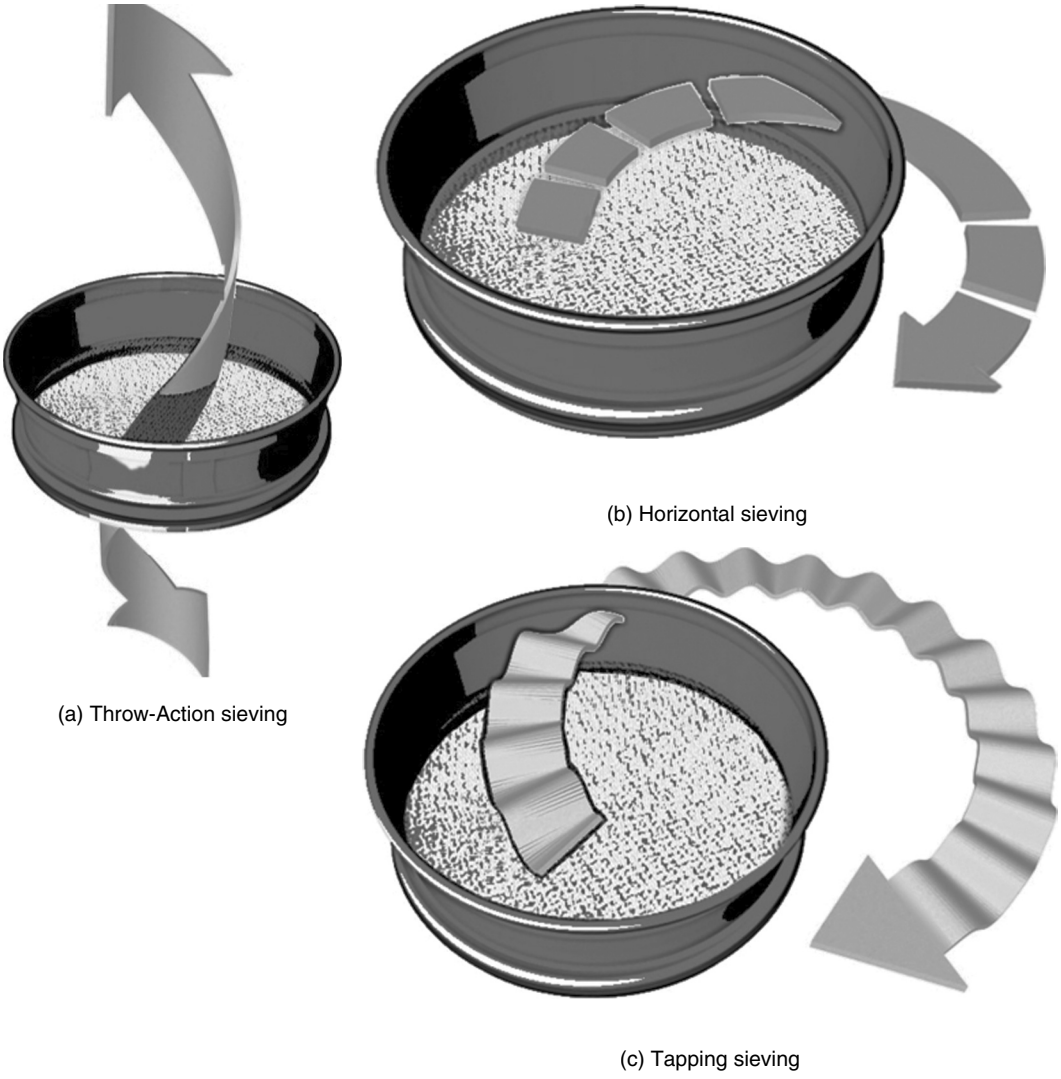

Fig. 4.1 *Shaking actions during sieving*

When the sieving is carried out by hand; the shaking is done with a varied motion: backwards and forwards, left to right, clockwise and anti-clockwise and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions. Typical sieving actions are illustrated in Fig. 4.1.

Depending upon the fineness modulus, the sands can be categorised as:

Type of sand	Fineness modulus
Fine sand	2.20–2.60
Medium sand	2.60–2.90
Coarse sand	2.90–3.20

2. **Grading of fine aggregate** The grading of a fine aggregate determined in accordance with IS: 2386 (Part I)-1963 shall be within the limits given in Table 4.1 for the grading zones referred to as I, II, III and IV. Where the grading falls outside the limits of any particular grading zone for the sieves other than 600-micron IS sieve by a total amount not exceeding five per cent, it is regarded as falling within that grading zone. This tolerance is not applicable to the percentage passing 600 micron IS sieve or to percentage passing any other sieve size on the coarser limit of Grading Zone I or finer limit of Grading Zone IV.

   The grading zones become progressively finer, from Grading Zone I to Grading Zone IV. The Grading Zone IV should not be used in RCC, until tests have been performed to ascertain its suitability. For concrete of high strength and durability, the mix proportion should be chosen according to the grading characteristics of fine aggregate used, the ratio of fine to coarse aggregate being reduced as the fine aggregate becomes finer from Grading Zone I to IV.

Table 4.1 *Grading zones for fine aggregates*

IS Sieve designation	Percentage passing for			
	Grading Zone I	Grading Zone II	Grading Zone III	Grading Zone IV
10 mm	100	100	100	100
4.75 mm	90–100	90–100	90–100	95–100
2.36 mm	60–95	75–100	85–100	95–100
1.18 mm	30–75	55–90	75–100	90–100
600 micron	15–34	35–59	60–79	80–100
300 micron	5–20	8–30	12–40	15–50
150 micron	0–10	0–10	0–10	0–10

Note: IS: 2386 (Part II)-1963 prescribes a method to determine the proportions of clay, silt and fine dust by sedimentation method. According to IS: 383-1970 the materials finer than 75 μm IS sieve should not exceed three per cent for uncrushed fine aggregate and 15 per cent for crushed fine aggregate. For every one per cent of clay in the fine aggregate, the characteristics strength of concrete can decrease by five per cent.

3. **Bulking of fine aggregate** The increase in the volume of a given mass of *fine aggregate* caused by the presence of water is known as *bulking.* The bulking of fine aggregate is caused by the films of water

which push the particles apart. The extent of bulking depends upon the percentage of moisture present in the sand and its fineness. It is seen that bulking increases gradually with moisture content up to a certain point and then it begins to decrease with further addition of water due to merging of films, until when the sand is inundated. At this stage, the bulking is practically zero. With ordinary sands, the bulking usually varies between 15 per cent and 30 per cent. A typical curve shown in Fig. 4.2 illustrates the variation of per cent bulking with moisture content. Finer sand bulks considerably more and the maximum bulking is obtained at higher water content than the coarse sand. In extremely *fine sand*, the bulking may be of the order of 40 per cent at a moisture content of 10 per cent but such sand is unsuitable for concrete. In the case of coarse aggregate, the increase in volume of sand is negligible due to the presence of free water as the thickness of moisture film is very small compared with particle size. The percentage bulking is obtained in accordance with IS: 2386 (Part III)-1963.

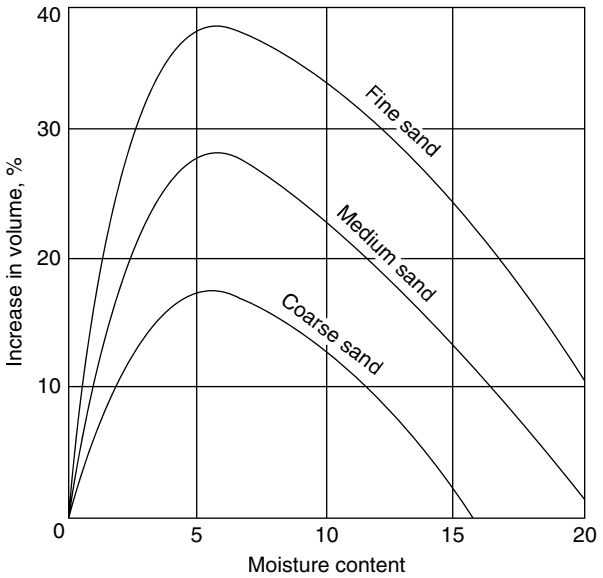

Fig. 4.2 *Effect of water content on bulking of sand*

If the sand is measured by volume and no allowance is made for bulking, the mix will be richer than that specified because for given mass, moist sand occupies a considerably larger volume than the same mass of the dry sand. This results in a mix deficient in sand increases the chances of *segregation* and *honey combing* of the concrete. If no allowance is made for the bulking of sand a nominal concrete mix 1:2:4, for example, will correspond to 1:1.74:4 for a bulking of 15 per cent. An increase in bulking from 15 per cent to 30 per cent will result into an increase in the concrete strength by as much as 12 per cent.

In volume batching, in the absence of bulking test, the water content in sand may be assumed between two to three per cent giving 25 per cent bulking.

4.2.2 General Characteristics of Fine Aggregates

Some of the important properties of aggregates commonly required are:

1. Bulk density (kg/litre)
   Fine sand 1.44
   Medium sand 1.52
   Coarse sand 1.60
2. Specific gravity of sand 2.65

4.3 COARSE AGGREGATE

The aggregate most of which is retained on 4.75 mm IS Sieve and contains only so much finer material as is permitted by IS: 383-1970, is termed as *coarse aggregate*. The aggregates are formed due to natural disintegration of rocks or by artificial crushing of the rock or gravels. Thus the aggregates derive many of their properties from the parent rocks. Classifications can be based on petrological character of the aggregate, e.g., igneous rocks, sedimentary rocks, metamorphic rocks, etc., and on the weight of the aggregate, e.g., heavy weight, normal weight, lightweight aggregate, etc.

The commonly used classifications to identify the particular lot of aggregate based on physical characteristics of the aggregate such as particle shape, surface texture, etc., is of great importance. Based on the shape, the aggregates can be described as:

1. Rounded aggregate, e.g., river or seashore gravel.
2. Irregular or partly rounded, e.g., pit-sands and gravels, cuboid rocks, etc.
3. Flaky aggregates, the aggregates whose least dimension (thickness) is less than the other two dimensions, e.g., laminated rocks.
4. Angular aggregates, the aggregates possessing well defined edges formed at the intersections of roughly planar surfaces, e.g., that obtained by crushing the rocks, etc.
5. Elongated aggregates, the aggregates whose greatest dimension (length) is very large compared to the other two dimensions.

The *angularity of aggregate* affects the workability or the stability of the mix which depends on the interlocking of the particles. The elongated and flaky particles also affect adversely the *durability* of concrete as they tend to be oriented in one plane with water and air voids forming underneath. The presence of these particles should be restricted to 10 to 15 per cent. The *angularity* of the aggregate can be estimated from the proportion of voids in a sample compacted as stipulated in IS: 2386 (Part I)-1963. The higher the angularity number, the more angular is the aggregate. The *elongation index* of an aggregate is defined as the percentage (by mass) of particles whose greatest dimension (length) is greater than nine-fifth times their mean dimension. Whereas, the *flakiness index* is the percentage (by mass) of particles having least dimension, i.e., thickness less than three-fifths of their mean dimension.

4.3.1 Grading and Surface Area of Coarse Aggregates

The curve showing the cumulative percentages of the material passing the standard set of sieves on the ordinate with the sieve openings to the logarithmic scale represented on the abscissae is termed *grading curve*, i.e., the grading of an aggregate represents the *particle size distribution*. The grading curve indicates whether the grading of a given sample conforms to that specified, or is too coarse or too fine, or deficient in a particular size.

The *grading of the aggregate* affects the *workability* which in turn controls the water and cement requirements, *segregation,* and influences the placing and finishing of the concrete. These factors represent the important characteristics of fresh concrete and affect its properties in the hardened state.

Smaller the size of the aggregate, greater is the *surface area* per unit mass or unit volume; the objective must therefore be to have as large a maximum aggregate size as possible and to grade it down in such a way that voids in the *coarse aggregate* are filled with the minimum amount of *fine aggregate.* The greatest contribution to this total surface area is made by the smaller size aggregate and therefore particular attention should be paid to the proportion and grading of fine aggregate. However, the maximum size of the aggregate that can be used for a certain job depends upon the size of the member and of the reinforcement used. For reinforced concrete work, the aggregate having a maximum size of 20 mm is generally considered satisfactory.

The graded coarse aggregates are generally supplied in nominal sizes given Table 4.2. For any one of the nominal sizes, the proportion of other sizes as determined by the method specified in IS: 2386 (Part I)-1963 are also given in Table 4.2.

Table 4.2 *Grading of coarse aggregates*

IS Sieve designation	Percentage passing for single -sized aggregate by mass Nominal size						Percentage passing for graded aggregate by weight; Nominal size			
	63 mm	40 mm	20 mm	16 mm	12.5 mm	10 mm	40 mm	20 mm	16 mm	12.5 mm
80 mm	100	-	-	-	-	-	100	-	-	_
63 mm	85–100	100	-	-	-	-	-	-	-	-
40 mm	0–30	85–100	100	-	-	-	95–100	100	-	-
20 mm	0–5	0–20	85–100	100	-	-	30–70	95–100	100	100
16 mm	-	-	-	85–100	100	-	-	-	95–100	-
12.5 mm	-	-	-	-	85–100	100	-	-	-	90–100
10 mm	0–5	0 - 5	0–20	0–30	0–45	85–100	10–35	25–55	30–70	40–85
4.75 mm	-	-	0–5	0–5	0–10	0–20	0–5	0–10	0–10	0–10
2.40 mm	-	-	-	-	-	0–5	-	-	-	-

Note: The material finer than 75 μm IS sieve should not exceed three per cent.

4.3.2 Strength of Aggregate

Mechanical strength tests form an important group for assessing the quality of *concrete aggregates.* An important attribute of any test is that there should be as little variation in its results as possible. When assessing the results of a test on a particular aggregate, it is essential that they should be judged in comparison with those for a representative range of that particular kind of aggregate.

The *compressive strength* of concrete cannot exceed that of the bulk of aggregate contained therein. An aggregate with higher *modulus of elasticity* generally produces a concrete with higher modulus of elasticity. The modulus of elasticity of aggregate also affects the magnitude of *creep* and *shrinkage* of concrete.

Aggregate Crushing Value IS: 383-1970 specifies that aggregate crushing value when determined in accordance with IS: 2386 (Part IV)-1963 shall not exceed 45 per cent for aggregate used for concrete other than for wearing surfaces and 30 per cent for concrete for wearing surfaces such as runways, roads and pavements.

The other related *mechanical properties* of aggregate which are important especially when the aggregate is subjected to high wear are *toughness* and *hardness.*

Aggregate Impact Value The *toughness* which is measured as the resistance of the aggregate to failure by impact is determined in accordance with IS: 2386 (Part IV)-1963. Aggregate impact value which is an alternative to the aggregate crushing value should not exceed 45 per cent by mass for aggregates used for concrete other than for wearing surfaces and 30 per cent by mass for concrete for wearing surfaces.

Aggregate Abrasion Values The *hardness* of the aggregate defined as its resistance to wear obtained in terms of *aggregate abrasion value* is determined by using Los Angeles machine. When determined in accordance with IS: 2386 (Part IV)-1963 using Los Angeles machine, IS: 383-1970 requires that satisfactory aggregate abrasion should not exceed the following values:

1. For aggregates for wearing surfaces: 30 per cent
2. For aggregates for concrete other than wearing surfaces: 50 per cent

The abrasion value of aggregate to be used in good quality concrete shall not exceed 16 per cent.

4.4 ALL-IN-AGGREGATES

If the combined aggregates are available they need not be separated into fine and coarse, but necessary adjustments may be made in the grading by addition of single-sized aggregates. The grading of the all-in-aggregate, when analysed as described in IS: 2386 (Part I)-1963 should be as given in Table 4.3.

Table 4.3 *Grading of all-in-aggregate*

IS Sieve designation	Percentage passing for all-in-aggregate	
	40 mm nominal size	*20 mm nominal size*
80 mm	100	–
40 mm	95–100	100
20 mm	45–75	95–100
4.75 mm	25–45	30–50
600 micron	8–30	10–35
150 micron	0–6	0–6

4.5 GAP-GRADED AGGREGATE

The *gap-grading* is defined as a grading in which one or more intermediate size fractions are absent. The term continuously graded is used to distinguish the conventional grading from gap-grading. On a grading curve *gap-grading* is represented by a horizontal line over the range of sizes omitted.

4.6 GENERAL CHARACTERISTICS

Some of the important properties of coarse aggregates commonly required are:

4.6.1 Fineness Modulus

The *fineness modulus* is a numerical index of fineness giving some idea of the mean size of the particles present in the entire body of the aggregate. The determination of fineness modulus consists in dividing a sample of aggregate into fractions of different sizes by sieving through a set of standard test sieves taken in order. Each fraction contains particles between definite limits. The limits being the opening sizes of standard test sieves. The material retained on each sieve after sieving represent the fraction of aggregate coarser than the sieve in question but finer than the sieve above. The sum of the *cumulative percentages* retained on the sieves divided by 100 give the *fineness modulus.* The sieves that are to be used for the *sieve analysis* of an aggregate (coarse, fine or all-in-aggregate) for concrete as per IS: 2386 (Part I)-1963 are 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm. 1.18 mm, 600 μm, 300 μm, and 150 μm.

The fineness modulus can be regarded as a weighted average size of a sieve on which material is retained, and the sieves being counted form the finest. For example, a fineness modulus of 6.0 can be interpreted to mean that the sixth sieve, i.e., 4.75 mm is the average size. The value of fineness modulus is higher for coarser aggregate. For the aggregates commonly used, the fineness modulus of fine aggregate varies between 2.0 and 3.5; for coarse aggregate between 5.5 and 8.0 and from 3.5 to 6.5 for all-in-aggregate.

The objective of finding fineness *modulus* is to grade the given aggregate for the most economical mix for the required strength and workability with minimum quantity of cement. If the test aggregate gives higher fineness modulus, the mix will be harsh and if, on the other hand, gives a lower fineness modulus it gives an uneconomical mix. For *workability*, a coarser aggregate requires lesser water-cement ratio.

4.6.2 Specific Gravity

The *specific gravity of* an aggregate is defined as the ratio of the mass of solid in a given volume of sample to the mass of an equal volume of water at the same temperature. Since the aggregate generally contains voids, there are different types of specific gravities.

The *absolute specific gravity* refers to the volume of solid material excluding the voids, and therefore, is defined as the ratio of the mass of solid to the mass of an equal void free volume of water at a stated temperature. If the volume of aggregate includes the voids, the resulting specific gravity is called the *apparent specific gravity.* As the aggregate generally contains both impermeable and capillary voids, (voids between particles) the apparent specific gravity refers to volume including impermeable voids only. It is therefore, the ratio of the mass of the aggregate dried in an oven at 100 to 110°C for 24 hours to the mass of the water occupying a volume equal to that of solids including impermeable voids or pores. The specific gravity most frequently and easily determined is based on the *saturated surface dry condition* of the aggregate because the water absorbed in the pores of the aggregate does not take part in the chemical reaction of the cement and can therefore be considered as a part of the aggregate. This specific gravity is required for the calculations of the *yield of concrete* or of the quantity of aggregate required for a given volume of concrete. The specific gravity of an aggregate gives valuable information on its quality and properties. It is seen that higher the specific gravity of an aggregate harder and stronger it will be. If the specific gravity is above or below that normally assigned to a particular type of aggregate, it may indicate that the *shape* and *grading o*f the aggregate has changed.

The specific gravity is determined as described in IS: 2386 (Part III)-2963. The specific gravity is given by

$$\text{Specific gravity} = \frac{c}{a-b} \text{ and}$$

$$\text{Apparent specific gravity} = \frac{a}{c-b}$$

where

a = mass of saturated surface dry aggregate in air,

b = mass of saturated surface dry aggregate in water and

c = mass of oven dry aggregate in air.

The specific gravity of majority of natural aggregates falls between 2.6 and 2.7; typically, for gravel 2.66 and for granite 2.80.

4.6.3 Bulk Density

The *bulk density* of an aggregate is defined as the mass of the material in a given volume and is expressed in kg/litre. The *bulk density* of an aggregate depends on how densely the aggregate is packed in the measure. The other factors affecting the bulk density are the particle shape, size, the grading of the aggregate and the moisture content. The shape of the particles greatly affects the closeness of the packing that can be achieved. For a coarse aggregate of given specific gravity, a higher bulk density indicates that there are fewer voids to be filled by sand and cement.

The bulk density of an aggregate can be used for judging the quality of aggregate by comparison with normal density for that type of aggregate. It determines the type of concrete for which it may be used. The bulk density is also required for converting *proportions by mass* into the *proportions by volume*. The bulk densities (in kg/litre) for some aggregates are:

Crushed stone	1.60
Crushed granite	1.68
Shingle	1.60

Stone screening	1.44
Brocken bricks	1.45
Brick dust (surkhi)	1.01
Slag	0.70

Bulk density may be used in calculating the percentage of *voids* in the aggregate from the expression:

$$\text{Void ratio} = 1 - \frac{\text{bulk density}}{\text{apparent specific gravity}}$$

The bulk density is determined as described in IS: 2386 (Part III)-1963.

4.6.4 Porosity of Aggregate

The pores in the aggregates vary in size over a wide range, the largest being large enough to be seen under a microscope or even with naked eye. They are distributed throughout the body of the material, some are wholly within the solid while the others are open to the surface of the particle. The porosity of some of the commonly used rocks varies from 0 to 20 per cent. Since the aggregates constitute about 75 per cent of the concrete, the *porosity* of aggregate contributes to the overall porosity of concrete. The *permeability* and the *absorption* affect the bond between the aggregate and the cement paste, the resistance of concrete to freezing and thawing, chemical stability, resistance to abrasion, and the specific gravity of the aggregate.

The percentage of water absorbed by an aggregate when immersed in water is termed the *absorption of aggregate.* The aggregate which is saturated with water but contains no surface free moisture is termed the *saturated surface dry aggregate.* The method for determining water absorption of an aggregate is described in IS: 2386 (Part III)-1963. If the aggregate is previously dried in an oven at 105°C to a constant mass before being immersed in water for 24 hours, the absorption is referred to as *oven dry basis*. On the other hand, the percentage of water absorbed by an air dried aggregate when immersed in water for 24 hours is termed absorption of aggregate (air dry basis). The knowledge of the absorption of an aggregate is important for concrete mix design calculations.

4.6.5 Moisture Content of Aggregate

The surface moisture expressed as a percentage of the mass of the saturated surface dry aggregate is termed *moisture content.* Since the absorption represents the water contained in the aggregate in saturated surface dry condition and the moisture content is the water in excess of that, the total water content of a moist aggregate is equal to the sum of absorption and moisture content. IS: 2386 (part III)-1963 describes the method to determine the moisture content of concrete aggregate.

The determination of moisture content of an aggregate is necessary in order to determine the net *water-cement ratio* for a batch of concrete. High moisture content will increase effective water-cement ratio to an appreciable extent and may make the concrete weak unless a suitable allowance is made. IS: 2386 (Part III)-1963 gives two methods for its determination. The first method namely the *displacement method* gives the moisture content as a percentage by mass of saturated surface dry sample; whereas, the second method, namely the *drying method,* gives moisture content as a percentage by mass of dried sample. The moisture content obtained by these two methods are quite different. The moisture content given by drying method will normally be the total moisture content due to free plus absorbed water.

4.6.6 Deleterious Substances in Aggregate

The *deleterious substances* found in the aggregates can be divided into three broad categories:

1. *Impurities* which interfere with the process of hydration of cements;
2. *Coatings* which prevent the development of bond between aggregate and the cement paste; and

3. *Unsound particles which* are weak to develop chemical reaction between the aggregate and cement paste.

The impurities in the form of organic matter interfere with the chemical reactions of hydration. These impurities generally consisting of decayed vegetable matter and appear in the form of humus or organic loam. These are more likely to be present in sand than in coarse aggregate which is easily washed. The effect of impurities is tested as per IS: 2386 (Part II)-1963.

The clay and other fine materials like silt and crusher dust may be present in the form of surface coatings which interfere with the bond between aggregate and the cement paste. Since the good bond is essential to ensure a satisfactory strength and durability of concrete, the problem of coating of impurities is an important one.

The total amount of deleterious materials shall not exceed five per cent as per IS: 383-1976.

The sand obtained from seashore or from a river estuary contains salts. If salt is not removed from the sand by washing it with fresh water before use, it absorbs moisture from air and may cause *efflorescence;* and slight corrosion of reinforcement may also occur.

4.6.7 Thermal Properties of Aggregates

The *thermal properties* of the aggregates affect the *durability* and the other qualities of the concrete. The principal thermal properties of the aggregate are:

1. Coefficient of thermal expansion
2. Specific heat
3. Thermal conductivity

If the coefficient of expansion of coarse aggregate and of cement paste differs too much, a large change in temperature may introduce differential movement which may break the bond between the aggregate and the paste and the durability of concrete subjected to freezing and thawing may be affected.

The *specific heat* of the aggregate is a measure of its heat capacity, whereas *thermal conductivity* is the ability of the aggregate to conduct the heat. These properties of the aggregate influence the specific heat and thermal conductivity of the concrete and are important in the case of mass concrete.

4.6.8 Alkali-Aggregate Reaction

The *alkali-aggregate reaction* is the reaction between the active silica constituent of aggregate and the alkalies in cement. The reaction starts with the attack on the silicious minerals in the aggregate by alkaline hydroxides derived from alkalies in the cement. As the result of this reaction, an alkali silicate gel is formed which being confined by the surrounding cement paste develops internal pressure due to expansion of gel on setting resulting in cracking and disruption of cement paste.

4.7 PREPARATION OF AGGREGATE SAMPLE FOR TESTING

The aggregates for the concrete should be of desired *grading.* Generally the coarse aggregate is separated into two or more size fractions depending upon the maximum size of aggregate used and recombined in such a manner as to produce a desired grading.

4.7.1 Sampling

Sampling is the process of selecting small *representative quantities* of a given material for the purpose of testing. Since the quality of large amount of material is to be determined on the basis of samples selected hence it is very essential that samples for testing must be truly representative.

Preparation of Main Sample To ensure the true representation, the main sample should be made up from about twelve smaller samples taken from various parts of the stock pile and thoroughly mixed.

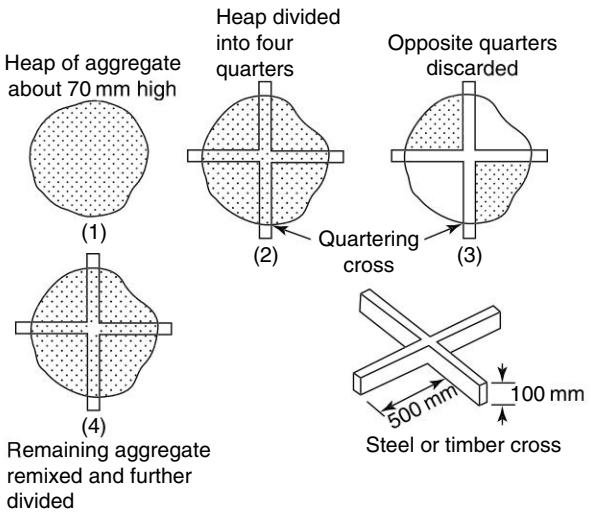

Fig. 4.3 *Reduction of main sample by quartering*

Reduction of Main Sample The main sample should be reduced to the size suitable for dispatch to a testing laboratory or for carrying out tests directly. The main sample is reduced by a method known as *quartering* as illustrated in Fig. 4.3.

1. Spread the main sample out into a layer of about 70 mm thick.
2. Divide this layer into four equal parts by means of a cross.
3. Discard two diagonally opposite quarters and remix the remainder.
4. Repeat this process until the sample is reduced to the amount required for testing.

In case, cross is not available, the division may be made with a shovel or a trowel.

Fine aggregate should be quartered when damp to prevent *segregation,* water should be added if necessary. If wetting is not possible, care must be taken to remove the whole of the rejected quarters leaving no fines or dust for inclusion in the quarter retained for remixing.

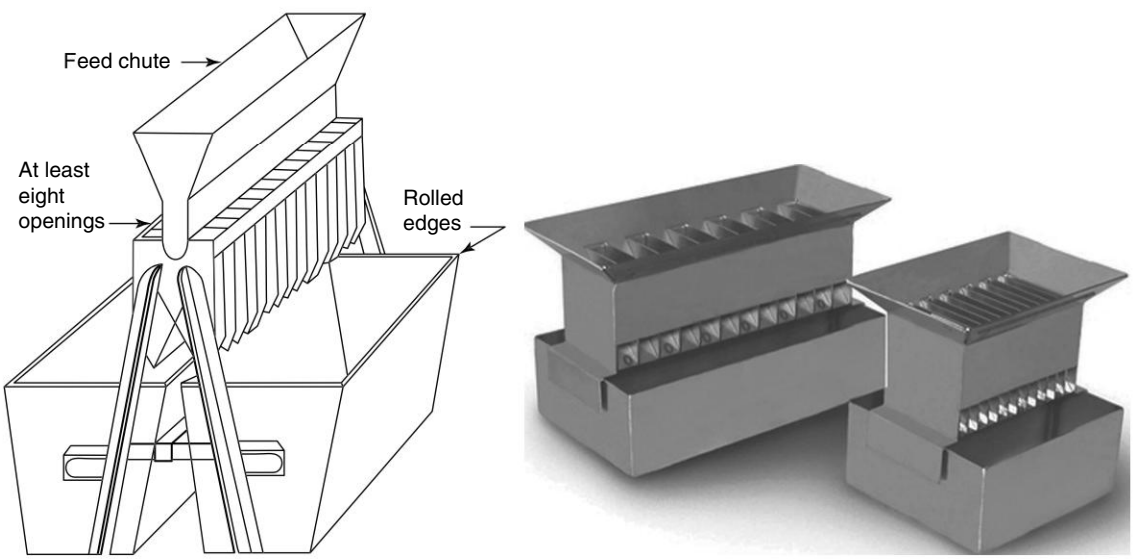

Fig. 4.4 *Sample splitter of riffle box type*

The alternative method of reducing is to use a *riffle box* shown in Fig. 4.4. It consists of a number of chutes arranged to slope alternatively to each side where the *split aggregate* is collected. The *main sample* is placed evenly across the top hopper. The riffle box split the main sample into two approximately equal and representative parts. One part is rejected and other is passed through the riffle box again. The process being repeated until a sample of required size is obtained.

EXPERIMENT NO. 1: Organic Impurities in Aggregates

Objective

To test the presence of organic impurities in aggregates.

Theory and Scope

The organic impurities like those resulting from the products of decay of vegetable matter interfere with the chemical reactions of hydration of cement. Such organic impurities are more likely to be present in fine aggregates; those in coarse aggregate can by removed during washing.

This test known as *colorimetric test* prescribed in IS: 2386 (Part II)-1973 is an qualitative method of making a preliminary determination of the acceptability of fine aggregates with respect to the requirements of specification that relate to organic impurities.

The principal value of this test method is to furnish a warning that injurious amounts of organic impurities may be present. When a sample subjected to this test produces a colour darker than the standard colour it is advisable to perform the test for the effect of organic impurities on the strength of mortar in accordance with the test prescribed in IS: 2386 (Part VI) – 1963. It consists in comparing the strength properties of concrete made with suspected aggregate and good aggregate.

Apparatus

A clear glass graduated medicine bottle of 350 ml capacity; three per cent solution of caustic soda (or sodium hydroxide) obtained by dissolving 3 g of sodium hydroxide in 100 ml of distilled water.

Fig. 4.5 *An image of graduated medicine bottle and colour chart*

Procedure

Step 1: Fill the graduated clear glass medicine bottle up to 75 ml mark with three per cent solution of sodium hydroxide.

Step 2: Add the sand gradually until the volume measured by the sand layer is 125 ml. Increase the volume to 200 ml by the addition of more of solution.

Step 3: Close the bottle with the stopper and shake vigorously and allow it to stand for 24 hours.

Step 4: Prepare a standard solution in a 350 ml bottle by adding 2.5 ml two per cent solution of tannic acid in 10 per cent alcohol. Add to this 97.5 ml of three per cent sodium hydroxide solution. Close the bottle with stopper, shake vigorously and allow it to stand for 24 hours.

Step 5: At the end of 24 hours compare the colour of the liquid above the sand obtained in Step 3 with that of freshly prepared standard solution.

Observations

Colour of the liquid:	
	Colourless
	Straw colour
	Darker colour

Precautions

1. The three per cent sodium hydroxide solution should be kept in glass bottle tightly closed with a rubber stopper. Handling sodium hydroxide with moist hands may result in serious harm. Care should be taken not to spill the solution for it is highly injurious to clothing, leather and other materials.
2. The sand should be tested as delivered and without drying.

Discussion

This test is mainly a negative test which means that if there is no colour change, no organic matter is present, but if the colour changes, the presence of organic matter is indicated. A colourless liquid indicates clean sand free from organic matter. A straw coloured liquid indicates some organic matter but not enough to be seriously objectionable. Darker colour means that the sand contains injurious amounts and should not be used unless it is washed and a retest shows that it is satisfactory. Not all the organic matter present in an aggregate are harmful and in most cases, it is desirable to test the strength properties made with such aggregates and compare with those made with aggregate known to be free from organic impurities. This test is, however, resorted to only when the impurities are detected by the colour test.

Viva-Voce Questions

1. What is meant by organic impurities? Do these impurities occur in fine or coarse aggregate or both?
2. How can the impurities in coarse aggregate be removed?
3. What is a colorimetric test? How does it indicate the degree of impurity?
4. How is a three per cent solution of sodium hydroxide prepared?
5. What will be the effect of dirty aggregate on the strength of concrete?
6. What is a standard solution and how is it prepared?
7. If organic impurities are indicated by the colour test, what further tests will be required?

Notes and Comments

EXPERIMENT NO. 2: Material Finer than 75 µm IS Sieve

Objective

To determine the amount of material finer than 75 micron IS sieve present in the aggregate by washing.

Theory and Scope

The material passing the 75 micron IS Sieve constitutes the portion which can be classified as silt (between 0.06 mm and 0.002 mm) and clay (smaller than 0.002 mm). These materials may be considered undesirable as constituents in aggregates because of their fineness and other physical characteristics, the presence of which may affect the strength, workability and long term performance of concrete. The clays which may be present as coating around the aggregates interfere with the bond characteristics. The fine particles increase the total specific surface area of aggregate thereby affecting the workability. It is difficult to precisely estimate what proportion of these will definitely pose adverse effects on the properties of concrete. The effect of these materials depends upon their size and shape, and their distribution in the aggregate. Nevertheless IS: 383-1970 has set limits about the presence of these deleterious constituents. The limit of deleterious materials in aggregates is given in Table 4.5.

Apparatus

Weighing balance of sufficient capacity and accurate to 0.1 per cent of the mass of test sample; Nest of two sieves; Oven capable of maintaining a uniform temperature of 105 ± 5°C.

Description of Apparatus

Nest of two sieves with lower being 75 micron IS sieve and the upper one being the 1.18 mm IS sieve; a container or pan of a size sufficient to hold the sample covered with water and to permit vigorous agitation without inadvertent loss of any part of sample or water.

Procedure

Preparation of sample The test sample is selected from material which has been thoroughly mixed and which contains sufficient moisture to prevent segregation. A representative sample, sufficient to yield not less than the appropriate weight of dried material, as given below, is selected:

Maximum nominal size of aggregate, mm	4.75	10	20	≥ 40
Approximate minimum weight of sample, g	500	2000	2500	5000

Step 1: Prepare a representative sample of the size above.

Step 2: Dry the test sample to a constant mass at a temperature of 105 ± 5°C. Cool and weigh the dried sample to the nearest 0.1 per cent.

Step 3: Place the weighed sample in the container and cover it with sufficient water.

Step 4: Agitate the contents of the container vigorously to dislodge the particles finer than 75 micron IS Sieve from the coarser particles and result in suspension of the particles.

Step 5: Pour the wash water containing the suspended and dissolved solids over the nested sieves arranged with coarser sieve on the top.

Step 6: Add water to the washed sample and repeat the operations in Steps (4) and (5) until the wash is clear.

Step 7: Return all the material retained on the nested sieves to the washed sample. Dry the washed aggregate to a constant mass at a temperature not exceeding 110°C. Weigh the dry aggregate to the nearest 0.1 per cent.

Step 8: Calculate the material passing the 75 micron IS sieve.

Observations and Calculations

Dry mass of the test sample,	W_1,	g	
Dry mass of the washed sample,	W_2,	g	
Material finer than 75 micron IS sieve $= \frac{W_1 - W_2}{W_1} \times 100$ per cent			

The quantity of material finer than 75 micron is…… per cent.

Precautions

1. A truly representative sample should be prepared.
2. The agitation of the aggregate should be sufficiently vigorous to result in complete separation and suspension of the finer material.
3. Care should be taken to avoid, as much as possible, the decantation of coarse particles of the sample into the nested sieves.
4. The hot sample should never be sieved
5. The sieve should not be allowed to come in to direct contact with hot drying device.
6. Avoid loss of material during transfer of sample from washing container to nested sieves and also during rinsing.

Discussion

The dust is not in itself a harmful constituent, provided it is not chemically reactive. Its only harmful effect is to increase the amount of mixing water required for a given workability and thereby reduce the strength of the concrete. Clays and silts are commonly present in many gravels and sand deposits. If present in large quantities they cause a serious reduction in strength, and unsoundness due to their retarding action on the hydration of the cement. They are harmful when they form a coating on the particles of aggregate and thus prevent the adherence of the cement. Clays are also deleterious in concrete owing to the swelling and shrinkage which result from alternate wetting and drying.

Table 4.4 *Limits of deleterious materials in aggregates (in percentage)*

Deleterious Substances (1)	Fine Aggregates		Coarse Aggregates	
	Uncrushed (2)	*Crushed* (3)	*Uncrushed* (4)	*Crushed* (5)
1. Coal and Lignite [IS: 2386 (Part II)- 1963]	1.00	1.00	1.00	1.00
2. Clay lumps [IS: 2386 (Part II)- 1963]	1.00	1.00	1.00	1.00
3. Soft fragments [IS: 2386 (Part 11)- 1963]	–	–	3.00	–
4. Material passing 75 micron IS sieve [IS: 2386 (Part I)- 1963]	3.00	15.00	3.00	3.00
5. Shale [IS: 2386 (Part II)- 1963]	1.00	–	–	–
Total	5.00	2.00	5.00	5.00

Note: The total percentage of all deleterious materials include serial nos. 1 to 5 for columns 2, 4. 5 and serial nos. 1 and 2 for column 3 only.

Viva-Voce Questions

1. What are the deleterious constituents?
2. How do the dust, clay and silt affect the performance of the concrete?
3. What is the significance of the determination of the material finer than 75 micron in the aggregates?
4. What are the limits set by IS: 383-1970 regarding the deleterious material?
5. Does the test give particle size distribution?
6. What precautions should be taken during the test?

Notes and Comments

EXPERIMENT NO. 3: Fine Silt and Clay (Sedimentation Process)

Objective

To determine the percentage of fine silt and clay or fine dust by sedimentation method.

Theory and Scope

The material between 0.060 mm and 0.002 mm is classified as *silt,* and still smaller particles are called *clay*. The presence of fine silt and clay may affect the strength, workability and long-term performance of concrete. These undesirable materials are termed *deleterious constituents*. IS: 383 - 1970 has set limits about the presence of these fine particles, whereas IS: 2386 (Part II)—1963 has prescribed a test to determine specifically the proportions of clay, silt and fine dust by the *sedimentation or gravimetric method.* This gravimetric method is used for determining the clay, fine silt and fine dust, which includes particles up to 20 micron. Differences in the nature and density of materials or in the temperature at the time of testing may vary separation point.

Apparatus

A watertight screw-topped glass jar; A device for rotating the jar about its longitudinal axis which is in horizontal position at a speed of 80 ± 20 rpm; Sedimentation pipette of approximately 25 ml capacity; 1000 ml measuring cylinder; Weighing balance of 10 kg capacity accurate to one g; Analytical weighing balance accurate to 0.001 g; Well-ventilated oven; Drying container.

Reagents

Sodium oxalate solution (0.8 g per litre) obtained by adding 8 g sodium oxalate solution to one litre of distilled water and diluted with distilled water to one-tenth.

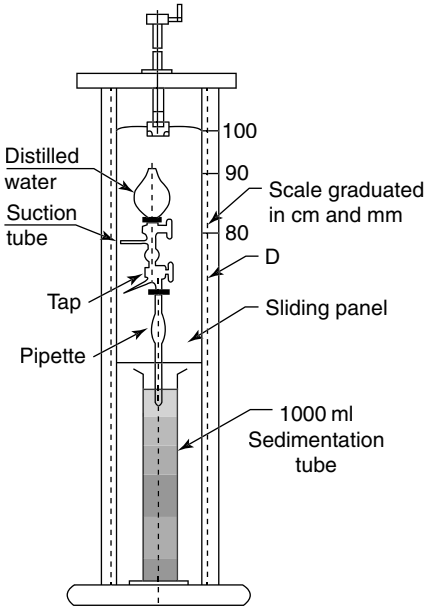

Fig. 4.6 *Sedimentation pipette for determination of clay and silt content*

Procedure

Step 1: Obtain a representative test sample of a mass specified by IS: 2386 (Part 1I)-1963 and reproduced in Table 4.5.

Step 2: Prepare the liquid suspension as given below.

(a) For fine aggregate

i. Weigh about 300 g of air dry sample passing 4.75 mm IS sieve.

ii. Place the weighed sample in the screw topped glass jar and cover with 300 ml of diluted sodium oxalate solution (0.8 g per litre).

iii. Tightly screw the cap with the washer on to the jar to have watertightness. Rotate the jar about its horizontal long axis at a speed of 80 ± 20 rpm for a period of 15 minutes.

iv. Pour the suspension into the 1000 ml measuring cylinder and wash the residue with successive 150 ml portions of sodium oxalate solution by gentle swirling. Transfer the washing to the cylinder by decantation. Repeat the washing until volume in the cylinder is made up to 1000 ml.

(b) Coarse aggregate

i. Weigh the test sample of the size given in Table 4.5.

ii. Place the sample in a suitable container and cover it with a measured volume of sodium oxalate solution (0.8 g per litre).

iii. Vigorously agitate the container to dislodge all adherent fine material.

iv. Transfer the liquid suspension to the 1000 ml measuring cylinder. Make up the volume to 1000 ml with sodium oxalate solution.

Step 3: Mix the suspension in the measuring cylinder thoroughly by inversion. Place the cylinder and the contents immediately under the pipette.

Step 4: Lower the pipette gently until its tip touches the surface of the liquid. Then lower it further 100 mm into the liquid.

Step 5: After three minutes, fill the pipette and the bore of tap by opening the bore and applying a little suction.

Step 6: Remove the pipette from the measuring cylinder and transfer its contents into a weighed beaker. Wash all adherent solids into the container by distilled water.

Step 7: Dry the contents of the container at 100 to 110°C to a constant mass. Cool and weigh the container with dry residue.

Step 8: Determine the percentage of clay, silt and fine dust.

Observations and Calculations

Type of aggregate			
Mass of original sample	w, g		
Mass of the empty container	W_1, g		
Mass of the container + dried residue	W_2, g		
Mass of the dried residue	$w_1 = W_2 - W_1$, g		
Volume of pipette	V, ml		
Mass of sodium oxalate in the residue	$w_2 = 0.0008\ V$, g		
Quantity of clay and fine silt,	$(w_1 - w_2)\times 100/w$ per cent		

Clay and fine silt content of sample is……. per cent.

Precautions

1. The representative test sample should be prepared from the main sample such that to have correct proportion of the finer material.
2. Wash the residue carefully so that no solids are lost while transferring the suspension to the measuring cylinder.
3. The pipette should be gently lowered.

Discussion

This method based on the fact that a water suspension has more density than pure water. Sand has the largest particle size and will settle faster than silt. Clay has the smallest particle size and will require about nine hours to settle for sampling. Thus, this method is able to give a good estimate of the levels of silt and clay in the sample.

IS: 383-1970 limits the *material passing through the* 75 *micron IS sieve* to three per cent by mass for fine aggregates and crushed or natural coarse aggregates and to one per cent for crushed rocks. There is no corresponding limitation of these constituents detected by the sedimentation test. The deleterious constituents determined by these two methods may or may not be the same. However, the British practise limits the proportion of clay, silt and fine dust content in aggregates (as determined by sedimentation method) to three per cent by mass in sand and one per cent by mass in crushed coarse aggregates.

The effect of such fine particles on the strength and workability of concrete may be appreciated by the fact that for every one per cent of clay in fine aggregate, the compressive strength of concrete may decrease by five per cent.

Table 4.5 *Mass of sample for sedimentation test*

Maximum size of the aggregate, mm	63 to 26	20 to 12.5	10 to 6.3	4.75 or smaller
Approximate mass of test sample, gm	6000	1000	500	300

Viva-Voce Questions

1. What are the deleterious constituents and why are they so called?
2. How are the deleterious constituents classified by the way of their actions?
3. How does the fine silt and clay affect the strength and workability?
4. What limits have been set by IS: 383-1970 for the presence of deleterious constituents?
5. What does the test for material passing 75 micron IS sieve indicate?
6. What is a representative sample?
7. How will you prepare standard sodium oxalate solution?
8. What is a suspension?
9. What precautions should be taken in the test?

Notes and Comments

EXPERIMENT NO. 4: Bulking of Fine Aggregates

Objective

Determine the necessary adjustment in the ratio 1: 1½: 3 (by volume) for the bulking of fine aggregate and to draw curve between water content and bulking of sand.

Theory and Scope

In concrete mix design, the quantity of fine aggregate used in each batch is related to the known volume of cement. The difficulty with measurement of fine aggregate by volume is the tendency of sand to vary in bulk according to moisture content. The extent of this variation is given by this test. If sand is measured by volume and no allowance is made for bulking, the mix will be richer than that specified because for given mass, moist sand occupies a considerably larger volume than the same mass of dry sand, as the particles are less closely packed when the sand is moist.

This experiment is intended to cover the field method of determining the necessary adjustment for bulking of the aggregate.

Apparatus

Balance; Cylindrical container; Graduated cylinder; Beaker; Metal tray; Steel ruler and Oven.

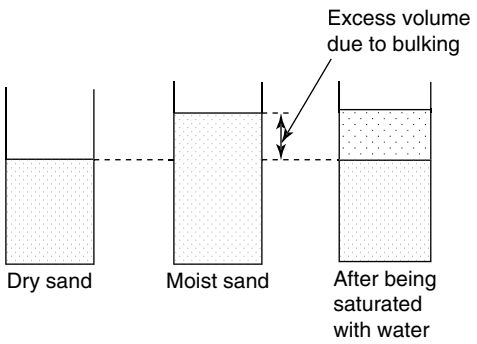

Fig. 4.7 *Concept of bulking of sand*

Procedure

Part 1: To determine bulking of fine aggregate

Step 1: Put sufficient quantity of the oven dry sand loosely into the container until it is about two-third full. Level off the top of sand and weigh the container. Calculate the mass of sand by deducting the mass of container.

Step 2: Push a steel ruler vertically down through the sand at the middle to the bottom and measure the height of sand. Let it be *h* mm.

Step 3: Empty the sand out into a clean metal tray without any loss.

Step 4: Add one per cent of water by mass of sand. Mix the sand and water thoroughly by hand.

Step 5: Put the wet sand loosely into the container without tamping it.

Step 6: Smoothen and level the top surface of the moist sand and measure its depth at the middle with the steel ruler. Let it be *h'* mm.

Step 7: Repeat the Steps 4 to 6 of the above procedure with two per cent of water by mass.

Go on increasing the percentage by one till bulking is maximum and starts falling down and ultimately bulking is zero, i.e., saturated sand occupies the same volume as dry sand.

Part 2: To determine bulking of fine aggregate (field test)

Step 1: Fill the container to about two-third full with given sand loosely.
Step 2: Level off the top of sand and measure the height by pushing a steel ruler vertically down through the sand at the middle to the bottom, let it be h mm.
Step 3: Take the sand out into a clean metal tray without any loss.
Step 4: Fill the container with water to half full.
Step 5: Pour the sand back into the container and stir it with a steel rod 6 mm in diameter so that volume may reduce to a minimum.
Step 6: Smooth and level the top surface of the inundated sand and measure its depth at the middle with the steel rule; let it be h' mm.
Step 7: Calculate percentage of bulking of sand due to moisture as follows.

$$\text{Percentage bulking} = \frac{h' - h}{h} \times 100$$

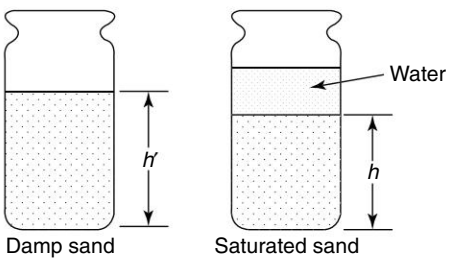

Fig. 4.8 *Field method for determining bulking of sand*

Observations and Calculations

Material details		
Mass of container with oven dry aggregate,	g	
Mass of empty container,	g	
Mass of the fine aggregate (sand),	g	
Height of dry sand h,	mm	

Mass of sand, g	Mass of added water	Total water per cent	Height of sand h', mm	Bulking $= \frac{h' - h}{h} \times 100$ per cent

Precautions

1. There should not be any inadvertent loss of sample.
2. Water should be measured accurately.
3. Container should be clean and dry.

Discussion

It is seen that bulking increases with increasing water content up to a certain point where it is maximum and then it begins to decrease until when the sand in inundated with bulking being practically nil as shown in Fig. 4.8. With ordinary sands, the bulking usually varies between 15 and 30 per cent. If, therefore, in volume batching no allowance is made for bulking, the mix will be richer than specified, e.g., when the sand has bulked by say 15 per cent the mix 1:2:4 by volume batching will correspond to 1: 1.74: 4.

Note: For 15 per cent bulking, the ratio 1:2:4 will correspond to $1:\frac{2}{1+\left(\frac{15}{100}\right)}:4$ i.e. 1:1.74:4, and for 30 per cent bulking the ratio 1:2:4 will correspond to $1:\frac{2}{1+\left(\frac{30}{100}\right)}:4$, i.e., 1:1.54:4.

An increase in bulking from 15 to 30 per cent will result into an increase in concrete strength by as much as 13 per cent. If no allowance is made for bulking, concrete strength may vary by as much as 25 per cent. The bulking of a given sample can be calculated as follows in the field and necessary adjustments can be made for.

In the absence of such a test, it is common to assume that the normal dampness present in sand results in 25 per cent bulking.

Viva-Voce Questions

1. What is bulking of aggregates and what is its significance?
2. How do the relative bulking tendencies of fine and coarse sands compare?
3. Why the bulking takes place only in sand and why not in coarse aggregate?
4. Is this test actually needed in field? If so, explain why?
5. If no allowance is made for bulking of sand, how is it going to affect the mix proportions?
6. What conclusion(s) can be drawn from the curve between moisture content and increase in volume of fine aggregates?
7. If no allowance is made for bulking of sand, how is it going to affect the mix proportions?

Notes and Comments

EXPERIMENT NO. 5: Specific Gravity and Water Absorption of Fine Aggregate

Objective

To determine the specific gravity, apparent specific and water absorption of fine aggregate.

Theory and Scope

This test covers the procedures for determining the specific gravity, apparent specific gravity and water absorption of fine aggregates.

The *specific gravity* of an aggregate is defined as the ratio of the mass of a given volume of sample to the mass of an equal volume of water at the same temperature.

1. **Percentage absorption** $= \dfrac{(W_4 - W_5)}{W_5} \times 100$
2. **Bulk specific gravity**

$$= \frac{\text{mass of sample in air}}{\text{loss in mass of sample in water}} = \frac{W_1}{W_1 - (W_3 - W_2)}$$

In this expression,

W_1 = mass of saturated surface dry sample in air,

W_2 = mass of basket in water,

W_3 = mass of basket + sample in water and

W_4 = mass of oven dry sample in air.

3. **Apparent specific gravity** $= \dfrac{W_2}{W_2 - (W_3 - W_1)}$

W_5 = mass of saturated surface dry sample.

The specific gravity of fine aggregate is generally required for calculations in connection with concrete mix design, for determination of moisture content and for the calculations of *volume yield of concrete.* The specific gravity also gives information on the quality and properties of aggregate. Departure of specific gravity from its standard value indicates change in *shape* and *grading.*

Absorption It influences the behaviour of aggregate in concrete in several important aspects. A highly absorptive aggregate, if used in dry condition, will reduce *effective water-cement ratio* to an appreciable extent and may even make the concrete unworkable unless a suitable allowance is made. Hence, determination of absorption of aggregate is necessary to determine net water-cement ratio.

Apparatus

Balance (capacity not less than 3 kg accurate to 0.5 g); Weight box; Le Chatelier flask of 500 ml capacity calibrated at specified temperature or a pycnometer; Distilled water: Conical mould (64 mm diameter at top and 90 mm diameter at bottom and 73 mm in height); Tamping rod 25 mm in diameter; A well-ventilated thermostatically controlled oven to maintain a temperature of 100 to 110°C; Metal tray (area 32500 mm^2); A source of supplying a current of warm air, such a hair drier; Fountain pen filler; Filter papers and Funnel.

Description of Apparatus

Typical Pycnometer shown in Fig. 4.9 is a glass jar of about one litre capacity having a metal conical screw top with a 6 mm diameter hole at its apex. The screw top is watertight when it is screwed on to the jar with a rubber or fibre washer inserted in the joint. There is a mark on the jar to correspond with a mark on the screw top so that the screw is tightened to the same position every time and the volume contained by the jar is constant throughout the test.

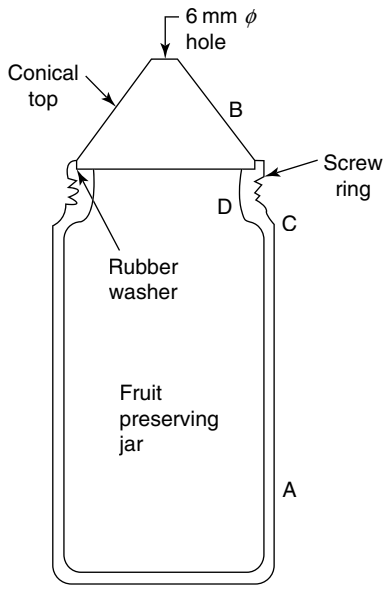

Fig. 4.9 *Typical pycnometer of a glass jar*

Procedure

Part 1: Specific gravity determination

Step 1: Calibrate the flask or Pycnometer by weighing it empty and full with water at room temperature. Roll and agitate the flask or Pycnometer gently in an inclined position, to eliminate air bubbles.

Step 2: Take about 1500 g sample of the fine aggregate and place it in the tray and cover with distilled water and soak for 24±½ hours at a temperature of 27 ± 5°C.

Step 3: Carefully drain the water from the sample by decantation. Expose the aggregate to a gently moving current of warm air to evaporate surface moisture; stir at frequent intervals to ensure uniform drying until no free surface moisture can be seen and the material just attains a 'free-running' condition. The free running condition (flowing freely) can be checked as in Step 4.

Step 4: Place the sand loosely in conical mould and tamp it on surface 25 times. Lift the mould vertically. If the sand retains its shape, it means *free surface moisture* is present. Continue the drying with constant stirring until the cone of sand slumps on the removal of the mould. This indicates that sand has reached a *surface dry condition.*

Step 5: Immediately weigh about 500 g of saturated surface dry sand in the flask or pycnometer.

Step 6: Fill the pycnometer or flask with distilled water to the top of the cone. Roll it, with the hole in the apex of the cone being covered with a finger, in an inclined position to eliminate air bubbles and replace with water by means of fountain pen filler so that the surface of the water in the hole is flat.

Step 7: Wipe the flask or pycnometer dry and weigh it accurately.
Step 8: Empty the contents of the pycnometer into the tray, care being taken to ensure that all the aggregate is transferred.
Step 9: The water shall then be carefully drained from the sample by decantation through a filter paper and any material retained returned to the sample. The sample shall be placed in the oven in the tray at a temperature of 100 to 110°C for 24 l/2 hours, during which period it shall be stirred occasionally to facilitate drying. It shall be cooled in the air-tight container and weighed.
Step 10: Calculate the specific gravity.

Part 2: Absorption test

Step 1: Weigh the remaining 1000 g of saturated surface dry sand in the tray of known weight.
Step 2: Dry the sample in an oven at 100–110°C for 24 hours.
Step 3: Weigh the dry sand with tray.
Step 4: Calculate absorption capacity as the percentage of oven dry mass.

Observations and Calculations

Mass of empty dry flask,	W g		
Mass of flask + water,	W_1 g		
Mass of saturated surface dry sample,	W_2 g		
Mass of flask + sample + water,	W_3 g		
Mass of oven dry sample,	W_4 g		
Specific gravity,	$\frac{W_4}{W_2-(W_3-W_1)}$		
Apparent specific gravity,	$\frac{W_4}{W_4-(W_3-W_1)}$		
Absorption of fine aggregate			
Mass of empty tray,	W_e g		
Mass of tray + saturated surface dry sample,	W_s g		
Mass of saturated surface dry sample,	$(W_s-W_e)=W_5$ g		
Mass of tray + oven dry sample,	W_o g		
Mass of oven dry sample,	$(W_o-W_e)=\mathrm{W}_6$ g		
Water absorption	$\frac{(W_5-W_6)}{W_6}\times 100$ per cent		

Specific gravity of sample is…….
Apparent specific gravity of sample is…….
Water absorption of sample is……. per cent.

Precautions

1. The entire sample should be frequently stirred to secure uniform drying.
2. Soon after immersion, air entrapped in or bubbles on the surface of the aggregate should be removed by gentle agitation with a rod.

The air trapped in the aggregate should be brought to surface by rolling the flask in inclined position.

3. All weighing should be accurate to the nearest gram.
4. Sand should not be allowed to stick to the sides of the jar or flask.
5. The water meniscus should be at flask mark.

Discussion

Instead of pycnometer any suitable vessel made from a one kg fruit preserving jar in which the glass lid is replaced by a sheet metal cone as shown in Fig. 6.1 can be used. The results of different repetitions should not differ more than 0.02 for specific gravity and 0.05 per cent for absorption.

Since concrete aggregates are normally used in a wet condition, the bulk specific gravity as determined for field use is based on the mass of saturated surface dry sample, rather than an oven dry sample.

Viva-Voce Questions

1. What are the apparent specific gravity and specific gravity? Which one is most often used in concrete calculations in the field and why?
2. Is specific gravity ever a requirement for concrete aggregates, if yes, Why?
3. Why is it necessary to remove the air bubbles from the flask containing water and aggregate at the time of weighing it?
4. What are the limits within which the duplicate determination should check?

Notes and Comments

EXPERIMENT NO. 6: Specific Gravity and Absorption of Coarse Aggregate

Objective

To determine the specific gravity and absorption of coarse aggregates.

Theory and Scope

The test procedure is used in determination of specific gravity and absorption of coarse aggregate.

The specific gravity of the aggregates is required for design of concrete mix and for the calculations of volume yield of concrete. In addition, specific gravity of an aggregate gives valuable information on its quality and properties. If the specific gravity is above or below that normally assigned to a particular type of aggregate, it may indicate that shape and grading of aggregate has altered.

The determination of absorption of aggregate is necessary to determine the amount of water to be added in concrete mix, i.e., net water-cement ratio. A highly absorptive aggregate, if used in dry condition, will reduce effective water-cement ratio to an appreciable extent and may even make the concrete unworkable unless a suitable allowance is made.

Apparatus

Balance of capacity of 5 kg and weight box; Wire basket; Water tub or container for immersing the wire basket in water; Suitable arrangement for suspending the wire basket from the centre of scale pan of balance; A well-ventilated thermostatically controlled oven to maintain a temperature of 100 to 110°C; A shallow tray of area not less than 65000 mm^2; Two dry soft absorbent cloths each not less than 750×450 mm for surface drying of the sample; An airtight container of capacity similar to that of the basket; A stout watertight container in which the basket may be freely suspended.

Description of Apparatus

A balance or scale of capacity not less than 5 kg, accurate to 0.5 g and of such a type and shape as to permit the basket containing the sample to be suspended from the beam and weighed in water.

Fig. 4.10 *Wire basket for weighing the coarse aggregate in water*

A wire basket, typically shown in Fig. 4.10, of 200 mm in diameter and 200 mm height of not more than 6.3 mm mesh or a perforated container of convenient size, preferably chromium plated and polished, with wire hangers not thicker than one millimeter for suspending it from the balance.

Procedure

Step 1: Take about 5 kg of aggregate by method of quartering; rejecting all material passing 10 mm IS sieve.

Step 2: Wash the aggregate thoroughly to remove dust, etc., from the surface of its particles. Dry the washed aggregate to constant mass at a temperature of 105 ± 5°C.

Note: Where the aggregate is used in moist condition it is not necessary to dry it to constant mass.

Step 3: Immerse the sample in water at 22 to 32°C for a period of (24 ± ½) hours (30 minutes for laboratory practise).

Step 4: Remove the aggregate from water and roll the same in a large piece of an absorbent cloth until all visible films of water are removed, although the surface of particles will still appear to be damp.

Step 5: Now, weigh 3 kg of this sample in the saturated surface dry condition and note down the mass as W_1 g.

Step 6: Place the weighed aggregate immediately in the wire basket and dip it in water. After immersion, remove the entrapped air by lifting the basket and allowing it to drop 25 times in 25 seconds. Weigh this basket with aggregate, while keeping it in water, with the help of the balance. Note its mass as W_3 g.

Step 7: Dry the sample in the shallow tray to the constant weight at the temperature of 100 to 110°C for (24 ± ½) hours.

Step 8: Cool the dried sample in airtight container and weigh.

Step 9: Calculate the specific gravities and absorption of the aggregate.

Step 10: Repeat the procedure for fresh aggregate.

Observations and Calculations

Material				
Mass of saturated surface dry sample in air	W_1,	g		
Mass of basket suspended in water	W_2,	g		
Mass of material + basket suspended in water	W_3,	g		
Mass of aggregate suspended in water	$(W_3 - W_2)$,	g		
Mass of oven dry aggregate in air	W_4,	g		
Bulk specific gravity saturated surface dry basis	$\frac{W_1}{W_1 - (W_3 - W_2)}$			
Apparent specific gravity	$\frac{W_4}{W_4 - (W_3 - W_2)}$			
Specific gravity	$\frac{W_4}{W_1 - (W_3 - W_2)}$			
Absorption, percent	$\frac{(W_1 - W_4)}{W_4} \times 100$			

Bulk specific gravity of aggregate (saturated surface dry basis) is……

Apparent specific gravity of aggregate……

Specific gravity of aggregate is……

Absorption of aggregate is……per cent.

Precautions

1. The mass of sample should be accurate at all stages and should be determined to the nearest 0.5 g.
2. The sample should be free from foreign matters.
3. After immersion and again at the end of the soaking period, air entrapped in or bubbles on the surface of the aggregate should be removed by gentle lifting the wire basket and allowing it to drop for 25 times. The entrapped air or surface bubbles of the aggregate can be removed by gentle agitation by rapid clockwise and anti-clockwise rotation of the vessel held between hands.
4. The large particles should be wiped surface dry individually.
5. Avoid evaporation during surface drying operation.
6. The absorbent cloth should be of such a type that it can absorb quite a large quantity of water.

Discussion

The specific gravity of an aggregate sample is the ratio between the mass in air and mass of an equal volume of water. For accurate results in laboratory, the allowance is made for the volume of voids between the particles and for the water absorbed by them.

It is seen that higher the specific gravity of aggregate, harder and stronger it will be. Average figures for the specific gravity of stone aggregate are: Gravel = 2.6; Lime stone = 2.7 and Granite = 2.75.

Two tests are made and the two samples should not be tested concurrently. Duplicate determination should check within 0.02 in case of specific gravity and 0.05 percent in case of absorption.

Viva-Voce Questions

1. What is the significance of this test?
2. What are the limits within which the duplicate determinations should check?
3. How does specific gravity vary with the hardness of stone?
4. What are the average specific gravities of the following aggregate: (a) gravel, (b) lime stone and (c) granite?

Notes and Comments

EXPERIMENT NO. 7: Bulk Density and Voids of Concrete Aggregates

Objective

To determine bulk density (unit mass) and voids content of concrete aggregates.

Theory and Scope

The bulk density is mass of the material in a given volume measured in kg/litre. Its determination is necessary for selecting proportions for concrete mixtures. The bulk density of an aggregate can be used for judging the quality by comparison with normal density for that type of aggregate. The bulk density determines the type of concrete for which it may be used. It is also required for converting proportions by mass into the proportions by volume and is used in calculating the percentage of voids in the aggregate.

This test method covers the determination of bulk density ('unit weight') of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. However, test method is most suitable for aggregates not exceeding 125 mm in nominal maximum size.

Apparatus

Weighing balance and weight box; Sample splitter; Cylindrical containers (3, 15 or 30 litre capacity); Shovel; Tamping rod (16 mm in diameter and 600 mm long, rounded at one end); piece of glass plate to be used for calibrating the container.

Description of Apparatus

As per IS: 2386 (Part III)-1963 the container should have nominal capacity of 3 litres (inside diameter 150 mm, inside height 170 mm and thickness of metal 3.15 mm) for aggregate under 4.75 mm, 15 litres (inside diameter 250 mm, inside height 300 mm and minimum thickness of metal 4.00 mm) for aggregate of size from 4.75 mm to 40 mm and 30 litres (inside diameter 350 mm, inside height 310 mm and minimum thickness of metal 5 mm) for aggregate over 40 mm.

The container should be machined on the inside and it should be strong enough so as not to change shape while in use and it should be protected against corrosion.

Procedure

(a) Determine the volume of container to be used accurately by filling it with water at 16.7°C and weighing the filled container. The mass of water in kg will give the volume of container in litres.
(b) Take the representative sample reduced by quartering.

Part 1: Compact mass determination

Step 1: Fill the container with aggregate in three layers, each layer being tamped with 25 strokes of the rounded end of the tamping rod, distributing the strokes evenly over the surface. The container is finally filled to overflowing.

Step 2: Strike off the surplus aggregate using tamping rod as straight edge.

Step 3: Weigh the container full of aggregate.

Step 4: Calculate the net mass of aggregate in the container and compute the unit mass of aggregate in kg/litre by dividing the net mass of aggregate in the container by the volume of the container.

Part 2: Loose mass determination

Step1: Fill the container with aggregate to overflowing by means of a shovel, the aggregate being discharged from a height not exceeding 50 mm above the top of container.

Step 2: Level off the surface of the aggregate with a straight edge.

Step 3: Determine the net mass of aggregate in the container.

Step 4: Compute the unit mass of aggregate by dividing the net mass of aggregate in container by volume of container.

Step 5: Calculate the bulk density in kg/litre and percentage of voids by the following formula:

$$\text{Percentage of voids} = \frac{G_s - \Upsilon}{G_s}$$

In this expression, G_s is specific gravity and Υ is the bulk density of aggregate in kg/litre.

Observations and Calculations

Material and size of aggregate,	mm		
Approximate volume of container,	litre		
Mass of container filled with water and glass plate,	W_1 kg		
Mass of empty container + glass plate,	W_2 kg		
Mass of water in container,	$W_c = W_1 - W_2$ kg		
Volume of container,	V litre		
Type of determination (compact mass or loose mass)			
Mass of empty container,	W_3 kg		
Mass of container full of aggregate,	W_4 kg		
Mass of aggregate in container	$W_a = W_4 - W_3$ kg		
Bulk density of aggregate,	$\Upsilon = \frac{W_a}{V}$ kg/litre		
Voids in aggregate,	$\frac{G_s - \Upsilon}{G_s}$ per cent		

Average bulk density of aggregate is……kg/litre.

Average voids in aggregate are…….per cent.

Precautions

1. The exact volume of container should be determined by filling it with water at 16.7°C, such that meniscus does not appear above the rim. A piece of glass plate will be found useful in filling the container. Fill the container with water overflowing and cover the container with sheet of glass plate sliding it from one side. If the water does not fill all the space under the glass plate, add water before the plate completely covers the surface. When the glass plate completely covers the surface of the container, there should be no air pocket visible under the glass. Weigh the container, glass plate and water.
2. The blows of tamping rod should be evenly distributed over the surface without forcibly striking the bottom with tamping rod.

3. In loose mass determination care should be taken to prevent, as far as possible, segregation of particle sizes of which the aggregate is composed.
4. The results with the same sample should check within 0.01 kg.

Discussion

The bulk density of an aggregate is affected by several factors and varies with specific gravity, shape, size and grading of the aggregate. It is measured by filling a container of known volume with aggregate and weighing it. The unit mass can be determined for any of the four conditions: (i) Dry loose mass, (ii) Dry compacted mass, (iii) Moist loose mass and (iv) Moist compacted mass.

The type of determination to be made is judged according to the operating conditions on the site.

For loose determination, the container is slightly overfilled by running material into it from a shovel held 50 mm above the top edge, the top is then leveled with straight edge before weighing. For compacted determination, the container is filled in three layers, each layer being tamped 25 times with the tamping rod. For moist unit weight, the moisture content of aggregate at the time of test should be recorded.

Viva-Voce Questions

1. What is meant by unit mass or bulk density?
2. How does unit mass differ from specific gravity?
3. If a given lot of aggregate weighs 36 kg and its bulk specific gravity is 2.70, what is its solid volume?
4. If unit mass of an aggregate is 1.54 kg/litre and its bulk specific gravity is 2.65, find percentage of voids?
5. What are the factors which influence unit mass of an aggregate?
6. What is the process of quartering an aggregate, why is it done?
7. What would be the effect upon unit mass if the fine and the coarse aggregates are combined?
8. What would be the effect upon unit mass if the aggregate be placed in the cylinder without rodding or shaking?
9. What would be the effect upon the unit mass, if damp fine aggregate be used?
10. Why is it that the unit mass of a mixture of fine and coarse aggregate is greater than that of separate materials?
11. At what percentage of fine aggregate does the maximum unit mass occur? What is the maximum unit mass value?

Notes and Comments

EXPERIMENT NO. 8: Moisture Content of Concrete Aggregates

Objective

To determine the moisture content (or surface moisture) in concrete aggregates by (a) displacement method and (b) drying method.

Theory and Scope

The determination of moisture content of an aggregate is necessary in order to determine net water-cement ratio for a batch of concrete. High moisture content will increase effective water-cement ratio to an appreciable extent and may even make the concrete weak unless a suitable allowance is made.

1. Displacement or pycnometer method

Apparatus

Weighing balance of capacity of 2 kg or more and sensitive to 0.5 g and a Pycnometer of about one litre capacity.

Description of Apparatus

Pycnometer is a cylindrical glass vessel having a metal conical screw top with a 6 mm diameter hole at the apex as shown in Fig. 4.11. The screw top shall be watertight when it is screwed on to the vessel, and if necessary a rubber or fibre washer shall be inserted in the joint.

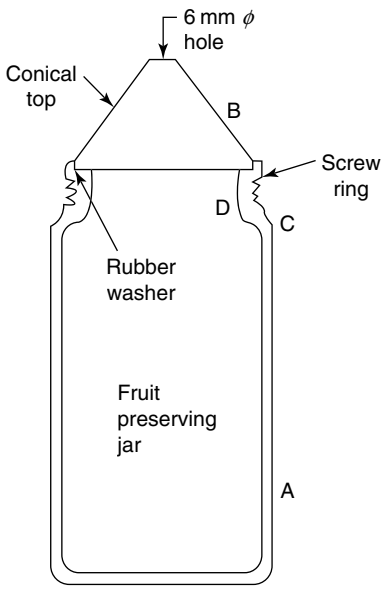

Fig. 4.11 *Pycnometer made from the fruit preserving jar*

Procedure

Step 1: Fill the Pycnometer with water right up to the hole at the top of cone B. Determine the mass in gm. Now empty the Pycnometer to half full.
Step 2: Weight about one kg of aggregate.
Step 3: Place the aggregate in the Pycnometer half full with water.
Step 4: Fill the Pycnometer with water up to the hole and remove the entrained air.
Step 5: Dry the outside of the Pycnometer and weigh it accurately.
Step 6: Calculate the water displaced by sample and determine the moisture content.

$$w = \frac{(\text{mass of water displaced in g} - \text{mass of sample in g/specific gravity})}{(\text{mass of sample in g} - \text{mass of water displaced in g})} \times 100$$

Observations and Calculations

Material			
Mass of moist sample	W_s, g		
Mass of Pycnometer or container full of water	W_a, g		
Mass of container, aggregate and water	W_b, g		
Mass of displaced water	$(W_s + W_a - W_b)$, g		
Specific gravity of aggregate, saturated surface dry basis,	G_s		
Surface moisture	w, (per cent)		

Specific gravity of aggregate (saturated surface dry basis) is……
Surface moisture of aggregate is……per cent.

Precautions

1. In order to ensure that rubber ring is always compressed to same extent, a mark should be made on the container and the ring. The ring is screwed down every time until the marks correspond and volume contained will be constant throughout the test.
2. When weighing the Pycnometer full of water, care must be taken to see that outside is dry.
3. The air bubble should be removed by rolling the Pycnometer on its side while a finger is being kept over the hole at the top of the cone.
4. The results from different trials must be within reasonable check.

Discussion

The displacement method gives the moisture content as a percentage by mass of saturated surface dry sample and not that of a dry sample; the results given by displacement method will not be the same as those given by drying method. The accuracy of method depends upon the accurate information on specific gravity of the material in the saturated surface dry condition.

When using displacement method, the most important operation is to remove air from the sample. If accurate results are to be obtained it is essential that the sample should be poured into water and not water into sample.

The Pycnometer is not very suitable for site use and the weight of sample should not be less than 200 gm; bigger samples will yield more accurate results.

2. Drying method or frying pan method

Apparatus

A balance of capacity 2 kg or more and sensitive to 0.5 g with weight box; Metal tray (frying pan) and a source of heat.

Procedure

Step 1: Weigh approximately 1000 g of aggregate from the representative sample to be tested by method of quartering in a metal tray.
Step 2: Heat the aggregate in tray for about 20 minutes.
Step 3: Weigh the tray with dry aggregate.
Step 4: Take the aggregate out and clean the tray thoroughly and weigh it.
Step 5: Express the loss in mass as a percentage of the dried sample to give the moisture content.

Observations and Calculations

Material			
Mass of tray and sample	W_1, g		
Mass of tray and dry sample	W_2, g		
Mass of empty tray	W_3, g		
Moisture (by difference)	$(W_1 - W_2)$, g		
Mass of dry aggregate	$(W_2 - W_3)$, g		
Moisture content, per cent 100	$w = \frac{W_1 - W_2}{W_2 - W_3 \times 100}$		

Moisture content aggregate is…….. per cent.

Precautions

1. For accurate results, the aggregate should be dried and weighed until there is no further loss in weight.
2. The aggregate should be turned over at intervals during the drying period to prevent over-heating of the parts of sample.
3. Heat should not be applied fiercely to avoid chemical change.

Discussion

Drying method gives the moisture content as a percentage by mass of dried sample and not that of a saturated surface dry sample.

When the drying is carried out between stated temperatures in an oven, a high degree of accuracy can be obtained. At the specified temperatures for the oven there is little risk with normal aggregates of chemical change taking place during operation. The normal drying period is 24 hours. The oven drying method is too

slow for the field and fairly quick results can be obtained by frying pan method. The moisture content given by this method will normally be the total moisture content due to free plus the absorbed water.

Viva-Voce Questions

1. What is moisture content?
2. Where is the knowledge of moisture content required?
3. What are the different methods for moisture content determination?
4. What is the formula used for computation of the percentage of surface moisture? What precautions are taken while performing this experiment?
5. Why is the accurate value of specific gravity of the material in a saturated surface dry condition needed?
6. On what factors does the accuracy of displacement method depend?
7. How does the value obtained by displacement method differ from that obtained by drying method? Which of these two methods is suitable for field determination and why?
8. What are the relative merits and demerits of these two methods?
9. What is the temperature of drying the sand for determining the moisture content?
10. As regards to moisture content, discuss the various states in which an aggregate may exist. (*Hint: Oven dry, air dry, saturated surface city and damp or wet*).

Notes and Comments

EXPERIMENT NO. 9: Fineness Modulus and Grain Size Distribution

Objective

To determine fineness modulus and grain size distribution of given: (a) coarse, (b) fine and (c) mixed aggregates.

Theory and Scope

Fineness modulus is only a numerical index of fineness giving some idea of the mean size of particles in the entire body of aggregate. Determination of fineness modulus may be considered as a method of standardisation of the grading of the aggregates. It is obtained by sieving a known mass of given aggregate on a set of standard sieves and by adding the cumulative percentages of mass of material retained on all the sieves and dividing the total percentage by 100.

The objective of finding the fineness modulus is to grade the given aggregate for obtaining an economical and workable mix with minimum quantity of cement. Certain limits of fineness modulus for fine, coarse and mixed or all-in-aggregates are given in Table 4.6.

Apparatus

Indian standard test sieves: fine wire cloth Nos. 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm, and square hole perforated plates 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm (refer to IS: 460-1978 and Table 4.7 for equivalent sieves); Weighing balance (sensitive to 1/1000th of the test sample); Sieve shaker; Trays; Rice plates; Drying oven (to operate between 100 to 110°C).

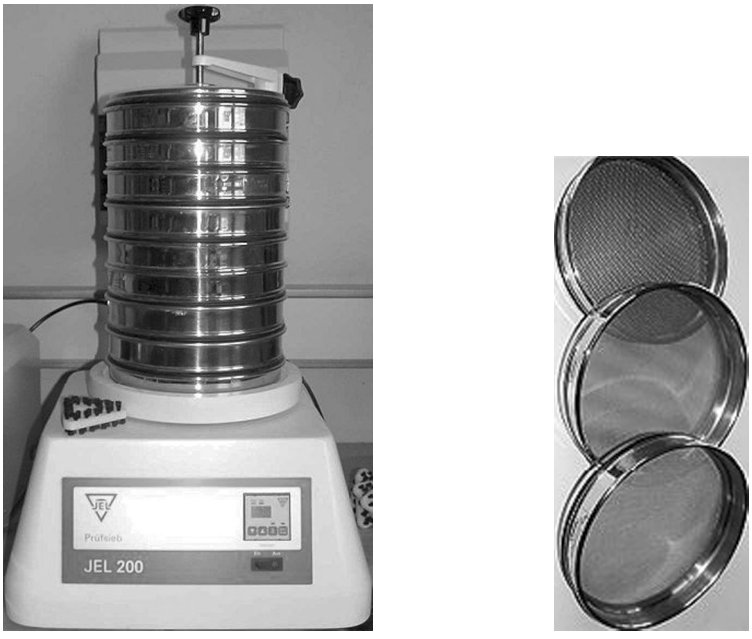

Fig. 4.12 *Test sieves used for gradation of fine aggregate*

Procedure

Part 1: Coarse aggregate

Step 1: Take 10 kg of coarse aggregate of nominal size 20 mm from a sample of 50 kg by quartering.
Step 2: Carry out sieving by hand. Shake each sieve in order; 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm over a clean dry tray for a period of not less than 2 minutes. The shaking is done with a varied motion: backwards and forwards, left to right, clockwise and anti-clockwise and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions.
Step 3: Find the mass of aggregate retained on each sieve taken in order.

Part 2: Fine aggregate

Step 1: Take 1 kg of sand from a laboratory sample of 10 kg by quartering and break clay lumps, if any, in a clean dry rice plate.
Step 2: Arrange the sieves in order of IS sieve nos. 4.75 mm, 2.36 mm. 1.18 mm, 600 μm, 300 μm and 150 μm keeping sieve nos. 4.75 mm at the top and 150 μm at the bottom. Fix them in the sieve shaking machine with the pan at the bottom and cover at the top.
Step 3: Keep the sand in the top sieve; carry out the sieving in the set of sieves as arranged in Step 2 for not less than 10 minutes.
Step 4: Find mass retained on each sieve.

Fig. 4.13 *Test sieves used for gradation of coarse aggregate*

Part 3: All-in-aggregate

Step 1: Take 10 kg of all-in-aggregate from a sample or prepare it from aggregates taken in proportion of 2: 5 by mass (16 kg: 40 kg) by quartering.
Step 2: Carry out preliminary separation of coarse and fine aggregates by sieving the all-in-aggregate on 10 mm sieve by hand and find out the masses.
Step 3: Carry out the sieving of coarse and fine aggregates as described in parts (a) and (b), respectively. The fine portion may be reduced in bulk by quartering (IS: 383-1970).
Step 4: Plot the grading curves for *a, b* and *c* showing percentage mass passing through the test sieves and calculate the fineness modulus as defined below.

Fineness modulus is an empirical factor which is obtained by dividing the sum of the cumulative percentages of aggregate retained on each Standard Sieve taken in order by 100. The order of sieves is taken as 80 mm, 40 mm, 20 mm, 10 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm and 150 μm.

Observations and Calculations

1. **Coarse aggregate**
   Mass of tray, W = ……..kg
   Mass of tray and C.A., (W + 10) = ……..kg

Sl. No.	Sieve no.	Mass retained	Percentage retained	Percentage passing	Cumulative percentage retained, C
1	80 mm				
2	40 mm				
3	20 mm				
4	10 mm				
5	4.75 mm				
6	Pan			ΣC	

Fineness modulus of coarse aggregate $= \dfrac{\Sigma C + 500}{100}$

2. **Fine aggregate**
   Mass of rice plate, W = ……..kg
   Mass of rice plate and F.A., (W + 1.0) = ……..kg

Sl. No.	Sieve no.	Mass retained	Percentage retained	Percentage passing	Cumulative percentage retained, *F*
1.	4.75 mm				
2.	2.36 mm				
3.	1.18 mm				
4.	600 µm				
5.	300 µm				
6.	150 µm				
7.	Pan			ΣF	

Fineness modulus of fine aggregate $= \dfrac{\Sigma F}{100}$

3. **All-in-aggregate**

Mass of tray,	W kg	
Mass of tray and M.A.,	(W+10) kg	
Mass of tray and F.A.,	kg	
Mass of tray and C.A.,	kg	

Sl. No.	Sieve no.	Mass retained	Percentage retained	Percentage passing	Cumulative percentage retained, *M*
1.	80 mm				
2.	40 mm				
3.	20 mm				
4.	10 mm				
5.	4.75 mm				
6.	2.36 mm				
7.	1.18 mm				
8.	600 μm				
9.	300 μm				
10.	150 μm				
11.	Pan			ΣM	

Fineness modulus of mixed or all-in-aggregate $= \dfrac{\Sigma M}{100}$

Precautions

1. Sieves should be cleaned before use.
2. Stiff worn out brushes should not be used.
3. The sieving must be done carefully to prevent the spilling of the aggregate.
4. Do not apply pressure to force the particles through the mesh.

Discussion

The main objective of this test is to determine the relative amount of various sizes of particles present in the aggregate. The experiment has an important bearing on the design of concrete mixes. From the results of sieve analysis one is able to proportion the fine and coarse aggregates in order to get a combined mix of required grading. A typical grading curve is shown in Fig. 4.14.

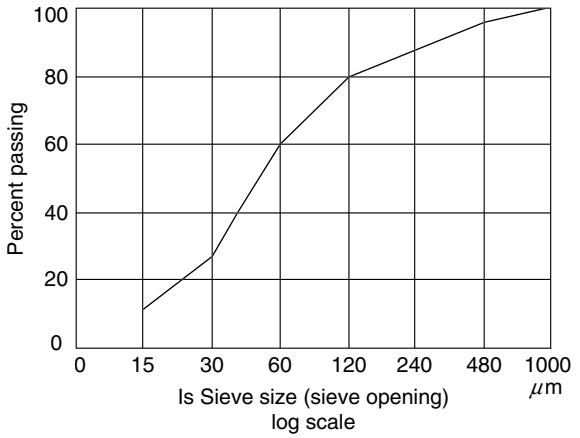

Fig. 4.14 *Typical grading curve*

Some specifications specify screens for coarse aggregates instead of sieves. Such instructions should be carefully noted as the results will be quite different for the same material. The difference will be greater while using crushed stone than with gravels. The sample should be dried to a constant mass at a temperature not exceeding 110°C.

The sample under test should satisfy the limitation given in Table 4.6 so that the aggregate may give good workability under economic conditions.

Table 4.6 *Limits of fineness modulus for different aggregates*

Type of aggregate	Maximum size of aggregate, mm	Fineness modulus	
		Minimum	*Maximum*
Fine aggregate	4.75	2.00	3.50
Coarse aggregate	20	6.00	6.90
	40	6.90	7.50
	75	7.50	8.00
All-in-aggregate	20	4.70	5.10
	25	5.00	5.50
	30	5.20	5.70
	40	5.40	5.90
	75	5.80	6.30

If the test aggregate gives higher fineness modulus, the mix will be harsh and if on the other hand gives a lower fineness modulus, it results in an uneconomical mix. For a given workability coarse aggregates require lesser water-cement ratio.

Table 4.7 *Equivalent designations of IS, Metric, BS, ASTM and Tyler test sieves*

Sl. No.	IS Sieve	Metric Sieve	BS Sieve	ASTM Sieve	Tyler Sieve
1.	4.75 mm	480	3/16”	4	4
2.	2.36 mm	240	7	8	8
3.	1.18 mm	120	14	16	14
4.	600 um	60	25	30	28
5.	300 urn	30	52	50	48
6.	150 um	15	100	100	100

Viva-Voce Questions

1. What are fine aggregate, coarse aggregate and all-in-aggregate? Give examples.
2. What is fineness modulus? What is its significance?
3. What is the significance of the grading of a mixed or combined aggregate?
4. What is meant by “good” grading?
5. What is the practical use of controlling the grading of concrete aggregates?
6. Why is quartering an aggregate done?

7. For the numbered sieves, what does the number indicate?
8. What is meant by the diameter of opening of a sieve?
9. Should the sample be weighed to a predetermined weight, if yes Why?
10. How are the test results expressed? Which method is more commonly used? What kind of graph is often drawn, using the test results?
11. How can the coarse and fine aggregates separated out from mixed aggregate?
12. What precautions are taken while performing the experiment?
13. Why is more than 1.0 kg of sand not taken in the sieve set made of wire cloth?
14. What is the time required to carry out sieving on a sieve shaker?
15. The fineness modulus of sand for concrete should lie within what range of values?
16. What do you understand from this curve?
17. How does the size of aggregate affect the fineness modulus?
18. What is a grading curve and what is its use?

Notes and Comments

NATIONAL STANDARDS

1. IS 383-1970 (2nd revision, reaffirmed 2011): *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*
2. IS 460 (Parts 1 and 2)-1985(3rd revision, reaffirmed 2008): *Specification for Test Sieves*
3. IS 2386 (Parts 1-8)-1963 (reaffirmed 2011): *Methods of Test for Aggregates for Concrete*
4. Part 1: *Particle size and shape*
5. Part 2: *Estimation of Deleterious Materials and Organic Impurities*
6. Part 3: *Specific Gravity, Density, Voids, Absorption and Bulking*
7. Part 4: *Mechanical Properties*
8. Part 5: *Soundness*
9. Part 6: *Measuring Mortar Making Properties of Fine Aggregates*
10. Part 7: *Alkali Aggregate Reactivity*
11. Part 8: *Petrographic Examination*
12. IS 2430-1986 (1st revision, reaffirmed 2009): *Methods for Sampling of Aggregates for Concrete*
13. IS 6461(Part 1)-1972 (reaffirmed 2011): *Glossary of Terms Relating to Cement Concrete: Part 1: Concrete Aggregates*
14. IS 9376-1979 (reaffirmed 2008): Specification for Apparatus for Measuring Aggregate Crushing Value and Ten Per cent Fines
15. IS 9377:1979 (reaffirmed 2008): *Specification for Apparatus for Aggregate Impact*
16. IS 10070:1982 (reaffirmed 2008): *Specification for Machine for Abrasion Testing of Coarse Aggregates*

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2. Gambhir, M. L., and Neha Jamwal, *Building Materials: Products, Properties and Systems*, McGraw-Hill Education (India), 2011.

WATER FOR CONSTRUCTION

Chapter 5

This section covers procedures for the tests generally performed on water to check its suitability for using it for construction works. The tests include determination of organic and inorganic impurities in the form of sulphates and chlorides; pH value and suspended matter/solids. The physical characteristics as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

5.1 INTRODUCTION

Water is the most important and least expensive ingredient of concrete. The functions of the water are as follows:

1. Water reacts chemically with cement to form the binding matrix in which the inert aggregates are held in suspension until the matrix has hardened.
2. Water serves also as a vehicle or lubricant between the fine and coarse aggregates in order that the concrete may be made more readily placeable in forms.

Generally, the cement requires about 30 per cent of its mass of water for hydration. Hence, the minimum water–cement ratio required is of the order of 0.3. The water–cement ratio is influenced by the grade of concrete, nature and type of aggregates, the workability and durability, etc. The excess water may cause laitance which prevents the bond between the successive layers of concrete and also leak through the joints of the formwork and makes the concrete honeycombed.

5.2 QUALITY OF MIXING WATER

The requirement for water is, 'water used in mixing concrete should be clean and free from injurious amounts of oils, acids, alkalies, organic materials or other deleterious substances'.

The presence of these impurities in the water may affect setting time of cement, strength of concrete and may cause corrosion of the reinforcement. If the water is fit for drinking it is generally accepted as suitable for making concrete. The suitability of doubtful water for making concrete can be determined by comparing the setting time of cement and the compressive strength of the mortar cubes using the water in question with those obtained by using *good water*. A tolerance of about 10 per cent is usually allowed when comparing the results.

The effluents from sewerage works, gas works and from paint, textile, sugar and fertiliser industry are harmful to the concrete. The tests show that water containing excessive amounts of dissolved salts reduces compressive strength by 10 to 30 per cent of that obtained using fresh water. In addition, the water containing large quantities of chlorides, e.g., sea water tends to cause persistent dampness and surface efflorescence. Sea water slightly accelerates the early strength of concrete, but reduces the 28 days strength of concrete by about

10 to 15 per cent. The sea water reacts with reactive aggregates in the same manner as alkalies in cement. Therefore, sea water should not be used if aggregates are known to be potentially alkali reactive. Seawater increases the corrosion of the reinforcing steel. The danger is more in tropical regions, particularly with lean mixes.

Algae in mixing water may cause a marked reduction in strength of concrete either by combining with cement to reduce the bond or by causing large amount of air entrainment in concrete.

The adverse effects on compressive strength of concrete due to various dissolved salts are:

Percentage of salts in water	Percentage reduction in compressive strength
0.5 SO_4	4.0
1.0 SO_4	10
5.0 NaCl	30
CO_3	20

The following guidelines may help in deciding the suitability of water mixing in concrete:

1. To neutralise 100 ml sample of water using phenophaline as an indicator, it should not require more than 5 ml of 0.02 normal NaOH.
2. To neutralise 100 ml of sample of water, using mixed indicator, it should not require more than 25 ml of 0.02 normal H_2SO_4.

The water suitable for mixing is also suitable for curing the concrete and washing of aggregates. The final decision as to the source of water supply is governed by the quality of concrete required depending upon the importance of structure and the cost of securing good water.

5.3 GRAVIMETRIC TESTING OF WATER

Gravimetric testing relies on some final determination of weight as a means of quantifying an sample. Since weight can be measured with greater accuracy than almost any other fundamental property, gravimetric analysis is potentially one of the most accurate classes of analytical methods available. However, samples may have to be extensively treated to remove interfering substances. The precision of this method has been estimated to be ± 4 mg or ± 5%. The settled wastewater may give better precision, on the order of ± 1 mg.

Total solids are dissolved solids plus suspended and settleable solids in water. In stream water, dissolved solids consist of calcium, chlorides, nitrate, phosphorus, iron, sulphur, and other ions particles that will pass through a filter with pores of around 2 microns in size. Suspended solids include silt and clay particles, algae, fine organic debris and other particulate matter. These are particles that will not pass through a two-micron filter.

Dissolved or filterable solid or residue may be determined directly by analysis of the filtered sample for total solids, or indirectly by determining the suspended solids and subtracting this value from the total solids.

Generally, the sample is dried in a 103° C to 110° C oven for about one hour and allowed to cool to room temperature in a desiccator. It is then weighed, and heated again for about 30 minutes. The sample is cooled and weighed a second time. The procedure is repeated until successive weighings agree to within

0.3 mg. The commonly used gravimetric methods for testing of water for construction are summarised in Table 5.1.

Table 5.1 *Commonly used gravimetric methods for testing of water for construction*

Type of analysis	Test for	Pretreatment
Physical	Total Solids	Evaporation
	Suspended Solids	Filtration
	Dissolved Solids	Filtration + Evaporation
	Oil & Grease	Extraction with $C_2Cl_3F_3$ + distillation of solvent
	Surfactants	Extraction into ethylacetate + evaporation
Precipitative	Mg	with Diammonium hydrogen phosphate and final pyrolysis
	Na	with zinc uranyl acetate
	SO_4	with Barium chloride

Permissible limits for solids as recommended by IS 456 - 2000 are listed Table 5.2:

Table 5.2 *Permissible limits for solids in water for construction*

Material	Tested as per	Permissible limit (Max.)
Organic	IS 3025 (Part-18)	200 mg/l
Inorganic	IS 3025 (Part-18)	3000 mg/l
Sulphates	IS 3025 (Part-24)	400 mg/l
Chlorides (as Cl –]	IS 3025 (Part-32)	2000 mg/l for concrete work not containing embedded steel and 500 mg/l for reinforced concrete work
Suspended matter	IS 3025 (Part-17)	2000 mg/l

EXPERIMENT NO. 1: pH Value of Water

Objective

To determine the pH value of water sample for use in concrete/mortar.

Theory and Scope

Water plays an important part in deciding the quality of the final product. The pH value of water is an indication of its acidity/alkalinity, the property that directly affects the strength of concrete, due to its chemical reaction with ingredients of cement.

The test determines quality of water for use in concrete/mortars.

Apparatus

Litmus paper pack

Procedure

Step 1: Collect the water sample representing water to be used for concreting or otherwise for any use involving its mixing with cement during construction.

Step 2: Insert litmus paper strip in water sample. Allow a reaction time of 10 to 20 seconds.

Step 3: Observe the change in colour and match with reference coloured cover strip. The colour will change according to level of concentration of acidic and alkaline substances in water.

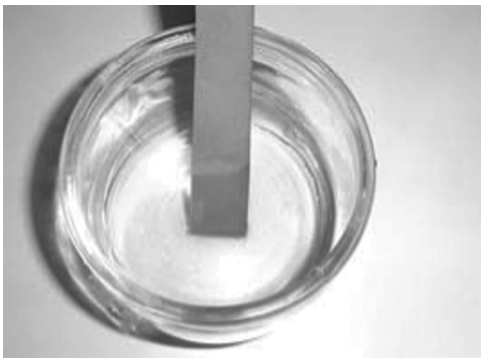
Fig 5.1 (*a*) *Reference coloured cover strip colour matching.*

Observations

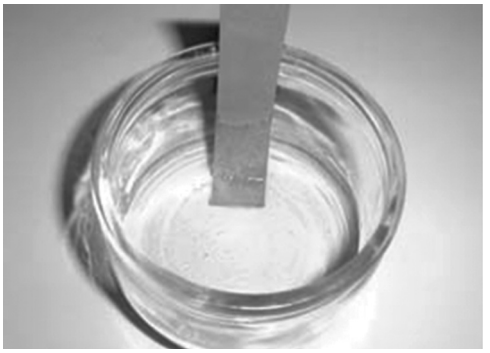
The pH value of water sample is ……..; water is suitable/unsuitable for the construction job.

Precautions

1. The sample of water taken for testing should be representative of water proposed to be used for concreting, taking in to consideration the seasonal variation.
2. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete.
3. The sample shall be stored in a clean container previously rinsed out with similar water.



(i) Acidic solution



(ii) Alkaline solution

(b) Water sample with litmus strip

(c) Handheld pH Meter

Fig. 5.1 *Determination of pH value of water sample*

Discussion

The test results are sufficiently accurate for determining quality of water for use in concrete/mortars. Accurate testing is possible by use of pH meter shown typically in Fig. 5.1(c) which is based on potentiometric measurement of hydrogen ion concentration in a sample.

pH meter It consists of a glass probe which is placed in the water. Inside the thin glass bulb at the end of the probe, there are two electrodes that measure voltage. One electrode is contained in a liquid that has a fixed acidity or pH value. The other electrode responds to the H^+ concentration of the water sample. The pH electrode produces a voltage that is proportional to the concentration of the H^+ concentration, and making measurements with a pH meter is therefore a form of potentiometry. A voltmeter in the probe measures the difference between the voltages of the two electrodes and translates it into pH and displays it on the little screen on the meter.

Before taking a pH measurement, the meter must be 'calibrated'. The probe is immersed in a solution that has a known and stable pH (a 'buffer solution'). The knobs on the box are used to adjust the displayed pH value to the known pH of the solution, thus calibrating the meter.

The water for construction purposes should be of neutral nature, i.e., pH from 6.0 to 8. In case of high pH 10 to 12 or a low pH 4 to 6, the water will need suitable treatment for correction of pH value.

Viva-Voce Questions

1. What is the significance of this test?
2. What is the principle of working of a pH meter?
3. What is the permissible pH value for suitability of water to be used for the construction job?
4. What will be colour of litmus paper when it is inserted in lemon juice?
5. What will be colour of litmus paper when dipped in a detergent?
6. What is a buffer solution?

Notes and Comments

EXPERIMENT NO. 2: Concentrations of Solids in Water

Objective

To test water sample for solid contents of various types such as non-filterable, filterable and total residues by gravimetric method.

Theory and Scope

The presence of solids in water in excessive concentrations may be deleterious to concrete or reinforcement due to their chemical reactions with cement in lowering its strength and physical interaction in changing its setting properties, workability, cracking phenomena, etc.

Total solids or residue is determined by the final mass of a dried sample divided by the original sample volume. Dissolved or filterable solid or residue may be determined directly by analysis of the filtered sample for total solids, or indirectly by determining the suspended solids and subtracting this value from the total solids.

Apparatus

Evaporating porcelain/borosilicate or platinum dish of 90 mm diameter and 100 ml capacity; Steam bath; Thermo-statistically controlled drying oven maintained at 180 ± 2°C; Desiccator with colour indicator desiccants; Electric muffle furnace maintainable at 550°C; Analytical balance of 200 g capacity and with accuracy of 0.1 mg.

Reagents

1. 0.1 normal HCL solution
2. 0.1 normal NaOH solution
3. Indicator solution of methyl orange
4. Indicator solution of phenolpthalein

Procedure

Part 1: Total solids procedure

Step 1: Preserve the collected sample in refrigerator at 4°C.

Step 2: Preheat a 100 ml evaporating dish at 180°C for one hour, cool in a drying oven or in the open air (protected from dust) for 15–20 minutes, bring to room temperature in a desiccator, and weigh. Repeat until a constant weight is achieved and store the dish in a desiccator.

Step 3: Measure 75 ml of sample or a volume sufficient to yield 200 mg total solids (TS), whichever is less with a pipette. Add this to the pre-weighed dish and evaporate to dryness in a drying oven maintained at a temperature 98°C to avoid boiling. Alternatively, a steam bath may be used.

Step 4: After complete evaporation, transfer the dish from steam bath to drying oven and heat to 180 ± 2°C and dry to constant mass; this period taken is usually one hour.

Step 5: Cool in a desiccator and weigh; as per normal procedure re-heat the sample and re-weigh to achieve a constant weight.

Step 6: Weigh the dish containing residue after cooling.

Step 7: After weighing, ignite the dish in muffle furnace at 550°C for one hour. Allow vessel to partially cool in air and transfer the same to desiccator, cool and weigh.

Part 2: Filterable solids procedure

Step 1: Wash a glass fibre filter by rinsing three times with 20 ml of distilled water. Maintain suction until the filter is dry.
Step 2: Dry this filter at 103–105°C for one hour and cool in a desiccator.
Step 3: Weigh the filter, then pass a water sample of sufficient volume to yield 50–200 mg suspended solids through it. Smaller volumes will result in reduced accuracy.
Step 4: Dry for at least one hour at 180 ± 2°C.
Step 5: Cool in a desiccator and weigh. As per normal procedure re-heat the sample and re-weigh to achieve a constant weight (a drop of no more than 0.5 mg).

Observations and Calculations

1. Total solid matter			
Mass of dish and residue before ignition,	W_1 mg		
Mass of dish and residue after ignition,	W_2 mg		
Mass of dish alone,	W_3 mg		
Volume of sample,	V ml		
Volatile residue, $\frac{(W_1 - W_2) \times 1000}{V}$	mg/litre		
Fixed residue, $\frac{(W_2 - W_3) \times 1000}{V}$	mg/litre		
2. Filterable solid matter			
Mass of filter and residue,	W_1 mg		
Mass of filter alone,	W_2 mg		
Volume of sample,	V ml		
Filterable solid matter, $\frac{(W_1 - W_2) \times 1000}{V}$	mg/litre		

Volatile residue is.....mg/litre.
Total fixed solids/residue is.....mg/litre.
Total dissolved solids is.....mg/litre.

Precautions

1. The sample of water taken for testing should be representative of water proposed to be used for concreting, taking in to consideration the seasonal variation.
2. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete.
3. The sample shall be stored in a clean container previously rinsed out with similar water.
4. The samples should be allowed to reach room temperature before weighing. Samples that are too hot will set up convection currents and the apparent sample weight will be incorrect. A slowly drifting apparent sample weight is indicative of this problem.
5. Chemicals should be placed in a weighing bottle, a plastic weighing tray or coated weighing paper. Chemicals should never be placed directly on the pan.
6. The analytical balance should be kept clean at all times.
7. As the test involves use of acids and alkalies, adequate safety measures should be taken.

Discussion

Most of the impurities in waters for construction are in the dissolved state, principally as inorganic salts. Thus, the parameters, 'total solids' and especially 'total dissolved solids' are of primary importance. Waters containing high concentrations of inorganic salts are not suitable as mixing water for concrete/mortar and other constructions.

Suspended or non-filtrable residue is measured directly by drying and weighing the solids retained during filtration. This approach is much more accurate for most waters than the indirect method of subtracting dissolved solids from total solids. Whatman glass fibre filters (nominal pore size 1.4 microns) are most commonly used. These may be placed in small aluminium foil weighing pans. Filters should be weighed, heated and dried while remaining in the aluminium pans. They should only be removed for actual filtering operations. They should always be handled with tongs.

Viva-Voce Questions

1. What are total solids and why are they important?
2. What is the significance of total, dissolved and suspended solids in water for construction?
3. How is sample water stored?
4. Why is a desiccator necessary in cooling and weighing operations?
5. Why is it necessary to weigh the dish and residue at the room temperature?

Notes and Comments

EXPERIMENT NO. 3: Sulphate Impurities in Water

Objective

To determine sulphate impurities in water sample.

Theory and Scope

In this precipitative gravimetric procedure the sulphate impurities are precipitated quantitatively as barium sulphate by adding barium chloride solution in excess under acidic conditions. Sulphate concentrations determined by the sampling and testing procedures used in this normally form the basis of a first approximation in assigning degree of severity of sulphate attack expected.

Sulphate contents of water can be determined by the standard analytical methods that can be carried out in any chemical laboratory. However, there is a need to distinguish highly soluble sodium and magnesium sulphates from calcium sulphate (gypsum), which has a low solubility. The sulphate concentrations are expressed as parts per million (ppm) of SO_4 or SO_3. Sea water generally has a relatively fixed concentration of sulphate.

Apparatus

Steam bath; Thermostatically controlled drying oven; Electric muffle furnace; Desiccator; Analytical balance to 0.1 mg accuracy; Filter paper-N42; Crucible with porous bottom of silica/porcelain with maximum porosity 5 microns; Ion exchange column.

Reagents

1. Dilute sodium hydroxide (0.25N)

(a) Measure 5 ml of 1 N sodium hydroxide solution into a 10 ml graduated cylinder, and measure 35 ml of deionized water in a 50 ml graduated cylinder.
(b) Combine the deionized water and the sodium hydroxide in a 200 ml, tall-form beaker.
(c) Add a stirring magnet to the beaker and stir on a magnetic stirrer; once the solution is thoroughly mixed, transfer into a drop-dispensing bottle.

2. Barium chloride solution (0.1N or 10 per cent)

(a) In a 500 ml beaker, weigh 50 ± 0.5 g of barium chloride; add de-ionised water to the barium chloride until achieving a total of 500 g of solution.
(b) Add a stirring magnet to the beaker and stir on a magnetic stirrer; once all the barium chloride dissolves, transfer the solution into an airtight container.

3. Indicator solution Methyl red indicator

Preparation of sample Before testing the sample following impurities are removed [IS 3025 (Part 24)]:

Sl. no.	Type of impurity	Removal if concentration more than	Method of clarification
1.	Alkalinity	–	Adjust pH below 8.00
2.	Turbidity	NA	Filter through 0.45 μm size filter
3.	Cat ions	200 ppm	Use ion exchange column
4.	Heavy metal	10 ppm	Use ion exchange column
5.	Silica	25 ppm	Evaporation in platinum

Procedure

Step 1: Clarify the sample as above to avoid interference, if necessary, and prepare about 500 ml of sample of 200 ppm concentration of sulphate ions. In case of lower concentrations; concentrate the volume to 150 ml by evaporating on hot plate.

Step 2: Place a 200 ml, tall-form beaker on an analytical balance and weigh 80 g of the filtered sample into the beaker. Record the mass of the sample to the nearest 0.5 mg.

Step 3: Add 2 to 3 drops of methyl red indicator in the sample; to this add 0.25 concentration HCL drop by drop till orange red colour appears as shown in Fig. 5.2.

Step 4: Heat the sample on a hot plate to near boiling and stir gently.

Step 5: Add warm barium chloride solution and continue to heat the solution till precipitation completes; add 2 ml in excess. This may take about 10 minutes.

Step 6: Digest precipitate at 80°C – 90°C for two hours.

Step 7: Remove the sample from the hot plate. Allow the sample to cool at room temperature for 15 minutes.

Step 8: Set up an Erlenmeyer flask and funnel with a No. 42 filter paper. Decant the solution through the filter paper to catch the precipitate. Wash the precipitate with hot distilled water until the washings are free of chloride ions. Test for chlorides by adding one to two drops of the filtrate to approximately 2 ml of the 0.1 N silver nitrate solution. Any turbidity indicates chlorides are present.

Step 9: Weigh a platinum crucible on an analytical balance; record its mass to the nearest 0.5 mg. Carefully, fold the filter paper with the precipitate and place in the crucible.

Step 10: Dry the precipitate in crucible at least for one hour.

Step 11: Set up the Meeker burner with gas and air. Adjust the gas and airflow to obtain a bright blue flame. Using heat-resistant tongs, slowly char the filter paper in the crucible to a white ash residue.

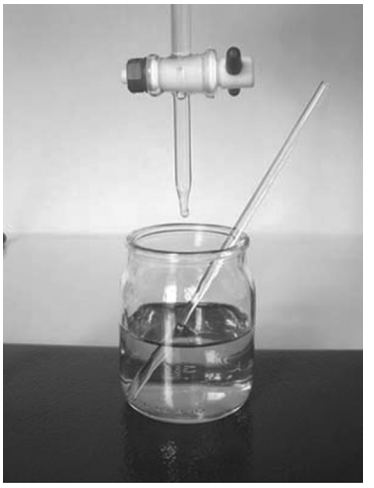


Fig. 5.2 *Dispensing of indicator solution*

Step 12: Place the crucible with the residue into the muffle furnace at a temperature of 800 to 1100°C for one hour

Step 13: Using heat-resistant tongs, remove the crucible from the muffle furnace. Place the crucible in a desiccator. Allow the crucible to cool to room temperature.

Step 14: Using an analytical balance, weigh the crucible to the nearest 0.5 mg.

Step 15: Determine the concentration of sulphate ions in the original sample.

Observation and Calculations

Mass of original sample solution,	W g	
Mass of the crucible,	W_1 g	
Mass the crucible and residue ,	W_2 g	
Mass of barium sulphate residue,	$W_b = W_2 - W_1$ g	
ppm Sulphate concentration,	$\frac{41.15 \times W_b \times (10{,}000)}{W}$	

Sulphate concentration in water is.....ppm.

Precautions

1. The sample of water taken for testing should be representative of water proposed to be used for concreting, taking into consideration the seasonal variation.
2. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete or as specified in the code.
3. The sample shall be stored in a clean container previously rinsed out with similar water.
4. Allow samples to reach the room temperature before weighing. Samples that are too hot will set up convection currents and the apparent sample weight will be incorrect. A slowly drifting apparent sample weight is indicative of this problem.
5. Blowing out of any sample from the crucible should not be allowed.
6. Chemicals should be placed in a weighing bottle, a plastic weighing tray or coated weighing paper. Chemicals should never be placed directly on the pan.
7. The analytical balance should be kept clean at all times.
8. As the test involves use of acids, adequate safety measures should be taken.

Discussion

The water containing large quantities of sulphate impurities tends to cause expansive reaction which causes deterioration and disintegration of concrete. Portland cement is vulnerable to attack by aqueous solutions of sulphate salts that occur in some underground and sea waters. The rate and degree of attack depend upon the amount of available (soluble) sulphate, the composition of the cement and certain characteristics of the aggregates. The sulphate attack on concrete is a result of chemical reaction between the sulphate ions and hydrated calcium aluminate and/or the calcium hydroxide components of cement paste.

The products resulting from these reactions are calcium sulpho-aluminate hydrate, commonly referred to as ettringite, and calcium sulphate hydrate, better known as gypsum have much higher volume than the solid

reactants and, as a consequence, stresses are produced may result in breakdown of the paste and ultimately causes deterioration and disintegration of concrete.

Viva-Voce Questions

1. What is the significance of sulphate concentration test?
2. How is the sulphate impurities precipitated in the test?
3. How is the sulphate concentration expressed?
4. What is the effect of presence of excessive sulphate impurities in water on the concrete?
5. What is the mechanism of the sulphate attack on concrete?
6. Why are certain impurities removed from the test sample before the test?

Notes and Comments

EXPERIMENT NO. 4: Chloride Impurities in Water

Objective

To determine chloride contents of a water sample.

Theory and Scope

This method of analysis of water for chloride ions is used to determine its suitability for concrete mix, curing, or similar uses.

In this gravimetric test method, the chloride ions are determined by precipitation with silver. Interfering ions likely to form insoluble silver salts are the bromide, iodide, cyanide, and reduced sulphur species (sulphite, sulphide, and thiosulphate). Fortunately, the reduced sulphur compounds can be pre-oxidised with hydrogen peroxide, and the others are rarely present at high concentrations.

Apparatus

Erlenmeyer flask of 250 ml capacity; Analytical balance with an accuracy of ± 0.5 mg; Burette of 50 ml capacity; Pipette of 50 ml capacity; Platinum crucible; Beakers (tall form) of 200 ml, 250 ml and 500 ml capacity; Desiccator; Drop-dispensing bottles; Filter paper, No. 42 (ash less); Class A volumetric flask of 500 ml capacity with stopper; Graduated cylinders of 10 ml, 25 ml, 50 ml and 100 ml capacities; Magnetic stirrer; Gravity filtration funnel.

Hot plate; Heat-resistant tongs; Muffle furnace capable of maintaining temperatures of 800 to 1100°C; Oven capable of maintaining a temperature of 100°C; pH meter with an accuracy of ± 0.1 pH or better, with automatic temperature compensation or pH paper, range 8 to 9.

Reagents

1. Silver Nitrate (0.1 N)

(a) Weigh 17 ± 0.5 g of silver nitrate powder and add it in to a graduated cylinder containing 1000 ml de-ionised water; add a stirring magnet and stir on a magnetic stirrer. Once all of the silver nitrate is dissolved, store the solution into a one litre light protective (brown) storage bottle.

(b) Dry approximately 5 g of sodium chloride at 100°C for at least 1 hour. Using an analytical balance, weigh 0.2 g of sodium chloride to the nearest 0.0005 g into a tared 200 ml, tall-form beaker.

(c) Add the 100 ml of de-ionised water to the beaker with the sodium chloride; put a stirring magnet and stir on a magnetic stirrer; once the solution is thoroughly mixed, add 10 drops of potassium chromate indicator to the solution.

(d) Fill a 50 ml burette with the silver nitrate solution and titrate the sodium chloride solution with the silver nitrate to the first colour change.

(e) Use the results from the titration to calculate the normality to at least three significant digits:

$$N = \frac{W}{(0.05844)V}$$

where

N = normality of the silver nitrate solution,

W = mass of sodium chloride used for the titration in grams and

V = volume of silver nitrate used for the titration in millilitres.

2. Potassium chromate indicator

(a) In a 250 ml beaker, weigh 50 ± 0.5 g of potassium chromate powder.
(b) Measure 100 ml of de-ionised water in a graduated cylinder and add it to the beaker with the potassium chromate.
(c) Add a stirring magnet to the beaker and stir on a magnetic stirrer. Once all of the potassium chromate is dissolved, transfer the solution into a drop-dispensing bottle.

3. Dilute nitric acid

(a) Measure 2 ml of nitric acid in a 10 ml graduated cylinder, and measure 38 ml of de-ionised water in a 50 ml graduated cylinder.
(b) Combine the de-ionised water and nitric acid in a 200 ml tall-form beaker; add a stirring magnet to the beaker and stir on a magnetic stirrer.
(c) Once the solution is thoroughly mixed, transfer into a drop-dispensing bottle.

4. Standard sodium chloride solution

(a) Measure 5 ml of 1 N sodium hydroxide solution into a 10 ml graduated cylinder, and measure 35 ml of de-ionized water in a 50 ml graduated cylinder.
(b) Combine the de-ionised water and the sodium hydroxide in a 200 ml, tall-form beaker.
(c) Add a stirring magnet to the beaker and stir on a magnetic stirrer; once the solution is thoroughly mixed, transfer into a drop-dispensing bottle.

5. Special reagents for removal of interference

(a) Aluminium hydroxide suspension
Dissolve 12.5 g of aluminium potassium sulphate in 1 litre of distilled water. Warm to 60°C and add 55 ml of concentrated ammonium hydroxide slowly while stirring. Transfer to large bottle after one hour and wash precipitate by successive additions with thorough mixing and decanting with distilled water until free from chloride.
(b) Phenolphthalein indicator solution
(c) Sodium hydroxide (1 N)
(d) Sulphuric acid (1 N)
(e) Hydrogen peroxide (30 per cent)

Procedure

Step 1: Weigh 50 g of the filtered sample into the 200 ml tall-form beaker placed on an analytical balance. Record the mass of the sample to the nearest 0.0005 g.
If the sample is highly coloured, add 3 ml of aluminium hydroxide mix, let it settle and filler.
Step 2: Using the pH meter or pH paper, add either dilute nitric acid or dilute sodium hydroxide to adjust the sample pH to between 8 and 9.
Step 3: Add 11 drops of potassium chromate indicator to the sample. Stir the solution until a solid yellow colour persists throughout the sample. Fill a 50 ml burette with the 0.1 N silver nitrate solution.
Step 4: Stir the solution with a magnetic stirrer. Titrate with standard silver nitrate solution by adding it drop by drop until a brick red (pinkish yellow) color persists throughout the sample.
Step 5: Determine the chloride ion concentration as follows.

$$\text{ppm chloride} = \frac{3.545\ VN(10,000)}{W} = \frac{35450\ VN}{W}$$

Observations and Calculations

Volume of silver nitrate used by sample,	V_1 ml		
Volume of silver nitrate used in blank filtration,	V_2 ml		
Mass of sample taken for filtration,	W g		
Normality of silver nitrate solution,	N		
Chlorides content, $\frac{(V_1 - V_2) \times \text{N} \times 35450}{\text{W}}$	ppm		

The ppm chloride of the water sample is ……

Precautions

1. The sample of water taken for testing should be representative of water proposed to be used for concreting, taking in to consideration the seasonal variation.
2. The sample shall not receive any treatment before testing other than that envisaged in the regular supply of water proposed for use in concrete.
3. The sample shall be stored in a clean container previously rinsed out with similar water.
4. As the test involves use of acids and alkalies, adequate safety measures should be taken.

Discussion

The water containing large quantities of chlorides, e.g., sea water tends to cause persistent dampness and surface efflorescence. Sea water slightly accelerates the early strength of concrete, but reduces the 28-day strength of concrete by about 10 to 15 per cent. The sea water reacts with reactive aggregates in the same manner as alkalies in cement. Therefore, sea water should not be used if aggregates are known to be potentially alkali reactive. Chloride ions increase the corrosion of the reinforcing steel. The danger is more in tropical regions, particularly with lean mixes.

Viva-Voce Questions

1. What is the significance of chloride concentration test?
2. How is the chloride impurities titrated in the test?
3. How is the chloride concentration expressed?
4. What is the effect of presence of excessive chloride impurities in water on the concrete?
5. Why are certain impurities removed from the test sample before the test?

Notes and Comments

NATIONAL STANDARDS

1. IS 3025(Part 11) - 1983 (reaffirmed 2003): *Methods of Sampling and Test* (*physical and chemical*) *for Water and Wastewate*r; Part 11: pH Value
2. IS 3025 (Part 17) - 1984 (reaffirmed 2002): *Methods of Sampling and Test (physical and chemical) for Water and Waste Water;* Part 17: Non-filterable Residue (total suspended solids)
3. IS 3025 (Part 18)-1984 (reaffirmed 2002): *Methods of Sampling and Test (physical and chemical) for Water and Waste Water;* Part 18: Volatile and Fixed Residue (total, filterable and non-filterable)
4. IS 3025(Part 24) - 1986 (reaffirmed 2003): *Methods of Sampling and Test (physical and chemical) for Water and Wastewater;* Part 24: Sulphates
5. IS 3025 (Part 32) - 1988 (reaffirmed 2003): *Methods of Sampling and Test (Physical and Chemical) for Water and Wastewater;* Part 32: Chloride

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FRESH CONCRETE

Chapter 6

This section describes various types of workability tests generally performed on fresh conventional concrete. The physical characteristics of fresh concrete as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

6.1 INTRODUCTION

From the mixing stage till it is transported, placed in formwork and compacted, the green or fresh concrete should satisfy a number of requirements which may be summarised as follows:

1. The mix should be able to produce a homogeneous fresh concrete from constituent materials of the batch under the action of mixing forces. A less mixable concrete mix requires more time to produce homogeneous and uniform mix.
2. The mix should be stable, in that it should not segregate during transportation and placing when it is subjected to forces during handling operations of limited nature. Any segregation that is caused during the transportation operation should be amenable to correction during remaining operations that follow. The tendency of bleeding should be minimised.
3. The mix should be cohesive and mobile enough to be placed in the form around the reinforcement and should be able to cast into the required shape without losing continuity or homogeneity under the available techniques of placing the concrete at a particular job.
4. The mix should be amenable to proper and thorough compaction into a dense, compact concrete with minimum voids under the existing facilities of compaction at site. A best mix from the point of view of compactability should achieve a 99 per cent elimination of the original voids present.
5. It should be possible to attain a satisfactory surface finish.

6.2 WORKABILITY

The diverse requirements of mixability, stability, transportability, placeability, mobility, compactability and finishability of fresh concrete mentioned above are collectively referred to as *workability.* The workability of fresh concrete is thus a composite property. It is difficult to define precisely all the aspects of the workability in a single definition. IS: 6461 (Part VII)-1973 defines *workability as that property of freshly mixed concrete* or *mortar which determines the ease and* ho*mogeneity with which it can be mixed, placed, compacted and finished*. The optimum of fresh concrete varies from situation to situation, e.g., the concrete which can be termed as workable for pouring into large sections with minimum reinforcement may not be equally workable for pouring into heavily reinforced thin sections. A concrete may not be workable when compacted by hand but may be satisfactory when vibration is used.

Sometimes the terms *consistency,* and *plasticity* are used to express the workability of a concrete mix. The consistency of the mix really means the wetness of the mix and a wetter mix need not have all the above desired properties. On the other hand, a too wet mix may cause segregation and may be difficult to be placed in formwork. Plasticity is the cohesiveness of the mix to hold the individual grains together by the cement matrix.

6.2.1 Factors Affecting Workability

The workability of fresh concrete depends primarily on the materials and mix proportions, and also on the environmental conditions.

1. **Influence of mix proportions** In the concrete comprising of cement-aggregate-water system *aggregates* occupy approximately 70 to 75 per cent of the total volume of concrete and economy demands that the volume of aggregates should be as large as possible. The total *specific area* of the aggregates is to be minimised to the extent possible by proper choice of size, shape and proportion of fine and coarse aggregates. Different size fractions are so chosen as to minimize the *void content,* such a mixture will need more water for lubricating effects to overcome the reduction in mobility due to dense packing of particles. The *water–cement ratio* in itself determines the intrinsic properties of cement paste and the requirements of workability such that there should be enough cement paste to surround the aggregate particles as well as to fill the voids in the aggregate. The *water content* of the mix is the primary factor governing the *workability* of the fresh concrete. It has been noticed that the change in the measured value of workability due to relative change in water content in concrete is independent of the composition of concrete within wide limits. The workability increases with water content.

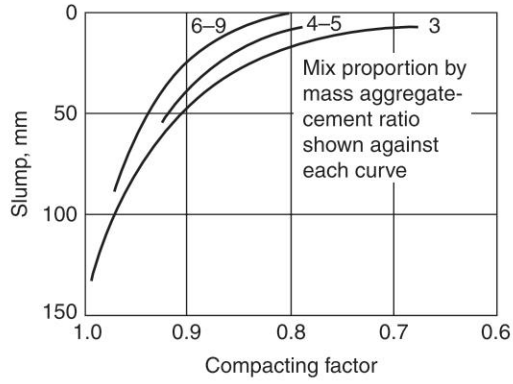

Fig. 6.1 *Effect of aggregate–cement ratio on the workability*

2. **Influence of aggregate properties** The effect of aggregate properties on the workability of fresh concrete can be summarised as:

   (a) For the same volume of aggregates in the concrete, use of coarse aggregates of larger size and/or rounded aggregates gives higher workability because of reduction in total *specific surface area* and particle interference. The use of elongated aggregates results in low workability primarily due to increase in particle interference.

   (b) The use of finer sand increases the specific surface area, thereby increasing the water demand for the same workability. In other words, for the same water content the use of finer sand decreases the workability.

   (c) Because of the greater contribution to the total specific area, the grading of fine aggregate is more critical than the grading of coarse aggregate. Nevertheless, the proportion of fine to coarse

aggregates should be so chosen as neither to increase the total specific surface area by excess of fine aggregates nor to increase the particle interference due to deficiency in fine aggregate.

(d) Generally, the mixes with higher *water–cement ratio* would require a somewhat fine grading and for mixes with low water–cement ratio (as in case of high strength concrete) a coarser grading is preferable. The effect of water content and aggregate size on the workability is shown in Fig. 6.2.

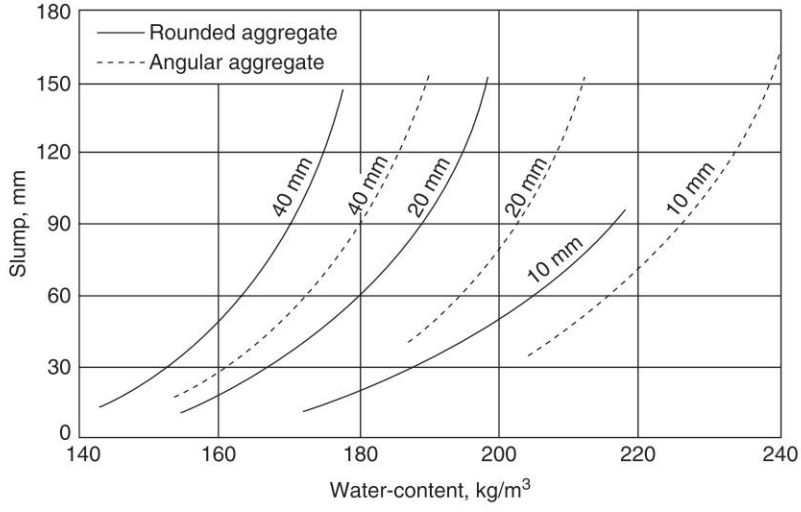

Fig. 6.2 *Effect of water–content and aggregate size on the workability*

3. **Effect of environmental conditions** The workability of a concrete mix is also affected by the temperature of concrete and therefore, by the ambient temperature. On a hot day, it becomes necessary to increase the water content of the concrete mix in order to maintain the desired workability. The amount of mixing water required to bring about a certain change in workability also increases with temperature.
4. **Effect of time** The fresh concrete loses workability with time mainly because of the loss of moisture due to evaporation. A part of mixing water is absorbed by aggregates or lost by evaporation in the presence of sun and wind, and part of it is utilised in the chemical reaction of hydration of cement. The loss of workability varies with the type of cement, the concrete mix proportions, the initial workability and the temperature of the concrete. In an average a 120 mm slump concrete may lose about 50 mm slump in the first one hour. The workability in terms of compacting factor decreases by about 0.10 during the period of one hour from the time of mixing. The decrease in workability with time after mixing may be more pronounced in concrete with plasticisers.

6.2.2 Segregation and Bleeding

The *stability* of a concrete mix requires that it should not segregate and *bleed* during the transportation, placing and finishing. *Segregation* can be defined as separating out of the ingredients of a concrete mix, so that the mix is no longer in a homogeneous condition. Only the stable homogeneous mix can be fully compacted. There are two types of segregation that can occur:

1. The separating out of coarser particles in a dry mix, and is termed as segregation.
2. Separation of cement paste, i.e., cement and water, from the mix in case of lean and wet mixes is termed as bleeding.

The segregation depends upon the handling, placing and compacting operations. The tendency of constituents to segregate increases with: the maximum size of the aggregate, amount of coarse aggregate and increased slump. In case of continued vibration over a longer time, the coarse aggregate tends to settle to the bottom and the scum rises to the surface. This formation of scum is termed laitance.

The *bleeding* is due to rise of water in the mix to the surface because of the inability of the solid particles in the mix to hold all the mixing water during settling of particles under the effect of compaction. The bleeding causes formation of a porous, weak and non-durable concrete layer at the top of placed concrete. In case of lean mixes, bleeding may create capillary channels increasing the permeability of the concrete. When the concrete is placed in different layers and each layer is compacted after allowing certain time to lapse before the next layer is laid, the bleeding may cause a plane of weakness between two layers.

6.2.3 Requirements of Workability

The workability of fresh concrete should be such that it can be placed in the formwork and compacted with minimum effort, without causing segregation and bleeding. The choice of workability depends upon the type of compacting equipment available, the size of the section and concentration of reinforcement. Compaction by band using rodding and tamping is not possible when compacting factor is less than 0.85. Ordinary techniques of vibration are not possible if the compacting factor falls below 0.70. In such cases, techniques like vibro-pressing have to be adopted. For heavily reinforced sections or when the sections are narrow or contain inaccessible parts or when the spacing of reinforcement makes the placing and compaction difficult, the workability should be high to achieve full compaction with reasonable amount of effort. Table 6.2 gives the requirements of workability for different conditions of placement of concrete. The ranges of values indicated are considered suitable for concretes having aggregates of nominal maximum size 20 mm. The values of workability will generally increase with the increase in the size of aggregate and will be somewhat lower for aggregates of smaller size than indicated. The workability requirement should be assessed depending upon the situation at hand. The aim should be to have the minimum possible workability consistent with satisfactory placement and compaction of concrete. An insufficient workability may result in incomplete compaction, thereby severely affecting the strength, durability and surface finish of concrete and may indeed prove to be uneconomical in the long run.

6.3 PREPARATION OF SAMPLE

6.3.1 Sampling

The sample must be truly representative of the concrete being used in construction. In the field, this may be achieved by taking samples from the containers in which the concrete is being transported from the mixer to its final position. The sample should be large enough for a slump or compacting factor test and for subsequent filling of three cube moulds.

For testing in laboratory, the concrete should be prepared in required proportions. The ingredients or aggregate should be obtained by proper sampling and subsequently adjusted to the required grading.

6.3.2 Quantities of Materials

To compute quantities of materials needed for a sample of concrete for the workability test, the information required is the proportion of material to be used and the size of test sample. It is better to make a batch of such a size as to leave 10 per cent excess after moulding the test specimens. If the concrete is required for any other purpose, the necessary amount of concrete should be added.

To calculate the mass of various materials required, the step-wise procedure is as follows:

1. Compute the volume of concrete needed for all purposes including 10 per cent excess.
2. Assume that freshly made concrete weights 2400 kg/m^3 and compute the mass of concrete needed.
3. Compute the mass of each material required keeping each in its proportion to others.

6.3.3 Weighing of Materials

All the materials should be weighed on the balances of specified sensitivity prescribed by the relevant standards.

6.3.4 Mixing

The concrete shall be mixed either by hand or in a suitable laboratory mixer in batches of such a size as to leave about 10 per cent excess of the test requirements. The aggregates must be mixed thoroughly to obtain a high quality concrete.

1. **Hand mixing** The ingredients are mixed in a watertight, clean, damp metal pan with a trowel or a shovel. The following procedures may be adopted:
   (a) Mix the cement and fine aggregate together in a dry state until they are thoroughly blended.
   (b) Add the coarse aggregate and mix the entire batch until the coarse aggregate is uniformly distributed throughout the batch.
   (c) Add the water and continue mixing until plastic concrete is of uniform colour and desired consistency is obtained.
2. **Machine mixing** While using machine mixing, the material is loaded in the above sequence and the mixing process should continue for two minutes to enable the particles to intermingle and become completely coated with cement paste.
   Precautions should be taken to compensate for mortar retained by mixer so that the finished batch as used would be correctly proportioned. And to eliminate segregation of machine-mixed concrete, it should be deposited on a watertight, clean sheet metal pan and remixed by shovel or trowel. The following procedure is used to ensure correct final proportions in a batch:
   Just before mixing the test batch the mixer should be buttered, mixing a batch proportioned to simulate closely the test batch. The mortar adhering the mixer after discharging is intended to prevent loss of mortar from the test batch.

6.4 PRINCIPLES OF MEASUREMENT OF WORKABILITY

In view of term workability being defined broadly earlier in Section 6.2, a number of different methods are available for measuring the workability of fresh concrete, but none of them is wholly satisfactory. Each test measures only a particular aspect of it and there is no single test method which measures the workability of concrete in its totality. However, by checking and controlling the uniformity of the workability, it is easier to ensure a uniform quality of concrete and hence uniform strength for a particular job.

Workability test procedures are generally classified as confined flow tests, free flow tests, vibration tests and those for very low slump concrete.

6.4.1 Conventional Concrete

Following standardised procedures for assessing the workability of conventional concrete are described in the manual:

1. **Free flow test methods**
   Slump test (*IS: 1199 – 1959: RA 2008*) The slump test is the most widely used, primarily because of the simplicity of the apparatus required and the test procedure. The slump test indicates the behaviour of compacted concrete cone under the action of gravitational forces. The test is carried out with a mould, called *slump cone*. The slump cone is filled with fresh concrete under standard conditions. The mould is lifted vertically without disturbing the concrete cone. The subsidence of concrete in millimetres is termed the slump.

2. Confined flow test methods

Compaction factor test (*IS: 1199 – 1959: RA 2008*) The compaction factor test gives the behaviour of fresh concrete under the action of external forces. It measures the compactability of concrete which is an important aspect of workability, by measuring the amount of compaction achieved for a given amount of work. The compaction factor test is considered to be more accurate than slump test, especially for concrete mixes of medium and low workability.

3. Vibration test methods

(a) *Vee-Bee consistency test* (*IS: 1199 – 1959: RA 2008*) The Vee-Bee test consists of moulding a fresh concrete cone in a cylindrical container mounted on a vibrating table. The concrete cone is subjected to vibrations till the concrete surface becomes horizontal, called *remoulding*. The time required for complete remoulding in seconds is considered as a measure of workability and is expressed as the number of Vee-Bee seconds. Thus, in Vee-Bee test the concrete in the test receives a similar treatment as it would be in actual practice. The test is suitable for stiff concrete mixes having low and very low workability.

(a) *Flow table test* (*IS: 1199 – 1959: RA 2008*) The flow table test consists of moulding a fresh concrete cone on the top of the platform of flow table, and giving specified number of jolts of standard magnitude. The spread of the concrete measured as the increase in diameter of concrete heap and expressed as the percentage of the original base diameter of cone, is taken as a measure of flow or consistency of the concrete. The flow table test is suitable in providing satisfactory performace for consistencies for which slump test can be used.

As each of the above tests measures only a particular aspect of workability, there is no rigid correlation between the workability of concrete as measured by different test methods. In the absence of definite correlations between different measures of workability under different conditions, it is recommended that for a given concrete, the appropriate test method be decided beforehand and workability expressed in terms of such test only rather than interpolating from the results of other tests. Table 6.3 gives the range of expected values of workability measure by different test methods for comparable concrete.

6.4.2 Workability Tests for Self-Compacting Concrete

Following standardised test procedures for self-compacting concrete have been described in Section 7 of the manual:

1. Slump flow test with T500 and VSI tests
2. J-Ring test
3. V-Funnel and T5 tests
4. L-Box test
5. Wet sieving stability test
6. Column segregation test

EXPERIMENT NO. 1: Slump Test

Objective

To determine, the consistency of concrete mix of given proportions by the slump test.

Theory and Scope

Slump is a measure indicating the consistency or workability of fresh cement concrete. This test can also be used to determine the water content to give specified slump value. In this test, fresh concrete is filled into a mould of specified shape and dimensions, and the supporting mould is removed. The unsupported fresh concrete cone flows to the sides resulting in a sinking in its height. This vertical settlement is known as slump. In this test, the slump increases as *water content* is increased. For different works different slump values have been recommended in Table 6.1.

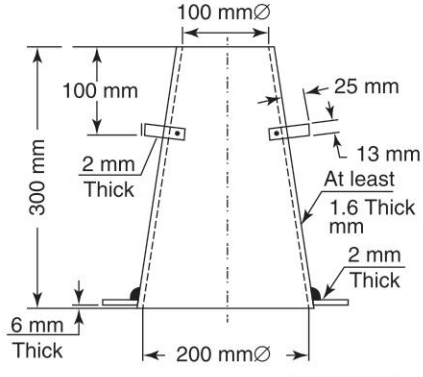

Fig. 6.3 *Typical slump cone*

Apparatus

Iron pan to mix concrete; Weighing platform machine; Spatula, Trowels; Slump test apparatus with 300 mm scale; Tamping rod; Balance to weigh up to 30 kg mass to an accuracy of to 10 g and graduated cylinder.

Description of Apparatus

The slump cone shown in Fig. 6.3 is a hollow frustum made of thin steel sheet, with internal dimensions as: the top diameter 100 mm, the bottom diameter 200 mm and the height 300 mm. It stands on a plane non-porous surface. To facilitate filling and vertical lifting from moulded concrete it is provided with a suitable guide attachment (not shown), foot pieces and lifting handles.

The tamping rod is 16 mm in diameter, 0.6 m long and is bullet pointed at the lower end.

Procedure

Step 1: Clean the internal surface of the mould thoroughly and dampen it with moist cloth.
Step 2: Place the mould on a smooth, horizontal, rigid and non-absorbent surface.
Step 3: Place the fresh concrete sample in the cleaned slump cone mould in four layers, each approximately 1/4 of the height of the mould. Tamp each layer 25 times with tamping rod distributing the strokes uniformly over the cross section of the mould. For the second and subsequent layers the tamping rod should penetrate in to the underlying layer.
Step 4: After the top layer is rodded, strike off the top with a trowel or tamping rod so that the mould is exactly filled.
Step 5: Remove the cone mould immediately from the concrete, raising it slowly and carefully in the vertical direction.
Step 6: As soon as the concrete settlement comes to a stop, measure the subsidence of concrete, i.e., the difference in level between the height of the mould and that of the highest point of the subsided concrete.
Step 7: This subsidence of concrete in mm is the slump of the concrete.

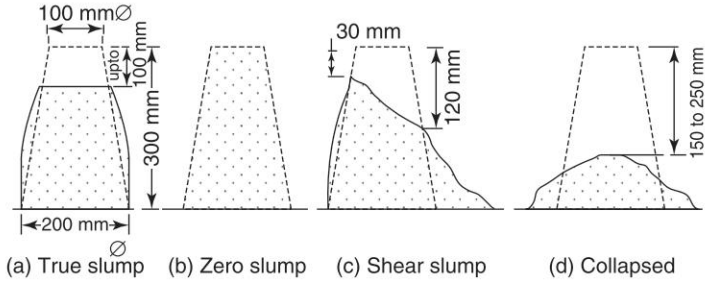

Fig. 6.4 *Types of slump with typical subsidence*

Observations and Calculations

Any slump specimen that collapses or shears off laterally as shown in Fig. 6.4 gives incorrect result and if this occurs the test is repeated, only true slump should be measured and reported.

The slump of fresh concrete sample is……..mm.

Precautions

1. The strokes are to be applied uniformly throughout the entire area of the concrete section.
2. The cone should be removed very slowly by lifting it upwards without disturbing the concrete. The unsupported concrete should be allowed to spread and settle before measuring the settlement.
3. The test should be completed within three minutes.
4. It should be ensured that the interior of the mould be clean and damp but not wet.
5. The base plate should be smooth and clean so that the contact is made with bottom of the mould around its whole circumference.
6. During filling the mould must be firmly pressed against its base.
7. On completion of tamping any surplus concrete is carefully removed with a trowel so that the mould is exactly filled. The surplus should not be forced into the mould.
8. Care should be taken not to cause subsidence by jarring the base.
9. Vibrations from nearby machinery might also increase subsidence, hence test should be made beyond the range of ground vibrations.

Discussion

During the test, when the concrete settles/slumps evenly all around is called *true slump*. In the case of very lean concrete one half of the cone may slide down the other which is called a shear slump; or it may collapse in case of very wet concretes as shown in Fig. 6.4. The slump test is essentially a measure of the consistency or the wetness of the mix. The test is suitable only for concretes of medium to high workability (i.e., slump 25 mm to 125 mm). The slump test is limited to concretes with maximum size of aggregate less than 40 mm.

The slump test is simple, rugged, and inexpensive to perform; results are obtained immediately without any calculation. The slump test is so well known that often the terms workability and slump are used interchangeably, even though they have different meanings; specifications are typically written in terms of slump. As compared to other commonly used concrete tests, such as for air content and compressive strength, the slump test provides acceptable precision. The test has been found to be useful in ensuring the uniformity among different batches of supposedly similar concrete under field conditions.

This test is not a true guide to workability, for example, a harsh mix cannot be said to have same workability as one with a large proportion of sand, even though they may have the same slump. For very stiff mixes having no slump, the slump test does not indicate any difference in concretes of different workability. It must be appreciated that the different concretes having same slump may have indeed different workability under the site conditions.

The slump test is a static test and therefore, the results are influenced by concrete thixotropy. The test does not provide an indication of the ease with which concrete can be moved under dynamic placing conditions, such as vibration. The slump test does not give an indication of plastic viscosity.

Table 6.1 *Recommended slump values for concrete for various jobs*

Sl. no.	Name of works	Slump, mm	Water-cement ratio
1.	Concrete for roads and mass concrete	25 to 50	0.70
2.	Concrete for R.C.C. beams and slabs	50 to 100	0.55
3.	Columns and retaining walls	75 to 125	0.45
4.	Mass concrete in foundation	25 to 50	0.70

Viva-Voce Questions

1. How is the workability and consistency of freshly mixed concrete defined?
2. What is slump of concrete? What is the significance of slump test?
3. What changes take place in a concrete mix as water content is varied? Is it sensitive to low water content?
4. If the concrete is rammed hard, will the slump value decrease or increase?
5. What are segregation and bleeding?
6. What are the undesirable effects of segregation and bleeding?
7. What is the slump range for concrete to be used for (a) road work, (b) beams, slabs, and staircases, (c) columns and retaining walls, (d) mass concrete, (e) domes and shells, (f) prestressed concrete and (g) prefabricated construction?
8. What are the limitations of this test? What precautions should be taken during the test?

Notes and Comments

EXPERIMENT NO. 2: Compaction Factor Test

Objective

To determine the workability of fresh concrete mix by compaction factor test.

Theory and Scope

Compaction factor test is adopted to determine the workability of concrete, where nominal size of aggregate does not exceed 40 mm. It is based upon the definition, that workability is that property of the concrete which determines the amount of work required to produce *full compaction.* The test consists essentially of applying a standard amount of work to standard quantity of concrete and measuring the resulting compaction. The compaction factor test to determine the workability of freshly prepared concrete is carried out as per IS: 1199-1959.

Apparatus

Compaction factor apparatus; Trowels; Graduated cylinder of 1000 ml capacity; Balance to weigh up to 30 kg (nearest to about 10 g); Tamping rod and Iron buckets.

Description of Apparatus

The compaction factor test apparatus consists of two conical hoppers, A and B, mounted vertically above a cylindrical mould C. The upper hopper A has internal dimensions as: top diameter 250 mm, bottom diameter 125 mm and height 225 mm. The lower hopper *B* has internal dimensions as: top diameter 225 mm, bottom diameter 125 mm and height 225 mm. The cylinder has internal dimensions as: 150 mm diameter and 300 mm height. The distances between bottom of upper hopper and top of lower hopper, and bottom of lower hopper and top of cylinder are 200 mm in each case. The lower ends of the hoppers are fitted with quick release flap doors. The hoppers and cylinder are rigid in construction and rigidly mounted on a frame. These hoppers and cylinder are easily detachable from the frame.

Procedure

Step 1: Keep the compaction factor apparatus on a level ground and moisten the inner surface of the hoppers and cylinder.

Step 2: Fasten the flap doors.

Step 3: Weigh the empty cylinder accurately and note down the mass as W_1 kg.

Step 4: Fix the cylinder on the base with fly nuts and bolts in such a way that the central points of hoppers and cylinder lie on one vertical line. Cover the cylinder with a plate.

Step 5: Fill the freshly mixed concrete sample in upper hopper gently and carefully with hand scoop without compacting.

Step 6: After two minutes, release the trap door so that the concrete may fall into the lower hopper bringing the concrete into standard compaction.

Step 7: Immediately after the concrete has come to rest, open the trap door of lower hopper and allow the concrete to fall into the cylinder bringing the concrete into standard compaction.

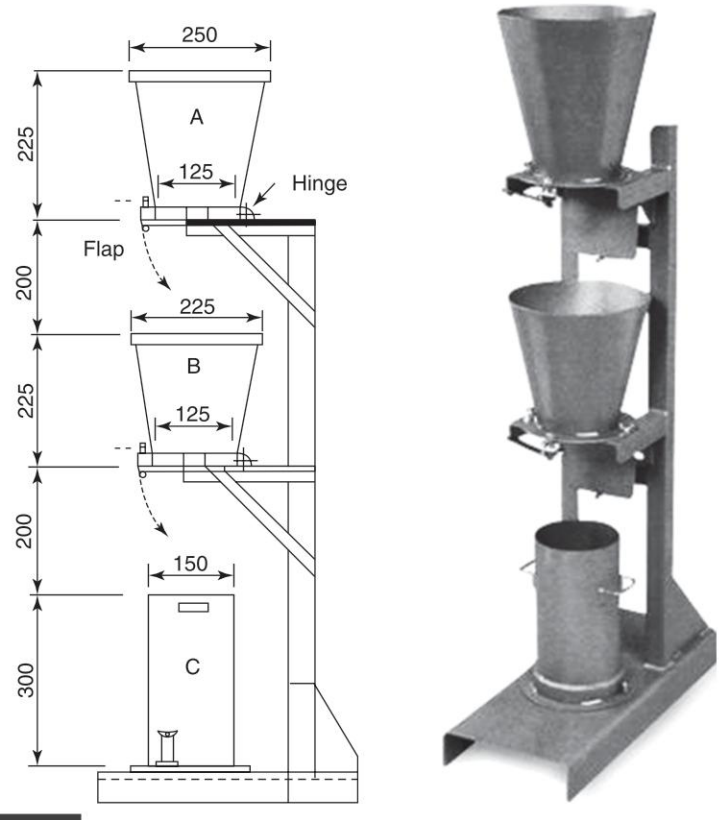

Fig. 6.5 *Compaction factor apparatus (all dimensions in mm)*

Step 8: Remove the excess concrete above the top of the cylinder by a pair of trowels, one in each hand, will blades horizontal slide them from the opposite edges of the mould inward to the centre with a sawing motion.

Step 9: Clean the cylinder from all sides properly. Find the mass of partially compacted concrete thus filled in the cylinder, say W_2 kg.

Step 10: Refill the cylinder with the same sample of concrete in approximately 50 mm layers, vibrating each layer so as to expel all the air and to obtain full compaction of concrete.

Step 11: Strike off excess to level the concrete and weigh the cylinder filled with fully compacted concrete. Let the mass be W_3 kg.

Observations and Calculations

Mass of empty cylinder,	W_1 kg		
Mass with partially compacted concrete,	W_2 kg		
Mass with fully compacted concrete,	W_3 kg		
Compaction factor,	$\text{C.F} = \dfrac{W_2 - W_1}{W_3 - W_1}$		

The compaction factor for the fresh concrete sample is……

Precautions

1. The test should be carried out on a level and firm ground.
2. The top hopper must be filled gently and to the same extent on each occasion and the time between the end of mixing and release of concrete from top hopper must be constant, two minutes will be convenient.
3. The outside of mould must be wiped clean before weighing and mass should be recorded to the nearest 10 g.
4. The mix should not be pressed or compacted in the upper hopper.
5. If the concrete in the hopper does not fall through when the flap is released, it should be freed by passing a metal rod similar to that used in slump test, vertically through its centre. A single steady penetration will usually affect release.
6. At the end of test the hoppers and cylinder must be washed clean and wiped dry.

Discussion

The compaction factor test which is popular in laboratory conditions is more sensitive and gives more consistent results than slump test, especially for concrete mixes of medium and low workability, i.e., compaction factor of 0.9 to 0.8, as are normally used when the concrete is to be compacted by vibration. Such concrete mixes of low workability may constantly fail to slump. For concrete of very low workability having compaction factor of the order of 0.70 or below, the test is not suitable, because this concrete cannot be fully compacted for comparison in the manner described in the test.

The compaction factor test is a dynamic test and thus is more appropriate than static tests for highly thixotropic concrete mixtures. It gives more information (i.e., about compactability) than the slump test. The test is able to indicate small variations in workability over a wide range.

However, the amount of work applied to the concrete being tested is a function of the friction between the concrete and the hoppers, which may not reflect field conditions. When maximum size of aggregate is large as compared with mean particle size the drop into bottom container will produce segregation and give unreliable comparison with other mixes of smaller maximum aggregate size.

The method of introducing concrete into mould bears no relationship to any of the more common methods of placing and compacting high quality concrete. For example, vibration is the main compaction method used in the field.

The large and bulky nature of the device, and requirement of a balance to measure the mass of the concrete in the cylinder reduces its usefulness in the field.

The relationship between the compaction factor and slump values is given in Fig. 6.1 whereas the approximate relationship between degree of workability and compaction factor is given in Table 6.2. The recommended values of compaction factor for use in various types of concrete works are also listed in the table.

Table 6.2 *Relationship between degree of workability and C.F., and recommended values for use for various types of concrete works*

Degree of workability	Slump, mm	Compaction factor	Use for which concrete is suitable
Very low	0 to 25	0.78	Roads vibrated by power operated machines
Low	25 to 50	0.85	Roads vibrated by hand operated machines,

(continued)

Table 6.2 *contd.*

Degree of workability	Slump, mm	Compaction factor	Use for which concrete is suitable
Medium	50 to 100	0.92	Mass foundation without vibration or lightly reinforced sections with vibration. Less workable, flat slabs, manually compacted reinforced concrete.
High	100 to 180	0.95	For section with congested reinforcement. Not suitable for vibrations.

Viva-Voce Questions

1. What is meant by workability of concrete?
2. How does a slump test compare with a compaction factor test?
3. How is the standard condition of concrete in compaction factor test achieved?
4. What is the distance between cylinder top and bottom of lower hopper?
5. Will the workability increase with increase in compaction factor value and if so, why?
6. What precautions should be taken in this test?
7. In what respects, compaction factor test is a better measure of workability than slump test?
8. What are the limitations of this method?

Notes and Comments

EXPERIMENT NO. 3: Vee-Bee Consistency Test

Objective

To determine the workability of freshly mixed concrete by Vee-Bee consistency test.

Theory and Scope

As in the case of other tests, this test also measures only a particular aspect of workability; the test gives an indication of the *mobility* and to some extent of the *compactability* of freshly mixed concrete. It measures the relative effort required to change a mass of concrete from one definite shape to another, i.e., from conical to cylindrical) by means of vibration. The amount of effort called *remoulding effort* is expressed as the time in seconds. This time required for complete remoulding in seconds is considered as a measure of workability and is expressed as the number of Vee-Bee seconds. The name Vee-Bee is derived from the initials of V. Bahrmer of Sweden who developed this test. The method is suitable for dry concrete; for concrete of slump in excess of 50 mm, the remoulding is so quick that the time cannot be measured.

Apparatus

Vee-Bee consistometer (IS: 1199-1959) shown in Fig. 6.6 consists of a vibrating table mounted on elastic supports; Cylindrical container; Sheet metal slump cone; Standard iron tamping rod; Weighing balance and Trowels.

Description of Apparatus

The *vibrating table* of size 380 mm long and 260 mm wide is supported on rubber shock absorbers at a height of about 305 mm above the floor level. An electrically operated vibrator is provided under the table. The assembly is mounted on a base which rests on three rubber supports.

The *sheet metal slump cone mould*, open at both ends is placed in the cylindrical container which is mounted on the vibration table by means of wing nuts. The cone is 300 mm high with its bottom and top diameters as 200 and 100 mm, respectively. A swivel arm holder is fixed to the base and into it is telescoped another swivel arm with funnel and guide sleeve. The swivel arm can be detached from the vibrating table. A graduated rod, to the one end of which a transparent disc can be screwed, is fixed to the swivel arm through the guide sleeve. The divisions on the scale on the rod record the slump of the concrete cone in the cylindrical container.

The standard iron tamping rod is 20 mm in diameter and 500 mm in length.

Procedure

Step 1: Place the sheet metal slump cone within the cylindrical container of the consistometer. Fill the cone in four layers, each approximately one quarter of the height of the cone. Tamp each layer with twenty five strokes of the rounded end of the tamping rod. The strokes are distributed in a uniform manner over the cross section of the cone and for the second and subsequent layers the tamping bar should penetrate into the underlying layer. After the top layer has been rodded, struck off level the concrete with a trowel so that the cone is exactly filled.

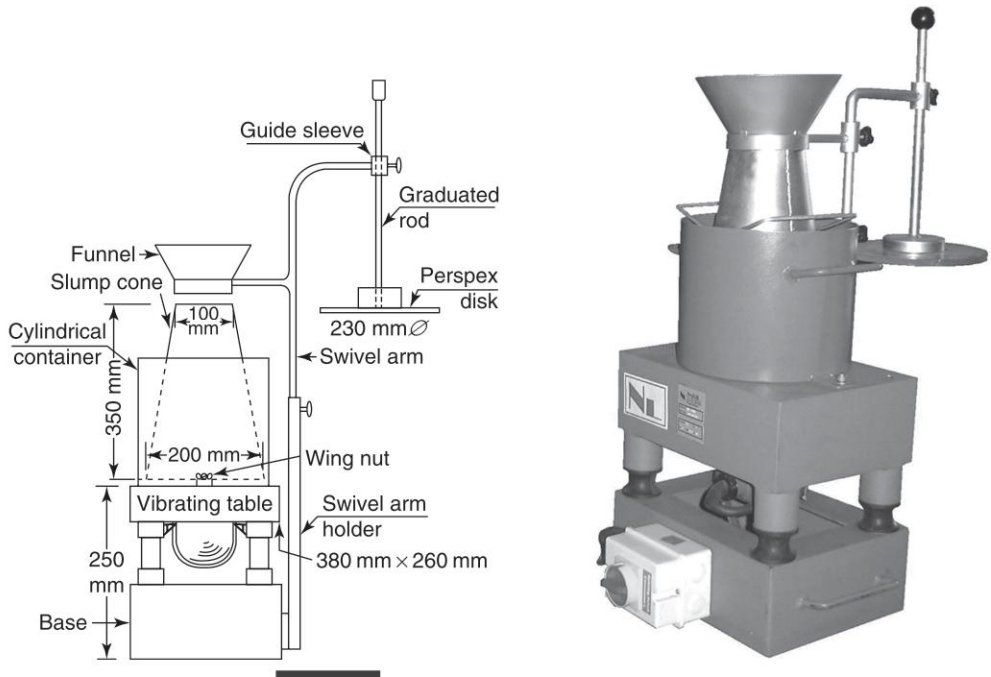

Fig. 6.6 *Consistometer (IS: 1199-1959)*

Step 2: Move the glass disc attached to the swivel arm and place it just on the top of the slump cone in the cylindrical container. Adjust the glass disc so as to touch the top of the concrete cone and note the initial reading on the graduated rod.

Step 3: Remove the cone mould from the concrete immediately by raising it slowly and carefully in the vertical direction. Lower the transparent disc on the top of concrete. Note down the reading on the graduated rod.

Step 4: Determine the slump by taking the difference between the readings on the graduated rod recorded in Steps 2 and 3 above.

Step 5: Switch on the electrical vibrations and simultaneously start the stop watch. Allow the concrete to be remoulded by spreading out in the cylindrical container. The vibrations are continued until the concrete is completely remoulded, i.e., the surface becomes horizontal and the whole concrete surface adheres uniformly to the transparent disc.

Step 6: Record the time required for complete remoulding in seconds which measures the workability expressed as number of Vee-Bee seconds.

Observations and Calculations

Initial reading on the graduated rod,	a mm		
Final reading on the graduated rod,	b mm		
Slump,	(b) – (a) mm		
Time for complete remoulding,	seconds		

The consistency of the concrete is…….Vee-Bee seconds.

Precautions

1. The internal surface of the mould should be thoroughly cleaned and freed from moisture.
2. The strokes of tamping rod should be applied uniformly through the full depth of the concrete of previous layer.
3. The slump cone should be removed slowly by lifting it upward so that the concrete cone is not disturbed.
4. The test should be performed away from any vibration source.
5. The remoulding of concrete should be considered as complete when the transparent disc rider completely covers the concrete and all cavities in the surface of the concrete have disappeared.

Discussion

Compared to the slump test and compaction factor test, Vee-Bee test has an advantage that the concrete in the test receives a similar treatment as it would be in actual practise. Since the completion of remoulding is ascertained visually, the difficulty of establishing the end point of test introduces a source of error which is more pronounced for concrete mixes of high workability and consequently records low Vee-Bee time. For concrete of slump in excess of 125 mm, the remoulding is so quick that time cannot be measured. The test is therefore, not suitable for concrete of higher workability, i.e., slump of 75 mm or above. To overcome this problem to some extent, an automatically operated device for recording the movement of the disc against time may be fitted. The Vee-Bee test is suitable for stiff concrete mixes having low and very low workability.

Out of the three methods recommended by IS: 1199-1959 namely, slump test; compaction factor test; and Vee-Bee consistency test, the slump test is perhaps the most widely used primarily because of its simplicity. But the test is suitable only for concretes of medium to high workability (i.e., slump 25 to 125 mm). For *very stiff mixes* having zero slumps, the slump test does not indicate any difference in the concretes of different workability. It should be appreciated that the different concretes having same slump may indeed have different workability under the site conditions. On the other hand, the *compaction factor test* has been held to be more accurate than slump test, especially for concrete mixes of *medium* and *low workability* (i.e., compacting factor of 0.9 to 0.8). For concrete of very *low workability* (i.e., compacting factor of 0.70 and below, which cannot be fully compacted in the manner described in the test) this test is not suitable. In addition, the tendency of some dry mixes to stick in the hoppers introduces a source of error.

Table 6.3 *Consistency measurements by various test methods (as per ACI Committee 211)*

Workability description	Workability measurement		Vee-Bee time seconds
	Slump, mm	*Compacting factor*	
Extremely dry	-	-	32–18
Very stiff	-	0.70	18–10
Stiff	0–25	0.75	10–5
Stiff plastic	25–50	0.85	5–3
Plastic	75–100	0.90	3–0
Flowing	150–175	0.95	-

There is no rigid correlation between the workability of concrete as measured by different methods. Table 6.3 gives the range of expected values obtained by different test methods for comparable concretes. In the absence of definite correlations between the different measures of workability under different conditions, it is recommended that for a given concrete, appropriate test method be decided before hand and the workability expressed in such test only rather than interpreting from the results of other tests.

Viva-Voce Questions

1. Why is the name Vee-Bee given to this test?
2. What property does it measure of the freshly mixed concrete?
3. What are the advantages and disadvantages of this method of test over the other methods?
4. Why is the Vee-Bee test considered to be a remoulding test?
5. Is there any correlation between different measures of workability under different condition?
6. What is the number of Vee-Bee seconds when the mix is (a) very dry, (b) dry, (c) plastic, (d) semifluid and (e) fluid?
7. What are the corresponding measurements by slump and compacting factor tests?

Notes and Comments

EXPERIMENT NO. 4: Flow Table Test

Objective

To determine the workability of freshly mixed concrete by the use of flow table.

Theory and Scope

The flow table test determines the fluidity or consistency of concrete by means of a flow table.

The test consists of moulding the fresh concrete in the form of a frustum of a cone on the top of the platform of flow table; The concrete cone is then given a specified number of jolts of specified magnitude. The spread of the concrete measured as the increase in diameter of concrete heap and expressed as the percentage of the original base diameter of cone, is taken as a measure of flow or consistency of the concrete.

This test examines stability and mobility aspect of workability. In general, the test will give a satisfactory performance for consistencies for which the slump cone test can be used. However, it should be noted that the flow test does not measure workability, as concretes having the same flow may differ considerably in their workability.

Apparatus

Flow table; Cone mould; Balance; Tamping rod; Calipers.

Description of Apparatus

The *flow table* shown in Fig. 6.7 shall conform to IS: 15-1959 and shall be rigidly mounted on a concrete base having a height of 400 to 500 mm and weighing not less than 140 kg. Motorised flow table (IS: 5512) is also available.

The *cone mould* shall be made of a smooth metal casting in the form of a frustum of a cone. The internal dimensions are: base diameter 250 mm, top diameter 170 mm, height 120 mm. The base and the top shall be open at right angles to the axis of the cone. The mould is provided with handles to facilitate lifting it vertically from the moulded concrete test specimen.

The *tamping rod* shall be of steel or some other suitable metal, 16 mm in diameter 600 mm long and bullet pointed at one end.

Procedure

Step 1: Moisten the clean table top and inside of the cleaned cone mould; Remove the excess moisture with a wet cloth before commencing the test.

Step 2: Centre the mould on the table platform and hold it firmly in place.

Step 3: Fill the mould in two equal layers, each layer being given 25 strokes with the standard tamping rod. The strokes shall be distributed in a uniform manner over the cross section of the mould and for the second layer shall penetrate into the underlying layer. The bottom layer should be tamped throughout its depth.

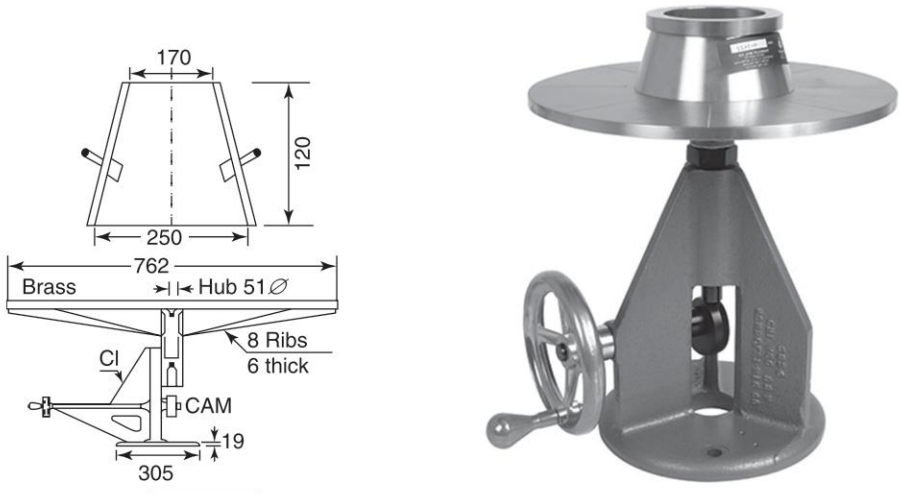

Fig. 6.7 *Flow table apparatus (all dimensions in mm)*

Step 4: After the top layer has been rodded struck off level the surface with a trowel so that the mould is exactly filled. Remove the excess concrete which has overflowed the mould and clean the area of table outside the mould.

Step 5: Remove the mould immediately by lifting it vertically by a steady upward pull.

Step 6: Turn the handle 15 times at a rate of 1 revolution per second, such that the concrete is given a jolt by raising and then dropping it by 12.5 mm.

Step 7: Measure the diameter of the spread concrete at six equally spaced positions along the circumference with calipers read to the nearest 5 mm and record the average.

Step 8: Obtain the flow or the consistency of concrete by expressing the increase in diameter of concrete specimen as the percentage of the original diameter of 250 mm.

Observations and Calculations

Original or base diameter,	d_1 mm	250	250
Spread diameter,	d_2 mm		
Increase the diameter,	$d_2 - d_1$ mm		
Flow,	$\frac{d_2 - d_1}{d_1}$ per cent		

The flow of the concrete is …….per cent.

Precautions

1. The top of the flow table and the inside of the mould should be wetted and thoroughly cleaned of any set concrete before commending the test.
2. The strokes of tamping rod should be distributed uniformly over the cross section of the mould.
3. The mould should be removed very slowly by lifting it upwards so that the concrete within the mould does not get disturbed.

Discussion

The flow test gives satisfactory performances for the concretes of consistencies for which the slump test can be used; but the results of the flow test are more reproducible than those given by slump test. The test is largely limited to laboratory use. The weakness of the flow test lies in the fact that the flow is uncontrolled and some of aggregate rides along only partly embedded in the concrete and that at the end of the test the mass is scattered instead of being homogenous.

The test suffers from the drawback that the concrete may scatter on the flow table with a tendency towards segregation.

Viva-Voce Questions

1. Which aspect of workability does this test measure?
2. How will you define the stability of a concrete mix?
3. What is meant by the segregation in concrete?
4. What is the difference between segregation and bleeding?
5. What is meant by the flow or consistency of concrete?
6. What precautions are taken in the test?
7. Why is the test largely limited to the laboratory use?
8. What is the main weakness of the test?
9. Comment on the statement, '*Concrete having the same flow may differ considerably in the workability*'.

Notes and Comments

EXPERIMENT NO.5: Density, Yield and Air Content of Fresh Concrete

Objective

To determine

1. *the density of concrete of given proportions*
2. *yield of concrete, i.e., the quantity of concrete produced per bag of cement, and also the cement factor i.e. the number of bags of cement required producing one cubic metre of concrete.*
3. *the air content of freshly mixed concrete (by gravimetric method).*

Theory and Scope

1. **Yield test** This test gives an idea of the quantity of concrete that can be produced per bag of cement for a particular mix ratio. With the help of yield of concrete we can determine the quantity of cement required for specified quantity of concrete.
2. **Air content test** The test gives the amount of air in concrete, both unwanted air as well as purposely entrained air. Therefore, the test is sometimes used as a check on the quality of concrete when very high strength or resistance to wear is required. The air is purposely entrained for two reasons:

   (a) To promote workability and reduce segregation and bleeding.
   (b) To increase the resistance to frost action.

   Considerably less air need to be entrained for the former purpose than for latter.

Apparatus

Standard cylindrical container of known volume of 7.08 litres; Tamping rod with a mass of 1.8 kg, 380 mm long and having a ramming face 25 mm square; Balance of an accuracy 0.01 kg and 30 kg capacity; Mixing tray; Trowel and a Measuring cylinder.

Procedure

Step 1: Prepare concrete of given mix proportions.
Step 2: Fill the standard container in layers of about 50 mm height and tamp each layer at least 60 times by tamping rod distributing the strokes uniformly all over the cross section. (In case of vibrated concrete the specified compaction is attained by means of an electricor pneumatic hammer or by means of a vibrating table).
Step 3: Tap the exterior surface of the cylinder until no large bubbles of air appear on the surface of the compacted concrete.
Step 4: Strike the concrete level and smooth finish with a flat.
Step 5: Clean the concrete from the exterior and weigh the filled container.
Step 6: Determine the volume of container by filling it with water at 16°C and sliding a glass plate over the top. Find volume by calculating the mass of water in container.

Observations and Calculations

1. **Density** $= \dfrac{\text{mass of concrete}}{\text{volume of container}} = \ldots\ldots\ldots \text{ kg/m}^3$

2. **Yield and cement factor** If W_a, W_s, W_c and W_w be the masses of coarse aggregate, sand, cement and water, respectively, taken to produce concrete, then

   Total mass of concrete produced for W_c kg of cement is given by

   $$W = W_a + W_s + W_c + W_w$$

   The total volume of concrete produced can be obtained from the following relationship:

   $$V = \frac{W}{\text{Density}}$$

   Thus the yield per bag of cement (with mass in one bag of cement being 50 kg) can be obtained is follows:

   $$V_1 = \frac{V}{\text{W}_\text{c}} \times 50$$

3. **Cement factor** Number of bags of cement required to produce one cubic metre of concrete $= \dfrac{1}{V_1}$.

4. **Air content** In the method described, the actual volume of concrete is determined by testing a sample using the standard unit mass method. The volume on an air free basis is calculated from the masses of individual materials used and their specific gravities.

   Absolute volume of coarse aggregate, $v_a = \dfrac{W_a}{1000 \times S_a} \text{ m}^3$

   Absolute volume of sand taken, $v_s = \dfrac{W_s}{1000 \times S_s} \text{ m}^3$

   Absolute volume of cement taken, $v_c = \dfrac{W_c}{1000 \times S_c} \text{ m}^3$

   Absolute volume of water added, $v_w = \dfrac{W_w}{1000} \text{ m}^3$

   where S_a, S_s and S_r are specific gravities of coarse aggregate, sand and cement, respectively; and may be taken as 2.55, 2.65 and 3.15, respectively.

   Then the total absolute volume of concrete, $v_1 = v_a + v_s + v_c + v_w$ and

   Air content $= \dfrac{V - v_1}{V} \times 100 \text{ per cent}$

5. Calibration of standard container			
Mass of container full of water,	W_f kg		
Mass of empty container,	W_e kg		
Mass of water in container,	$(W_f - W_e)$ kg		
Volume,	$V = (W_f - W_e)$ litres		

6. Actual unit mass (or density) of concrete			
Mass of container full of concrete,	W_{cf} kg		
Mass of empty container,	W_e kg		
Mass of concrete in container,	$W = (W_{cf} - W_e)$ kg		
Density or unit mass of concrete,	$\frac{W}{V}$ kg/m^3		

7. Yield of cement			
Mass of coarse aggregate,	W_a kg		
Mass of fine aggregate,	W_s kg		
Mass of cement,	W_c kg		
Mass of water,	W_w kg		
Total mass of concrete produced,	W kg		
Density of concrete from (6),	kg/m^3		
Volume of concrete produced,	$V = \frac{W}{\text{Density}}$ litres		
Yield for a bag of cement,	$V_1 = \frac{V}{W_c} \times 50$ m^3		

8. Cement factor			
Number of bags per cubic metre of concrete,	$\frac{1}{V_1}$		

9. Air content of concrete			
Absolute volume of coarse aggregate,	$\frac{W_a}{S_a}$ m^3		
Absolute volume of fine aggregate,	$\frac{W_s}{S_s}$ m^3		

(continued)

Absolute volume of cement taken,	$\frac{W_c}{S_c}$ m^3		
Absolute volume of water added,	$v_w = W_w$ m^3		
Total absolute volume of concrete,	v_1 m^3		
Air content,	$\frac{V - v_1}{V} \times 100$ per cent		

Precautions

1. Determine the mass of water and concrete to an accuracy of 10 g.
2. Strokes should be uniformly distributed all over the section.
3. Exterior should be cleaned before weighing the filled container.
4. Bubbles should be removed by tapping the exterior surface.
5. The container should have an adequately stiff rim at the top which should be accurately turned and true on its upper surface.
6. Accurate determination of specific gravity of individual materials is necessary together with careful levelling of the concrete.

Discussion

The method requires a number of calculations for computing the volume of air free concrete which seems rather complicated. However, once the volume of air free concrete is computed for a given mix and material, it need not be recalculated for each air determination as on a construction job mix and materials are not changed frequently.

Knowledge of percentage of entrained air present is of vital importance. Air may be required either to improve the workability or to increase the resistance of concrete to frost action. Because of the loss in strength caused by presence of air as shown in Fig. 6.8, it is essential to ensure that only minimum quantity necessary to achieve these objectives should be present.

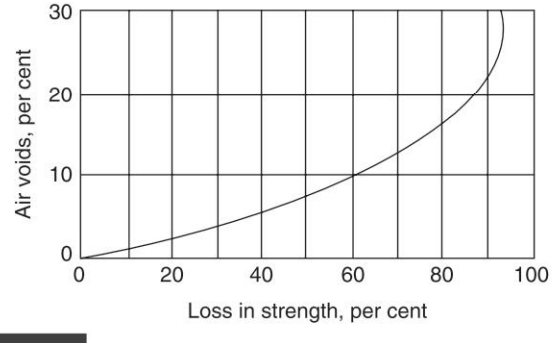

Fig. 6.8 *Effect of air voids on the strength of concrete*

Viva-Voce Questions

1. What is meant by density of concrete, yield of concrete and cement factor?

2. What is the significance of yield test?
3. What does air content test indicate? Can this test be used as a check on the quality of concrete?
4. What properties of concrete are affected by air entrainment? Why the air is sometimes purposely entrained in concrete?
5. If the air is entrained in excess of that required for promoting workability and for protection against frost, how is it going to affect the strength of the concrete?
6. What is air entraining agent?
7. What is the basic concept involved in making the air-content determination?
8. How is the air content of concrete expressed?
9. What precautious should be taken during the test?
10. What other methods are available for air content determination?

Notes and Comments

NATIONAL STANDARDS

1. IS 1199-1959 (reaffirmed 2008): *Methods of Sampling and Analysis of Concrete*
2. IS 6461 (Part 10) -1973 (reaffirmed 2011): *Glossary of Terms Relating to Cement Concrete; Part 10: Tests and Testing Apparatus*

REFERENCES

1. BS EN 12350-2:2000, *Testing of Fresh Concrete: Slump Test*
2. BS EN 12350-3:2000, *Testing of Fresh Concrete: Ve-Bee Test*
3. BS EN 12350-4:2000, *Testing of Fresh Concrete: Degree of Compactability*
4. BS EN 12350-5:2000, *Testing of Fresh Concrete: Flow Table Test*
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SELF-CONSOLIDATING CONCRETE

Section 7

This section describes the various standardised tests generally performed on self-consolidating concrete (SCC). The physical characteristics of SCC as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

7.1 INTRODUCTION

Self-Consolidated Concrete (SCC) has properties that differ considerably from conventional slump concrete. SCC is highly workable/flowing concrete that can move under the force of gravity without vibration during mixing, transportation, handling and placement. Consequently, it can flow through densely reinforced and complex structural elements under its own weight and adequately fill all voids without segregation, excessive bleeding, excessive air migration (air popping), or paste separation of materials.

ASTM C1017 defines **flowing concrete** as *concrete that is characterised as having a slump greater than 190 mm while maintaining a cohesive nature*. Flowing concrete can be proportioned with an even higher slump to be self-levelling, which means that it is capable of attaining a level surface with little additional effort from the placer. However, to obtain a properly consolidated self-levelling concrete, "some compaction will always be required". SCC must also be viscous or cohesive enough so that the mortar suspends and carries coarse aggregate, maintaining a homogenous, stable mixture, resistant to segregation, bleeding, excessive air migration or paste separation.

Thus SCC is always "highly flowing", but "highly flowing" may not qualify as SCC. SCC must have both dynamic and static stabilities; dynamic stability during mixing, transportation, handling and placement, while static stability during setting and curing. The dynamic stability constitutes SCC's workability which is a function of its rheology. SCC is so highly flowing that the conventional slump test cannot distinguish between different levels of SCC flowability, as these are 280+ mm in slump. Conventional slump concrete brought to this level of slump does not have this stability.

7.2 ADVANTAGES

In general, cost savings and/or performance enhancement tend to be the driving forces behind the popularity of SCC an alternative to conventional slump concrete. Requirements of better quality construction at lower costs of labour, materials and equipment coupled with tougher environmental and safety regulations has given impetus to its use. The less intensive construction environment results in labour and time savings from higher productivity and greater flexibility of design. Thus, SCC offers the following areas of advantages:

1. Reduced in-place cost due to higher productivity and reduced labour requirements.
2. Improved work environment and safety.
3. Improved aesthetics: SCC provides unequaled formed surfaces.
4. Enhanced design flexibility.

Due to higher strengths resulting from the high powder content SCC has found applications where high strengths are needed for design purposes. Thus, the greatest current application for SCC is in precast/prestressed concrete production with economic benefits.

7.3 RHEOLOGY

Rheology is the science of the deformation and flow of materials. It is a complex phenomenon; as a simplification the rheological behaviour of the concrete is generally expressed in terms of two physical properties or parameters namely, *yield stress* and *plastic viscosity*.

1. **Yield stress** It is the measure of the amount of energy required to make SCC flow. To be considered SCC, concrete must flow easily under its own weight, i.e., gravity, so its yield stress must be very low.
2. **Plastic viscosity** It is the measure of the resistance of SCC to flow due to internal friction. SCC must have a high viscosity in order to suspend aggregate particles in a homogenous manner within the concrete matrix without segregation, excessive bleeding, excessive air migration, or paste separation.

   Thus, SCC must have low yield stress and high viscosity. However, due to higher powder contents SCC bleeds less than conventional slump concrete and can also lead to plastic shrinkage cracking if not properly protected and cured, particularly in flatwork.

Currently the most common field test, the slump test, is related only to the yield stress. However, the plastic viscosity of SCC is the critical parameter that controls flowability/pumpability and ease of finishing of concrete. The basic requirement of workability is its stability (resistance to segregation) which enables SCC to remain homogenous throughout mixing, transportation, placing, and have static stability during finishing and curing operations. In practice, SCC's workability characteristics are measured in four ways:

1. **Flowability or filling ability or deformability** This property represents the ability of SCC to flow into forms through densely reinforced and complex structural elements under its own weight; however, this property does not suggest that all SCC is self-levelling. The flowability is measured using slump flow.
2. **Passing ability or passability** (***resistance to blocking***) It is a measure of ability of the concrete to flow under its own weight through confined spaces, such as the narrow openings between reinforcing bars, and fill open spaces in the formwork without segregation or blocking. Although increasing the filling ability typically increases passing ability, a high level of filling ability does not assure passing ability. Applications of passing ability may range from unreinforced or lightly reinforced sections with no passing ability requirements to narrow sections containing highly congested reinforcement with strict passing ability requirements.

   Passing ability is primarily affected by the aggregate characteristics and the paste volume. Reduction in the maximum aggregate size, reduction in coarseness of an aggregate grading and improvement in the aggregate shape and angularity increase the passing ability. Increasing the paste volume reduces the volume of aggregates and reduces the inter particle friction between aggregates. In addition, reducing the paste yield stress or viscosity improves passing ability.
3. **Stability or segregation resistance** Stability of the concrete is its capacity to sustain a homogenous composition in a fresh state during and after the process of transport and placing. It includes both static and dynamic stability. Dynamic stability describes segregation resistance when concrete is not at rest, such as during mixing, transportation and placing; whereas, the static stability describes segregation resistance when concrete is at rest, i.e., during setting and curing. No test method is available for dynamic stability; therefore, dynamic stability is usually measured indirectly along with passability using the L-box or the J-ring tests.

All mixtures must exhibit segregation resistance. However, Requirements for dynamic stability may be higher for sections with highly congested reinforcement, conditions where concrete is subjected to vibration, or applications were concrete is dropped from vertical heights or required to flow long horizontal distances.

Static stability is affected by the relative densities of the aggregate and paste, the rheology of the paste with time, the aggregate shape and grading, and the characteristics of the element (such as width and spacing of reinforcement). Dynamic stability is mainly affected by the cohesiveness and passing ability of the concrete.

4. **Viscosity** The rheological property defining SCC mixes is viscosity. Viscosity is generally assessed by the T_{500} time during the slump-flow test or assessed by the V-funnel flow time. The T_{500} time does not measure the viscosity of SCC but is related to it because it describes the rate of flow. Concrete with a low viscosity will have a very quick initial flow and then stop. Concrete with a high viscosity may continue to creep forward over an extended time. The T_{500} flow time can be placed into two categories, low (VS1) or high (VS2).

For an appropriate specification of SCC to cover these requirements, the SCC characteristics are placed into different categories; the generally used classification system detailed in Table 7.1.

Table 7.1 *Basic characteristics, test methods and classification of SCC in the fresh state*

Characteristic	Test method	Measured value	Classification
Flowability/filling ability	Slump-flow test	total spread	SF1, SF2, SF3
Viscosity/ flowability (measure of the speed of flow)	T_{500} Slump-flow test	flow time	VS1, VS2
	V-funnel test	flow time	VF1. VF2
Passing ability (flow without blocking)	L-box test	passing ratio	PA1, PA2
	J-ring test	step height, total flow	PAJ
Segregation resistance	Sieve segregation test	percent laitance	SR1, SR2
	Settlement column	segregation ratio	

7.4 PRODUCTION AND QUALITY CONTROL

SCC requires a higher level of quality control than conventional slump concrete. Combined aggregate grading, strictly controlled mix water, controlled cement source, and the use of advanced admixtures require a greater awareness on the part of all production personnel. To minimise normal variation of materials; following key items need special monitoring:

1. Coarse and fine aggregate grading
2. Coarse aggregate void volume
3. Aggregate moistures

The flowability of a concrete mix is a complex interaction of the inter-particle friction in the aggregate phase, and the fluidity of the paste phase. The water-to-powder ratio and admixtures control the fluidity of the paste phase. If the aggregate particles have too much friction due to poor grading or shape, the paste will have to be very fluid to compensate and achieve the desired concrete flowability. If the paste is too fluid, segregation will occur.

Thus, the approach generally followed is to select the best grading and shaped aggregate economically possible, to use high-paste contents to increase space between the aggregate particles, finally to control the rheology of the mix by adjusting the water-to-powder ratio and using appropriate admixtures.

Although, the mix proportions of SCC vary with the application, there are some general parameters of mixes which are based on the experience and can guide to produce trial mixes for quality SCC:

1. **Coarse aggregate content** For normal-density aggregates its specific volume content typically is 28–32 per cent of the concrete volume; the balance 68–72 per cent being mortar.
2. **Paste fraction** It is approximately 35–37 per cent of the mix. For rounded well-graded fine aggregate this will be lower, for poor grades or manufactured fine aggregate this will be higher.
3. **Powder (cement, supplementary cementitious materials and inert powder materials with particle sizes passing the 150 mm sieve)** Powder content is generally in the 295–365 kg/m^3 range.
4. **Fine aggregate** The fine aggregate (passing the 3/8″ (9.5 mm) sieve) to total aggregate ratio is usually 45–55 per cent, with 50 per cent being typical.
5. **Water content** The water content for the preliminary mix should be such as to get 25–75 mm slump in concrete without SCC admixtures. This would include water-reducing admixture or retarders for set control.
6. **Water–cement ratio** It is based on the durability requirements. Generally, powder content requirements for SCC properties will require that water-cement ratio is low enough and resultant strength high enough for most applications; however these parameters need to be confirmed later.
7. **Air content** Air content is governed by durability consideration. Air can improve the viscosity of a mix and increase the paste volume, but may adversely affect paste density.

7.5 SPECIFICATION CLASSIFICATION OF SCC

7.5.1 Flowability

Slump-flow value describes the flowability of a fresh mix in unconfined conditions. It is a sensitive test that will normally be specified for all SCC, as the primary check that the fresh concrete consistence meets the specification. Visual observations during the test and/or measurement of the T_{500} time can give additional information on the segregation resistance and uniformity of each delivery. The typical slump-flow classes for a range of applications are given in Table 7.2.

Table 7.2 *SCC flowability classification based on slump flow*

SCC Classification	Slump flow, mm	Typical application
SF1	550–650	Housing slabs, Pump injecting concrete e.g. tunnel linings), piles and some deep foundations.
SF2	660–750	Normal applications requiring flowable concrete as walls and columns
SF3*	760–850	Highly congested rebar in vertical applications or structures with complex shapes

* High possibility for segregation requires careful check of trial mix

SF3 mixes of this class typically perform better than SF2 classified mixes in vertical casting applications. SF3 mixes are also known to give a better finish than the other two classes. Segregation control of SCC is a complex problem. When concretes with a slump flow of over 850 mm are used, special attention must be given to limit concrete segregation.

7.5.2 Viscosity

The viscosity of SCC is assessed from T_{500} flow time. It is useful during mix development. It may be helpful to measure and record the T_{500} time while doing the slump-flow test as a way of confirming uniformity of the

SCC from batch to batch. There are two classification ranges of viscosity VS1 and VS2. The typical viscosity classes for a range of applications are given in Table 7.3.

Table 7.3 *SCC viscosity classification based on T_{500} and V-funnel time t_2*

SCC Classification	Time to flow, s		Typical application
	T_{500}	t_v	
VS1/VF1 (Low Viscosity)*	≤ 2	≤ 8	Structures with highly congested reinforcement, requiring perfect surface finish
VS2/VF2 (High Viscosity)	2-7	9 to 25	Applications require flowable concrete as columns and walls

* High possibility for segregation requires careful check of trial mix

VS1 mixes are capable of self-levelling and highly prone to segregation, while VS2 mixes have a higher resistance to segregation than VS1 mixes but might exhibit negative effects in surface finishing (blow holes).

7.5.3 Passability

Common tests to measure the passability of SCC include the J-ring and L-box tests. The passability ratios are classified as either PA1 or PA2. PA1 represents concretes with an L-box ratio of 0.8 and above for tests performed with two rebar barrier. The typical passability classes for a range of applications are given in Table 7.4.

Table 7.4 *SCC passability classification based on L-box height ratio*

SCC Classification	L-box height ratio	Typical application
PA1 (High passability)	≥ 0.8	Highly congested reinforcement
PA2 (Low passability)*	< 0.8	Applications require flowable concrete as slabs, vertical structures like walls

*PA2 >0.80 with 3 rebars

7.5.4 Segregation Resistance

The segregation resistance of SCC is measured through sieve segregation test and column segregation test. The segregation resistance is classified as SR1 and SR2. The typical segregation resistance classes for a range of applications are given in Table 7.5.

Table 7.5 *Segregation resistance classes (Sieve segregation test)*

Class	Segregation resistance, per cent	Typical application
SR1	≤ 20	Thin slabs and for vertical applications with a flow distance < 5 m; and confinement gap or rebar spacing > 80 mm
SR2	≤ 15	Vertical applications with a flow distance > 5 m; and confinement gap or rebar spacing > 80 mm

SR2 may also be used for tall vertical applications with a confinement gap < 80 mm and flow distance is less than 5 m but if the flow distance is more than 5 m a target SR value of less than 10 per cent is recommended.

7.6 TEST PROCEDURES FOR SCC

7.6.1 Testing Fresh Concrete

Self-compacting concrete is characterised by its special properties in fresh state namely flowability, viscosity, blocking tendency, self-levelling, and stability of mixture. However, the tests for filling and passing abilities of self-compacting concrete are generally sufficient to monitor production quality at site. Because SCC flows so readily, the flowability is measured in terms of spread instead of slump, i.e., instead of measuring the slumping distance vertically; the mean spread of the resulting concrete patty is measured horizontally as shown in Fig. 7.1.

A number of tests have been suggested to evaluate the properties of fresh SCC but the commonly used field methods are: Slump flow/inverted slump flow which also includes visual stability index (VSI) and T_{500} test methods. ASTM has standardised three tests for SCC namely the J-ring test for passing ability, the slump flow test for flow ability, and the column segregation technique for segregation resistance. The European Guidelines for Self-Compacting Concrete Specification, Production and Use, 2005, has standardised four tests namely, slump flow test with T_{500}, V-funnel and T_5 Tests; L-box test and sieve stability test.

In evaluating the workability of SCC, tests should measure filling ability, passing ability and segregation resistance independently. Such an approach is preferred to pass/fail-type tests that measure multiple aspects of workability. Measuring each property individually provides a more direct insight into the performance of the concrete and allows more effective troubleshooting. These advantages outweigh the need to conduct multiple tests.

To evaluate the workability of SCC, the slump flow test (with T_{500} and VSI) should be used for filling ability, the J-ring test for passing ability, and the column segregation test or sieve stability test for segregation resistance.

For quality control measurements in the field, only the slump flow test is needed in most cases. The slump flow spread should be used to adjust the HRWRA (High-Range water-reducing admixture) dosage to achieve proper slump flow for self-flow, T_{500} should be used to measure indirectly plastic viscosity and to detect changes in materials and mixture proportions, and VSI should be used to identify significant segregation. The nine common test methods currently available are divided in two categories, standardised and non-standardised tests.

Standardised Tests This category of tests include following tests which are described in this section:

1. Slump flow test with T_{500} and VSI tests (European Guidelines-2005) and (ASTM C 1611/C 1611M-05)
2. J-ring test (ASTM C 1621/C1621M-06)
3. V-funnel and T_5 tests (European Guidelines-2005)
4. L-box test (European Guidelines-2005)
5. Sieve stability test (European Guidelines-2005)
6. Column segregation test (ASTM C 1610/C 1610M-06)

Non-standardised Tests There are variations in the test apparatus, test procedure, and measurement of test results that are important to interpreting results consistently. The test apparatus mainly varies in the dimensions. The test procedure mainly varies in the amount of time from filling the mould to releasing the concrete for free flow. This period can be lengthened to measure segregation. Whatever period is chosen, it should be consistent for all tests. The following tests fall in this category and are not described in this section:

1. U-box test
2. Fill-box test
3. Orimet test

The slump flow test can be used in both the laboratory and field. For many cases, the slump flow test is the only test needed in the field for quality control. The slump flow spread should be used to adjust the HRWRA dosage to ensure the ability of the concrete to flow under its own mass. T_{500} should be used in the laboratory for developing and qualifying mixtures to assess plastic viscosity and should be used in the field to detect unexpected changes in materials and mixture proportions. The VSI can be used to catch cases of severe segregation; however, it is not reliable as an assurance of adequate segregation resistance. Mixtures with high VSI should be investigated further but not necessarily rejected.

7.6.2 Visual Stability Index Test

The visual stability index provides an approximate visualisation of concrete flow; however, it is not adequate to evaluate segregation resistance. The VSI reading mainly reflects the ability of the concrete to flow laterally. More specifically, it characterises whether the paste exhibits adequate rheology to move aggregates to the periphery of the slump flow patty and to prevent a mortar halo and whether the concrete is susceptible to severe bleeding.

The VSI reading recorded when performing the slump flow test may be able to identify significant segregation problems, especially inadequate paste volume and severe bleeding. However, the short duration of the test may not indicate segregation that occurs over a longer period of time. The subjective nature of the VSI determination further limits the precision of the test. If concrete exhibits a poor VSI, further investigation is warranted. Concrete with a good VSI should not be considered resistant to segregation.

In terms of rheology, yield stress is the fundamental difference between the workability of SCC and conventionally placed concrete. The static yield stress must be sufficiently high to prevent segregation while the dynamic yield stress must be sufficiently low for self-flow.

The VSI test ranks the stability of the SCC on a scale of 0-3, with 0 indicating highly stable SCC and 3 indicating unacceptable SCC. The rating is based on the visual inspection of the slump flow patty immediately after it stops flowing. The appearance of the patty describes the surface bleed, mortar halo, and aggregate distribution as shown in Fig. 7.1.

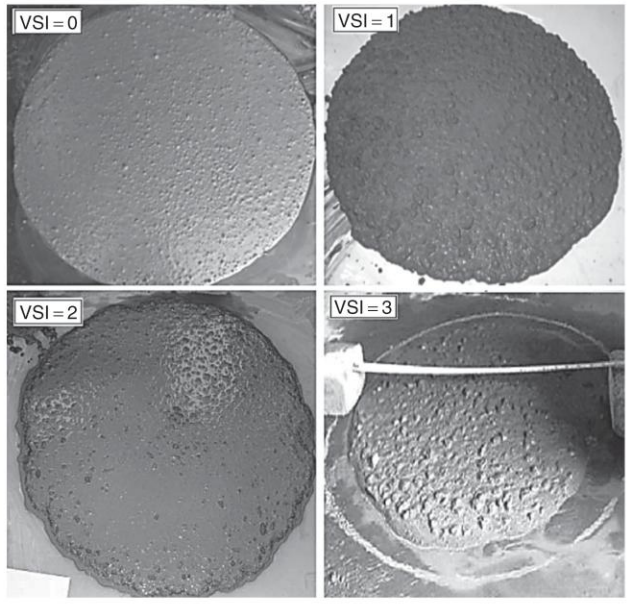


Fig. 7.1 *Visual stability index ratings*

Thus, VSI = 0 is for high-quality SCC and VSI = 1 for acceptable SCC; whereas, VSI = 2 is a case of marginal or borderline quality and qualified QC personnel should evaluate this mix further before advising acceptance or rejections and corrective action on batches that are to follow. VSI = 3 SCC mix is rejected. The visual stability index ratings are summarised in Table 7.6.

Table 7.6 *Visual stability index ratings (ASTM C 1611)*

VSI Ratings	Visual stability index criteria
0 = Highly stable	No evidence of segregation or bleeding; very good aggregate distribution and materials carried to the outer edge of the slump flow without bleeding
1 = Stable	Mix starts to exhibit a mortar halo and possibly some bleed water/separation observed as a sheen on surface of concrete
2 = Unstable	Mix exhibits more separation, i.e., slight mortar halo ≤10 mm, and/or uneven distribution of aggregate, e.g., an aggregate pile in the centre of the concrete mass.
3 = Highly Unstable	Mix showing all the signs of segregation, separation, bleeding, and instability; typically, segregation is indicated by a large mortar halo >10 mm and/or a large aggregate pile in the center of the concrete mass.

7.6.3 Testing Hardened Concrete

The laboratory procedures of determination of properties of hardened SCC are similar to those used for conventional slump concrete.

EXPERIMENT NO. 1: Slump Flow Test (with T_{500} and VSI)

Objective

1. *To determine the filling ability of self-consolidating concrete using slump flow test.*
2. *To measure the T_{500} time.*
3. *To assess the stability of the concrete qualitatively after performing the slump flow test using visual stability index (VSI).*

Theory and Scope

The slump flow and T_{500} time procedures are the tests to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions. The result is an indication of the filling ability of SCC. The T_{500} time is also a measure of the speed of flow and hence the viscosity of the self-compacting concrete. The test can be conducted in the laboratory or on the field. The test can be used to monitor the consistency of fresh, unhardened SCC and its unconfined flow potential.

The test is conducted as standardised in the European Guidelines for self-compacting concrete. The procedure consists of pouring fresh concrete into a slump cone and withdrawing the cone upwards; the time from the moment of commencing upward movement of the cone to when the concrete has flowed to a diameter of 500 mm is measured; this is the T_{500} time. The largest diameter of the flow spread of the concrete and the diameter of the spread at right angles to it are then measured and the mean is the slump flow.

Apparatus

Cone mould; Base plate; Trowel; Container; Ruler graduated from 0 mm to 1000 mm at intervals of 1 mm and Stopwatch measuring to 0.1 s.

Description of Apparatus

The apparatus is shown in Fig. 7.2.

Cone mould in the shape of a truncated cone with the internal dimensions 200 mm diameter at the base, 100 mm diameter at the top and a height of 300 mm.

Base plate is of a stiff, flat, smooth and non-absorbent surface with a minimum thickness of 2 mm. The surface shall not be readily attacked by cement paste or be liable to rusting. Base plates made from sealed/laminated plywood, acrylic plastic or steel with a plane area of at least 900 mm × 900 mm are suitable for performing this test. A smooth, plastic base plate is typically the best. The deviation from flatness shall not exceed 3 mm at any point when a straight edge is placed between the centres of opposing sides.

The centre of the plate shall be marked with a cross, the lines of which run parallel to the edges of the plate and with circles of 200 mm diameter and 500 mm diameter having their centres coincident with the centre point of the plate. The circle marking the central location is for the slump cone and the other concentric circle of 500 mm diameter is for measuring the T_{500} value.

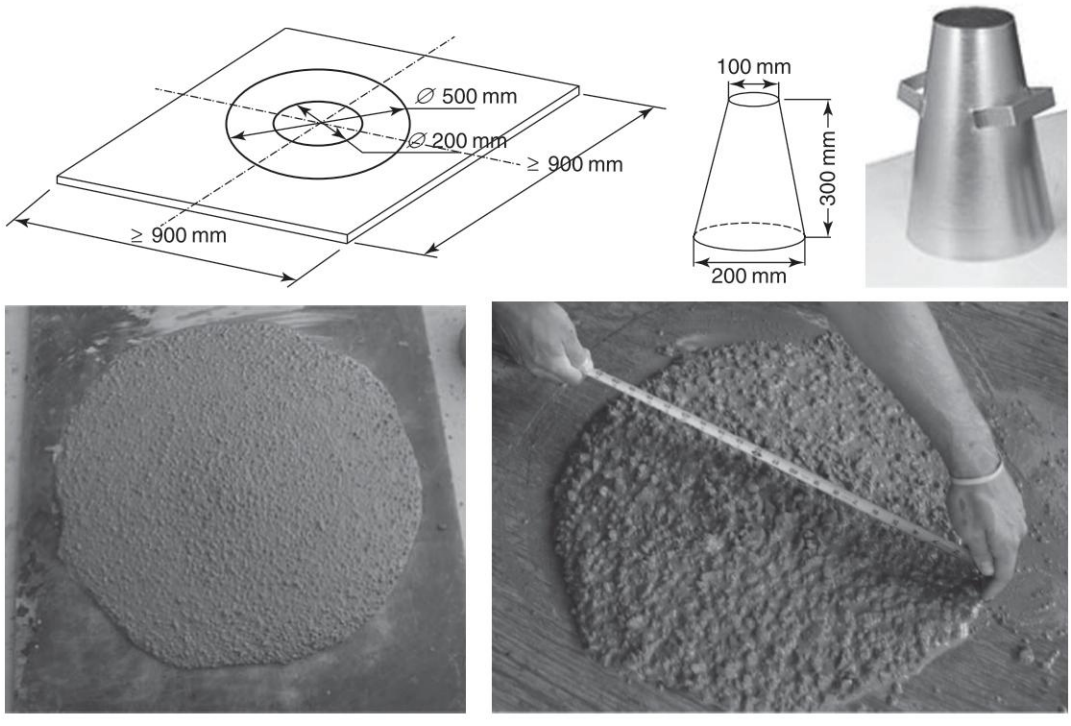


Fig. 7.2 *Base plate reference marks; Slump cone and typical spread of SCC*

Procedure

Step 1: Collect a sample of about 6 litre of concrete to perform the test using normal sampling procedure.

Step 2: Position the base plate on level stable ground such that it is fully supported and level.

Step 3: Place the cone coincident with the 200 mm circle on the baseplate and hold in position by standing on the foot pieces (or use the weighted collar), ensure that no concrete leaks from under the cone.

Step 4: Dampen the base plate and inside of slump cone mould without any surplus water; using a suitable container fill the entire mould continuously without any agitation or rodding; slightly overfill the mould.

Step 5: Strike off the surface of the concrete level with the top of the mould by a sawing motion of the trowel. Allow the filled cone to stand for not more than 30 seconds; during this time remove any spilled concrete from the baseplate to preclude interference with the movement of the flowing concrete.

Step 6: Remove the cone mould by a steady upward lift with no lateral or torsional motion and allow the concrete to flow out freely. Start the stop watch immediately the cone ceases to be in contact with the baseplate and record the time taken to the nearest 0.1 s for the concrete to reach the 500 mm circle at any point.

The time elapsed from the instant the cone mould is raised from the concrete to the moment concrete reaches the 500 mm spread circle is called T_{500} time.

Step 7: Wait for the concrete to stop flowing and then without disturbing the baseplate or concrete, measure the largest diameter d_m of the resulting circular flow spread of concrete to the nearest 10 mm. When a halo is observed in the spread of concrete, it shall be included as part of the diameter of the concrete. Measure a second diameter of the flow spread d_p at right angles to the previous measured diameter to the nearest 10 mm.

If the measurement of the two diameters differs by more than 50 mm, the test is invalid and shall be repeated.

Step 8: Calculate the average of the two measured diameters; this is the slump flow in mm. Report the slump flow to the nearest 10 mm.

Step 9: Check the concrete spread for segregation:

(a) The cement paste/mortar may segregate from the coarse aggregate to give a border or ring of paste/mortar, called Halo, extending several millimetres beyond the coarse aggregate.

(b) Segregated coarse aggregate may also be observed in the central area.

Report the extent of segregation at both locations. Check with VSI criteria listed in Table 7.6, if the test was satisfactory or unsatisfactory.

Observations and Calculations

Largest diameter of the circular spread of the concrete,	d_m mm	
Diameter of circular spread of the concrete at right angles,	d_p mm	
Slump flow, $\frac{d_m + d_p}{2}$ mm		
Temperature of the concrete at the time of test,	°C	
Time taken in completing the test,	seconds	

The slump flow =……mm.

T_{500} time =……..second.

Precautions

1. The sample of concrete from which test specimens are made shall be representative of the entire batch.
2. It should be ensured that the plate be level, flat, and free of any standing water, as all these can affect slump flow and observed stability.
3. The cone mould should be slightly overfilled in one lift without rodding or tapping.
4. The cone mould should be raised in 3 ± 1 second.

Discussion

The slump flow test is the most widely used test for characterising SCC and is a simple, inexpensive, robust, and effective test for measuring filling ability. The slump flow (yield stress) is the main fundamental difference between SCC and conventional slump concrete. The horizontal spread reflects the ability of the concrete to flow under its own mass (yield stress) while the T_{500} time and VSI provide indications of the plastic viscosity and segregation resistance, respectively. However, the test does not provide a complete description of filling ability because it does not fully reflect harshness and the ability to fill all corners of the formwork. The VSI fails to measure stability or segregation resistance adequately, but it provides a valuable visualisation of concrete flow.

ASTM C 1611/C 1611M test procedure allows both the orientations of the cone namely inverted and normal or upright with the warning that the procedure (normal or inverted) used to qualify the mix design is also used during production QC testing. The final spread is the same regardless of the orientation; however, the T_{500} time is greater with the inverted orientation. The inverted orientation is generally preferred because

(i) the larger end of the cone is more easily filled with less spillage, (ii) the mass of concrete in the cone is sufficient to hold the cone down, thus eliminating the need for second person to stand on the foot pedals of the cone and (iii) the T_{500} is greater and can be measured with increased precision. The test results may also be influenced by the speed with which the slump cone is lifted. The 100-mm diameter of the bottom of the cone is sufficiently large such that test results are not typically influenced by passing ability.

The higher the slump flow (SF) value, the greater its ability to fill formwork under its own weight. A SF value of at least 650 mm is required for SCC. The T_{500} time is a secondary indication of flow. A lower time indicates greater flowability. The Brite EuRam Research has suggested that a time of three to seven seconds is acceptable for civil engineering applications, and two to five seconds for housing applications.

It is possible to assess the stability of the concrete qualitatively after performing the slump flow test using the visual stability index (VSI) criteria which are listed in Table 7.6. In case of severe segregation, most coarse aggregate will remain in the centre of the spread or patty of concrete, and mortar and cement paste at the concrete periphery. In case of minor segregation a border (ring) of mortar without coarse aggregate can occur around the outside circumference of concrete after flowing from the slump cone. This is called *Halo* and is included as a part of the diameter of the concrete. If none of these phenomena appear it is no assurance that segregation will not occur since this is a time related aspect that can occur after a longer period.

It is difficult to produce self-consolidating concrete that is both flowable and non-segregating using coarse aggregates larger than 25 mm. Therefore, this test method is considered applicable to self-consolidating concrete having coarse aggregate up to 25 mm in size.

Variations in the test procedure standardised in ASTM C 1611/C 1611M:

1. The cone mould is raised such that it moves a distance of 225 ± 75 mm in 3 ± 1 second.
2. The entire test from start of the filling through removal of the mold is completed within an elapsed time of 2½ minutes.
3. The spread is measured and reported to the nearest 5 mm.

Viva-Voce Questions

1. What is SCC?
2. What is the significance of slump flow test?
3. What are the limitations of slump flow test?
4. What is Halo and what does it indicate?
5. What is T_{500} time?
6. What is the major disadvantage of slump-flow (unrestricted/unconfined) test?
7. What is visual stability index (VSI) rating?

Notes and Comments

EXPERIMENT NO. 2: J-Ring Test

Objective

1. *To determine the passing ability of self-consolidating concrete using J-ring test.*
2. *To determine the filling ability and passing ability of self-consolidating concrete using J-ring test.*

Theory and Scope

The J-ring test extends common filling ability test methods in order to characterise passing ability. The J-ring test is carried out using the same procedure as used for slump flow measurement described in Section 2. The slump cone can be used upright or inverted. If used upright, it must be modified by removal of the foot pieces so that the cone will fit into the J-ring apparatus. The J-ring devise is placed in the centre of the slump flow board and the slump cone is placed inside the J-ring and is filled in one lift. The cone is raised as per requirements of the relevant standard. The SCC flows through the reinforcing bars of the J-ring onto the slump flow base plate. The diameter of the slump flow patty is measured to provide the J-ring flow, d_r. The average of differences between the heights of concrete just inside and outside of the J-ring measured at four equally spaced locations is calculated to assess the passing ability of SCC.

Apparatus

Open steel J-ring device; Slump mould or cone; Base plate; Trowel; Scoop and Ruler.

Description of Apparatus

J-ring, as shown in Fig. 7.3, is open steel ring of rectangular cross section 30 × 25 mm with a 300 mm diameter. Vertical holes drilled in the ring allow threaded plain or deformed reinforcing bars to be attached to the ring. Each bar is 100 mm long. Bar can be of different diameters and spacing of the bars can be adjusted in accordance with normal reinforcement considerations; typically reinforcement bars may be of length/height 100 mm, diameter 10 mm and spacing of 48 ± 2 mm.

Cone mould without foot pieces in the shape of a truncated cone with internal diameter of 200 mm at the base, 100 mm diameter at the top and a height of 300 mm, conforming to relevant standards.

Base plate is of a stiff non-absorbent material, at least 700 mm square, marked with a circle showing the central location for the slump cone, and further concentric circles for measurement of concrete patty diameter.

Procedure

Step 1: Collect a sample of about 6 litre of concrete to perform the test using normal sampling procedure.

Step 2: Position the clean and moistened base plate on level stable ground such that it is fully supported and level.

Step 3: Place the J-ring centrally on the base plate and slump cone inside it coincident with the 200 mm circle on the base plate and hold firmly in position, ensure that no concrete leaks from under the cone.

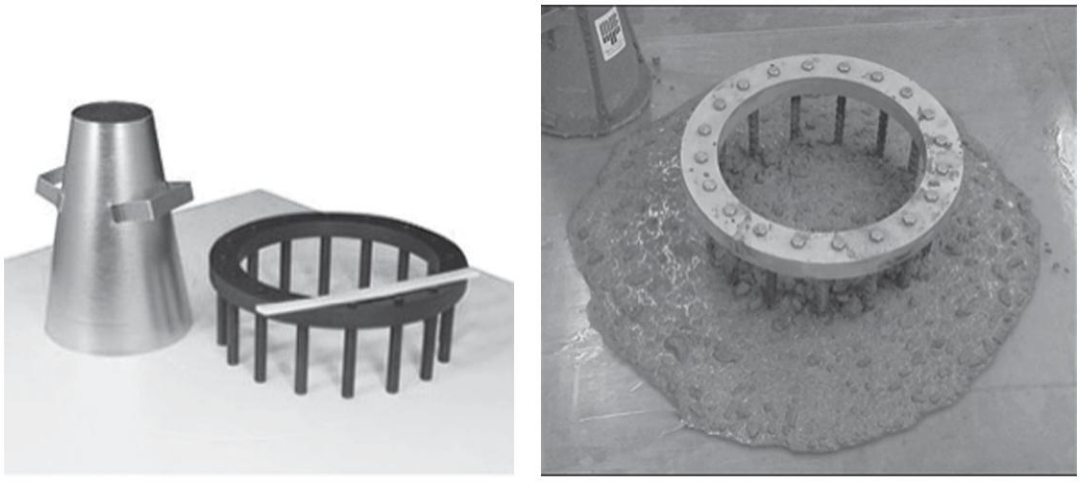


Fig. 7.3 *J-ring used in conjunction with the slump flow*

Step 4: Dampen the base plate and inside of slump cone mould without any surplus water; using a suitable container pour the sample concrete in the cone mould in one lift; slightly overfilling the mould.

Step 5: Strike off the surface of the concrete level with the top of the mould by a sawing motion of the trowel. Allow the filled cone to stand for not more than 30 seconds; during this time, remove any spilled concrete from the base plate to preclude interference with the movement of the flowing concrete.

Step 6: Raise the cone mould vertically to a height of 230 ± 75 mm in 3 ± 1 second and allow the concrete to flow out freely through the reinforcing bars of the J-ring onto the base plate.

Step 7: Wait for the concrete to stop flowing and then without disturbing the base plate or concrete, measure the largest diameter d_m of the slump flow patty to the nearest 5 mm. When a halo is observed in the slump flow patty, it shall be included as part of the diameter of the slump flow patty. Measure a second diameter of the slump flow patty d_p at right angles to the previous measured diameter to the nearest 5 mm.

Step 8: Calculate the average of the two measured diameters; record this as the J-ring slump flow in mm.

Step 9: Measure the difference between in the heights of concrete just inside the bars and that just outside the bars. Calculate the average of the difference in height at four locations in mm.

Record the details of any border of mortar or cement paste without coarse aggregate at the edge of the pool of concrete.

Observations and Calculations

Largest diameter of the circular spread of the concrete,	d_m mm	
Diameter of circular spread of the concrete at right angles,	d_p mm	
J-ring flow,	$d_r = \dfrac{d_m + d_p}{2}$ mm	
Height inside the ring (mean of four readings),	h_1 mm	

Height outside the ring(mean of four readings),	h_2 mm	
Difference in height between the inside to outside of the ring,	$h = (h_1 - h_2)$ mm	
Temperature of the concrete at the time of test,	°C	
Time taken in completing the test,	minutes	

Precautions

1. The sample of concrete from which test specimens are made shall be representative of the entire batch.
2. It should be ensured that the plate be level, flat, and free of any standing water, as all these can affect slump flow and observe stability.
3. The cone mould should be slightly overfilled in one lift without rodding or tapping.
4. The cone mould should be raised in 3 ± 1 second.
5. The cone mould should be slightly overfilled in one lift without rodding or tapping.
6. The whole test has to be performed within 6 minutes.

Discussion

The J-ring test is a simple and effective test for independently measuring the passing ability and should preferably be performed with the slump cone in the inverted position. Test results are reported as the difference in height between the concrete inside and that just outside the J-ring measured at four equally spaced locations. The use of multiple measurements is important because some variation in blocking around the ring is possible. The difference in height between the concrete inside and outside the J-ring is an indication of passing ability or the degree to which the passage of concrete through the bars is obstructed. Based on the appearance of the concrete after the test visual blocking index (VBI) rating can be assigned in accordance with Table 7.6.

The measurement of the difference in slump flow with and without the J-ring is not beneficial; since, the difference in slump flow values is often within the precision of the slump flow test. Similarly, the measurement of T_{500} with the J-ring is unnecessary because this measurement made with the unobstructed slump flow test provides a better measurement of viscosity and the change in height between the inside and outside of the J-ring provides an adequate indication of passing ability. The difference in height between the inside to outside of the ring is the recommended approach because of its simplicity, precision, and ability to reflect the extent of passing ability.

The J-ring bars can principally be set at any spacing to impose a more or less severe test of the passing ability of the concrete. However, bars can be spaced at different intervals: in accordance with normal reinforcement considerations, i.e., three times the maximum aggregate size might be appropriate. However, the arrangement of reinforcing bars of constant size placed at spacing stipulated in ASTM C 1621 is more practical because it allows the same J-ring apparatus to be used in all cases without adjustment.

The J-ring can distinguish the ability of concrete to flow through obstacles better than the L-box or U-box. The J-ring slump flow values can be used for quality control instead of using both the J-ring slump flow and

the unrestricted slump flow. However, the L-box test is generally favoured because of the availability of more field experience with the L-box.

Viva-Voce Questions

1. What is SCC?
2. What is the significance of J-ring test?
3. How does the J-ring spread compares with the unrestricted slump flow?
4. What is visual stability index (VSI) rating?
5. To what extent is J-ring spread reduced as compared to unrestricted slump flow?
6. In what respect J-ring test superior to slump-flow test?

Notes and Comments

EXPERIMENT NO. 3: V-Funnel Test

Objective

Determine the viscosity and the filling ability or flowability of the SCC with a maximum aggregate size of 20 mm.

1. *V funnel test.*
2. *V funnel test at T_5 minutes.*

Theory and Scope

The V-funnel flow time is defined as the time period a standard volume of SCC will take to pass a narrow opening; it gives an indication of the filling ability of SCC provided that blocking and/or segregation do not take place. The flow time of the V-funnel test is to some degree related to the plastic viscosity. The method is considered alternative method to T_{500} for filling ability.

The V-funnel test is used to measure the filling ability of self-compacting concrete with a maximum aggregate size of 20 mm and can also be used to judge its stability, i.e., the resistance to segregation.

The test consists in filling the funnel with fresh concrete and the time taken by it to flow through the apparatus measured and recorded as the V-funnel flow time. After this the funnel is refilled with concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Apparatus

V-funnel test frame; Bucket or container (12+ litres) for taking concrete sample; Straight edge or trowel for leveling the concrete; Scoop and Stopwatch with the accuracy of 0.1 second for recording the flow time.

Description of Apparatus

V-funnel made to the dimensions (tolerance ± 1 mm) as illustrated in Fig. 7.4 is fitted with a quick release, watertight gate at its base and supported so that the top of the funnel is horizontal. The V-funnel shall be made from metal; the surfaces shall be smooth, and not be readily attacked by cement paste or be liable to rusting.

Container having a volume larger than the volume of the funnel to hold the test sample.

Procedure

Part 1: Flow time

Step 1: Collect a test sample of about 12 litres of concrete to perform the test using normal sampling procedure.

Step 2: Clean the funnel and bottom gate.

Step 3: Place the cleaned V-funnel test frame on a firm and flat ground, with the top opening horizontally positioned. Moisten the inside surfaces of the funnel including the trap door. Keep the trap door open to allow any surplus water to drain out.

Step 4: Close the trap door and place a bucket underneath it in order to collect the concrete to be passed.

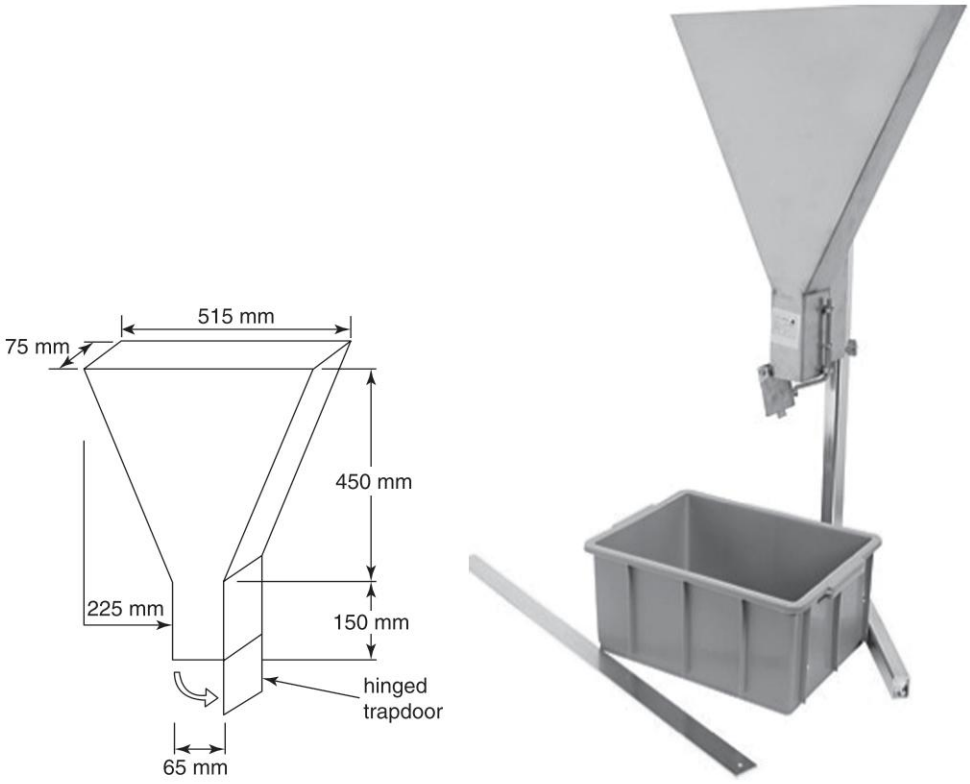


Fig. 7.4 *V-funnel test equipment (rectangular section) to determine the flow time of SCC*

Step 5: Fill the apparatus completely with sample of concrete without any agitation or tamping; simply strike off the concrete level with the top of the funnel with the trowel or straight edge.

Step 6: After a delay of 10 ± 2 seconds from filling the funnel, open the trap door and start the stopwatch at the same moment the gate opens.

Step 7: Allow the concrete to flow out under gravity; look inside the funnel and stop the watch at the moment when clear space is visible through the opening of the funnel. Record the stopwatch reading indicating the time from instant of opening the trap door to discharging the concrete completely, as the V-funnel flow time t_v to 0.1 second. The whole test has to be performed within 5 minutes.

Part 2: Flow time at T_5 minutes

Step 1: Close the trap door and refill the V-funnel immediately without cleaning or moistening the inside surfaces of the funnel again.

Step 2: Place a bucket underneath.

Step 3: Fill the apparatus completely with concrete without compacting or tapping, simply strike off the concrete level with the top with the trowel.

Step 4: Open the trap door 5 minutes after the second fill of the funnel and start simultaneously the stopwatch.

Step 5: Allow the concrete to flow out under gravity and record the time for the discharging concrete completely; this is indicated by visibility of light from the top through the funnel. It gives the flow time at T_5 minutes.

Step 6: Clean the V-funnel after testing.

Observations and Calculations

V-funnel flow time,	t_v second	
T_5 time,	second	
Temperature of the concrete at the time of test,	°C	
Time taken in completing the test,	minutes	

V-funnel flow time =…… second.
T_5 time =……..minutes.

Precautions

1. V-funnel test frame should be placed securely on a firm and level surface.
2. The inside surfaces of the apparatus should be just moistened with no surplus water to avoid change in mix proportions.
3. Dot not touch or move the V-funnel until it is empty.
4. Do not clean or moisten the inside surfaces of the funnel when it is filled second time.
5. The filling of the concrete should be in a consistent time frame; such as filling quickly with a single bucket of concrete or more gradually with a scoop.
6. The whole test has to be performed within five minutes.

Discussion

Since the test measures V-funnel flow time, i.e., the ease of flow of the concrete; shorter flow times indicate greater flowability. For self-compacting concrete, a flow time of 10 seconds is considered appropriate. The inverted cone shape restricts flow and prolonged flow times may give some indication of the susceptibility of the mix to blocking. High flow time can also be associated with low deformability due to a high paste viscosity, and with high inter-particle friction. The test is not suitable when the maximum size of the aggregate exceeds 20 mm.

When the concrete is allowed to rest for some time, the segregation of concrete will show a less continuous flow with an increase in flow time. The greater the increase in flow time, the greater will be the concrete's susceptibility to segregation. Further, non-uniform flow of concrete from the funnel suggests a lack of stability or segregation resistance.

Conclusion

The test is relatively simple to perform and result combines three basic characteristics of filling ability, passing ability and segregation resistance. The test can be used as a pass/fail test measuring multiple aspects of workability. However, the test does not provide an independent indication of filling ability, passing ability, or segregation resistance; thus is ineffective for troubleshooting in case of problematic mixtures with high V-funnel times.

Although the apparatus is simple, but the test frame is large, bulky, and must be placed on a level surface; the effect of the angle of the funnel and the wall effect on the flow of concrete are not clear. Alternatively, an O-shaped funnel with circular cross section, and the orimet which consists of a cylinder with a narrowed opening at the bottom can be used.

Viva-Voce Questions

1. What is the significance of V-funnel flow test for self-compacting concrete?
2. What is meant by representative sample?

3. Why is the inside surfaces of the apparatus moistened and surplus water removed?
4. Why does the flow time increase significantly when segregation of concrete occurs?
5. What does the non-uniform flow of concrete from the funnel suggest?
6. Why does the flow time increase after the concrete is allowed to rest for some time?
7. What are the advantages and disadvantages of V-funnel flow test?

Notes and Comments

EXPERIMENT NO. 4: L- Box Test

Objective

To measures the flowability of the concrete and to assess extent of blocking by the reinforcement.

Theory and Scope

The L-box test measures the filling (flowing) and passing ability of self-compacting concrete to flow through tight openings including spaces between reinforcing bars and other obstructions without segregation or blocking. There are two variations; the two bar test and the three bar test. The three bar test simulates more congested reinforcement.

Fresh concrete is initially placed in the vertical portion of the box and sliding gate between the vertical or horizontal portions of the box is opened and the concrete is allowed to flow through the spaces or gaps between vertical, smooth reinforcing bars into horizontal portion of the box. The time for concrete to reach points 200 mm (T_{200}) and 400 mm (T_{400}) down the horizontal portion of the box is recorded.

After the concrete comes to rest in the apparatus, the heights of the concrete at the end of the horizontal portion, H_2, and at the beginning of the horizontal portion, H_1, are measured. The filling ability or flowability of self-compacting concrete is described in terms of passing ratio, H_2/H_1.

Apparatus

L-box of a stiff non-absorbent material; Ruler; Container or bucket; Trowel; Scoop and Stopwatch.

Description of Apparatus

The apparatus which consists of a rectangular-section box of steel, plastic or plywood in the shape of an 'L', shall be of rigid construction with surfaces that are smooth, flat and not readily attacked by cement paste or liable to rusting. The vertical and horizontal portions are separated by a moveable gate, in front of which vertical lengths of reinforcement bars are fitted. The horizontal portion of the box is marked at 200 mm and 400 mm from the gate. The vertical hopper may be removable for ease of cleaning. With the gate closed, the volume of the vertical hopper shall be (12.6 to 12.8) litres when filled level with the top.

The fixtures holding the reinforcement bars shall have two smooth bars of 12 mm diameter with a gap of 59 mm for the two bar test and three smooth bars of 12 mm diameter with a gap of 41 mm for the three bar test. These assemblies shall be interchangeable. Locate the bars in the L-box so that they are vertical and equidistant across the width of the box. General arrangement of L-box is illustrated in Fig. 7.5 and the dimensions are with tolerance of ± 1 mm. Instead of steel mould, a mould built of 12 mm coated formwork plywood with the end grain sealed can also be used.

Ruler graduated from 0–300 mm in intervals of 1.0 mm.

Container of capacity more than 14 litres to hold the concrete sample.

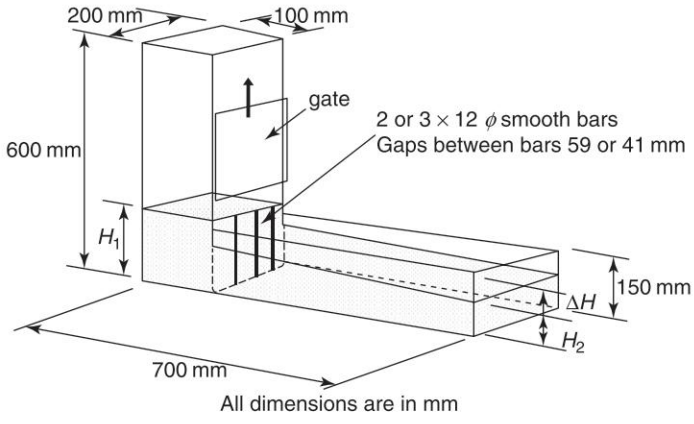


Fig. 7.5 *Details of L-box test*

Procedure

Two operators are required if times are measured, and a degree of operator error is inevitable.

Step 1: Collect a representative sample of concrete of about 17 litres to perform the test using normal sampling procedure.

Step 2: Set the apparatus on a level, firm horizontal base; ensure that the sliding gate can open freely.

Step 3: Moisten the inside surfaces of the apparatus and remove any surplus water.

Step 4: Close the sliding gate between the vertical and horizontal sections. Pour the concrete sample from the container into the hopper of the L-box to fill the vertical section of the apparatus; allow it to stand for 60 ± 10 seconds.

Step 5: Lift the sliding gate and start the stopwatch simultaneously.

Step 6: Allow the concrete to flow out into the horizontal section of the box and record T_{200} and T_{400}, the times taken for the concrete to reach the 200 and 400 mm marks, respectively.

Step 7: When the concrete has stopped flowing, measure the depth of the concrete at the end of the horizontal portion of the L-box at three positions equally spaced across the width of the box. These three measurements are used to calculate the mean depth of concrete as H_2 mm.

Step 8: The procedure of Step 7 is used to calculate the depth of concrete immediately behind the sliding gate as H_1 mm.

Step 9: Calculate the passing ability, PA as: PA = H_2/H_1 to the nearest 0.01.
The whole test has to be performed within 5 minutes.

Observations and Calculations

Type test: two bar or three bar test		
Height of concrete behind the sliding gate,	H_1 mm	
Height of concrete at the end of horizontal portion,	H_2 mm	
Passing ability ratio,	PA = H_2/H_1	
Temperature of the concrete at the time of test,	°C	
Time taken in completing the test,	minutes	

Passing ability, PA = ……

Precautions

1. Apparatus should be set on a level, firm horizontal base to avoid jamming of the sliding gate.
2. The inside surfaces of the apparatus should be just moistened with no surplus water to avoid change in mix proportions.
3. Any delays in opening the box would likely reduce the blocking ratio because of any segregation.
4. The whole test has to be performed within five minutes.

Discussion

The L-box test measures both passing ability and filling ability of SCC because the extent to which concrete flows down the horizontal portion of the box depends on the yield stress (filling ability) of the concrete and the extent of blocking caused by the row of bars. It enables visualisation the flow of the concrete in the test, especially any blocking behind the bars.

The stability, i.e., resistance to segregation can be assessed visually. A concrete sample with coarse aggregate particles that reach the far end of the horizontal part of the box exhibits good resistance to segregation. However, there is no evidence of what effect the wall of the apparatus and the consequent 'wall effect' might have on the concrete flow, but this arrangement does, to some extent, replicate what happens to concrete on site when it is confined within formwork. The passing ability ratio, H_2/H_1, for most tests should be 0.85 to 0.90.

The major advantages of the L-box test over J-ring test is that the amount of mass available to push concrete through the bars is more representative of field conditions than in the J-ring test. The relationship between the test results and field performance is better established than for the J-ring test.

However, the test does not the measure the passing ability sufficiently independent of filling ability, i.e., it does not distinguish between passing ability and filling ability. Therefore, the test is essentially a pass/fail test because it is not clear whether concrete with a low blocking ratio exhibits inadequate filling ability, passing ability, or both.

The term blocking ratio generally defined as the ratio of concrete height in the horizontal portion to that in the vertical portion of the box is a misnomer, because higher blocking ratios correspond to less blocking, greater filling ability, or both. A term such as passing ratio is more appropriate.

The L-box does reflect field conditions; however, the number of bars through which the concrete must pass is limited. The J-ring has more bars and would likely exhibit less variability from one test to another. The L-box, however, has an advantage over the J-ring in that a larger mass of concrete is available to push concrete through the bars. On visual inspection of the area around the rebar, an even distribution of aggregate indicates good passing ability.

The test can be used as a reference test for passing ability. However, if the L-box results are used to qualify an SCC mixture design, then an L-box with the same rebar spacing and dimensions should be used during production QC testing.

The test is not as simple as the slump flow test, the test apparatus is relatively bulky, difficult to clean, and thus, not well-suited for use in the field. The L-box test is preferred to the U-box test.

Viva-Voce Questions

1. What is the significance of L-box test for self-compacting concrete?
2. What is meant by representative sample?
3. What is the underlying principle of this test?
4. Which properties of SCC are assessed directly or indirectly by L-box test?
5. What do the coarse aggregate particles of concrete sample reaching the far end of the horizontal part of the box indicate?
6. Why are the inside surfaces of the apparatus moistened and surplus water removed?

Notes and Comments

EXPERIMENT NO. 5: Sieve Stability Test

Objective

To determine the resistance of self-compacting concrete to segregation.

Theory and Scope

The sieve stability test is used to assess the resistance of self-compacting concrete to segregation.

In the test, fresh concrete sample is allowed undergo static internal segregation for 15 minutes (in a bucket). The top layer of the sample 4.8 ± 0.2 kg is then poured into a sieve with 5 mm square apertures. After two minutes, the weight of material which has passed through the sieve is recorded. The segregation ratio is then calculated as the proportion of the sample through the sieve.

The potential segregation is expressed as the ratio between the mass of mortar passing through the 5 mm sieve and the initial mass of the top layer.

Apparatus

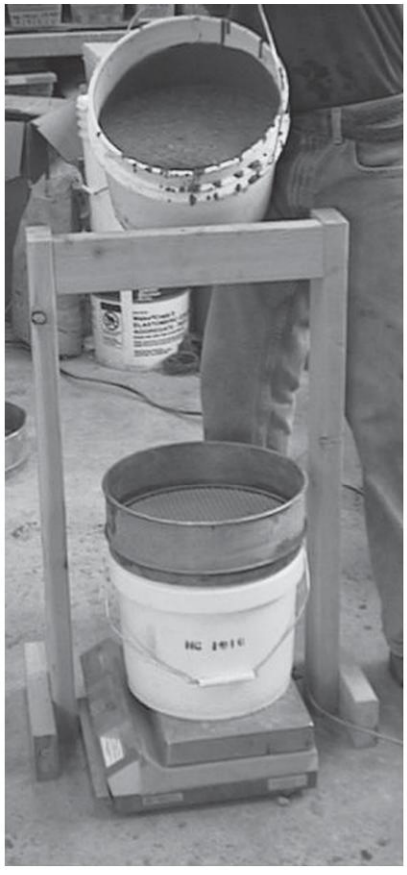


Fig. 7.6 *Sieve stability test*

Perforated plate sieve; Weighing machine; Positioning Frame; Sample container; Stopwatch.

Description of Apparatus

Perforated plate sieve with frame diameter 300 mm and height 40 mm having 5-mm square apertures conforms to ISO 3310-2. It is complete with a pan from which the sieve can easily be removed by lifting vertically.

Weighing machine that has a flat platform which can accommodate the sieve receiver and has a capacity of at least 10 kg, calibrated in increments of ≤ 20 g.

Sample container of 11 – 12 litres capacity having an internal diameter 300 ± 10 mm with a lid.

Frame to position container 500 mm over sieve.

Procedure

Step 1: Collect a sample of about 11 litres of concrete to perform the test using normal sampling procedure.

Step 2: Place 10 ± 0.5 litres of concrete sample in the sample container and fit the lid to prevent evaporation.

Step 3: Allow the concrete to stand in a level position, without disturbance, for 15 ± 0.5 minutes.

Step 4: Place the pan on the levelled weighing machine and record its mass W_p grams. Then place the sieve on the pan and record the mass.

Step 5: At the end of the standing period allowed in Step 3, remove the lid from the sample container and record whether any bleed water has appeared on the surface of the concrete.

Step 6: With the sieve and pan still on the weighing machine, immediately pour (4.8 ± 0.2) kg concrete (including any bleed water) from the sample container placed at a height of (500 ± 50) mm onto the centre of sieve. The concrete is poured evenly over the sieve without agitating the container. Record the actual mass of concrete W_c grams on the sieve.

Step 7: Allow the concrete to stand in the sieve for 120 ± 5 seconds and then remove the sieve vertically without agitation. Record the mass of the pan and any mortar that has passed into the pan W_{ps} grams.

Step 8: Calculate the segregated ratio *SR* from the following equation and reported to the nearest one per cent:

$$SR = \frac{(W_{ps} - W_p)}{W_c} \times 100 \text{ per cent}$$

Observations and Calculations

Mass of the empty sieve pan,	W_p gram	
Actual mass concrete poured on sieve,	W_c gram	
Mass of the pan and passed mortar,	W_{ps} gram	
Segregated ratio, SR,	$\frac{(W_{ps} - W_p)}{W_c} \times 100$ per cent	
Time taken for the test,	seconds	
temperature of the concrete at the time of test,	°C	
Presence of bleed water, if any, after standing for 15 min		

Segregated portion is……..per cent.

Precautions

1. It should be ensured that the weighing machine is level and free from vibration.
2. The concrete in the sample container should not be agitated during pouring and should be poured evenly over the sieve in one smooth continuous movement.
3. The sieve should be removed gently from the pan because any agitation could cause additional material to pass the sieve.

Discussion

The sieve stability test, also called wet-sieve stability test, is used to assess the degree to which a SCC mix is likely to segregate. The test measures mainly the static segregation. When concrete is left undisturbed in the bucket for 15 minutes, any segregation or bleeding that occurs is due to static segregation. Segregation of coarse aggregate and bleeding lead to more mortar and paste at the top of the specimen, which is then poured onto and passes through a sieve. The amount of mortar passing the sieve depends to some extent on dynamic segregation resistance because viscous, cohesive mortar is less likely to pass through the sieve. Since this evaluation of dynamic segregation is determined after the concrete has remained undisturbed for 15 minutes, it may not reflect the dynamic segregation resistance of the concrete during placement conditions where the concrete is sheared continuously. It is likely that dropping the concrete onto the sieve does not fully break-down the effects of viscosity.

The test requires approximately 20 minutes to perform including filling the bucket, waiting for the 15 minute rest period, pouring the concrete on the sieve and allowing it to remain there for 2 minutes, and measuring the final mass of material passing the sieve.

Higher the amount of mortar passing through the sieve greater will be the liability to segregation. It is generally noticed that if the percentage of mortar which has passed through the sieve, the segregation ratio, is between 5 and 15 per cent of the weight of the sample, the segregation resistance is considered satisfactory. Below 5 per cent the resistance is excessive, and likely to affect the surface finish; there may be possibility of blow holes. For the typical percentages of mortar passing through the sieve, the degree of potential segregation can be interpreted as given in Table 7.7.

Table 7.7 *Segregation potential with percentage of sample passing the sieve*

Sample passing the sieve, per cent	Potential of segregation
< 5	Could be too cohesive/viscous
5-15	Provides optimum resistance to segregation
15-30	Likelihood segregation
>30	Possibility of severe segregation.

When using the test in the laboratory to qualify mixture proportions, mixtures should be prepared with the range of water contents and slump flows expected during production. If these mixtures exhibit adequate segregation resistance and the slump flow test is used in the field to control concrete rheology indirectly, it is not necessary to use the sieve stability test in the field.

The test is simple to perform and provides an independent measurement of segregation resistance. However, the test conditions are neither directly representative of field conditions for static segregation nor fully take in to account dynamic stability.

The test is slow and requires an accurate weighing machine, making it unsuitable for use as a rapid acceptance test in the field.

Viva-Voce Questions

1. What is the significance of sieve stability test for self-compacting concrete?
2. What is the purpose of keeping the sample concrete placed in bucket undisturbed for 15 minute?
3. Which property of SCC is related to sieve stability test?
4. For the concrete with percentage of sample passing the sieve as 20, what is the possible degree of segregation?

Notes and Comments

EXPERIMENT NO. 6: Column Segregation Test

Objective

To determine the resistance of self-compacting concrete to segregation by column segregation test.

Theory and Scope

The column segregation test provides an independent measurement of stability or segregation resistance by replicating static conditions in formwork and quantifying the segregation of coarse aggregate after a fixed time. However, the test does not measure dynamic stability. This test method as standardized in ASTM C 1610 consists of placing the concrete into a standardised PVC pipe and left undisturbed for 15 minutes. The segregation is computed as a function of the relative amount of aggregate in the top and bottom quarters of the pipe. The use of only the top and bottom sections is the preferred approach because it requires less work and the relative difference in aggregate mass in the middle two sections is likely to be low in most cases.

For the column segregation test, the maximum segregation should be less than 15 per cent for most cases but may need to be reduced in some applications. The sampling conditions should be well defined.

Apparatus

Column segregation test pipe in four/three parts; spring clamps; Base plate (the bottom PVC pipe section is permanently attached to the base plate); Collector plates; Two No. 4 sieves; Scoop or bucket to load concrete into column; Stopwatch; Drying containers or dishes of minimum 5 litre capacity; Oven or laboratory micro-wave and a balance.

Description of Apparatus

The column segregation test apparatus (ASTM C1610) consists of a 200 mm diameter, 660 mm long vertical PVC pipe split into four 165 mm tall sections. In an alternative arrangement, two middle sections are replaced with single 330 mm long section. The sections are clamped together to form a watertight seal.

Procedure

Step 1: Collect a sample of about 22 litres of concrete to perform the test using normal sampling procedure.

Step 2: Assemble the PVC pipe sections. Use the clamps to secure each PVC pipe section firmly and to ensure a watertight seal.

Step 3: Place the assembled apparatus on a firm, level surface.

Step 4: Fill the column with concrete with no external compaction effort.

Step 5: Allow the concrete to remain undisturbed for 15 minutes.

Step 6: Use the collector plate to remove individually each PVC pipe section with the concrete material inside.

Step 7: Individually transfer the contents of the top and bottom pipe sections to separate No. 4 sieves. Discard the contents of the middle section(s). Wash each concrete sample over the No. 4 sieve to remove all paste and fine aggregate, leaving behind only clean coarse aggregates on each sieve.

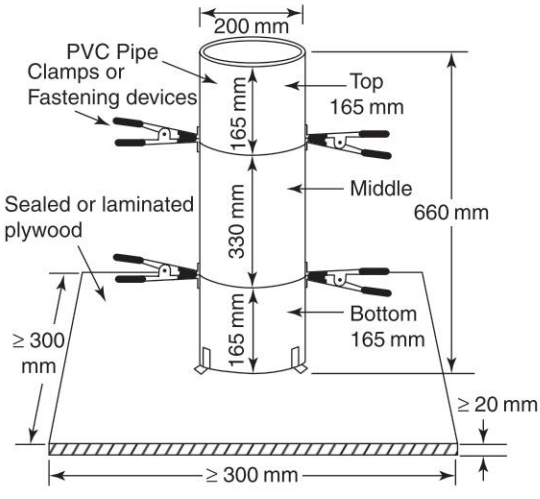


Fig. 7.7 *Dimensions of column segregation apparatus*

Step 8: Collect the coarse aggregates retained on each sieve in a separate container for each pipe section. Dry each sample in an oven or microwave until it reaches a constant mass.

Step 9: Measure the mass of each sample of coarse aggregates.

Step 10: Compute static segregation.

Fig. 7.8 *Aggregate washed over No. 4 sieve from the column segregation apparatus*

Observations and Calculations

Mass of aggregate retained on No. 4 sieve from bottom pipe section,	W_{bottom} g	
Mass of aggregate retained on No. 4 sieve from top pipe section,	W_{top} g	
(*a*) $W_{bottom} > W_{top}$		
Segregated ratio, $SR = \frac{(W_{bottom} - W_{top})}{(W_{bottom} + W_{top})} \times 100$	per cent	
(*b*) $W_{bottom} < W_{top}$		
Time taken for the test.	second	
Temperature of the concrete at the time of test,	°C	

Segregated ratio is……..per cent.

Precautions

1. The process of filling the column should not cause segregation.
2. During removal of concrete from the pipe sections care should be taken to minimise the spilling of concrete.

Discussion

Static stability or segregation resistance can be measured with either the column segregation test or sieve stability test. The results of the column segregation test and the sieve stability test are closely related; a 15 per cent static segregation in the column segregation test corresponds to a 15 per cent reading from the sieve stability test. The column segregation test is relatively difficult and time consuming to perform and requires the use of a balance; hence the test is not considered appropriate as a rapid field acceptance test. Thus, the test is laboratory test.

When using the test in the laboratory to qualify mixture proportions, mixtures should be prepared with the range of water contents and slump flows expected during production. If these mixtures exhibit adequate segregation resistance and the slump flow test is used in the field to control concrete rheology indirectly, it is not necessary to use the column segregation test in the field.

The salient features of the test are:

1. Results are computed as a function of the relative amount of aggregate in just the top and bottom sections of the pipe. The use of only the top and bottom sections is the preferred approach because as it requires less work and the relative difference in aggregate mass in the middle two sections is likely to be low in most cases.
2. ASTM C 1621 requires the concrete to be left undisturbed for 15 minutes, as most but not all segregation occurs within the 15 minute duration of the column segregation test.
3. The test takes at least 30 minutes to perform including filling the column, allowing the concrete to remain undisturbed for 15 minutes, collecting the concrete from the column, washing and sieving the aggregate, and drying the aggregate to its saturated surface-dry condition. If the aggregate is oven-dried, results are not available for at least several more hours. In case the aggregates are to be dried to saturated-surface dry condition instead of oven, dried towels are required to dry surface moisture from aggregates. Determination of mass of the aggregates in saturated-surface dry condition may increase the variability of test results.

4. As in the case of sieve stability test, errors in sampling can influence test results significantly.

   Concrete should not be segregated when it is first put into the column. The process of filling the column should not cause segregation. Any dynamic segregation occurring during the loading of the concrete can influence test results. Because paste rheology strongly influences the degree of static segregation, the rheology of the concrete at the anticipated time of placement in the field should be considered. For instance, a laboratory-mixed concrete that is tested immediately after mixing may not be similar to the same mixture that is mixed in a truck, transported for 30 minutes, and then pumped to its final location. Mixtures with workability retention beyond the time of placement are more likely to segregate over time because the yield stress and plastic viscosity remain low for a longer time.

Viva-Voce Questions

1. What is the significance of column segregation test for self-compacting concrete?
2. What is the purpose of keeping the sample concrete placed in pipe undisturbed for 15 minutes?
3. Which property of SCC is related to column segregation test?
4. How are the results computed in column segregation test?
5. What are the crucial steps in performance of column segregation test?

Notes and Comments

EXPERIMENT NO. 7: Self-Compacting Concrete Mix Proportioning

Objective

To design self-compacting concrete mix using locally available materials.

Theory and Scope

As per the latest revision of IS 10262-2009, from durability considerations the amount of cement in concrete shall not be less than 300 kg/m^3 of concrete. With fixed cement content using the locally available materials, it is possible to tailor the properties of self-compacting concrete to meet the demands of any particular application.

In this test self-compacting concrete mix containing 350 kg/m^3 of cement has been proportioned with using locally available materials for housing slabs and deep foundations. For this application, the workability required in terms of slump-flow value is in the range of 600 mm.

Apparatus

Universal compression testing machine; Sieve sets for finding maximum nominal size; Weighing balance; Cone mould; Base plate; Trowel; Container; Ruler graduated from 0 mm to 1000 mm at intervals of 1 mm and Stopwatch measuring to 0.1 s; 150 mm cube mould.

Procedure

Step 1: Select locally available materials with the best grading and shaped aggregate economically possible.

(a) G-43 grade Portland cement with specific gravity of 3.12
(b) Normal-density coarse aggregate, preferably of maximum nominal size of 20 mm
(c) Rounded well-graded fine aggregate
(d) Pulverised fly ash as filler material: use good quality fine fly ash

Step 2: Determine the following properties of envisaged ingredients as per relevant code:

(a) Specific gravity of cement
(b) Average values of specific gravity and absorption of the coarse aggregate
(c) Average specific gravity and absorption of the fine aggregate
(d) Specific gravity of fly ash
(e) Specific gravity of the superplasticisers (given by the supplier)
(f) Specific gravity of stabiliser (specified by the supplier)

Step 3: Decide the contents of ingredients in different trial batches.

Step 4: Calculate quantities of the ingredients for each of the trial mixes by absolute volume method.

Step 5: Mix the materials as per normal procedure.

Step 6: Perform slump flow test.

Measure the largest diameter of the resulting circular flow spread of concrete and also measure a second diameter of the flow spread at right angles to the previous measured diameter. Calculate the average of the two measured diameters; this is the slump flow in mm. Report the slump flow to the nearest 10 mm.

If the measurement of the two diameters differs by more than 50 mm, the test is invalid and shall be repeated.

Step 7: Check the concrete spread for stability of mix which appears in the form of segregation and bleeding.

Step 8: Fill three 150 mm cubes with concrete and test them after 28 days of curing; calculate average compressive strength.

Repeat the above procedure for other trial mixes.

Observations and Calculations

1. Material characteristics	
(a) Specific gravity of cement	
(b) Specific gravity of coarse aggregate	
(c) Absorption of coarse aggregate	
(d) Specific gravity of fine aggregate	
(e) Absorption of fine aggregate	
(f) Specific gravity of fly ash	
(g) Specific gravity of the superplasticisers (given by the supplier)	
(h) Specific gravity of stabiliser (specified by the supplier)	

Required slump-flow value or housing slabs, etc.	In the range of 600 mm
1. Fixed or predefined parameters	
(a) Amount of cement	350 kg/m^3
(b) Water/powder ratio by mass	0.38
(c) Stabiliser (cohesion agent) content	0.85–0.9 per cent of cement
2. Trial or variable parameters	
(a) Amount of fly ash content	30 and 35 per cent of cement
(b) Fine to coarse aggregate ratio by mass	1.0 and 1.1
(c) Superplasticiser content by mass of powder (i.e., cement and fly ash)	0.9 and 1.0 per cent

3. Quantities of the ingredients for each of the trial mixes				
(a) Trial batch number	TB1	TB2	TB3	TB4
(b) Water, kg				
(c) Filler, kg				

(d) Cement,	kg				
(e) Fine aggregate,	kg				
(f) Coarse aggregate,	kg				
(g) Superplasticiser,	kg				
(h) Stabiliser,	kg				
(i) Slump flow,	mm				
(j) Average cube strength,	MPa				

The trial mix TB1/TB2/TB3/TB4/…….is suitable and its compressive strength is……MPa.

Precautions

1. All the precautions pertinent to mixing of materials for trial batches should be observed.
2. To avoid variations due to mixing, the mixing process of trial mixes should be standardised.
3. The slump flow test, cube casting, curing and testing should be done according to the specifications.
4. The fresh concrete spread should be carefully observed for stability and finishing properties. The instability of mix appears in the form of segregation at the centre of spread or patty and bleeding at its periphery.

Discussion

First revision of IS 10262-2009: Concrete Mix Proportioning-Guidelines has followed the format of ACI mix proportioning method; the European Nations do not have common concrete mix design method because it considers mix design a part of concrete production. However, it exercises control through EN 206-1. It is immaterial whether the concrete mix is proportioned by British DoE method or DIN or some other method, as long as it satisfies the requirements/specifications.

According to IS 10262-2009 the provisions of IS 456-2000 through reference constitute its own provisions. The most important provision is concerning the durability. As per IS 456-2000 stipulations from durability considerations for reinforced concrete, the amount of cement shall not be less than 300 kg/m^3 of concrete. In the conventional concretes generally used in India, the cement content varies between 325 to about 400 kg/m^3.

In view of above observations, with fixed cement content of say 325, 350, 375, 400 kg/m^3, etc., and using the locally available appropriate materials, it is possible to tailor the properties of self-compacting concrete to meet the demands of any particular application, as a substitute of conventional concrete.

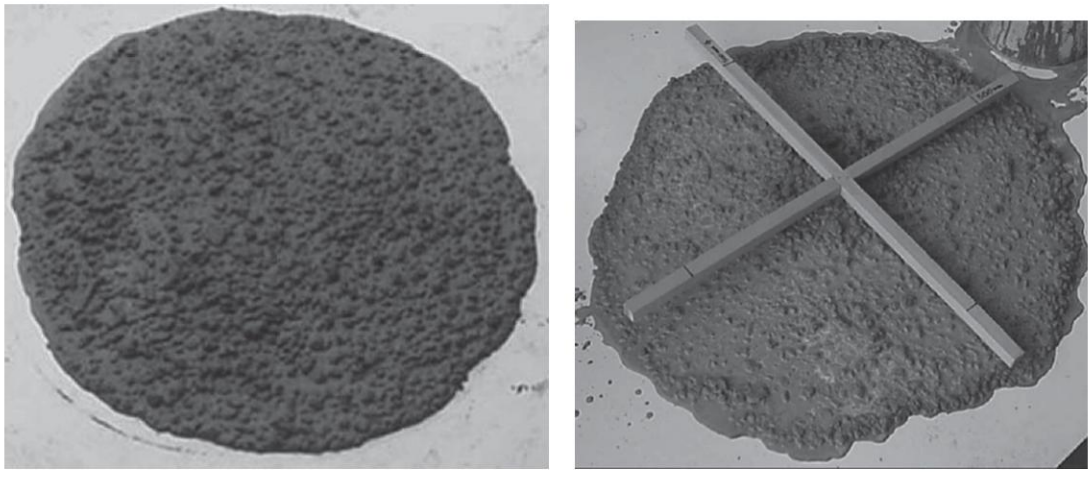
Typically, for the case of self-compacting concrete mix design with fixed cement content of 350 kg/m^3 and slump-flow value (spread or patty diameter) in the range of 600+ mm. The following procedure may be adopted for preparing trial mixes:

1. Fixed parameters	
(a) Amount of cement	350 kg/m^3
(b) Water/powder ratio by mass	0.38
(c) Stabiliser (cohesion agent) content	0.85–0.9 per cent of cement

2. Trial batches	
(a) Amount of fly ash content	(30 and 35 per cent of cement)
(b) Fine to coarse aggregate ratio by mass	(1.0 and 1.1)
(c) Superplasticiser content by mass of powder (i.e., cement and fly ash)	(0.9 and 1.0 per cent)

With this content of cement, compressive strength in the range 35 MPa is expected.

The method described in this test can be considered as an extension of the latest revision of IS 10262-2009 for concrete mix proportioning guidelines. Typical spreads for stable and unstable mixes are shown in Figs. 7.9(a) and (b), respectively.



(a) Spread for a stable mix (b) Spread for an unstable mix

Fig. 7.9 *Typical spreads for stable and unstable mixes*

Viva-Voce Questions

1. What is SCC?
2. What is the objective of mix design?
3. What is the significance of slump flow test?
4. What are the limitations of slump flow test?
5. What is Halo and what does it indicate?
6. What is T_{500} time?
7. What is the major disadvantage of slump flow (unrestricted/unconfined) test?
8. What is visual stability index (VSI) rating?
9. What should be the characteristics of the locally available materials to be used in SCC mix?
10. Why is the specific gravity of all the materials required in this test?
11. What is nominal maximum size of coarse aggregate?
12. What are the basic parameters considered fixed in proportioning SCC mix in the given procedure?
13. How is the batch weight of materials per unit volume of concrete obtained?
14. What is suitable slump-flow value of the SCC mix to be used for housing slabs, piles and deep foundations?

Notes and Comments

NATIONAL STANDARDS

1. IS 456-2000 (4th revision, reaffirmed 2011): *Code of Practice for Plain and Reinforced Concrete*.
2. IS 460(Parts 1 and 2)-1985(3rd revision, reaffirmed 2008): *Specification for Test Sieves*.
3. IS 2386 (Part 3) -1963 (reaffirmed 2011): *Methods of Test for Aggregates for Concrete*: Part 3: *Specific Gravity, Density, Voids, Absorption and Bulking*.
4. IS 3812 (Part 1)-2003 (2nd revision, reaffirmed 2007): *Specification for Pulverized Fuel Ash*: Part1: *For Use as Pozzolana in Cement, Cement Mortar and Concrete*.
5. IS 10262-2009 (1st revision): *Concrete Mix Proportioning— Guidelines*.

REFERENCES

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2. ASTM C 1611/C 1611M-05; *Standard Test Method for Slump-Flow of Self-Consolidating Concrete*, ASTM International.
3. ASTM C 1621/C1621M-06; *Standard Test Method for Passing Ability of Self-Consolidating Concrete by J-Ring*, ASTM International.
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9. ISO 3310-2; Test sieves – *Technical Requirements and Testing* – Part 2: *Test Sieves of Perforated Metal.*
10. ISO 5725:1994; *Precision of Test Methods – Determination of Repeatability and Reproducibility for a Standard Test Method by Inter-laboratory Tests*.

HARDENED CONCRETE

Section 8

This section describes the destructive tests generally performed on hardened concrete; these include various types of strengths, elastic properties and the physical characteristics of hardened concrete as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

8.1 INTRODUCTION

One of the important properties of the hardened concrete is its strength which represents the ability of concrete to resist forces. If the nature of the force is to produce compression, the strength is termed as *compressive strength*. The compressive strength of the hardened concrete is generally considered to be the most important property and is often taken as an index of the overall *quality of concrete.* The strength can indirectly give an idea of the most of the other properties of concrete which are directly related to the structure of hardened cement paste. A stronger concrete is dense, compact, impermeable, and resistant to weathering and to some chemicals. However, a stronger concrete may exhibit higher *drying shrinkage* with consequent *cracking,* due to the presence of higher cement content. Some of the other desirable properties like shear and tensile strengths, modulus of elasticity, bond, impact and durability, etc., are generally related to the compressive strength. As the compressive strength can be measured easily on standard sized cube or cylindrical specimens, it can be specified as a criterion for studying the effect of any variable on the quality of concrete. However, the concrete gives different values of any property under different testing conditions. Hence, the *method of testing,* the *size of specimen,* and the *rate of loading* are stipulated while testing the concrete to minimise the *variation in test results.* The statistical methods are commonly used for specifying the quantitative value of any particular property of hardened concrete.

8.2 PROPERTIES OF HARDENED CONCRETE

The important properties of concrete in hardened state are: (i) strength, (ii) impermeability, (iii) durability, (iv) shrinkage, (v) creep, (vi) elasticity, (vii) thermal properties, and (viii) fire resistance. The hardened concrete should have required strength, durability and impermeability. It should have maximum elasticity and minimum shrinkage, creep and thermal expansion. The above properties are briefly described below.

8.2.1 Strength of Concrete

Even though the concrete exhibits a small amount of *plastic strain,* a fracture under static loading takes place at a moderately low total strain of 0.001 to 0.005 at failure. For this reason, concrete is considered as brittle material. Depending upon the nature of stresses, the strength of concrete is categorised as follows:

1. **Compressive strength** The compressive strength of concrete is defined as the load which causes the failure of specimen, per unit area of cross section in uniaxial compression under given rate of loading. The

strength of concrete is expressed as MPa. Other strengths are generally prescribed in terms of percentage of compressive strength. As the compression tests are easy to perform, they are most frequently conducted. The compressive strength at 28 days after casting is taken as a criterion for specifying the quality of concrete. This is termed as grade of concrete. IS 456-2000 stipulates the use of 150 mm cube specimens for determination of compressive strength of concrete; whereas, the British practice is to use 150 mm cubes except for the concrete with aggregate size less than 25 mm, where 100 mm cubes are tested. The American practice is to use cylinder specimens of 150 mm diameter with 300 mm height. The cylinder specimens are capped to make the top surface even and parallel to the bottom surface and perpendicular to the axis of the cylinder. However, the condition of stressing of concrete in compression in a structure is simulated more appropriately by a test cylinder; hence test cylinders give more representative and realistic values of strength.

2. **Flexural strength** The flexural strength expressed in terms of modulus *of rupture* is defined as the maximum tensile stress in the concrete at rupture in a flexure test. The stress in extreme fibre σ_{cb} is given by $\sigma_{cb} = \frac{Mc}{I}$ where M is the bending moment in Nmm at the failure section, c is the distance of extreme fibre from neutral axis in mm, and I is the second moment of area of the cross section in mm^4.

   The loading arrangement with symmetric loads (P) acting at 1/3 points produces a pure bending zone with constant bending moment and zero shear force in the middle third of the span. If the fracture occurs within the middle third of the span the flexural strength is given by

$$\sigma_{cb} = \frac{PL}{bd^2}$$

   If the fracture occurs outside the middle third, but within 5 per cent of span length, the flexural strength is given by

$$\sigma_{cb} = \frac{3Pa}{bd^2}$$

   where L is span in mm, a is distance between section of fracture and the nearest support in mm. and d is the average depth of specimen in mm. However, if the fracture occurs more than five per cent outside the middle third, the test results are discarded.

   The concrete test specimen *for flexural strength* is a *prism* of cross section 100 mm × 100 mm and 500 mm in length. It is loaded on a span of 400 mm. The value of *modulus of rupture* ranges from 11 to 23 per cent of the *compressive strength* and an average value of 15 per cent is generally adopted. The modulus of rupture is useful as a design criterion for concrete pavements.

3. **Tensile strength** The tensile strength is one of the basic and important properties of the concrete. The concrete is not usually expected to resist the direct tension because of its low tensile strength and brittle nature. However, the determination of tensile strength of concrete is necessary to determine the load at which the concrete members may crack. The tension is important in limiting the cracks caused by shrinkage, etc.

   The methods to determine the tensile strength of concrete can be broadly classified as (i) direct methods and (ii) indirect methods. Because of the difficulties associated with the direct tension test, a number of indirect methods have been developed to determine the tensile strength. In these tests, in general, a compressive force is applied to a concrete specimen in such a way that the specimen fails due to tensile stresses developed in the specimen. The tensile stress at which the failure occurs is termed the tensile strength of concrete.

   The *tensile strength* is obtained indirectly by subjecting a horizontal concrete cylinder to a vertical compressive force along two opposite generating lines of the cylinder. Due to compressive force, the cylinder is subjected to uniform tensile stress over a depth of 0.67 D acting horizontally. This force splits the cylinder vertically in two halves. The tensile stress developed is taken as an index of tensile strength of concrete and is given by

$$\sigma_{sp} = \frac{2P}{(\pi dl)}$$

where σ_{sp} is the indirect tensile strength of concrete expressed as MPa, P is the load causing rupture, d diameter of cylinder and l is length in mm. The test is known as *split test* and the strength the *split tensile strength.*

The concrete has low tensile strength; it ranges from 8 to 12 per cent of its compressive strength. An average value of 10 per cent is generally adopted.

4. **Shear strength** In the concrete member subjected to bending, the shear stress is accompanied by tensile and compressive stress. The shear failures are due to resulting *diagonal tension.* The shear strength is generally 12 to 13 per cent of compressive strength.
5. **Bond strength** The resistance of concrete to the slipping of reinforcing bars embedded in concrete is called *bond strength.* The bond strength is provided by adhesion of hardened cement paste, and by the friction between concrete and reinforcement. It is also affected by shrinkage of concrete relative to steel. On an average, bond strength is taken approximately as 10 per cent of the compressive strength. The bond strength is determined by *pull out test* and is defined as the unit load required causing a slippage of 0.25 mm. The load which causes this amount of slippage divided by the area of contact between the reinforcing bar and the concrete gives bond strength on concrete.

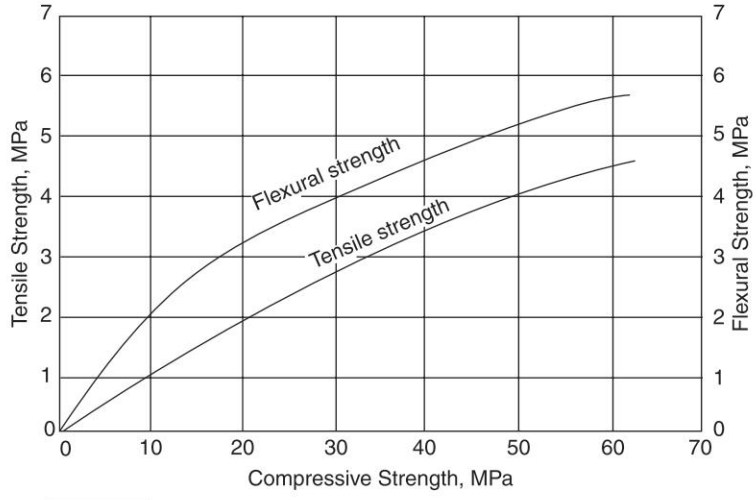


Fig. 8.1 *Relationship between various strengths of concrete*

8.2.2 Factors Affecting Strength of Concrete

The following factors affect the compressive strength of concrete:

1. **Water–cement ratio** The *compressive strength* of concrete at a given age and cured under prescribed conditions is assumed to depend primarily on two factors only namely, *water–cement ratio* and *degree of compaction.* According to the Abrams law, for a fully compacted concrete, its strength is taken to be inversely proportional to the water–cement ratio which is defined as the ratio of mass of water added to the mass of cement in the mix. The *water–cement ratio* determines the *porosity* of the hardened cement paste at any stage of *hydration* and hence affects the strength of concrete. The compaction reduces the air voids thereby resulting in increased strength.
2. **Aggregate–cement ratio** For a concrete with *workability* maintained at a satisfactory level, (water-cement ratio being held constant) the compressive strength of concrete is found to increase with the increase in *aggregate–cement ratio.* However, in *high strength concrete* mixes of low workability in

such situation where due to increase in aggregate-cement ratio, the workability is reduced to such an extent that the concrete cannot be compacted properly, the above is not true. As a matter of fact, in high strength mixes of low workability, a decrease in aggregate-cement ratio may result in small increase in compressive strength, provided the water content in the mix is also reduced proportionately.

3. **Cement content** For a given *water–cement ratio* if the cement content is increased to enhance the workability of the concrete mix, the compressive strength increases with the increase in the richness. However, for a particular water–cement ratio there would always be optimum *cement content* resulting in 28-day compressive strength being the highest. Increasing the cement beyond the optimum may not increase the strength of the concrete.

   It has been noticed that greater the 7 day strength of cement, the greater the compressive strength of concrete at 28 days.
4. **Age at testing** Although the cements of different types result in different rate of gain of initial strength, the strengths at later age tend to become similar. Therefore, cement which results in comparatively lower strength at 28 days would have proportionately greater increase in strength at the later ages and *vice versa.* The mix proportions themselves influence the rate of gain of strength, e.g., a concrete with lower water–cement ratio tend to attain high early strength, therefore further gain in strength at later ages is approximately smaller.
5. **Compaction and curing** A thorough compaction is the basic necessity to successful concrete production. The compaction eliminates most of the air pockets on the surface of concrete. The presence of even five per cent voids in the hardened concrete due to incomplete compaction may result in a decrease in compressive strength by about 35 per cent.

   The concrete starts attaining strength immediately after *setting* is completed and the strength continues to increase with time provided that sufficient moisture is available for hydration of cement which can be assured only by proper moist curing. Moist curing for first 7 to 14 days may result in compressive strength being about 90 per cent of that of 28 days moist curing. IS: 456-1978 stipulates a minimum of 7 days moist curing, while IS:7861 (Part I)-1975 stipulates a minimum of 10 days curing under hot weather conditions.
6. **Rate of loading** A higher rate of loading is found to result in higher *recorded compressive strength.* In a static loading test, the rate of loading should be so adjusted to complete the test in a period of 2 to 3 minutes. Within this time range the effect of *rate of loading* is insignificant. The rate of loading for cube specimens has been stipulated as 14 MPa per minute.

8.3 IMPERMEABILITY OF CONCRETE

The *impermeability* of concrete which is defined as the resistance to the passage of water through its body is equally important as the compressive strength for hydraulic structures. The excess water beyond that required for complete *hydration of cement* on evaporation gives rise to the pores. The *water–cement ratio* determines the *porosity* of hardened cement paste. The degree of compaction also affects the volume of voids in the concrete. The permeability of concrete is not only a simple function of porosity but also depends on the size, distribution and continuity of the pores.

8.4 DURABILITY OF CONCRETE

The durability of concrete can be interpreted to mean its resistance to the deteriorating influences of external agencies like weathering attack by natural or industrial liquids and gases, bacterial growth, etc., or by internal agencies like *alkali-aggregate reaction,* volume changes due to non-compatibility of thermal and mechanical properties of aggregate and cement paste, etc. In case of reinforced concrete, the ingress of moisture or air

will facilitate the corrosion of steel, leading to an increase in the volume of steel and consequent cracking and spalling of concrete cover.

A durable concrete is dense, workable and placeable, and has low permeability under the given situation. The *durability* of concrete can be described under the heads: (i) resistance to wear; (ii) resistance to weathering and (iii) resistance to chemical attack.

8.5 SHRINKAGE

During setting and hardening of concrete the cement forms *gel* with water which crystallises in due course. On crystallization, it gives out free water and shrinks; this volume change results in fine cracks on the surface. The richer mixes absorb more water in the beginning which is released subsequently on crystallisation resulting in higher values of *shrinkage.* Most of the shrinkage takes place in the first few days as the superfluous water evaporates, but slow process of gel formation and consequent shrinkage goes on for a long time.

The term shrinkage is loosely used to describe the various aspects of volume changes in concrete due to loss of moisture at different stages due to different reasons. Shrinkage can be classified in the following types:

1. **Plastic shrinkage** Loss of water by evaporation from the surface of freshly placed concrete or by the absorption by aggregate or subgrade is believed to be the reasons of plastic shrinkage. The loss of water results in the reduction of volume. The aggregate particles or the reinforcement comes in the way of subsidence due to which cracks may appear at the surface or internally around the aggregate or reinforcement.
2. **Drying shrinkage** The drying shrinkage of concrete is analogous to the mechanism of drying of timber specimen. The loss of free water contained in hardened concrete, does not result in any appreciable dimension change; it is the loss of water held in gel pores that causes the change in the volume.

   Cement paste shrinks more than mortar and mortar shrinks more than concrete. Concrete made with smaller size aggregate shrinks more than concrete made with bigger size aggregate. The finer the gel the more is the shrinkage. The shrinkage increases with the increase in temperature, reduction in atmospheric humidity and increase of fines in concrete.
3. **Autogeneous shrinkage** Autogeneous shrinkage is of importance in mass of concrete in the interior of a concrete thick section or a dam.
4. **Carbonation shrinkage** Carbonation shrinkage is caused by the reaction of carbon dioxide present in the atmosphere with hydrated cement in the concrete in the presence of water. As the calcium carbonate formed occupies lesser volume than the calcium hydroxide replaced, shrinkage takes place. The magnitude of carbonation shrinkage is very small when compared to long term drying shrinkage; this aspect is not of much significance.

8.6 CREEP

When a concrete member is subjected to a load it undergoes a certain amount of deformation. The instantaneous deformation is elastic and disappears on the removal of load. However, if the load is sustained for a longer period, the deformation continues to increase with time even when the load on the member is kept constant. This phenomenon of increase in deformation of concrete under constant stress is termed as *creep* of concrete. The creep is also known as *plastic flow, plastic yield* or *plastic deformation.* The creep does not disappear completely on removal of sustained load. Thus the deformation beyond instantaneous strain is the creep which is function of time. The creep in concrete is more than the elastic deformation.

The creep in concrete is desirable because it causes redistribution of stress in reinforced concrete structures. Creep is, however, undesirable as it causes excessive deformations and deflections.

8.7 MODULUS OF ELASTICITY

Like many other structural materials the concrete behaves elastically to a certain degree. Generally, it is considered to behave elastically only up to 10 to 15 per cent of ultimate strength. The modulus of elasticity can be determined by loading a capped cylindrical specimen to uniaxial compression and measuring deformation across a gauge length of 200 mm; a typical stress-strain curve is shown in Fig. 8.2. It is seen that under sustained loading the strain increases with time, i.e., the concrete exhibits *creep.* For practical purposes, the instantaneous strain occurring during loading is considered elastic and the subsequent increase in strain is regarded as creep. Thus, the modulus of elasticity based on the slope of the line joining origin to any point on stress-strain curve at which deformations are to be calculated can effectively be used. This modulus is termed *secant modulus of elasticity*.

8.8 POISSON'S RATIO

The knowledge of Poisson's ratio is required for the analysis of concrete slabs, arch dams, etc. The value of Poisson's ratio is determined by testing a prism specimen in uniaxial compression and measuring axial compressive strain in direction of stress and tensile strain in the lateral direction. The ratio of lateral strain to axial strain gives the value of Poisson's ratio. This value at the allowable stress varies from 0.15 to 0.20.

8.9 THERMAL PROPERTIES

The thermal properties of concrete are important in the study of the insulating properties of concrete, temperature conditions in mass concrete and development of stresses due to thermal expansion of concrete. Like most of the materials, the concrete expands with the rise in temperature and contracts on its fall. If the concrete is restrained against the expansion or contraction the stresses will be induced.

The average value of coefficient of thermal expansion for ordinary concrete is taken as 11×10^{-6} per °C. This value is close to that for the steel making it a suitable material to be used with steel in reinforced cement concrete construction.

8.10 RESISTANCE TO FIRE

When the concrete is subjected to a high temperature gradient, the aggregates expand and the cementitious material loses its water of crystallisation and thus shrinks. This results in the hot surface layers to separate and spall from the cooler interior of the body. This causes the concrete to crack and crumble. From this point of view, quartz aggregate which has a large coefficient of expansion should be avoided. The broken bricks are more fire resistant. Similarly, the broken stone is better than gravel in its fire resistance. The loss of strength is considerably lower if the aggregate does not contain silica. The leaner mixes appear to suffer a relatively lower loss of strength than richer mixes. Low conductivity of concrete improves its fire resistance. Hence, *lightweight concrete* is better fire resistant than ordinary concrete.

8.11 TESTING OF HARDENED CONCRETE

8.11.1 Preparation of Test Specimens

The equipments required are as follows:

1. **Moulds** Cast iron moulds used should be made in two halves which can be bolted together to form a true cube. The inside faces of the mould must be machined until perfectly smooth. Each mould shall be provided with a machined metal base plate. Means shall be provided for securing the base plate to the mould. The assembled mould and base plates shall be watertight and shall be *oiled with mineral oil* before use.

2. **Tamping rod** For consolidating the concrete in the moulds, a *steel tamping rod* is required and it is best to use one of standard dimensions so as to maintain a certain degree of uniformity in compaction. The tamping rod shall conform to IS specifications.
3. **Vibrating table** A vibrating table may be used for compacting the specimens of stiff mixtures.

8.11.2 Number of Specimens

Three or more test specimens for each variable should be made for each period or condition of test.

8.11.3 Quantities of Materials

For computation of quantities of materials needed for a batch of concrete the information required is (i) proportion of material to be used, (ii) size of test specimen and (iii) number of test specimens.

It is better to make a batch of such a size as to leave 10 per cent excess after moulding the test specimens. If the concrete is required for any other purpose, the necessary amount of concrete should be added. For computation of the mass of various materials required for the batch, following step-wise procedure may be adopted:

1. Compute the volume of concrete needed for all purposes including 10 per cent excess.
2. Consider that freshly made concrete weights 2400 kg/m^3 and compute the mass of concrete needed.
3. Compute the mass of each material required keeping its proportion to others.

For example, consider the case of quantities of materials required for making three 150 mm cubes and also for air determination requiring 6 litre of concrete with 10 per cent excess. The concrete mix proportion is 1: 2: 4 (by mass) and water-cement ratio 0.6. The quantities of materials required may be estimated as:

Volume of 3 cubes $= 3 \times 3.375$ litres

Total concrete = Concrete for cubes + Concrete for air determination + 10 per cent of total for excess
$= 10.125 + 6.000 + 1.6125 = 17.75$ litres

The mass of batch $= 2400 \times 17.75 \times 10^{-3} = 42.5$ kg

For the required mix proportion, the sum of parts of cement, aggregate and water is
$= 1 + 2 + 4 + 0.6 = 7.6$

Therefore, mass of cement $= 42.5/7.6 = 5.6$ kg

Mass of fine aggregate $= (42.5/7.6) \times 2 = 11.2$ kg

Mass of coarse aggregate $= (42.5/7.6) \times 4 = 22.4$ kg

Mass of water = $0.6 \times$ mass of cement = $0.6 \times 5.6 = 3.36$ kg.

Note: A rough guide to the amount of water needed in the case of nominal concrete to be consolidated by hand around the reinforcement bars may be expressed as

Mass of water = (mass of cement/3) + (combined mass of dry aggregates/20)
$= 1.87 + 1.68 = 3.55$ kg

This is equivalent to water–cement ratio of 0.63.

The mixes which are to be vibrated generally require about 15 per cent less water.

For further illustration, consider the surface moisture contents of sand and coarse aggregate to be 3 and 1 per cent, respectively.

The sand being damp already holds three per cent of 11.2 kg = 0.336 kg

Similarly, water adhering to coarse aggregate amounts to 1 per cent of 22.4 kg = 0.224 kg

The total amount of water already present in mix = 0.56 kg, therefore, the quantity of free water to be added is $(3.36 - 0.56) = 2.8$ kg.

8.11.4 Weighing of Materials

All the materials should be weighed on the balances of specified sensitivity/accuracy prescribed by the Standards.

8.11.5 Mixing

The concrete shall be mixed either by hand or in a suitable *laboratory mixer* in batches of required size. The aggregates must be mixed thoroughly to obtain a quality concrete.

1. **Hand mixing** The ingredients are mixed in a water-tight, clean, damp metal pan with a trowel or a shovel. The following procedure should be adopted.
   (a) Mix the *cement* and *fine aggregate* together in a *dry state* until they are *thoroughly blended.*
   (b) Add the *coarse aggregate* and mix the entire batch until the *coarse aggregate* is *uniformly distributed* throughout the batch.
   (c) Add the *water* and continue mixing until *plastic concrete* is of *uniform colour* and of desired consistency is obtained.
2. **Machine mixing** The type of mixer in most common use consists basically of a *metal drum* fitted internally with a series of *curved blades.* The drum is made to revolve by a petrol or diesel oil engine or by electric motor which also supplies power for raising the *loading hopper* so that it may discharge the ingredients into the drum. As the drum revolves, some of the mixture is caught up on each blade and carried around until it reaches a point where it slides off and caught on another rising blade. This process continues for two minutes and enables the particles to intermingle and become completely coated with cement paste.

   Just before mixing the test batch the mixer should be *buttered* by mixing a batch proportioned to simulate closely the test batch. The mortar retained by the mixer after discharging is intended to prevent loss of mortar from the test batch. To eliminate segregation of machine-mixed concrete, it should be deposited on a water-tight, clean sheet metal and remixed by shovel and trowel.

8.11.6 Moulding Specimens

This can be done in two steps:

1. **Filling the moulds** Prior to the filling of the moulds, the workability test should be carried out. The same sample of concrete can be used for both purposes provided that it is compacted before the *initial set* has taken place.

   The cubes shall be formed by placing the concrete in the mould in three *roughly equal layers,* each layer being *rammed 25 times* with round end of the tamping rod. The *strokes shall be distributed uniformly over the cross section of the mould* and shall *penetrate in to the underlying layer.* The bottom layer shall be rodded throughout its depth. After the top layer has been rodded, *surface of the concrete* shall be *struck off* with a trowel. Prolonged and vigorous floating is to be avoided as it tends to spoil the uniformity of the mix by bringing too much mortar to the surface.

   When *stiff mixtures* are being used it will be necessary to *compact the specimen by vibration.* The *period of vibration* applied to each specimen shall be kept *constant throughout the series of tests.* The degree of compaction, indicated by the density of concrete, has great influence on its strength. The relation between strength ratio and density ratio is given in Fig. 8.2.

   When moulding several specimens from a batch of concrete, it is advisable to fill one third of all moulds before putting second third in any and finish second third of all before putting the final third in any. This will help in securing more uniform specimens. The concrete should be scraped from the areas in the pan from where the concrete has been removed, as considerable amount of mortar will be left in the pan unless removed from the edges during the moulding of specimens.
2. **Capping of cylindrical specimens** The cylindrical specimens should be capped to secure and perfectly plane face and to make it right angle to the axis of the specimen. The capped surface shall not depart from plane by more than 0.25 mm.

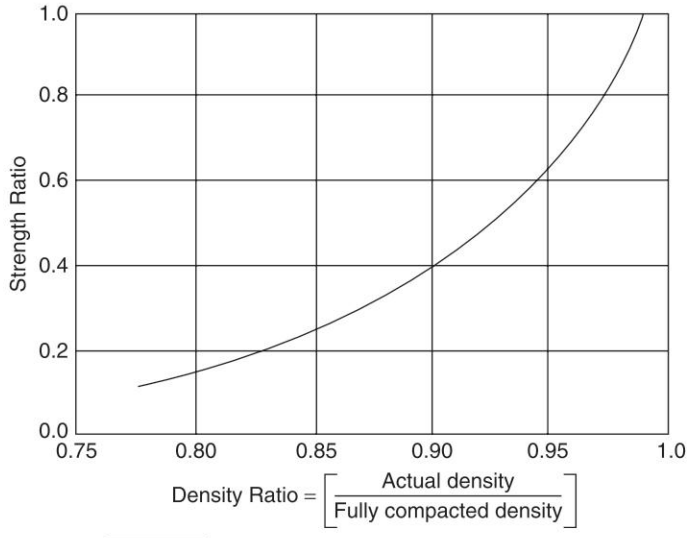


Fig. 8.2 *Effect of compaction on strength*

The specimen may be capped with a thin layer of stiff, neat cement paste after concrete has ceased setting in the moulds, usually 2 to 4 hours after moulding. The cement paste for capping is mixed 2 to 4 hours before it is to be used in order to avoid the tendency of the cap to shrink. The cap is formed by means of a glass plate 6 mm in thickness.

For capping hardened specimens, a mixture of Portland cement and sulphur with granular material is used.

8.11.7 Removal of Specimens from Moulds

For 24 hours, following casting, the specimens must remain in their moulds, which are covered with damp sacks and stored in condition of moderate temperature in a place free from vibration. The test specimens shall be removed within 48 hours after moulding. The moulds are unbolted, carefully taken apart and cleaned ready for reuse. Each specimen should be marked with its *reference number* and *date of casting.* Each person must workout his own system of marking with pencil or *waterproof ink.*

8.11.8 Curing

Curing means creation of an *environment* which is *favourable to the setting and hardening of the concrete.* The desirable conditions are a suitable *temperature* as it *governs the rate of chemical action* involving setting and hardening, a provision of sufficient moisture or the prevention of loss of moisture and the avoidance of *premature stressing or disturbance.*

The method of curing which is generally adopted is complete immersion of specimens in a pond of water with 50 mm deep water over it, from the time the specimens leave their moulds until they are dispatched to the testing laboratory. If possible, the temperature should be kept within 10°C to 25°C. The specimens should not be exposed to a stream of running water. If storage in water is desired, a saturated lime solution shall be used.

Sometimes to keep the temperature lower than the surrounding atmosphere, the specimens are covered with damp sand under burlap which is continuously kept wet by spraying water over it.

8.12 TESTING OF HARDENED CONCRETE

8.12.1 Compression Testing

Compression test is conducted on a compression testing machine; any fault in compression testing machine can introduce errors in determining compressive strength of concrete. The specimens should be crushed in a saturated condition as the water content of concrete affects the result and it would otherwise be difficult to ensure standard testing conditions. Typical compression testing machine and flexural test accessory are shown in Fig. 8.3.

A compression testing machine of any type but of sufficient capacity which would provide the *rate of loading* prescribed by relevant Standards can be used. The most common type of test machine is hydraulically operated. The testing machine is equipped with two *bearing blocks* with *hardened faces* (platens). The *upper platen* can be raised or lowered by means of a heavy screwed bolt. The upper platen bears on the upper surface of the specimen to which the load is applied. The *bearing faces* when new shall not depart from a plane by more than 0.0125 mm at any point. The planeness can easily be tested with *straight edge* or *feeler gauges*, etc.

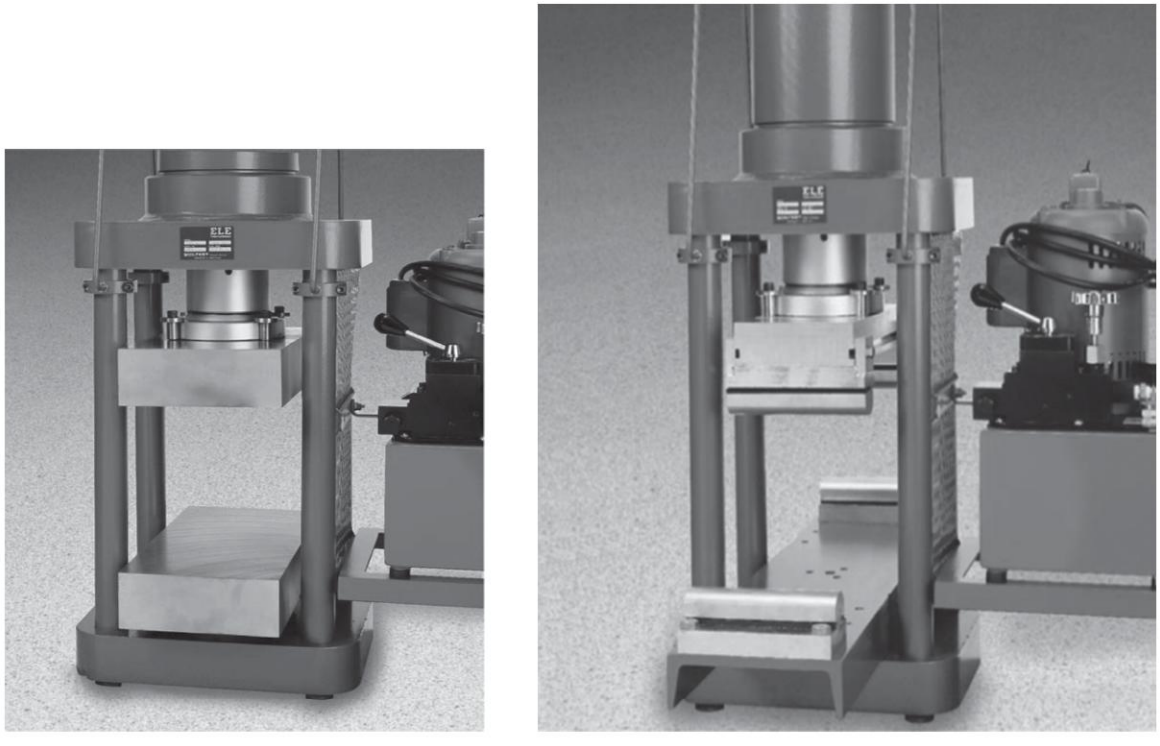


Fig. 8.3 *Typical compression testing machine and flexural test accessory*

8.12.2 Testing Procedure

The specimens, stored in water, should be tested immediately after they are removed from the water and any surface water, grit and slight projection should be removed. The cubes should be placed in testing machine so that the load is applied to the *opposite sides* as cast and not to the top and bottom as cast.

The specimen must be accurately placed within *location marks* on the *bottom platen* so that it is *truly concentric* with the spherical seat of *upper platen.* The bearing face should be wiped clean before test specimen is placed on it.

The test specimens during the period between their removal from water pond and testing should be kept moist by wet blanket covering. The diameter or side of the test specimen should be determined to the nearest 0.25 mm by averaging two perpendicular diameters or two right angle sides of the face on which load is applied. After placing the specimen, the *moving head* (top platen) is brought in contact with the specimen by moving the screw and then start application of load.

As the specimen nears the *failure point* in the compression test its *rate of yield* increases considerably and the *movements* of the platens of the testing machine must be *speeded* in order to maintain *constant rate of application* of the load. If the test machine is not capable of speeding up, the rate of application of load decreases as the failure point is reached and this results in reduction of the load at which failure takes place. In hydraulically operated machines, the load shall be applied at a constant rate within the range 0.14 to 0.35 MPa. The load shall be increased until specimen fails and maximum load carried by specimen during test should be recorded. The *type of failure* and *appearance of concrete* should also be noted.

The main factors causing *variation of test results* are:

1. *Eccentric loading due to misalignment* of the various parts of the testing machine.
2. *Inability to maintain a uniform rate of loading* right up to the point at which the specimen fails.
3. *Lack of planeness* of platens.

8.12.3 Tension Test

Tensile strength can be determined (i) in indirect tension; and (ii) in bending. The tensile strength determined by these two methods gives different values. The most commonly used indirect tension test consists of applying a compressive line load along the opposite generators of a concrete cylinder placed with its axis horizontal between the compressive platens as shown in Fig. 8.10. Due to the compression loading a fairly uniform tensile stress is developed over nearly 2/3 of the loaded diameter as obtained from an elastic analysis. The magnitude of this tensile stress σ_{sp} (acting in a direction perpendicular to the line of action of applied loading) is given by the formula (IS: 5816-1970):

$$\sigma_{sp} = \frac{2P}{\pi dl} = 0.637 \left(\frac{P}{dl} \right)$$

where P is the applied load in kN; d and l are the diameter and the length of specimen in mm, respectively. Due to the tensile stress, the specimen fails by splitting vertically into two halves as shown in Fig. 8.9; this test is also called the *split test.* The *tensile strength* of concrete determined by this method is sometimes referred to as *split tensile strength* of concrete.

8.12.4 Flexure Testing

The method used in flexure testing is the third-point loading method. The test specimen should be turned on its side with respect to its position as moulded and centred on bearing blocks. The load applying blocks shall be brought in contact with the upper surface at the third points between the supports. If the *full contact* is not obtained between specimen and load applying blocks and supports due to the surface of the specimen being out of plane, the surface of the specimen where they are to be in contact with blocks or supports should be grounded or capped to produce full contact.

The load should be applied at a uniform rate and in such a manner as to avoid shocks. During the application of the first half of the *maximum anticipated failure load* a higher rate of loading should be permitted, after which the load shall be applied at such a rate that the increase in *extreme fibre stress* is approximately 0.7 MPa/minute.

8.12.5 Non-Destructive Testing of Concrete

The main objective of *non-destructive* methods as applied to concrete is to obtain reliable estimate of quality of concrete in a structure without relying solely on the results from the test specimens which are not necessarily representatives of structural concrete.

8.13 RECORDING OF OBSERVATIONS AND CALCULATIONS

1. In all cases appropriate number of observations should be taken and entered in a suitable tabular form to be so planned that it gives all details of the observations and in certain cases also the results of the calculations.
2. The observations and results are to be directly entered in the manual in which final fair report of the work has to be written.
3. In calculation of results, no advantage will be gained by using more than just the necessary number of figures. Thus use of contracted and approximate methods of calculations and also the use of tables up to a limited number of figures is desirable.
4. The free and frequent use of graph in representation of the observations and interpretation of the results, will give more accurate information than the tabular form.

EXPERIMENT NO. 1: Strengths of Cement Concrete

Objective

1. To determine the compressive strength of concrete of given proportions by testing:
   (a) Cube specimens and
   (b) Cylindrical specimens
2. To determine the flexural strength of concrete of given proportions.

Theory and Scope

The compressive strength of the hardened concrete is generally considered to be an index of the overall quality of concrete. There are two types of standard test specimens, namely cubes and cylinders, used to determine the compressive strength of concrete and its suitability for the job. The common sizes of test specimens are listed in Table 8.1. The crushing test is used to determine the compressive strength of 150 × 150 × 150 mm concrete cubes and 150 mm diameter and 300 mm high cylinders at 28 days.

Flexure test method covers the determination of the flexural strength of concrete in tension by the use of a simple 100 × 100 × 500 mm long concrete beam/prism with third-point loading.

The flexural strength of concrete is used in the design of concrete pavements subjected to wheel loads wherein inadequate subgrade support results in bending moments and/or the volume changes due to temperature/shrinkage causes tensile stresses. The testing of concrete in flexure yields more consistent results than those obtained with tension test on mortar; the flexure test is also more easily carried out and may even be more convenient than the crushing test for use in the field since in this test much smaller loads are required.

Apparatus

Compression testing machine and 50 kN transverse testing machine or transverse testing attachment; Cube moulds 150 × 150 × 150 mm; Cylinder moulds 150 mm diameter and 300 mm height; Prism moulds 100 × 100 × 500 mm long; Capping apparatus; Mixer; Weighing machine; Ramming or tamping rod; Buckets and base plate.

Description of Apparatus

Testing machines The testing machines should be of adequate capacity and capable of maintaining the stipulated rate of loading. For this test, 2000 kN compression testing machine and 50 kN transverse testing machine are required.

Moulds for the test cubes The cube moulds with base plate are of steel or cast iron with internal faces machined flat to a tolerance of ± 0.25 mm. When the mould is properly assembled, its height and distance between opposite faces should be correct to ± 2.5 mm. All the inferior angles between internal faces should be 90 ± 0.5°. The machined base plate is large enough to prevent leakage of cement slurry during filling of the mould. Springs, clips or screws are used to assemble the mould on the base plate. Typical moulds and concrete specimens are shown in Fig. 8.4.

Moulds for test cylinders The standard size of test cylinder is 300 mm in height and 150 mm in diameter. These moulds are also of cast iron.

Tamping rod It is a 16-mm diameter rod 650 mm in length and bullet pointed at the lower end.

Fig. 8.4 *Typical moulds and concrete specimens*

Procedure

Part 1: Prepare the sample for testing

Step 1: Take representative sample of fresh concrete in case monitoring the quality of fresh concrete.

Step 2: In the case of trial mix testing, calculate the materials required for the test batch. Mix them thoroughly in a mechanical mixer until uniform colour of concrete is obtained.

The trial mix materials may also be mixed by hand in such a manner as to avoid loss of water. In mixing by hand, the cement and fine aggregate shall be first mixed dry to uniform colour and then the coarse aggregate is added and mixed until the coarse aggregate is uniformly distributed throughout the batch. Now the water shall be added and whole is mixed until the resulting concrete is uniform in colour. Mix at least for 2 minutes.

Part 2: Pour concrete in the moulds oiled with medium viscosity oil

Step 1: Fill concrete in cube moulds in two layers each of approximately 75 mm and ramming each layer with 35 blows evenly distributed over the surface of layer.

Step 2: Fill the cylinder moulds in four layers each of approximately 75 mm and ramming each layer with 35 evenly distributed strokes.

Step 3: Fill the prism moulds in two layers each of approximately 50 mm deep and ramming each layer heavily.

Part 3: Struck off concrete flush with the top of the moulds and cover with a glass plate to prevent evaporation of water.

Part 4: Immediately after being made, they should be covered with wet mats or sacks.

Part 5: Cure the specimen

Step 1: Remove the specimens from the moulds after 24±½ hours; store the cube and prism specimens in clean water at 27+2^{o}C, until the time of test.

Step 2: After 24 hours of casting, cap the cylinder specimens by neat cement paste of 35 per cent water content on the capping apparatus. After another 24 hours the specimens are immersed into water for final curing.

Part 6: Testing of specimens

Test the cube and cylinder specimens immediately on removal from water and while they are still in wet condition. Keep the test specimens in moist condition during the period of their removal from the curing pit and till testing by the wet blanket coverings. The size of specimens is determined to the nearest of 0.2 mm, by averaging the perpendicular dimensions at least at two places. The length of cylinder including cap is measured to the nearest 2 mm. The mass of each specimen is also recorded.

Step 1: Testing of the wet cube and cylinder specimens.

(a) Wipe clean the bearing surface of the test specimens and remove any loose material from the surface.

(b) Place the specimen centrally on the location marks of the compression testing machine. As the spherically seated block is brought to rest on the specimen, rotate the movable portion gently by hand so that uniform seating is obtained.

(c) Apply the load slowly without shock and increase it continuously at a rate of 14 MPa/minute or 300 kN/minute for cube and 250 kN for cylinder. The load is increased until the specimen fails and record the maximum load carried by each specimen during the test. Also report the type of failure and appearance of material at failure surfaces and cracks.

Step 2: Testing of the wet prism.

(a) Place the prism specimen on two 20 to 40 mm diameter steel roller supports on the 50 kN transverse testing machine; the length of the rollers shall be at least 10 mm more than the width of the test specimen. Use two similar steel rollers, equally spaced between the outer rollers, for providing loading points to the specimens. The distance between the outer or supporting rollers, i.e., span is 3*d* and the distance between the inner or loading rollers is *d*.

> **Note:** The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the rollers. For moulded specimens, the mould filling direction shall be normal to the direction of loading.

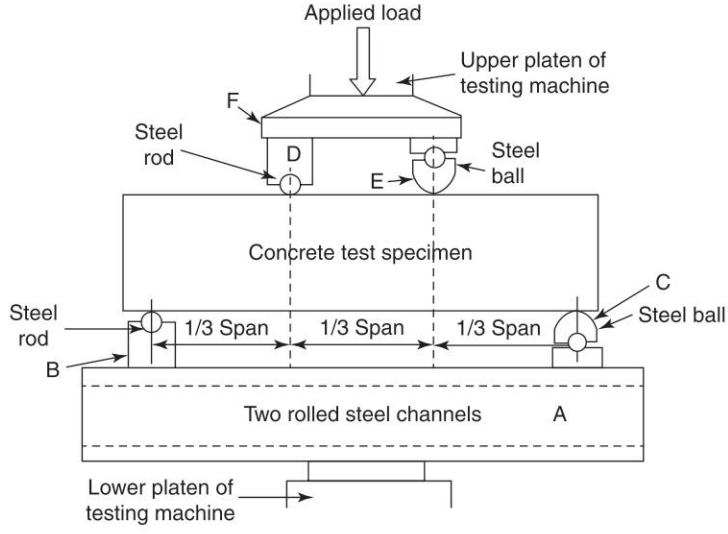


Fig. 8.5 *Typical adaptor for flexural testing of concrete*

(b) Apply the load slowly without shock at such a rate as to increase the stress at a rate of 0.06 ± 0.04 MPa/second. Record the load at first crack and also at failure, i.e., the maximum load.

i. Cube strength $= \dfrac{\text{average load}}{\text{area of cross section}}$

ii. Cylinder strength $= \dfrac{\text{average load}}{\text{area of cross section}}$

iii. Flexural strength $= \dfrac{M}{Z} = \dfrac{(W\,L/6)}{(bh^2/6)} = \dfrac{W\,L}{bh^2}$

In this expression, W is the breaking load in Newton; b and h are the lateral dimensions of the cross section in millimetres. L is the distance between supporting rollers or effective span in mm. All strengths are in MPa.

Observations and Calculations

1. Compressive strength of concrete cube					
Specimen no.	Area of concrete cube specimen, $A = 150 \times 150$ mm^2	Maximum applied load at failure, kN		Compressive strength, MPa	
		7 days	28 days	7 days	28 days
1. 2. 3.					
Average compressive strength nearest to 0.5 MPa Specified compressive strength, MPa					

2. Compressive strength of concrete cylinder					
Specimen no.	Area of concrete cylinder $A = (\pi \times 150^2/4)$ mm^2	Maximum applied load at failure, kN		Compressive strength, MPa	
		7 days	28 days	7 days	28 days
1. 2. 3.					
Average compressive strength nearest to 0.5 MPa Specified compressive strength, MPa					

3. Flexural strength of concrete prism					
Specimen no.	Size of beam mould $100 \times 100 \times 500$ mm $b = 100$ mm $h = 100$ mm $L = 400$ mm	Maximum applied load at failure, W kN		Flexural strength, MPa (WL / bh^2): $a > 133$ mm $(3WL / bh^2)$: $113 < a < 133$ mm	
		7 days	28 days	7 days	28 days
1 2 3					
Average flexural strength nearest to 0.5 MPa Specified flexural strength, MPa					

***Note:** a is the distance between the line of fracture and the nearest support measured on central line of the tensile side of the specimen; if the fracture occurs more than 5 per cent outside the middle third, i.e., $a < 113$ mm, the test results are discarded.

TEST REPORT

The following information is normally included in the report of each compression test specimen:

(a) Identification mark,
(b) Date of test,
(c) Age of specimen,
(d) Curing conditions,
(e) Weight of specimen,
(f) Dimensions of specimen,
(g) Cross-sectional area,
(h) Maximum load,
(i) Crushing strength,
(j) Appearance of fractured faces of concrete and type of fracture if it is unusual.

Precautions

1. The material used for mix should be dried and brought to room temperature before use.
2. All materials should be weighed to an accuracy of 1.0 g.
3. The concrete should be mixed in a manner as to avoid loss of water.
4. Both the mould and base plate should be lightly oiled before use to prevent the concrete from sticking to the moulds.
5. Excess compaction should be avoided with more workable mixes, particularly when using vibration as this is likely to result in segregation and loss of cement slurry from the spaces between moulds and their base plates.
6. The blows should be uniformly distributed over the surface of each layer.
7. When compaction is completed the moulds should be slightly overfull, the surplus be struck off flush with trowels.
8. On no account must the specimens be allowed to dry, even partially and they must be tested in wet condition. Specimens when received dry should be kept in water for 24 hours before testing.
9. The bearing surfaces of the compression testing machine should be wiped clean; and any loose material should be removed from the surfaces of the specimen which would be in contact with the compression platens.
10. The cube and cylinder specimens should be placed in testing machine centrally on platens.
11. At least three specimens should be used for each test and mean crushing strength of three being taken as crushing strength of concrete. While calculating the average load, if any, individual variation from the average is more than 15 per cent the test results are rejected and test is repeated.
12. In cylinder test specimens, the capping should be plane and parallel with bottom surface of cylinder. Specimen should be tested wet, with top and bottom surfaces in direct contact of the platens of the testing machine.

Discussion

Compressive strength test provides the most reliable means of assessing the quality of concrete. The height of test piece in relation to its lateral dimension greatly influences the result. The more slender the test pieces lower will be its crushing strength as shown in Fig. 8.6. The strength of concrete obtained with ratio height/ lateral dimension as 0.5, 2, 4, and 10 is about 125, 75, 70 and 65 per cent, respectively, of the strength when this ratio is unity.

Table 8.1 *Common sizes of test specimens*

Size of cubes	Cylinders		Maximum size of aggregate
	Diameter	Height	
75 × 75 × 75 mm	–	–	Mortar
100 × 100 × 100 mm	150 mm	300 mm	With aggregate up to 20 mm nominal maximum size
150 × 150 × 150 mm	150 mm	300 mm	With aggregate up to 30 mm nominal maximum size

The cubes are better in the sense that they afford accurately plane and parallel faces for testing and no special bedding material has to be used. In case of cylinder, its top surface has to be especially prepared to ensure good contact with testing machine.

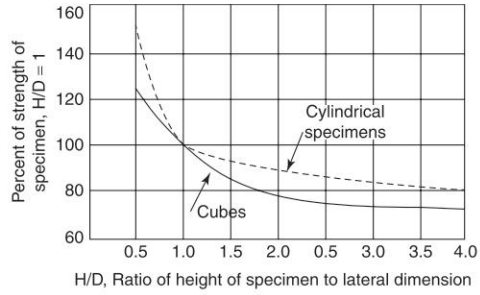


Fig. 8.6 *Variation of compressive strength with height/lateral dimension ratio of specimen*

The internal surface of the moulds should be machined flat to a tolerance of ±0.25 mm because even slight convexity or concavity will cause an appreciable change in recorded strength.

Specimens should remain in water right up to the time of test; even an hour's drying may have an appreciable effect upon the crushing strength. The specimen should be sent away for test so as to arrive at least two days before the testing date and they should be kept covered in wet sand during transport to the testing laboratory and should then be stored in water at 16°C to 30°C until the time of actual test.

In general, the failure of concrete under compression occurs due to shear on the planes inclined at an angle of $(45 - \varnothing/2)$ with the axis of loading resulting in a formation of cone of failure as shown in Fig. 8.7(a). The resistance of concrete to shear is provided by cohesion and internal friction between concrete particles. The angle of internal friction $\varnothing$ is approximately equal to 20°. However, in actual test, the presence of friction at the bearing plates at the ends of specimen restrains the internal expansion of concrete under compressive load. If this friction is reduced by using lubricants at the bearing surfaces, the failure occurs by splitting of concrete into series of vertical columns as shown in Fig. 8.7(e). This splitting failure occurs due to development of tensile strains along the perpendicular direction. As the concrete is weak in tension, a lower value of compressive strength is obtained. However, the effect of friction at the bearing surface decreases with the distance from the bearing surface. Therefore, the concrete specimens with smaller values of H/D ratio will record higher compressive strength. Hence, the compressive strength based on cube test specimens (H/D = 1) is larger than that obtained by testing standard cylinder specimens (H/D = 2). These two strengths can be roughly related as: cylinder strength, $f_c = 0.8 \times$ cube strength (σ_{cu}), for the concretes of grade M15 to M25.

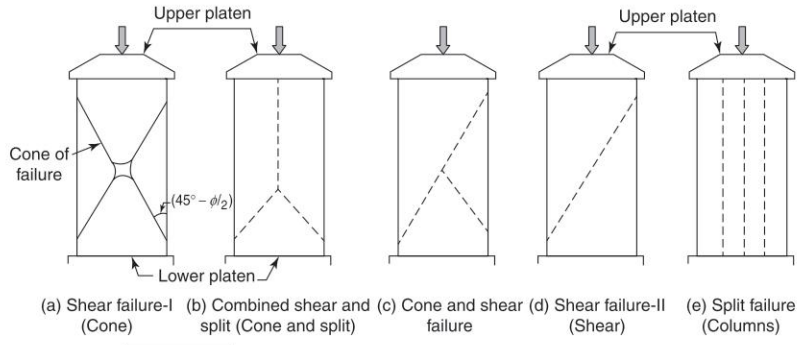


Fig. 8.7 *Failure modes of compression specimen*

Factors affecting results of crushing strength test

1. **Effect of size and shape of test specimen** Larger specimen gives a lower crushing strength than its smaller counterpart cast from identical materials. With the increase of slenderness ratio crushing strength decreases as shown in Fig. 8.6.
2. **Effect of loading** A quicker rate of loading will give an apparent increase in strength of test specimen. A rate of loading of 14 MPa/minute should always be used.
3. **Effect of position of application of load** Variation of modulus of rupture with beam size with centre-point load and third-point load are shown in Fig. 8.8.

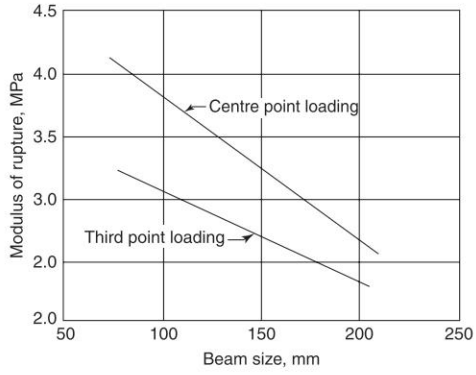


Fig. 8.8 *Variation of modulus of rupture with beam size point of application of load*

Viva-Voce Questions

1. How does strength correlate with other properties of hardened concrete?
2. Why is the strength tests commonly made?
3. What are different types of standard test specimens?
4. What is the relationship between length and diameter for compression test cylinder?
5. What is relationship between diameter of cylinder and maximum size of aggregate?
6. What does the flexure test measure?
7. Why is the flexure test preferred against tension test?
8. What are the size requirements of flexure test specimens?
9. What are the requirements for the mould, including base and cover plates?
10. What is the minimum number of specimens of a kind to be made for each age at testing?

11. What is the requirement concerning the size of the batch?
12. What procedure is adopted for mixing the batch (a) by hand and (b) mechanical mixer?
13. What is meant by buttering the mixer?
14. What is the method of compacting concrete, while preparing standard cubes and cylinder specimens?
15. What are the requirements for curing the specimens?
16. What is meant by capping the cylinder? How is it done?
17. What are the requirements concerning wetness or dryness of test specimens?
18. What are the rates of loading for compression tests?
19. What is the nature of compression failure of axially loaded concrete?
20. What type of loading is used in laboratory flexure tests?
21. What is the rate of loading in flexure test?
22. How are flexure test results expressed?
23. What precautions are exercised during moulding and testing of specimens?
24. What is the permissible variation in strength of a specimen while taking the average?
25. Why the cubes are tested on sides and not along the direction of casting?
26. In what respects, the cubes are better than the cylinder specimens?
27. What is the tolerance of internal flat surface of the mould?
28. What is the qualitative effect on indicated compressive strength of (a) size of concrete specimen, (b) slenderness, (c) moisture content and (d) rate of loading?
29. What is the approximate ratio of compressive strength of concrete to the tensile strength and to the flexural strength?
30. What variations in bearing conditions of concrete compression specimens are important?
31. Discuss the effect of rate of loading on indicated compressive strength of concrete, with approximate values?
32. Does the friction between the platens of compression testing machine and specimen affect the strength?
33. How does flexure specimen fail under the test?
34. What is the difference between cube strength and cylinder strength?

EXPERIMENT NO. 2: Split Tensile Strength of Concrete

Objective

To determine the split tensile strength of cylindrical concrete specimens of given mix proportions.

Theory and Scope

This test method which covers the determination of the splitting tensile strength of cylindrical concrete specimens consists of applying a diametral compressive force along the length of a cylindrical specimen. This loading induces tensile stresses on the plane containing the applied load; thus inducing tensile failure rather than compressive failure. Plywood strips are used so that the load is applied uniformly along the length of the cylinder. The maximum load is divided by appropriate geometrical factors to obtain the splitting tensile strength.

Apparatus

Compression testing machine; Two packing or bearing strips; Supplementary steel bearing bars; Cylinder moulds of 150 mm diameter and 300 mm height; Weighing machine; Mixer and Tamping rods.

Description of Apparatus

A compression testing machine of adequate capacity and with an arrangement for applying the load at the specified rate is required. The bearing face of both platens shall provide a minimum loading area of 12 mm × the length of the cylinder so that the load is applied over the entire length of the specimen. Typical loading arrangement for split tensile strength test of concrete cylinder is shown in Fig. 8.9.

Bearing or packing strips are 3 mm thick, 12 mm wide plywood strips of length slightly longer than that of the specimens conforming to IS: 303-1970 for each specimen. The bearing strips are placed between the specimen and the upper and lower bearing blocks of the testing machine (or between the specimen and supplementary bearing bars if used). The strips shall be used once only.

Supplementary bearing bars are 50 mm wide, 75 mm thick and 300 mm long steel bars.

Procedure

Step 1: Preparation of test sample: The test sample should be sufficient for casting three cylinders of 150 mm diameter × 300 mm length (about 40 kg).

(a) Take representative sample of fresh concrete in case monitoring the quality of fresh concrete.
(b) In the case of trial mix testing calculate the materials required for the test batch. Mix them thoroughly in a mechanical mixer until uniform colour of concrete is obtained.

In mixing by hand, the cement and fine aggregate shall be first mixed dry to uniform colour and then the coarse aggregate is added and mixed until the coarse aggregate is uniformly distributed throughout the batch. Now the water shall be added and whole is mixed until the resulting concrete is uniform in colour. Mix at least for two minutes.

Step 2: Pour concrete in moulds oiled with medium viscosity oil. Fill the cylinder mould in four layers each of approximately 75 mm and ram each layer more than 35 times with evenly distributed strokes.

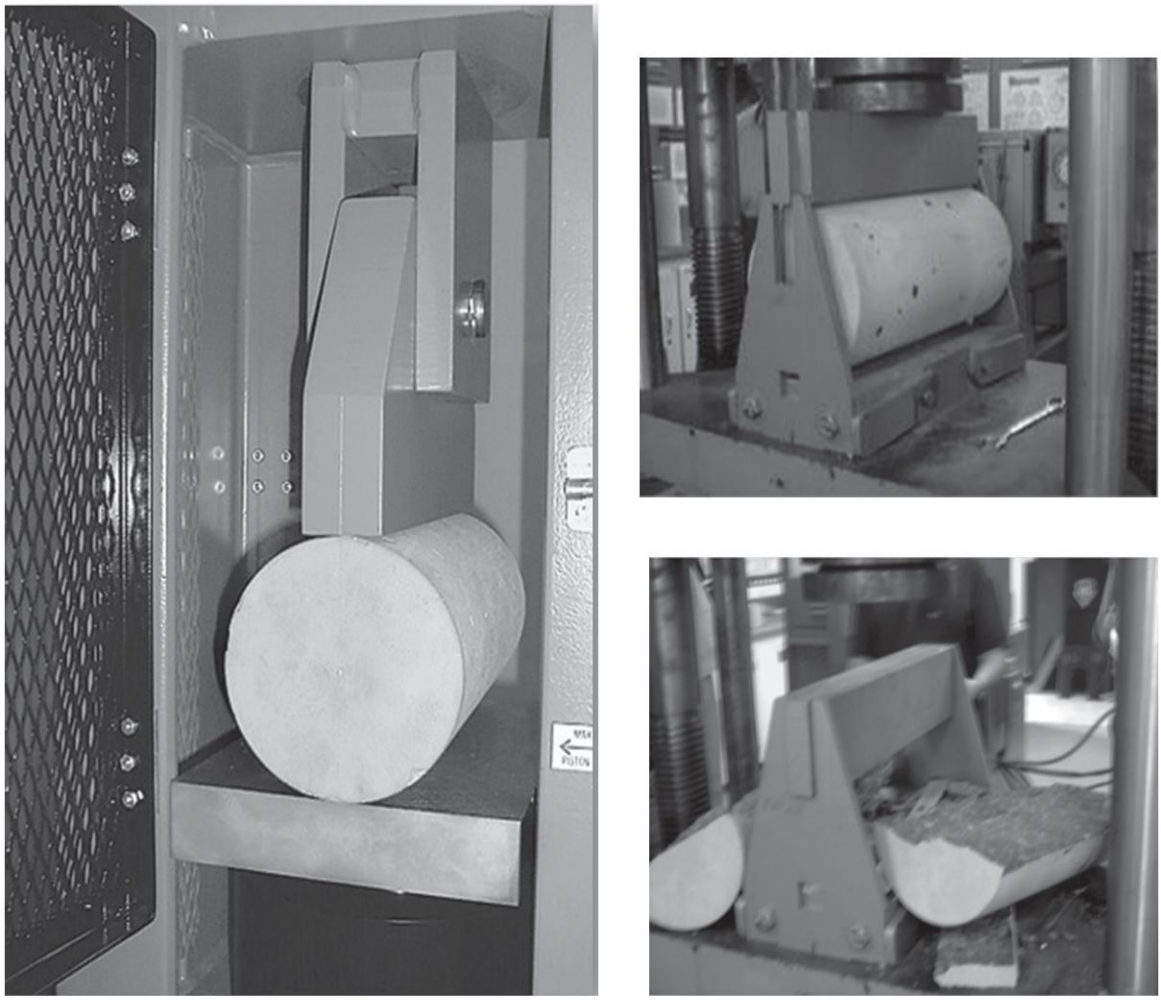


Fig. 8.9 *Split tensile strength test of concrete and failure mode of concrete cylinder*

Step 3: Remove the surplus concrete from the top of the moulds with the help of a trowel.

Step 4: Cover the moulds with wet mats and put the identification marks after about 3 to 4 hours.

Step 5: Remove the specimens from the moulds after 24 hours and immerse them in water for the final curing. The tests are usually conducted at the ages of 7 and 28 days. The age shall be calculated from the time of addition of water to the dry ingredients.

Step 6: Test at least three moist-cured concrete cylinders specimens for each age of test as follows:

(a) Draw four lines on the sides of specimen to mark the edges of load plane; the diametrical lines on two ends of the specimen are in the same axial plane. Use the marked lines to align the test specimen before applying the load. The loading configuration of the test is shown in Fig. 8.10.

(b) Determine the diameter of the specimen to the nearest 0.2 mm by averaging the diameters of the specimen lying in the plane of pre-marked lines measured near the ends and the middle of

the specimen. The length of the specimen also shall be record to the nearest 0.2 mm by averaging the two lengths measured in the plane containing the pre-marked lines.

(c) Centre one of the plywood strips along the centre of the lower platen or bearing block. Place the specimen on the plywood strip and align it so that the lines marked on the end of the specimen are vertical and centred over the plywood strip. Place the second plywood strip lengthwise on the cylinder centred on the lines previously marked on the ends of the cylinder.

(d) Position the assembly so that the lines marked on the ends of the specimen are vertical and the projection of the plane passing through these two lines intersect the centre of the platen.

Step 7: Apply the load without shock and increase it continuously at a rate to produce a split tensile stress of approximately 1.4 to 2.1 MPa /minute until no greater load can be sustained. Record the maximum load applied to the specimen.

Step 8: Note the appearance of concrete and any unusual feature in the type of failure.

Step 9: Compute the split tensile strength of the specimen to the nearest 0.05 MPa.

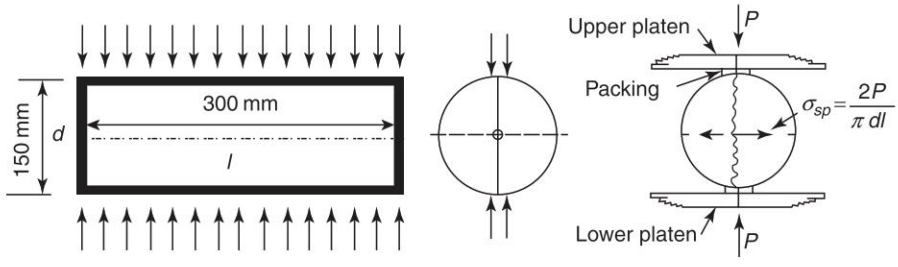


Fig. 8.10 *Loading arrangement for determination of the split tensile strength*

Observations and Calculations

Identification mark and the date of test				
Age of the specimen at the date of test				
Curing history				
Mass of specimen,	kg			
Maximum load at failure,	P kN			
Diameter of the specimen,	d mm			
Length of the specimen,	l mm			
Splitting strength of concrete, $\sigma_{sp} = \frac{2P \times 1000}{\pi dl} = 637\left(\frac{P}{dl}\right)$	MPa			
Type of fracture and appearance of concrete on the fractured face.				

Split tensile strength of concrete is……MPa.

Precautions

1. The mould and the base plate must be oiled lightly before use.
2. The specimen should be made and cured as per IS: 515-1959.
3. The specimen should be tested immediately on removal from the water whilst they are still wet. The specimens when received dry should be kept in water for 24 hours before they are taken for testing.
4. The surface water and grit should be wiped off the specimens and any projecting fins removed from the surface which is to be in contact with the packing strips.
5. The bearing surfaces of the test machine and of the packing strips shall be wiped clean.
6. The cylinder should be placed in testing machine centrally.
7. The load should be applied without shock.

Discussion

The *tensile strength* of concrete determined by this method is generally referred to as *split tensile strength* of concrete. The test has been standardised for concrete specimens with diameter larger than four times the maximum size of coarse aggregate or 150 mm whichever is greater. The length of the specimens shall not be less than the diameter and not more than twice the diameter. For routine testing, the specimens shall be cylinders 150 mm in diameter and 300 mm in length; for concrete having maximum nominal size of aggregate greater than 40 mm, the sample of aggregate shall be screened to exclude aggregate of size larger than 40 mm.

The ratio of the split tensile strength to cylinder compressive strength not only varies with the grade of the concrete but is also dependent on the age of concrete. This ratio is found to decrease with time after about a month. The flexural strength as obtained by rupture test is found to be greater than the split tensile strength.

The flexural tensile strength of concrete is related to its compressive strength as

$$f_{cr} = 0.7\sqrt{f_{ck}}$$

where f_{cr} = tensile strength of concrete in MPa and
f_{ck} = characteristic strength of concrete in MPa.

Split tensile strength is popular because of the following advantages:

1. The test is simple to perform and gives more consistent results than that given by other tests.
2. The strength determined is closer to the actual tensile strength of concrete than the modulus of rupture value.
3. The cylinders need not be capped.
4. The same moulds and testing machine can be used for compression and tension tests.

Similar to the splitting of the cylinder cubes can also be split either (a) along its middle parallel to the edges by applying opposite compressive forces through 15 mm square bar of sufficient length or (b) along one of its diagonal planes by applying compressive forces along two opposite edges. In the side splitting of cubes, the tensile strength is obtained from $\sigma_{sp} = 0.642\ P/S^2$ and in diagonal splitting it is determined from $\sigma_{sp} = 0.5187\ P/S^2$ where P is the failure load and S is the side of the cube.

Viva-Voce Questions

1. What are the different methods for determining the tensile strength of concrete?
2. What is the basic difference between the direct and indirect methods used in the tensile strength determinations? Which one is superior and why?

3. What is the significance of split cylinder test?
4. What is the relation between tensile strength and compressive strength?
5. Why are plywood strips used in this test?
6. What is the relation between split strength and the flexure strength?
7. What is the rate of loading in split cylinder test? Can the cubes also be splitted? If yes, which one of these tests will give more reliable results?

Notes and Comments

EXPERIMENT NO. 3: Modulus of Elasticity of Concrete

Objective

To plot stress-strain curve for concrete of given mix proportions and to determine the modulus of elasticity by means of a compressometer as per IS: 516-1959.

Theory and Scope

This test method covers determination of modulus of elasticity of moulded concrete cylinder or prism. The modulus of elasticity is defined as the slope of the chord from the origin to a point on the stress-strain curve representing some percentage of ultimate strength of concrete as determined by compression test as shown in Fig. 8.11(a). This is called *secant modulus* and provides a stress to strain ratio value for hardened concrete at specified age and curing conditions.

The modulus of elasticity of concrete is a fundamental parameter in analysis and design of reinforced and plain concrete structural members. There are two types of elastic modulus. The *static modulus* is measured by plotting the deformation of a cylinder under an applied load, usually 30–40 per cent of the ultimate load. The *dynamic modulus* is determined by resonance methods or by the measurement of ultrasonic pulse velocity (UPV). The two test procedures do not give the same measured value of the modulus.

The results obtained from this experiment are used to study the behaviour of concrete subjected to prolonged loading which has special importance as the concrete is not truly elastic material as it possesses the ability to 'creep' during and after the application of load. There are some preliminary loading cycles to remove the effect of creep; the phenomenon has been explained in this experiment.

Apparatus

Compression testing machine; Compressometer; Mixing pan; Tamping bar; Trowels; Capping apparatus.

Description of Apparatus

Testing machine The testing machines should be of adequate capacity and capable of maintaining the stipulated rate of loading. For this test 2000 kN compression testing machine is required.

Compressometer Compressometer is used to determine the deformation and strains on 150 mm diameter and 300 mm high cement concrete cylinder specimen when subjected to compressive loads. It consists of a frame with a bottom ring and a top ring with hardened and tapered tightening screws to firmly clamp the compressometer over the cylinder specimen. Two spacers hold the two frames in position. A dial gauge typically with a range of 12 mm and readable to 0.002 mm is mounted on the upper ring and the tip of the dial gauge rests on an anvil. The zero on the dial gauge can be set by adjusting the anvil screw. They shall be capable of measuring strains to an accuracy of 2×10^{-6}. Two types of compressometer are available:

1. Compressometer with a dial gauge and
2. Compressometer with a digital indicator or a LSCT transducer which can be used with data acquisition systems through the use of loggers.

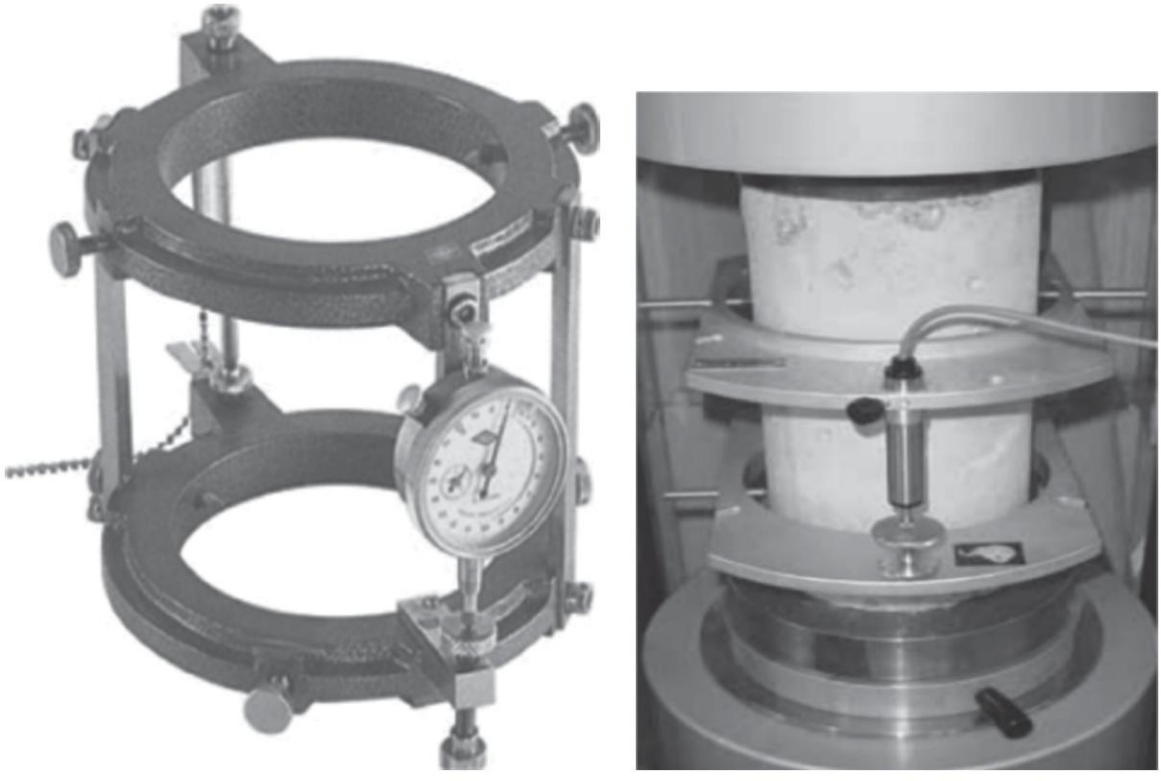


Fig. 8.11 *(a) Compressometer with a dial gauge and (b) Compressometer with a LSCT transducer*

Procedure

Part 1: Preparation of test sample

The test sample should be sufficient for casting three cylinders of 150 mm diameter × 300 mm height (about 40 kg) and three 150 mm cubes (25 kg).

Calculate the materials required for the test batch. Mix them thoroughly in a mechanical mixer until uniform colour of concrete is obtained.

In mixing by hand, follow the standard procedure and mix for at least 2 minutes.

Step 1: Cast three 150 mm cubes and three 150 × 300 mm cylinders following the standard procedure adopted in preceding tests.

Step 2: Apply proper capping to the top of the cylinders.

Step 3: Cure the specimens under water for 28 days.

Step 4: Test the three cubes in wet condition for 28 day ultimate compressive strength and determine the average compressive strength f_{cu} to the nearest 0.5 MPa.

Step 5: Place the concrete cylinder upright. Unscrew the contact screws (generally two on the upper lock ring, three on the lower lock ring) until the points are flush with the inside surface of the rings.

Step 6: Place the compressometer over the wet concrete test specimen locating the specimen at the center of the ring. Place three equal height blocks under the lower ring. The height of the blocks should be vertical to provide the correct placement of compressometer parallel to its axis in such a way that the gauge points are symmetrical about the centre of the specimen and in no case are nearer to either end of the specimen than a distance equal to half the diameter of the specimen. Hand-tighten the contact screws in the lower and upper rings against the specimen; remove the spacers. Follow the instructions supplied by the manufacturer relevant to the measuring equipment.

Step 7: Place the specimen with attached compressometer immediately on the lower platen of the test machine.

Step 8: Carefully align the axis of the specimen with the centerline of the upper thrust block of the cross head.

Step 9: Lower the crosshead down until it is in almost contact with the specimen.

Step 10: Adjust the dial gauges to zero.

Step 11: Load the specimen at a rate of 14 MPa/minute until a load of $[(f_{cu}/3) + 0.5]\ A_c \times 10^3$ kN is reached, where f_{cu} and A_c are the average compressive strength of cubes and sectional area of cylinder, respectively. Maintain the load at this stress for at least 1 minute and then reduce it gradually to an average stress of 0.15 MPa. Note the dial gauge reading on the compressometer.

Step 12: If the dial-gauge reading (deformations) is not zero, repeat step 11 until the dial gauge reading, upon unloading is zero.

Step 13: Finally at third or fourth cycle, load the test cylinder at the rate of 14 MPa/minute and continue the loading slowly until 35 per cent of ultimate load is reached. Record the compressometer readings continuously at 10 approximately equal increments of load. If data acquisition system is used, sample deformations and load simultaneously at much shorter interval.

Step 14: Calculate the stress and strains for each cylinder as follows:
Stress, $\sigma = P/A$
where P is the applied load and A is the cross-sectional area of the cylindrical specimen.
Strain, $\varepsilon_x = d/L_o$
where d is the longitudinal deformation of specimen obtained from the dial gauge reading and L_o is the gauge length, the distance between rings, and is generally equal to 200 mm for 150 mm diameter specimens.

Step 15: After loading to 35 per cent of ultimate cube strength and recording the load versus displacement data, unload the specimen. Remove the compressometer (the compressometer may be left in place when appropriate to generate the entire stress vs. strain curve to failure).

Step 16: Perform an unconfined compression test in accordance with codal provisions, i.e., at the specified loading rate.

Step 17: Plot the stress-strain curve (stress on the ordinate and strain on the abscissa).

Step 18: Calculate the (secant) modulus of elasticity E at 35 per cent of cube strength to the nearest 100 MPa as follows:

$$E = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - 0.00005}$$

where σ_2 is the stress corresponding to 35 per cent of ultimate load, σ_1 the stress corresponding to a strain of 0.00005, and ε_2 the strain at a stress of σ_2.

Observations and Calculations

The strains at the various loads in the last two cycles are calculated separately for each compressometer and the results shall be plotted graphically against the stress. Straight lines shall be drawn through the points for each compressometer; the slopes of these two lines shall be determined and from them the average value shall be found. If the difference between the individual values is less than 15 per cent of the average value,

this average value, expressed in MPa to the nearest 100 MPa is recorded as the modulus of elasticity of the concrete. If the difference is greater than 15 per cent, the specimen should be re-centred in the testing machine and the test repeated. If the difference after re-centreing and testing is still greater than 15 per cent of the average value, the results of the test shall be discarded.

Cube strength of concrete of given mix proportions	Specimen No.	Load, kN	Strength, Mpa	Average cube strength, MPa
	1.			
	2.			
	3.			

Compressometer Readings

Sl. No.	Test cylinder 1		Test cylinder 2		Test cylinder 3	
	Load, kN	C.R.	Load, kN	C.R.	Load, kN	C.R.
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						

C.R. stands for compressometer reading.

Calculations

1.	Sectional area of cylinder,	mm^2	17671.46
2.	Gauge length of cylinder, L_0	mm	
3.	Stress due to load P, $\frac{P}{\text{Area}}$	MPa	
4.	Strain $= \frac{d}{L_0}$		

Stresses and Strains

Sl. No.	Load, kN	Stress, MPa	Strain in Specimens		
			I	II	III
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

Secant Modulus

Average strength of cubes	MPa			
35 per cent of cube strength,	MPa			
Specimen No.		I	II	III
Strain at 35 per cent of cube strength				
Secant modulus at 35 per cent of cube strength,	MPa			

Average secant modulus is…… MPa.

Precautions

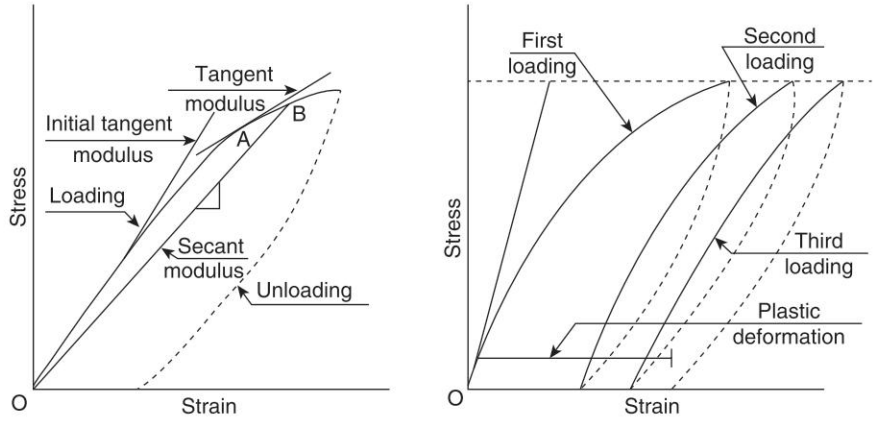
1. While filling the moulds compacting strokes should be uniformly applied over the whole surface.
2. The specimen for determining the modulus of elasticity should be loaded and unloaded three times to the stress of one third of ultimate strength.
3. The compressive strain shall be read at intervals during second and third loading and if they differ by more than five per cent, the loading should be repeated until strains of successive cycles do fall within this limit.
4. Two compressometer may be used to check on eccentric loading. If the slopes of stress-strain relations determined from each extensometer differ more than 15 per cent of average value, the test specimen should be centred again within the testing machine and test repeated until they fall within this limit.

Discussion

In this test, modulus of elasticity is determined by measuring the compressive strain when a cylindrical test specimen with height at least twice its diameter is subjected to a compressive stress and plotting the stress-

strain curve. The modulus of elasticity is taken as the slope of the chord from the origin to some chosen point *A* on the stress-strain curve as shown in Fig. 8.12(a). This is called secant modulus. Sometimes modulus of elasticity is taken as slope of the tangent at the origin called initial tangent modulus or the slope of tangent at some arbitrary chosen point *B* (called tangent modulus). However, the tangent at the origin is difficult to draw accurately. These are all measurements of the static modulus. The initial tangent modulus is also approximately equal to the dynamic modulus and, by definition, is only applicable at very low stress levels. The most generally useful measure is the secant modulus. The modulus of elasticity of lightweight aggregate concrete is about 60–70 per cent of that of normal weight concrete.

The curvature of the stress-strain curve and the deformation will be relatively greater if the rate of application of the load is slower, as in that case the concrete will have time to creep. If the concrete is repeatedly loaded and unloaded it is seen that effect of creep diminishes with each repetition, i.e., stress-strain curve becomes more linear (flatter) with each repetition of loading as shown in Fig. 8.12(b).



(a) Concrete subjected to single loading (b) Concrete subjected to repeated loading

Fig. 8.12 *Stress-strain curves for concrete subjected to loading*

The ultimate compressive strength of concrete shall be determined by testing three cubes at the time when the specimen is tested for determining the modulus of elasticity. The modulus of elasticity of concrete is related to its 28-day compressive strength. For normal weight concrete, it is given by

As per ACI: $E_c = 4700\sqrt{f_c}$

As per BIS: $E_c = 5000\sqrt{f_{ck}}$

where

E_c = Elastic modulus of concrete in MPa and
f_c = Uniaxial compressive strength of concrete after 28 days curing in MPa.

The modulus of elasticity increases with age and with reduction in water-cement ratio as does the compressive strength. It is also affected appreciably by mix proportions, since the aggregate has a higher elastic modulus than the cement paste (mortar) as illustrated in Fig. 8.13 and, therefore, a leaner mix will have a higher value than a richer mix with same water-cement ratio. Similarly, type of aggregate also affects the elastic modulus of the concrete in accordance with its own elastic modulus.

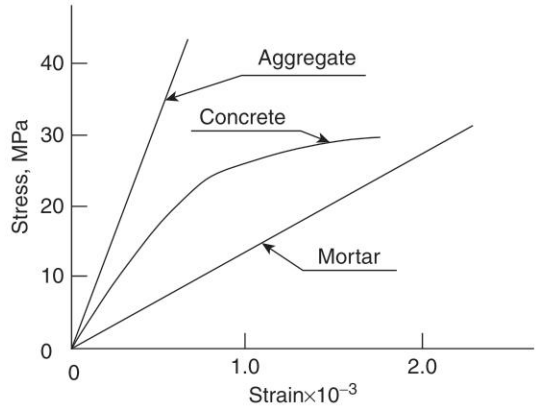


Fig. 8.13 *Stress-strain curves for aggregate, cement mortar and concrete*

The modulus of elasticity values obtained are usually less than moduli derived under rapid load application, e.g., dynamic or seismic rates and are usually greater than values under slow load application or extended load duration, provided other test conditions remain the same.

The modulus of elasticity measured using 100 × 200 mm cylinders on an average are higher than that obtained from 150 × 300 mm standard test cylinders. The method is equally applicable to diamond-drilled concrete cores when under longitudinal compressive stress.

In practice, *effective modulus of elasticity* which takes into account the movement due to creep, is used.

$$\text{Effective modulus} = \text{True modulus (ignoring creep)} \times \frac{1}{\varepsilon + c}$$

In this expression, ε and c elastic strain and creep movement under unit stress in the time under consideration.

The use of two dial gauges along two diametrically opposite generators can eliminate the effects of eccentric loading. Repeated loading and unloading reduces the subsequent creep so that the stress-strain curves on third or fourth loading exhibits only small curvature. Thus the specimen is subjected to a number of loading and unloading cycles to a stress level equal to 1/3 the ultimate strength of concrete. The cycles are generally repeated until the deformation observations differ not more than 5 per cent. From the stress-strain curve the secant modulus can be determined at the level of working stress in concrete.

Compressometer-Extensometer consists of a third ring between the two compressometer rings attached at the mid-height of the specimen at two diametrically opposite points which carries an dial or digital indicator to measure horizontal extension in the diameter of the test specimen. This allows a combined determination of both modulus of elasticity and Poisson's ratio.

The modulus of elasticity can also be determined by testing concrete beams in flexure.

Viva-Voce Questions

1. Why is the secant modulus of elasticity the most practical one?
2. What are the requirements of the specimen to be subjected to compressive stress for determining modulus of elasticity?
3. What is the significance of elasticity?
4. What is the rate of loading in this test?
5. What precautions are taken while recording the dial readings?
6. Why the specimen is loaded and unloaded a number of times before actually taking readings?
7. How is the elastic modulus calculated?

8. What is the stress level to which the specimen loaded?
9. What is the range of values of modulus of elasticity for concrete?
10. How is the modulus of elasticity effected by age, mix proportions, water-cement ratio, aggregate, free moisture and strength?
11. What is the effect of rate of loading on the modulus as determined?
12. What is effective modulus?
13. What is meant by creep?

Notes and Comments

EXPERIMENT NO. 4: Coefficient of Shrinkage and Expansion

Objective

To determine the

1. *Coefficient of drying shrinkage.*
2. *Moisture movement.*
3. *Coefficient of expansion of cement concrete for different water-cement ratios, e.g., 0.5 and 0.7.*

Theory and Scope

The test is used for determining hydraulic axial shrinkage of concrete, using normal aggregates. When concrete is cast and cured under wet conditions and subsequently dried, it shrinks in volume during the drying process; this is called the *initial drying shrinkage.* Any subsequent expansion due to re-saturation is called *moisture movement* as indicated in Fig. 8.14.

Volume change is one of the most detrimental properties of concrete which is responsible for the presence of unsightly cracks. The cracks affect the long-term strength and durability of concrete structure. One of the important factors that contribute to the cracks in floors and pavements is that due to shrinkage. As shrinkage is an inherent property of concrete it demands greater understanding of the various properties of concrete, which influence its shrinkage characteristics.

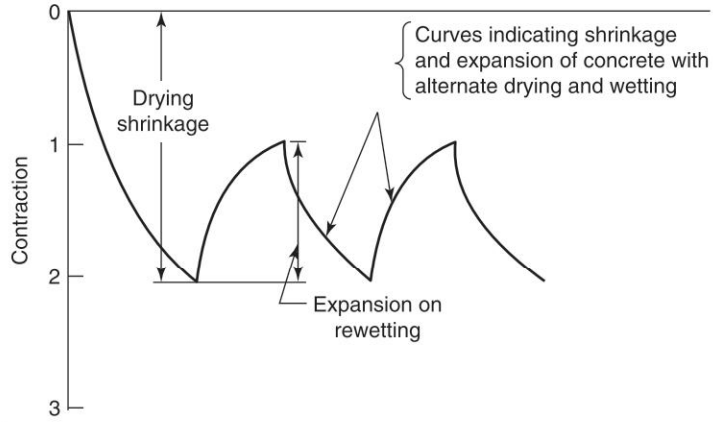


Fig. 8.14 *Drying shrinkage and moisture movement with alternate drying and wetting*

In restrained concrete members, excessive shrinkage may result in the development of tensile stresses sufficiently high to cause cracking. These stresses may be as high as 3.5 MPa, large enough to cause cracks in concrete unless it is suitably reinforced. In prestressed concrete members, the shrinkage has the effect of reducing the force exerted by tensioned reinforcement, a factor which has to be taken into account in calculations.

Compressive stresses are set up in restrained concrete members due to the expansion of concrete on wetting (moisture movement).

Apparatus

Weighing balance with weights; Prism moulds; Shrinkage tester; Calibration bar and precision dial gauge (0.001 mm sensitivity, i.e., the datum reading); Drying oven; Mixing pan; Graduated cylinder; Trowels; Tamping rod.

Description of Apparatus

Steel shrinkage prism moulds The 100 × 100 × 300 mm prism mould consists of cast iron sides with a wooden base. It is of a standard length such that the length of the specimen plus the length of two knobs (inserts), when attached at its two indented ends, equals the length of standard rod. The standard rod made of invar steel exactly 340 mm in length is used as a comparison bar.

Shrinkage tester This consists of horizontal rectangular steel frame moving along its length on rollers. The rollers are mounted on a wooden base provided with four levelling screws. The frame has a fixed stud on one short side to register with one of the reference points of the specimen and a micrometer screw capable of reading accurately to 0.01 mm on the other side.

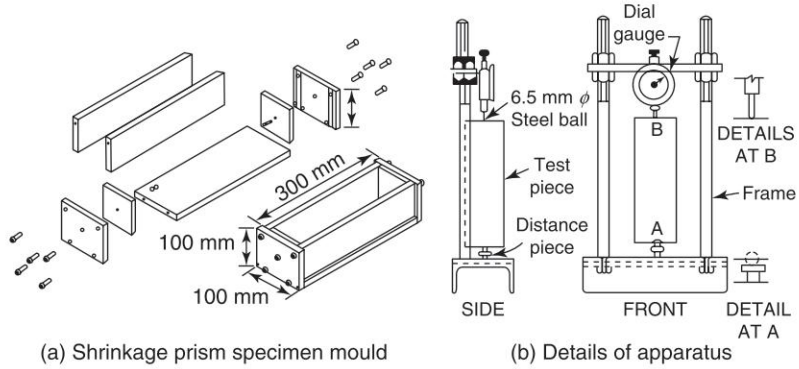


Fig. 8.15 *Typical prism mould and apparatus for drying shrinkage and moisture movement tests*

The micrometer screw has an arrangement by which only a fixed pressure can be applied by the screw against the specimen or the standard rod. The screw would be disengaged as soon as this standard pressure is exceeded so that any error due to unequal pressures is eliminated. Alternatively, in some testers a dial gauge is used instead of micrometer screw as shown in Fig. 8.15(b).

Procedure

Step 1: Take 1:2:4 as mix proportions by mass and prepare the concrete with 24 kg of coarse aggregate for each mix.

Step 2: Prepare two concrete specimens with water-cement ratio of 0.5 and 0.7 each.

Step 3: Make a hole of about 12 mm diameter and 25 mm deep at the top of specimens to fill mercury for taking the temperature of concrete specimen.

Step 4: Mould the stainless steel plugs with spherical ends into the specimen.

Step 5: Cure concrete specimens for 28 days.

Step 6: Remove the specimens from the curing tank and measure initial lengths (L_1) of wet specimens on the shrinkage tester immediately after the removal from the curing tank.

Step 7: Fix the reference points (the standard plugs 20 mm long) in the indentations made at the ends of the specimens for taking the measurements.

Step 8: Keep these specimens in an oven to dry at a temperature of 50 ± l°C for one week in a relative humidity of 17 per cent (obtained by saturated $CaCl_2$ solution).

Step 9: Remove the specimens from the oven and allow them to cool for at least four hours.
Step 10: Measure the lengths (L_2) of the specimens on shrinkage tester and determine the initial drying shrinkage.
Step 11: Again immerse the specimens in water in such a manner that one of the larger faces of the specimen just breaks surface in the water and leave these specimens immersed in water for another one week, after which determine the final wet measurement (L_3).
Step 12: Calculate the moisture movement as the difference between the dry measurement and final wet measurement expressed as percentage of the dry length.

Note: Record the temperature of the specimens at the time of length measurement in all the above cases and apply the *temperature correction* while calculating coefficient of drying shrinkage and moisture movement. In a standard test all the measurements are taken at the same temperature of 24°C.

Coefficient of expansion Use the same specimens for determining the coefficient of expansion.
Step 1: Dry the specimens in an oven for seven days.
Step 2: Take the dry measurement (L_4) of the specimens after cooling and also record body temperature.
Step 3: Place these specimens again in an electric oven adjusted to give a temperature of about 180°C and keep them there for about an hour so that the entire mass of the specimen attains same temperature.
Step 4: Measure the lengths (L_5) of the specimens along with their increased body temperature.
Step 5: Calculate the coefficient of expansion as follows:

$$\frac{\text{Increase in length}}{\text{Initital length} \times \text{Rise of temperature}}$$

Observations and Calculations

1. For shrinkage and moisture movement

Water-cement ratio		L_1, mm	Temperature, °C	L_2, mm	Temperature, °C	L_3, mm	Temperature °C	L_4, mm	Initial drying shrinkage		Moisture movement		Drying shrinkage	
										Average		Average		Average
0.5	1													
	2													
0.7	1													
	2													

2. For coefficient of expansion

Water - cement ratio		Dry length L_4, mm	Temperature, °C	Final length, L_5, mm	Temperature °C	Coefficient of expansion	
							Average
0.5	1						
	2						
0.7	1						
	2						

Precautions

1. While casting the specimen, the strokes of tamping rod should be uniformly distributed over the longitudinal section of the prism.
2. Plugs should be removed soon after the setting starts.
3. It is essential to make comparison measurement every time with standard rod because any change in length of frame carrying micrometer screw and fixed stud of shrinkage tester, will influence the reading considerably.
4. All measurements should be taken at the same temperature of 24°C and temperature correction should be applied.

Discussion

During setting, the concrete undergoes a very slight expansion due to hydration of cement but on subsequent drying it shrinks. The extent of this shrinkage depends upon the mix proportions and water-cement ratio. The shrinkage increases with cement content or with water-cement ratio as shown in Fig. 8.16. Most of this drying shrinkage takes place during the first few weeks after casting. The average reduction in length of a concrete specimen which might be expected after 28 days is 0.03 per cent and at the end of 12 months this value would probably be increased to 0.05 per cent.

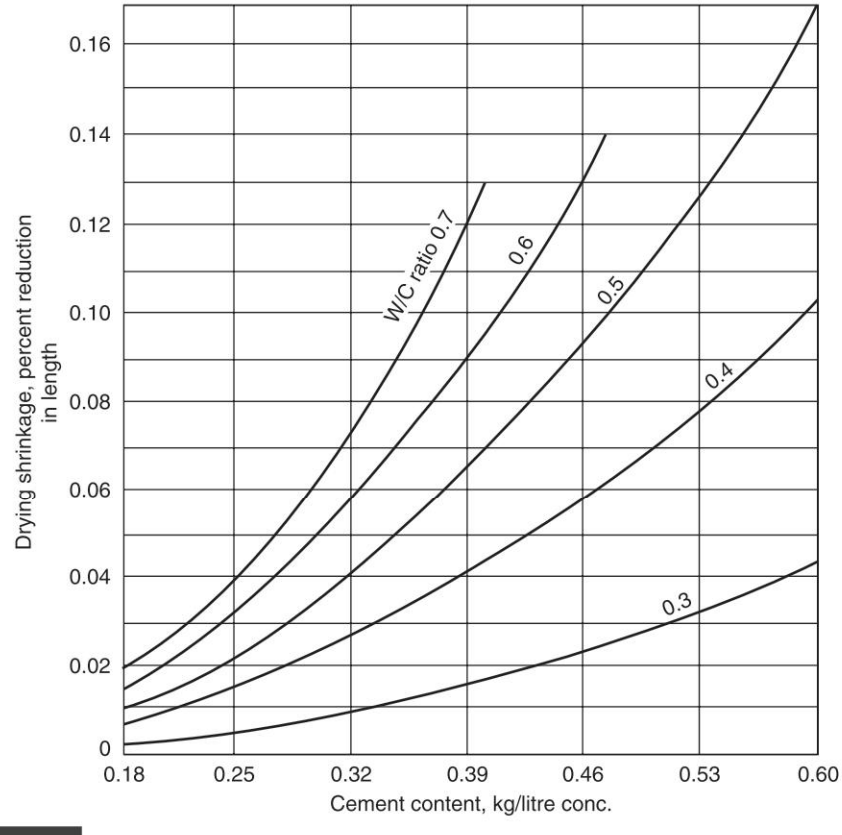


Fig. 8.16 *Variation of drying shrinkage with cement content and water-cement ratio*

Rate of shrinkage is greater when concrete is dried at high temperature and low atmospheric humidity than that dried at low temperature and high atmospheric humidity as shown in 8.17.

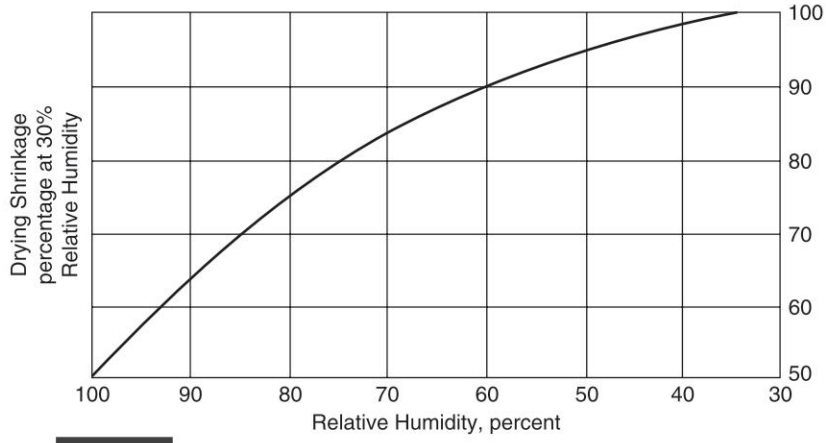


Fig. 8.17 *Effect of relative humidity on the shrinkage of concrete*

The shrinkage of concrete is also influenced by the type of the aggregate as given in Fig. 8.18. If shrinkage is restrained, cracking may occur and the concrete will require adequate reinforcement to limit crack widths. In prestressed concrete, shrinkage will result in loss of prestress. In asymmetrically reinforced concrete, deflections will increase. Axially loaded columns or walls may be subject to increased shortening and creep may be increased with increased shrinkage.

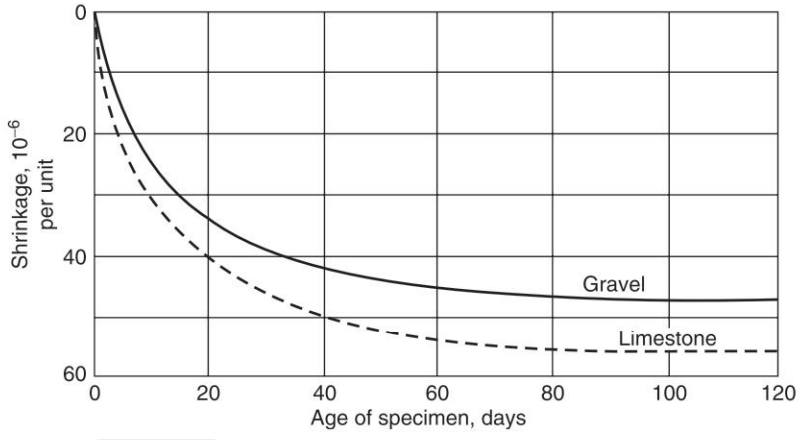


Fig. 8.18 *The effect of type of aggregate on shrinkage*

Porous mixes resulting from the use of too much sand or too much water should not be used if moisture movement is to be kept to a minimum.

The coefficient of thermal expansion, α_c, of concrete is a measure of the free strain produced in concrete subject to a unit change in temperature and is usually expressed in micro-strain per degree centigrade; values typically lay in the range 8–13 μ/°C. The occurrence of thermal strain has a number of design implications as: need to provide joints to accommodate the thermal movement; the provision of tolerances for elements attached to the concrete, for example, cladding panels. Design of reinforcement is required to control crack widths when the thermal contraction is restrained.

Viva-Voce Questions

1. Why is contraction usually of more significance than expansion in a concrete structure?
2. What is initial drying shrinkage?
3. What is the effect of shrinkage on concrete members?
4. What is moisture movement? What is its significance?
5. What is the requirement of immersion of specimen in water, before taking final wet measurement?
6. What factors affect shrinkage and expansion of concrete due to moisture changes?
7. How is the shrinkage of cement paste related to its fineness?
8. What effect does the type of aggregate and its maximum size have upon shrinkage of concrete?
9. Two concretes are of same dry mix, but one has a wetter consistency, how would their shrinkage compare?
10. Why is the unit shrinkage less for a large mass than for a small specimen?
11. Two concretes have same water-cement ratio, but one is a richer mix, how would their shrinkage compare?
12. How is the shrinkage affected by the curing conditions?
13. What is the effect of aggregate and richness of the mix upon thermal volume changes of concrete?

Notes and Comments

NATIONAL STANDARDS

1. IS 456:2000 (4th revision, reaffirmed 2011): *Code of Practice for Plain and Reinforced Concrete*.
2. IS 516:1959 (reaffirmed 2008): *Methods of Test for Strength of Concrete*.
3. IS 1199-1959 (reaffirmed 2008): *Methods of Sampling and Analysis of Concrete*.
4. IS 5816:1999 (1st revision, reaffirmed 2008): *Method of Test for Splitting Tensile Strength of Concrete*.
5. IS 6461 (Part 10) -1973 (reaffirmed 2011): *Glossary of Terms Relating to Cement Concrete; Part 10: Tests and Testing Apparatus*.

REFERENCES

1. AASHTO TP 60-00-2004: *Standard Test Method for Coefficient of Thermal Expansion of Hydraulic Cement Concrete.*
2. AS 1012.13-1995*: Methods of Testing Concrete – Determination of Drying Shrinkage of Concrete for Samples Prepared in the Field or in the Laboratory Standards, Australia*.
3. ASTM C39: *Compressive Strength of Cylindrical Concrete Specimens.*
4. ASTM C78: *Flexural Strength of Concrete* (*Using Simple Beam with Third-Point Loading*).
5. ASTM C469 / C469M – 10: *Standard Test-Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.*
6. ASTM C617: *Capping Cylindrical Concrete Specimens.*
7. BS ISO 1920-8:2009: *Testing of concrete- Determination of the Drying Shrinkage of Concrete for Samples Prepared in the Field or in the Laboratory.*
8. Gambhir, M. L., *Concrete Technology*, 4th Edition, Tata McGraw-Hill Education, 2009
9. Gambhir, M. L. and Neha Jamwal, *Building Materials: Products, Properties and Systems*, Tata McGraw-Hill Education, 2011.

NON-DESTRUCTIVE TESTING

Section 9

This section describes the non-destructive tests generally performed on hardened concrete. These include rebound hammer test, ultrasonic pulse velocity test and dynamic modulus of elasticity test. The physical characteristics of hardened concrete as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

9.1 INTRODUCTION

The main objective of *non-destructive* methods as applied to concrete is to provide reliable estimate of quality of concrete in a structure without relying solely on the results from the test specimens which are not necessarily representatives of structural concrete.

There can be no direct measurement of strength properties of structural concrete since the derivation of strength involves destructive stresses. It is, therefore, necessary to measure some other physical property of structural concrete which is related to the strength and which can be obtained by non-destructive methods. One such property is the *dynamic Young's modulus,* e.g., ratio of *longitudinal stress* to corresponding *stain.* This estimation is based on the fact that as the cement hardens, there is rapid increase in *shear modulus* and *Young's modulus* accompanied by corresponding rapid increase in the strength of concrete. However, once hardening process has slowed down, variation in strength of the concrete is markedly affected by the percentage of voids present, the more porous the concrete the lower its strength.

9.2 TEST METHODS

A number of non-destructive methods of testing of concrete have been developed and some of them have been standardised as well.

The comparatively more popular methods for the NDT of concrete, with some typical applications, are briefly described in this section.

9.2.1 Schmidt/Rebound Hammer Test

The rebound hammer, a spring-loaded steel hammer, is principally a surface hardness tester. It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The method basically measures the modulus of elasticity of the near surface concrete. The principle is based on the absorption of part of the stored elastic energy of the spring through plastic deformation of the surface concrete and the mechanical waves propagating through the stone while the remaining elastic energy causes the actual rebound of the hammer. The distance travelled by the mass, expressed as a percentage of the initial extension of the spring, is called the *rebound number*.

There is little apparent theoretical relationship between the strength of concrete and the rebound number of the hammer. However, within limits, empirical correlations have been established between strength properties and the rebound number.

Calibrate the apparatus set up by making measurements on two standard reference specimens in which the pulse transit times are known accurately. The measurement obtained should not differ from the known value for the reference specimen by more than 0.5 per cent.

9.2.2 Resonance Methods

The test specimen is usually the standard specimen prescribed for flexure or compression test. In these methods, the beams with the ends free from restraint are set into vibration in either *longitudinal* or *flexural modes* and dynamic response is recorded. A typical resonant frequency tester is shown in Fig. 9.1.

1. **Longitudinal vibrations** A beam clamped at its midpoint as shown in Fig. 9.2(a) is vibrated by an electro-dynamic vibration generator and piezo-crystal pick-ups are moved along the sides until they make mechanical contact with the end of the beam without imposing any appreciable restraint on the ends of the beam.

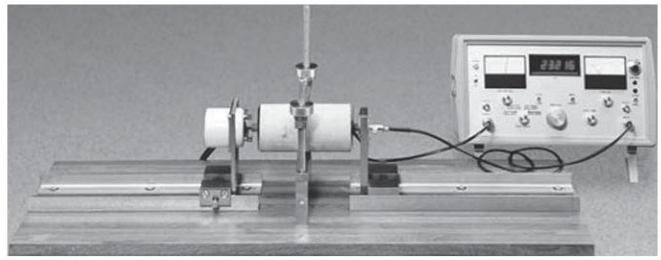


Fig. 9.1 *Resonant frequency tester*

A *variable frequency oscillator* supplies electrical oscillation to the vibration generator and the specimen or element is forced into longitudinal vibration. The vibrations of the free ends of the specimen are detected by vibration pick-up and the amplified magnitude is indicated on the output meter. The frequency, at which displacement becomes appreciable, called *resonance condition*, is obtained by varying the frequency of the oscillator until maximum reading is registered by the output meter.

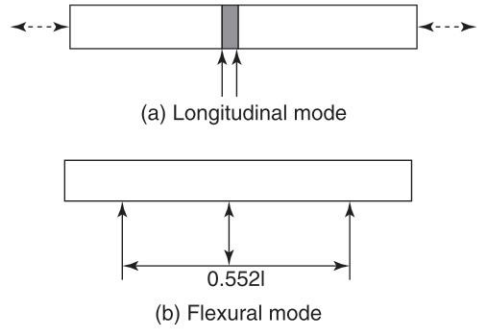


Fig. 9.2 *Arrangement for different modes of vibration*

The *lowest frequency* at which *longitudinal resonance* occurs is the *fundamental longitudinal resonant frequency*, *n* and its relation with dynamic modulus is as

$$E = \frac{4n^2 l^2 \rho}{g}$$

where

E = modulus of elasticity of the material,
L = length of the specimen and
ρ = weight of the specimen per unit volume.

For a specimen of known dimensions the only parameter to be determined is the *natural frequency of vibration.* In addition to the fundamental resonant frequency there are higher frequencies at which resonance occurs. These are called *harmonics* and for long thin beams they occur at simple multiple of fundamental resonant frequency. The test set-up is illustrated in Fig. 9.3.

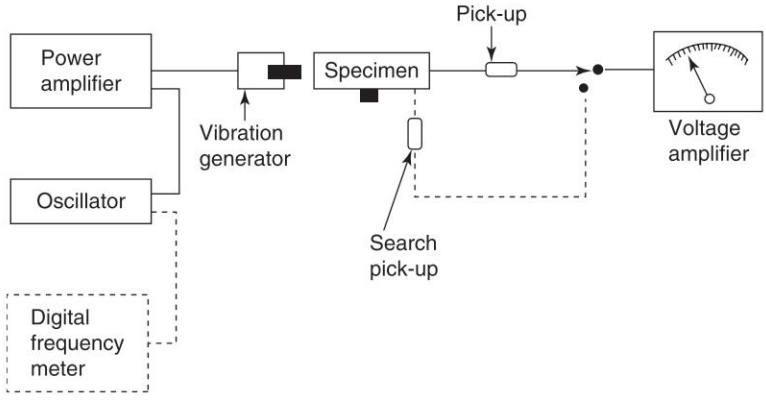


Fig. 9.3 *Test set-up for resonance method*

Limitations

1. The expression is applicable to the beams which are very long in relation to their cross section.
2. If the mass of pick-ups attached to the ends of the beam are not negligible with respect to the mass of the beam itself, errors in the resonance will occur.

2. **Flexural vibrations** In this method of testing, a beam is set into flexural vibration by so called *sonic method*. The beam is supported symmetrically on two narrow supports separated by $0.552l$ as shown in Fig. 9.2(b). The vibration is applied to mid-section of the beam and the pick-up is located at one of the free ends. This arrangement can only be used to determine fundamental resonant frequency which is related to E. The resonant frequency method deviates from the elastic theory due to

(a) Effect of damping,
(b) Effect of heterogeneity,
(c) Effect of anisotropy, and
(d) Effect of loading at the ends of the specimen.

9.2.3 Ultra-Sonic Pulse Velocity Test

This test involves measuring the velocity of sound through concrete for assessing quality of concrete. In this method, a sound pulse of high frequency is applied on one boundary of the specimen and the time interval is measured for the pulse to travel to an opposite boundary or to be reflected back to the first boundary. The pulse consists of a damped train of mechanical vibrations and the reference position to which the time interval is measured is taken to be the onset of the transient defining the start of the pulse. Since, ultrasonic

pulse velocity testing equipment measures the sound velocity in the concrete it is related to the compressive strength of the concrete. A typical ultrasonic concrete tester is shown in Fig. 9.4.

The pulse generally produced either from a hammer blow or an electroacoustic transducer. When an impulse force is applied three distinct types of waves travel in the material. The fastest wave having particle displacements in the direction of travel is called *longitudinal* or *compressional* or the *P-wave*. The second fastest is the shear or S-wave with particle displacements at right angle to the direction of travel. These are the body waves travelling throughout the material in all directions. Another type of wave motion travels along the surface with particle motion in the form of a retrograde ellipse with a component normal to the surface and a smaller component in the direction of travel. This is called *Rayleigh wave*. Body waves travel uniformly in all the directions.

Since, concrete is a multi-phase material, speed of sound wave in concrete depends on the relative concentration of its constituent materials, degree of compacting, moisture content, and the amount of discontinuities present. Generally, high pulse velocity readings in concrete are indicative of concrete of good quality.

The pulse velocity is not governed by the size or shape of the specimen and hence the tests may be performed in the laboratory as well as in the field on actual structure. An abrupt change in the density of the transmission path results in most of the waves being reflected. Thus by comparing the time of travel of pulse and its amplitude, the presence of voids or cracks inside the structure can be located. The ultrasonic pulse method like resonance method has the advantages for these repetitive types of tests in that the method is easier to apply, the results are more reproducible and the same specimen can be used throughout. In addition, ultrasonic pulse method has advantage over resonance methods because almost any shape of specimen can be tested and often a pulse will pass through a specimen which is too heavily damped to be brought into resonance. The method can also determine localized difference occurring in the specimens such as may be caused by difference in compaction.

Fig. 9.4 *Ultrasonic concrete tester*

Transducer arrangement

The receiving transducer detects the arrival of that component of the pulse, which arrives earliest. This is generally the leading edge of the longitudinal vibration. Although the direction in which the maximum energy is propagated is at right angles to the face of the transmitting transducer, it is possible to detect pulses, which have travelled through the concrete in some other direction. It is possible, therefore, to make measurements of pulse velocity by placing the two transducers on either:

1. opposite faces (direct transmission),
2. adjacent faces (semi-direct transmission) or
3. the same face (indirect or surface transmission).

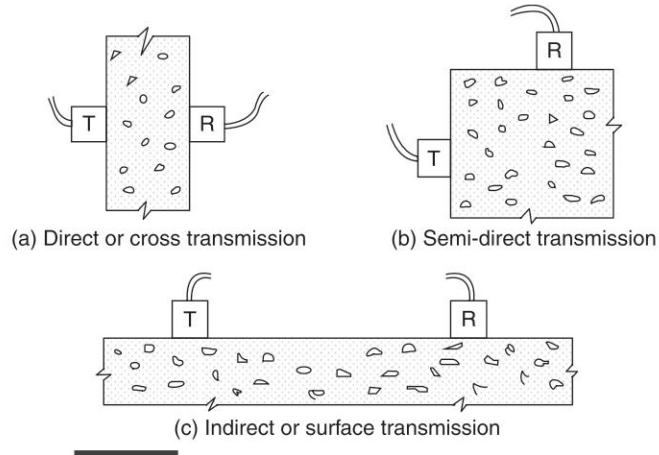


Fig. 9.5 *Typical arrangements of transducers*

Limitations

1. A large number (at least 9) of measurements are required on standard concrete beam, whereas only one measurement is required in resonance method.
2. In ultrasonic pulse method, a personal judgment is required to define the onset of the pulse, whereas resonant frequency is not subjected to personal error.
3. In this test ultrasonic waves cannot be induced at right angles to the surface; hence, they cannot detect transverse cracks.
4. The ultrasonic pulse method requires two operations as against one for resonant-type test.

In general, resonance method is preferred. The apparatus used for sending pulses in ultrasonic pulse method is known as *ultrasonic apparatus* and *soniscope*, whereas the one used in resonance method is known as *sonic testing apparatus*.

EXPERIMENT NO. 1: Rebound Number of Hardened Concrete

Objective

To assess the likely compressive strength of concrete with rebound hammer test.
To determine the relation between rebound number and compressive strength of concrete.

Theory and Scope

This test method covers the determination of a rebound number of hardened concrete using a spring-driven steel hammer called Rebound hammer. Rebound number is used for assessing the likely compressive strength of concrete with the help of suitable correlation between rebound index and compressive strength. A correlation is developed by simultaneously testing the two properties on the same sample and establishing acceptance criterion.

It works on the principle that the rebound of an elastic mass depends on the hardness of the surface against which the mass impinges. The method consists in imparting a predetermined amount of energy to a steel plunger in contact with a surface of concrete by impacting the steel hammer, and the distance that the hammer rebounds is measured as rebound number or rebound index or rebound units.

This test method may be used to assess the in-place uniformity of concrete, to delineate regions in a structure of poor quality or deteriorated concrete, and to estimate in-place strength development.

Apparatus

Rebound hammer; Abrasive stone; Test anvil and Instrument guide.

Description of Apparatus

Rebound hammer consists of a spring-loaded steel hammer which when released strikes a steel plunger in contact with the concrete surface. The hammer must travel with a consistent and reproducible velocity. The rebound distance of the steel hammer from the steel plunger is measured on a linear scale attached to the frame of the instrument.

Several types and sizes of rebound hammers are commercially available to accommodate testing of various sizes and types of concrete construction. A typical rebound hammer is shown in Fig. 9.6.

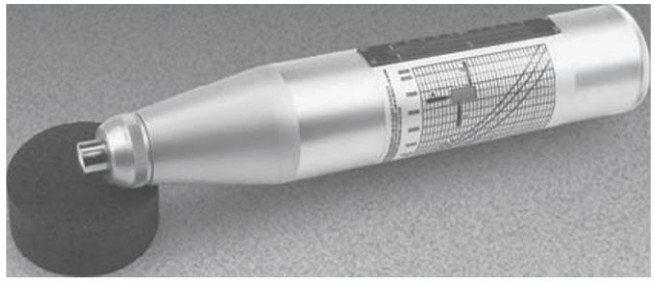


Fig. 9.6 *A typical rebound hammer*

Abrasive stone consists of medium- grain texture silicon carbide or equivalent material.

Test anvil, approximately 150-mm diameter by 150-mm high carbon tool steel cylinder, has an impact area hardened to Rockwell 65–67 C.

The **instrument guide** facilitates to centre the rebound hammer over impact area and keep the instrument perpendicular to the surface.

Procedure

Step 1: Determination of rebound number

(a) *Select the test surface as follows* Concrete members to be tested shall be at least 100 mm thick and fixed within a structure. Smaller specimens must be rigidly supported. Areas exhibiting honeycombing, scaling or high porosity should be avoided. Trowelled surfaces generally exhibit higher rebound numbers than screeded or formed finishes. If possible, structural slabs should be tested from the underside to avoid finished surfaces.

(b) *Prepare the test surface as follows* A test area shall be at least 150 mm in diameter. Heavily textured, soft, or surfaces with loose mortar shall be ground smooth with the abrasive stone Smooth-formed or trowelled surfaces do not have to be ground prior to testing.

(c) Hold the instrument firmly so that the plunger is perpendicular to the test surface.

(d) Gradually push the hammer toward the test surface until the hammer impacts.

(e) After impact, maintain pressure on the instrument and, if necessary, depress the button on the side of the instrument to lock the plunger in its retracted position.

(f) Estimate and record the rebound number on the scale to the nearest whole number.

(g) Take 20 readings from each test area. No two-impact tests shall be closer together than 20 mm.

(h) Examine the impression made on the surface after impact, and if the impact crushes or breaks through a near surface air void disregard the reading and take another reading.

Step 2: Correlation between compressive strength and rebound number

The most satisfactory way of establishing a correlation between compressive strength of concrete and its rebound number is to measure both the properties simultaneously on concrete cubes. The test cube specimens should be as large a mass as possible in order to minimise the size effect on the test result of a full scale structure. 150-mm cube specimens are preferred for calibrating rebound hammers of lower impact energy (2.2 Nm), whereas for rebound hammers of higher impact energy, for example 30 Nm, the test cubes should not be smaller than 300 mm.

(a) If the specimens are wet cured, remove them from wet storage and keep them in the laboratory atmosphere for about 24 hours before testing.

(b) Place the concrete cube specimen in a compression testing machine under a fixed load based on the impact energy of the hammer, e.g., the fixed load required is of the order of 7 MPa when the impact energy of the hammer is about 2.2 Nm. The load should be increased for calibrating rebound hammers of greater impact energy and decreased for calibrating rebound hammers of lesser impact energy.

(c) Determine at least nine rebound numbers by impacting on each of the two vertical faces of the cubes as cast and accessible while using the rebound hammer. The points of impact on the specimen must not be nearer an edge and other impact point than 20 mm.

(d) Increase the load continuously at uniform rate and determine the compressive strength as per IS 516-1959.

(e) Repeat the procedure of Steps (a) to (c) for other cube specimens and determine the average rebound number each cube.

(f) Obtain a correlation between rebound numbers and strength of wet cured and wet tested cubes.

Observations and Calculations

Discard readings differing from the average of 20 readings by more than six units and determine the average of the remaining readings. If readings appear to be erroneous due to extremely high or extremely low rebound numbers, discard these readings without recording them.

1. For strength of concrete at the given location The report should contain the following information:	
Date and identification of location tested	
Design strength of concrete tested, MPa	
Hammer identification, type and No.	
Orientation of hammer during test	
Average rebound number	
Strength of concrete at the location tested, MPa	

Remarks regarding unusual conditions are observed.

2. For correlation between compressive strength and rebound number			
Specimen no.	**Average rebound number**	**Crushing load, kN**	**Compressive strength, MPa**
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			

Precautions

1. The surface should be smooth, clean and dry; loosely adhering scales should be rubbed off with a grinding wheel or stone, before testing.
2. Test surface exhibiting honeycombing, scaling, or high porosity should be avoided. If possible, structural slabs should be tested from the underside to avoid finished surfaces.
3. The instrument should be kept perpendicular to the surface.
4. The point of impact should be at least 20 mm away from edge or shape discontinuity.
5. Rebound hammers shall be periodically serviced and verified for their proper operation. Test anvils may be used for verification. However, verification on an anvil will not guarantee that the hammer will yield repeatable data at other points on the scale.

Discussion

To use this test method to estimate the compressive strength requires a relationship between strength and rebound number. The relationship is established for a given concrete mixture and the given rebound hammer over the range of concrete strength that is of interest. To estimate the strength during construction, the relationship is established by performing rebound number tests on moulded test specimens and measuring the strength of the same or companion moulded specimens. To estimate strength in an existing structure, the relationship is established by correlating rebound numbers measured on the structure with the strengths of cores taken from corresponding locations.

For a given concrete mixture, the rebound number is affected by moisture content of the test surface, the method used to obtain the test surface (type of form material or type of finishing) and the depth of carbonation. These factors need to be considered in preparing the strength relationship and interpreting test results.

Other factors that may affect the results of the test are as follows:

1. Concrete at 0°C or less may exhibit very high rebound values. Concrete should be tested only after it has thawed.
2. The temperatures of the rebound hammer itself may affect the rebound number.
3. For readings to be compared the direction of impact (horizontal, downward, upward, etc.,) must be the same or established correction factors shall be applied to the readings.
4. Different hammers of the same nominal design may give rebound numbers differing from 1 to 3 units and therefore, conduct the tests with the same hammer in order to compare results.

Extreme high and low readings, generally due to air-voids, steel reinforcement, or coarse aggregates close to the surface, are discarded and not recorded. The average of recorded rebound number can then be applied to the proper rebound number chart/ relation to obtain an estimated compressive strength. Ground and unground surfaces should not be compared.

To obtain a correlation between rebound numbers and strength of wet cured and wet tested cubes, it is necessary to establish a correlation between the strength of wet tested cubes and the strength of dry tested cubes on which rebound readings are taken. A direct correlation between rebound numbers on wet cubes and the strength of wet cubes is not recommended.

Depending upon the impact energy, the hammers are classified into four types, i.e., N, L, M and P. Type N hammer having impact energy of 2.2 N-m is suitable for grades of concrete from M15 to M45. Type L hammer is suitable for lightweight concrete or small and impact sensitive part of the structure. Type M hammer is generally recommended for heavy structures and mass concrete. Type P is suitable for concrete below M15 grade.

Viva-Voce Questions

1. What is a rebound number?
2. What is the significance and use of this test?
3. What are the factors affecting rebound number of a concrete mixture?
4. How is a relationship established between rebound numbers and strength of an existing structure?
5. For estimating the strength during construction, how is a relationship established between rebound numbers and strength?
6. How is rebound value affected by the temperature of concrete?
7. What is the effect of temperature of rebound hammers on the rebound value?
8. What is the function of anvil test?
9. Why is it preferable to test the structural slabs from the underside?
10. What are the factors that may affect the results of the test?

Notes and Comments

EXPERIMENT NO. 2: Ultrasonic Pulse Velocity Test

Objective

To assess the quality of the concrete by the ultrasonic pulse velocity test.

Theory and Scope

The ultrasonic pulse velocity of concrete is mainly related to its density and modulus of elasticity. This in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete. This test is based on the principle that comparatively higher velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poorer quality due to presence a crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse energy is attenuated and lower velocities are obtained. In case of discontinuity, the wave passes around the discontinuity thereby making the path longer; consequently, lower observed velocities are recorded.

The method consists in inducing an ultrasonic pulse by an electro-acoustic transducer which undergoes multiple reflections at the boundaries of the different material phases within the concrete. Because the velocity of the pulses is almost independent of the geometry of the material through which they pass and depends only on its density and elastic properties, pulse velocity test is a convenient technique for investigating structural concrete.

The receiving transducer detects the onset of the longitudinal waves, which is the fastest.

Apparatus

Ultrasonic pulse velocity apparatus consisting of

1. Electrical pulse generator
2. Transducers - one pair
3. Amplifier
4. Electronic timing device

The apparatus should be capable of measuring transit times to an accuracy of one per cent over a range of 20 microseconds to 10 milliseconds.

Description of Apparatus

Transducer operating within the frequency range of 20 kHz to 150 kHz.

Piezoelectric and **magneto-strictive** types of transducers may be used, the latter is preferable for the lower part of the frequency range.

Electronic timing device capable of measuring the time interval elapsing between the onset of a pulse generated at the transmitting transducer and the onset of its arrival at the receiving transducer. Typical electronic timing device is shown in Fig. 9.7.

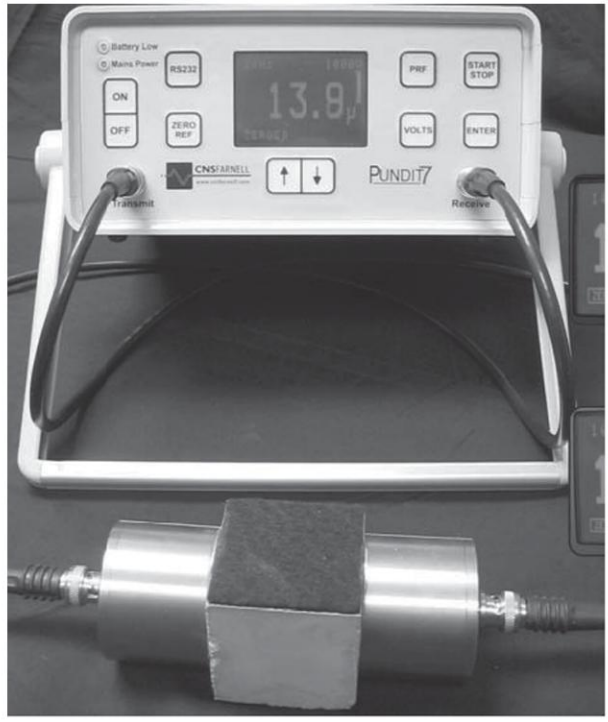


Fig. 9.7 *Typical electronic timing device*

Two types of the electronic timing devices are available, first one where the leading edge of the pulse is displayed in relation to the suitable time scale, the second with a direct reading digital display. If both the forms of timing apparatus are available, the interpretation of results becomes more reliable.

Test requirements of the test set-up:

1. The apparatus should be capable of measuring transit times to an accuracy of ±1 per cent over a range of 20 microseconds to 10 milliseconds.
2. To ensure a sharp pulse onset, electronic pulse applied to the transmitting transducer should have a rise time of not greater than one quarter of its natural period.
3. The apparatus should maintain its performance over the range of ambient temperature, humidity and power supply voltage stated by the manufacturer.
4. The interval between pulses should be low enough to ensure that the onset of the received signal in small concrete test specimens is free from interference by reverberations produced within the preceding working cycle.

Procedure

Step 1: Select the most suitable test points on the material to be tested. Measure the path length (L) to be traversed in the concrete before the pulse of vibrations is converted into an electrical signal by the second transducer.

Step 2: Erect a platform/staging of suitable height to provide an access to the test points (pre-decided and marked locations). For selection of receiving locations following should be considered.

As the ultrasonic pulse impinges on the surface of the material, its maximum energy is propagated at right angles to the face of the transmitting transducer and best results are, therefore, obtained

when the receiving transducer is placed on the opposite face of the concrete member (direct transmission or cross-probing).

When two opposite faces of the structural member may not be accessible for measurements, the receiving transducer is also placed on the same face of the concrete members (surface probing). Surface probing is not as efficient as cross probing, because the signal produced at the receiving transducer has amplitude of only 2 to 3 per cent of that produced by cross-probing and the test results are greatly influenced by the surface layers of concrete which may have different properties from that of concrete inside the structural member.

The indirect velocity is invariably lower than the direct velocity on the same concrete element. This difference may vary from 5 to 20 per cent depending largely on the quality of the concrete under test. For good quality concrete, a difference of about 0.5 km/sec may generally be encountered.

Step 3: Smoothen the rough and uneven concrete surfaces to make the pulse velocity measurement possible.

Step 4: Connect the transducers to the sockets marked "TRAN" and "REC" and switch on the Pulse velocity meter.

Step 5: Using the reference or standard calibration bar supplied along with the equipment, check the instrument zero. Apply a smear of grease to the transducer faces before placing it on the opposite ends of the bar. Adjust the 'SET REF' control until the transit time for the bar engraved on it appears on the instrument read-out. This process may be called calibration of the apparatus set-up. The measurement obtained should not differ from the known value for the reference bar or specimen by more than ± 0.5 per cent.

Step 6: For the maximum accuracy, select suitable microsecond range for the measured path length. For path length up to 400 mm microsecond range may be selected as 0.1.

Step 7: Apply couplant to the faces of the transducers, i.e., acoustical coupling between the concrete and the face of transducer (petroleum jelly or grease may serve the purpose). Mount the pulse transmitting transducer on one surface of the concrete member by pressing it hard onto the surface of the material under test.

Step 8: Mount the second transducer, called electrical signal receiving transducer, on the other surface of the concrete member at the predetermined location with acoustical coupling between the concrete and the face transducer and an electronic timing circuit to measure the transit time, 'T' of the pulse.

Step 9: Generate a longitudinal vibration pulse by transmitting or electro acoustical transducer, which is held in contact with one surface member.

Step 10: Continue holding the transducers onto the surface of the material until a consistent reading appears on the display, which is the time in microsecond for the ultrasonic pulse to travel the distance 'L'. Record the transit time 'T' of the pulse as the mean value of the display readings when the units digit hunts between two values.

Step 11: Compute the pulse velocity, 'V' given by: $V = L/T$.

Observations and Calculations

Type of transmission	(a) Opposite faces (direct transmission), (b) Adjacent faces (semi-direct transmission) or (c) The same face (indirect or surface transmission).		
Receiving point no.	Travel length, L mm	Transit time, T sec	Pulse velocity, L/T mm/sec

Interpretation of Results

Based on the actual values of the pulse velocity obtained during the test, the code has suggested a criterion for assessing the quality of concrete as given in Table 9.1 which can be considered satisfactory only to a general extent. However, when the comparison is made amongst different parts of a structure, which have been built at the same time with supposedly similar materials, construction practises and supervision, the assessment of quality becomes more meaningful and reliable.

Table 9. 1 *Ultrasonic pulse velocity and quality of concrete [IS: 13311 (Part 1) – 1992]*

Pulse velocity, km/sec	Concrete quality grading
Above 4.5	Excellent
3.5 to 4.5	Good
3.0 to 3.5	Medium
Below 3.0	Doubtful quality further investigations necessary

The assessment of compressive strength of concrete from ultrasonic pulse velocity values is not adequate. The statistical confidence of the correlation between ultrasonic pulse velocity and the compressive strength of concrete is not very high due to large number of parameters involved, which influence the pulse velocity and compressive strength of concrete to different extents. However, if actual concrete materials and mix proportions adopted in a particular structure are available, then estimate of concrete strength can be made by establishing suitable correlation between the pulse velocity and the compressive strength of concrete specimens made with such materials and mix proportions, under environmental conditions similar to that in the structure.

The estimated strength may vary from the actual strength by ±20 per cent. The correlation so obtained may not be applicable for concrete of another grade or made with different types of materials.

Precautions

1. In case of rough and uneven concrete surface, it is necessary to smooth the surface where the transducer is to be mounted to make the pulse velocity measurement possible.
2. The equipment should be calibrated before starting the observation and at the end of test to ensure accuracy of the measurement and performance of the equipment.
3. To ensure proper transmission of ultrasonic pulse generated at the transmitting transducer into the concrete and its detection by the receiving transducer, it is essential that there be adequate acoustical coupling between the concrete and the face of each transducer.
4. Do not move the transducers while a reading is being taken, as this can generate noise signals and errors in measurements.
5. The leads from two transducers should be prevented from coming into close contact with each other when the transit time measurements are being taken. If this is not done, the receiver lead might pick-up extraneous signals from the transmitter lead and would result in an incorrect display of the transit time.

Discussion

A complex system of stress waves is developed which includes longitudinal (compressional), shear (transverse) and surface (Rayleigh) waves. Moreover, the pulse velocity in concrete is influenced by the surface conditions and moisture content of concrete; path length which depends upon shape and size of the

concrete member; temperature of concrete; stress level in concrete and presence of reinforcement in the concrete member. These parameters influence the pulse velocity as follows:

1. Smoothness of contact surface under test affects the measurement of ultrasonic pulse velocity. Generally, the concrete surfaces are sufficiently smooth to ensure good acoustical contact of transducer with the concrete surface. The rough and uneven concrete surface should be smoothened to make the pulse velocity measurement possible.
2. In general, pulse velocity through concrete increases with increased moisture content of concrete as is seen in Table 9.2. This influence is more for low strength concrete than high strength concrete. The pulse velocity of saturated concrete may be up to 2 per cent higher than that of similar dry concrete.
3. Variations of the concrete temperature between 5 and 30°C do not significantly affect the pulse velocity in concrete. At temperatures between 30 to 60°C there can be reduction in pulse velocity up to 5 per cent. Below freezing temperature, the free water freezes within concrete, resulting in an increase in pulse velocity up to 7.5 per cent as shown in Fig. 9.2.

Table 9. 2 *Effect of temperature on pulse velocity [BS 1881 (Part 203) -1986]*

Temperature, ^{o}C	Correction to the measure pulse velocity, per cent	
	Air dried concrete	Water saturated concrete
60	+5	+4
40	+2	+1.7
20	0	0
0	–0.5	–1
–4	–1.5	–7.5

4. Due to concrete being heterogeneous, it is essential that path lengths be sufficiently long so as to minimise the error introduced due to its heterogeneity. In field testing, this does not pose any difficulty as the pulse velocity measurements are carried out on thick structural concrete members. However, in the laboratory where generally small specimens are used, the path length can affect the pulse velocity readings.

   To minimise the effect of the shape and size of the concrete member on the pulse velocity the code has recommended selection of the transducer natural frequency for different path lengths and minimum transverse dimensions of the concrete members.

Table 9. 3 *Natural frequency of transducers for different path lengths [IS l3311 (Part 1) –1992]*

Path length, mm	Natural frequency of transducer, kHz	Minimum transverse dimensions of members mm
up to 500	150	25
500-700	≥60	70
700-l 500	≥40	150
above 1500	≥20	300

5. The micro-cracks develop in concrete subjected to relatively high stress may result in the reduction of pulse velocity. This reduction in pulse velocity is generally insignificant unless the stress is greater than about 60 percent of the ultimate strength of the concrete.

6. The pulse velocity measured in reinforced concrete in the vicinity of reinforcing bars is usually higher than in plain concrete of the same composition; as the pulse velocity in steel is 1.2 to 2.0 times that in plain concrete. Under certain circumstances, the first pulse to arrive at the receiving transducer is partly through concrete and partly through steel.

   In view of the above it is well recognised that concrete strength cannot be calculated with acceptable accuracy from the longitudinal pulse velocity v_L alone; supplementary tests measuring material characteristics of the concrete are needed. One approach for improvement is the use of multi-variable formulas considering the age of concrete as a supplement to the longitudinal pulse velocity. Another promising approach, which provided up to 25 per cent improvement in the strength estimation, is the use of surface waves instead of longitudinal waves. Thus, continued research in these two directions towards the development of a concrete strength versus ultrasonic pulse velocity relationship is justified.

Determination of dynamic Young's modulus of elasticity

The dynamic Young's modulus of elasticity E of the concrete may be determined from the pulse velocity and the dynamic Poisson's ratio μ, using the relationship

$$E = \frac{\rho(1+\mu)(1-2\mu)}{1-\mu} V^2 = \rho f(\mu) V^2$$

where

$$f(\mu) = \frac{(1+\mu)(1-2\mu)}{1-\mu}$$

E = Young's Modulus of elasticity,
ρ = density in kg/m^3 and
V = pulse velocity in m/second.

The factor $f(\mu)$ may be calculated from the relation,

$$f(\mu) = \frac{(2nl)^2}{V^2}$$

where

n = fundamental resonant frequency in cycles per second and
l = length of specimen in m.

The value of V is obtained from the pulse velocity test and the fundamental resonant frequency n of the beam in longitudinal mode of vibration from the resonance test. From these measurements, the factor $f(\mu)$ and consequently the dynamic Young's modulus of elasticity E of the concrete may be obtained.

Viva-Voce Questions

1. What is the main objective of non-destructive testing of concrete?
2. How can the strength of the concrete be estimated from non-destructive methods?
3. What are the different non-destructive methods used in practise?
4. What are the factors influencing the pulse velocity in concrete?
5. How does resonance method differ from pulse velocity method?

6. What is effect of moisture content on the pulse velocity in concrete?
7. If the concrete temperature is varied from 70°C to below freezing temperature, how will the pulse velocity in concrete will vary?
8. What is the effect of stress level on pulse velocity in concrete?
9. How is the pulse velocity influenced in reinforced concrete?

Notes and Comments

EXPERIMENT NO. 3: Dynamic Modulus of Elasticity of Concrete

Objective

To determine the dynamic modulus of elasticity of concrete specimens.

Theory and Scope

This test covers the procedure for determining the fundamental longitudinal resonant frequencies of concrete prisms and cylinders for the purpose of calculating dynamic (Young's) modulus of elasticity and dynamic Poisson's ratio. The electro-dynamic method as specified in IS 516 - 1959 is used for measuring the fundamental natural frequency of the specimen. As this is a non-destructive test, the same specimens may subsequently be used for the flexural strength test specified in Section 8.

The test procedure is intended primarily for detecting significant changes in the dynamic modulus of elasticity of laboratory or field test specimens that are undergoing exposure to weathering or other types of potentially deteriorating influences. The test method may also be used to monitor the development of dynamic elastic modulus with increasing maturity of test specimens.

Apparatus

The apparatus consists of a variable frequency oscillator; an Electro-magnetic exciter; an Electro-magnetic pick-up transducer or a piezo-electric gauge (large mass: miniature crystal accelerometer); an Amplitude indicator consisting of a voltmeter, milliammeter or cathode ray oscilloscope; an Audio-frequency amplifier; and a Fixed clamp or support.

Description of Apparatus

Variable frequency oscillator Typical specifications are:
Frequency range: 10 Hz to 100 kHz in 4 (switched) ranges,
Accuracy or setability: Better than ± 0.5 per cent of reading (preferably 0.1 per cent),
Fine Control: Two speed controls (typically10:1 and 50:1),
Output: Typically to 14 V pk-pk into 3 ohms with output power not less than 5 watts.
Stability: Typically 0.05 per cent, 10–12 minute after turned on.

Electro-magnetic exciter unit It is of small mass moving-coil or variable small mass air-gap type device. If the moving-coil type is used, the former and coil should have as low an inertia as possible, the mass being not more than 0.2 per cent of the mass of the specimen (the former should be of light card or paper). If a variable air-gap exciter unit is used, this shall be of a similar type to the pick-up unit. A typical instrument set up is illustrated in Fig. 9.8.

Electro-magnetic pick-up unit It is of the ordinary telephone or alternatively, a piezo-electric gauge type unit with its mass is not more than 0.2 per cent of the mass of the specimen.

Fixed clamp or support with a maximum width of 1/20th of the length of the specimen; if a variable air-gap exciter unit is used in conjunction with a variable air-gap pick-up, the support shall be metallic and earthed.

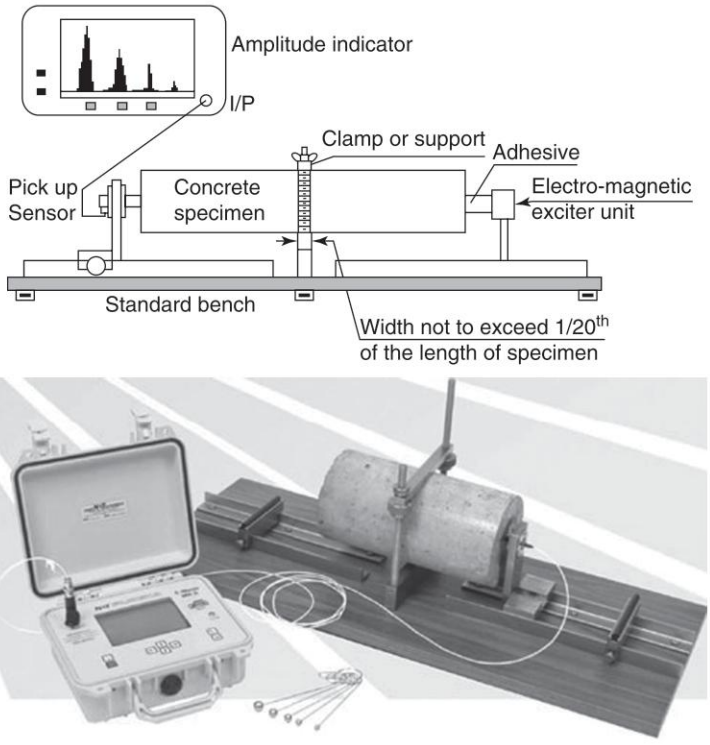


Fig. 9.8 *Test set-up for determination of fundamental frequency by electro-dynamic method*

Procedure

1. Prepare three test prism specimens 150×150×400 mm long of given mix proportions for each age of test. In case of cylinder specimens, the height/diameter or height/width ratio shall be at least 2. Follow the standard procedure for compaction and curing.
2. Determine the weight and dimensions of the specimens as follows:
   (a) Weigh the wet specimen to an accuracy of 0.25 per cent of its weight.
   (b) Determine the length of the specimen to an accuracy of ±1 mm by taking the average of at least four symmetrically placed measurements.
   (c) Determine the breadth and depth of specimen to an accuracy of ±0.2 mm by taking the average in each case of at least six measurements spaced equally along the length of the specimen.
3. Balance and clamp the specimen immediately on removal from water while still in a wet condition at its centre on the fixed support.
4. In case of a moving-coil type of exciter unit, fix the moving-coil portion to the middle of one end face of the specimen by means of resin (applied with an electric soldering iron) or other suitable adhesive.
5. Place a lightly greased disk of tinfoil of 50 mm diameter on the centre of the other end of the specimen to ensure adhesion. Place the pick-up unit with its diaphragm as close as possible to the foil but not allow the pick-up unit to touch the tinfoil or the specimen.
6. Drive the exciter unit by the variable frequency oscillator
7. Feed to the indicator the oscillations received by the pick-up unit which are amplified by the audio-frequency amplifier in such a manner as to show the amplitude of the oscillations received.

8. Vary the frequency of excitation until resonance is achieved in the fundamental mode of longitudinal vibration. Resonance is indicated by the maximum deflection of several maxima of the indicator corresponding to various modes of vibration. Frequencies within ±10 per cent of the expected or computed value should be investigated.
9. Record this frequency as the natural frequency of the fundamental mode of longitudinal vibration.

Observations and Calculations

Date of test …….. ...
Identification mark on each specimen……
Age of specimen……..
Curing conditions……

Weight of wet specimen,	W kg			
Average length of specimen,	l mm			
Average breadth of specimen,	b mm			
Average depth of specimen,	d mm			
Density of specimen,	$w = \left(\frac{W}{b\,d\,l}\right) \times 10^9$ kg/m^3			
Fundamental frequency of longitudinal vibration of specimen,	n cycles/sec			
Dynamic modulus of elasticity, $E = 4.083\ (n^2\ l^2\ w)\ \ 10^{-11}$	MPa			

Dynamic modulus of elasticity of the concrete of specimen is……..MPa.

Precautions

1. The exciter unit should be securely connected to the centre of one end face of the specimen by means of suitable adhesive.
2. The diaphragm of the pick-up unit should be as close as possible to the tinfoil but should not be allowed to touch the tinfoil or the specimen.
3. The transducers should not be disturbed while test is being performed.

Discussion

The value of the dynamic modulus of elasticity obtained by this test method is generally greater than the static modulus of elasticity obtained in Section 8. The difference depends, in part, on the strength level of the concrete. The conditions of casting, the moisture content, and other characteristics of the test specimens significantly influence the results obtained.

Different dynamic modulus of elasticity values may result from widely different resonant frequencies of specimens of different sizes and shapes of the same concrete. Therefore, it is not advisable to compare results from specimens of different sizes or shapes.

Resonance is indicated by a maximum displacement of the indicator, but several maxima may be obtained, and experience is necessary to know which the required maximum is. Frequencies within ±10 per cent of the expected value, calculated from the formula should be investigated. Values of the modulus of elasticity range

from 1.4×10^4 MPa for low-quality concretes at early ages to 5×10^4 MPa for high-quality concretes at greater ages. This represents a frequency range of 125 00/l cycles per second to 225 00/l cycles per second, where l is the length of the specimen in mm. It is usually possible to obtain resonance also at the frequency of the first harmonic which is twice the fundamental frequency and these two conditions are normally the best defined.

There are equipment having a semi-automatic feature that eliminates cumbersome manual scanning; this unit automatically scans the frequencies and registers the maximum amplitude. The unit automatically stops scanning at the beginning of the band containing the resonant frequency.

Viva-Voce Questions

1. What is the main objective of non-destructive testing of concrete?
2. How can the modulus of elasticity of the concrete be estimated from non-destructive methods?
3. What are the different non-destructive methods used in practise?
4. What are factors influencing the fundamental frequency of concrete specimen?
5. What is resonance? How does it differ from pulse velocity test?
6. How is the desired frequency identified on the indicator unit?
7. How does the dynamic modulus of elasticity of concrete compare with static modulus of elasticity?
8. What is the range of modulus of elasticity in concretes of various shades?
9. What is the accuracy to which the breadth and depth of specimen are measured?
10. What is the accuracy to which the length of the specimen is measured?

Notes and Comments

NATIONAL STANDARDS

1. IS 516 – 1959 (reaffirmed 2008): *Methods of Test for Strength of Concrete*.
2. IS 6461 (Part 10) -1973 (reaffirmed 2011): *Glossary of Terms Relating to Cement Concrete*; Part 10: *Tests and Testing Apparatus*.
3. IS 13311 (Part 1) -1992 (reaffirmed 2008): *Non-destructive Testing of Concrete*: Part 1: *Ultrasonic Pulse Velocity*.
4. IS 13311 (Part 2) -1992 (reaffirmed 2008): *Methods of Non-destructive Testing of Concrete*; Part 2: *Rebound Hammer*.

REFERENCES

1. ASTM C215 – 08; *Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Frequencies of Concrete Specimens*.
2. BS EN 1881-209:1990; *Testing Concrete-Recommendations for the Measurement of Dynamic Modulus of Elasticity*.
3. BS EN 12504-4:2004; *Testing Concrete – Determination of Ultrasonic Pulse Velocity*.
4. BS EN 13791: 2007; *Assessment of In-situ Compressive Strength in Structures and Precast Concrete Components*.
5. Gambhir, M. L., *Concrete Technology*, 4th Edition, McGraw-Hill Education (India), 2009.
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CONCRETE MIX DESIGN

Section 10

This section describes the concrete mix design procedures commonly used to design concrete mixtures. Concrete mix design is most important component of production of concrete. The physical characteristics of fresh and hardened concretes as controlled by concrete mix design are critical for ensuring quality structures that are safe, durable and economical.

10.1 INTRODUCTION

The process of selecting suitable ingredients of concrete and determining their relative amounts with the objective of producing a concrete of the required strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance level of concrete in its two basic states, namely, the fresh or plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted. The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g., quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean a mix as possible. From technical point of view the rich mixes may lead to high shrinkage and cracking in structural concrete, and evolution of excessive heat of hydration in mass concrete which may cause cracking. The actual cost of the concrete is related to the cost of materials required for producing a minimum mean strength called *characteristic strength* that is specified by the designer of the structure. This depends on the quality control measures, but there is no doubt that the *quality control* adds to the cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and the type of the job. The cost of labour depends on the workability of mix, e.g., a concrete mix of inadequate workability may result in a high cost of labour to obtain a degree of compaction with available equipment.

10.2 BASIC CONSIDERATIONS OF CONCRETE MIX DESIGN

The requirements which form the basis of selection and proportioning of mix ingredients are:

1. **Strength and durability** The minimum compressive strength required from structural considerations which in turn is governed by w/c ratio is the basic requirement. Possible requirements for resistance to environmental exposure, e.g., to freeze-thaw and chemical attack must be considered. Maximum water–cement ratio and/or maximum cement content to give adequate durability for the particular site conditions is a major consideration. However, limit on maximum cement content to avoid shrinkage cracking due to temperature cycle in mass concrete should be considered.
2. **Workability** The adequate workability necessary for full compaction with the compacting equipment available minimal bleeding and segregation; water requirements for workability depend on the

aggregate rather than the cement characteristics. Therefore, a balance or compromise must be made between strength and workability.

3. **Economy** The material costs are most important in determining the relative costs of different mixes. The labour and equipment costs, except for special concretes, are generally independent for the mix design.

Since cement is more expensive than aggregate, cement content can be minimised by: (i) using the lowest slump that will permit handling, (ii) using a higher coarse to fine aggregate, ratio and (iii) possible use of admixtures.

10.3 TYPES OF MIXES

10.3.1 Nominal Mixes

In the past, the specifications for concrete prescribed the proportions of cement, fine and coarse aggregates. These mixes of fixed *cement-aggregate ratio* which ensure adequate strength are termed *nominal mixes.* These offer simplicity and under normal circumstances, have a margin of strength above than specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength. Nominal mix concrete may be used for concrete of grade M20 or lower.

10.3.2 Standard Mixes

The nominal mixes of fixed cement-aggregate ratio (by volume) vary widely in strength and may result in under-rich or over-rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed *standard mixes.* To fulfill the strength requirement suitable modifications or adjustments are required to be made in selecting the ratio of fine to coarse aggregates. The requirement of *minimum compressive strength* makes the specifications unduly restrictive when good quality materials are available, but elsewhere it may not be possible to achieve an adequate strength using the prescribed mix proportions. These mixes are by definition conservative, but are useful as off-the-shelf sets of proportions that allow the desired concrete to be produced without the use of high degree of control. The concrete mixes are designated into a number of grades, e.g., Ml5, M20, M25, M30, M35, and M40. In this designation, the letter M refers to the mix and the number refers to the specified 28-day cube strength of mix in MPa. For the ordinary concrete from which quite undemanding performance is expected, the nominal or standard mixes may be used.

10.3.3 Designed Mixes

In these mixes, the performance of the concrete is specified by the designer but the mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in most economical production of concrete with appropriate properties. However, the *designed* mix serves as a guide since this does not guarantee the correct mix proportions for the prescribed performance. For the concrete with undemanding performance *nominal* or *standard mixes* (prescribed in the codes by quantities of dry ingredients per cubic metre and by slump) may be used only for very small jobs, when the 28-day strength of concrete does not exceed 30 MPa. No control testing is necessary reliance being placed on the masses of the ingredients.

10.4 FACTORS AFFECTING THE CHOICE OF MIX PROPORTIONS

The various factors affecting the mix design are:

10.4.1 Compressive Strength

It is one of the most important properties of concrete and influences many other desirable properties of the hardened concrete. The mean *compressive strength* required at a specified age, usually 28 days, determines

the *nominal water-cement ratio* of mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the *degree of compaction.* According to Abram's law, the strength of fully compacted concrete is inversely proportional to the *water-cement ratio.* The water-cement ratio determines the *porosity* of hardened cement paste at any stage of *hydration.* Thus the water cement ratio and the degree of compaction both affect the volume of voids in concrete thereby influencing the strength of concrete.

Whereas strength depends on the w/c ratio, economy depends on the percentage of aggregate present that would still give a workable mix. Thus the aim of the mix design should always be to get concrete mixtures of optimum strength at minimum cement content and acceptable workability.

Since the actual strength of concrete is a variable *quantity,* the mean *strength* which is higher than the specified minimum or characteristic compressive strength is aimed or targeted at in the mix design. As per IS: 456–2000, the characteristic compressive strength is defined as that value below which not more than five per cent of the test results are expected to fall. It is the major factor influencing the mix design. Depending upon the degree of control available at the site, the concrete mix has to be designed for a *target mean compressive strength* which is somewhat higher than the characteristic strength.

10.4.2 Workability

The *degree of workability* required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of compaction to be used. For the narrow and complicated section with large number of corners or inaccessible parts, the concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting equipment available at the site.

10.4.3 Durability

The *durability* of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the *water–cement ratio* to be used. The water-cement ratio is fundamental factor controlling durability because it determines the *permeability of cement-paste* and, therefore, to a large extent of concrete. The strength is not an adequate means of ensuring durability because it depends not only on the water-cement ratio but also on the cement properties. When the concrete is subjected to chemical attack a suitable type of cement or admixture has to be used, this has to be accounted in the design. If the *air entrainment* is used to enhance the durability, it has to be taken into account in the mix design. Thus strength, type of cement and admixture, and durability determine between them the *water-cement ratio* required.

10.4.4 Air-Entrainment

Generally, air entrainment is recommended for nearly all concretes, principally to improve resistance to freezing when exposed to water and deicing chemicals. Air-entrained concrete contains microscopic air cells which relieve internal pressure on the concrete by providing tiny chambers for the expansion of water when it freezes.

10.4.5 Maximum Nominal Size of Aggregate

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular *water-cement ratio,* because the workability of concrete increases with increase in maximum size of aggregate. However the compressive strength tends to increase with the decrease in the size of coarse aggregate because the smaller size aggregates present a larger surface area for bonding with *mortar matrix.* Moreover, the stress concentration in the mortar aggregate interfaces decreases with the reduction in the maximum size of the aggregate. The maximum size of aggregates is limited by the size of the section and spacing of the reinforcement. According to IS: 456–2000 and IS: 1343–1980, the maximum nominal size of the aggregate should not be more than one-fourth of the minimum thickness of the member, and it should be restricted to 5 mm

less than the minimum clear distance between the main bars or 5 mm less than the minimum cover to the reinforcement or 5 mm less than the spacing between the prestressing cables. Within these limits, the nominal maximum size of the aggregate may be as large as possible, because larger the maximum size of aggregate, smaller is the cement requirement for a particular *water–cement ratio.*

However, the improvement in .the properties of concrete with an increase in the size of aggregate does not extend beyond about 40 mm. For high strength concretes for reinforced and prestressed works 10 or 20 mm size of aggregates is preferable. The choice of maximum size is also governed by the availability of material and by its cost.

10.4.6 Grading and Type of Aggregate

The *grading of aggregate* influences the mix proportions for a specified *workability* and *water-cement ratio.* Coarser the grading leaner will be mix which can be used. Very lean mix is not desirable since it does not contain enough finer material to make the concrete cohesive.

The *type of aggregate* (in terms of surface texture, shape, etc.) influences strongly the *aggregate-cement ratio* for the desired *workability* and stipulated *water-cement ratio.* An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

10.4.7 Quality Control

The strength of concrete varies from batch to batch over a period of time. The variation in strength results from the variations in the properties of mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. Controlling these variations is important in lowering the difference between the minimum strength and characteristic mean strength of the mix and hence reducing the cement content. The factor controlling this difference is termed the *quality control.* The degree of control is ultimately evaluated by the variation in test results usually expressed in terms of the coefficient of variation.

10.5 EXPRESSING MIX PROPORTIONS

The common method of expressing the proportions of ingredients of a concrete mix is in the terms of parts or ratios of cement, fine and coarse aggregates. For example a concrete mix of proportions 1:1:2 means that the cement, fine aggregate and coarse aggregate are in the ratio of 1:1:2 or the mix contains one part of cement, one part of fine aggregate and two parts of coarse aggregate. The amount of water, admixtures and entrained air, if any, are expressed separately. The proportions are either by volume or by mass. This should be explicitly specified. The *water-cement ratio* is usually expressed by mass and is defined as the ratio of the mass of water in concrete mix, exclusive of the water absorbed by the aggregates, to the mass of cement. The amount of *entrained air* in concrete is expressed as a percentage of the volume of concrete. The amount *of admixture* is expressed relative to the mass of cement. Other form of expressing mix proportions is by *cement-aggregate ratio* which is the ratio of cement to the sum of fine and coarse aggregates.

10.6 MIX DESIGN PROCEDURE

The general step-by-step procedure for proportioning of concrete mixes is summarised below.

1. **Required material information** The tests for relevant material properties are: the sieve analysis of both fine and coarse aggregates, determination of unit weight, specific gravities, and absorption capacities of aggregates.
2. **Choice of workability** Workability is generally specified for a particular job. However, if it is not specified; an appropriate value of workability in terms of slump, compacting factor or Vee-Bee time (as per specification) is selected as recommended by the code. As a general rule, the lowest slump that will permit adequate placement, compaction and finishing should be selected.

3. **Maximum aggregate size** The maximum nominal size of the aggregate, which is economically available, is selected as per the specified requirements. It is determined by sieve analysis, should conform to the limitations based on the minimum dimension of structural members, and the clearance between reinforcing bars and forms. These restrictions may limit maximum aggregate size to 40 mm, except in mass concrete applications. A reduced maximum aggregate size for a given w/c ratio can achieve higher strengths.
4. **Estimation of mixing water and air content** An estimation of the amount of water required for air-entrained and non-air-entrained concretes can be obtained from the code provisions. Air-entraining admixtures are used to make the concrete frost-resistant. Concrete is routinely air-entrained in the colder regions.
5. **Water/cement ratio** This component is governed by target strength and durability requirements.

   (*a*) *Target strength* The mean target strength is estimated from the specified characteristic strength and the level of quality control. In case of non-availability of strength vs. w/c ratio data for a certain material, a conservative estimate can be made for the accepted 28-day compressive strength.

   For the estimated mean target strength, water–cement ratio is selected from the curves or tables provided by the relevant code.

   (*b*) *Durability* The water–cement ratio so chosen is compared with that required for durability, the lower value is adopted. If there are severe exposure conditions, such as freezing and thawing, exposure to seawater, or sulfates, the w/c ratio requirements may have to be adjusted.

6. **Calculation of cement content** Once the water content and the w/c ratio are determined, the amount of cement per unit volume of the concrete is found by dividing the estimated water content by the w/c ratio. The cement content so calculated is checked against the minimum cement required from durability considerations and to ensure good finishability and workability.
7. **Estimation of coarse or fine aggregate content** The percentage of coarse or fine aggregate in concrete or total aggregate is determined from the characteristics of coarse and fine aggregates as recommended in the relevant code.
8. **Estimation of fine or coarse aggregate content** When the percentage of one aggregate is determined the other may be established by, the mass method and the volume method. The "volume" method is generally preferred, as it is somewhat more exact procedure. When percentage of coarse aggregate is known, the volume of fine aggregates is determined by subtracting the volumes of cement, water, air, and coarse aggregate from the total concrete volume.
9. **Adjustment for moisture in the aggregate** Suitable adjustment in the water content for the concrete is made to account for the moisture content of the aggregate.
10. **First trial batch** Using the proportions developed in the preceding steps; trial batch of concrete is mixed using only as much water as is needed to reach the desired slump (but not exceeding the permissible w/c ratio).

    The fresh concrete should be tested for slump, unit weight, yield, air content, its tendencies to segregate, bleed, and finishing characteristics. Also, hardened concrete samples for compressive and flexural strengths are cast as per standard codal procedures. After the required period of curing, the specimens are tested in wet condition for the compressive and flexural strengths of the mix.
11. **Trial batches** Based on the tests on first trial batch, additional trial batches obtained by making suitable adjustment in water–cement ratio or aggregate–cement ratio or in proportions of cement, sand and aggregate, are tested till the final mix composition is arrived at.
12. **Final proportions** The final proportions are expressed either on mass or volume basis.

    Most of the available mix design methods are essentially based on the above procedure. The methods use empirical relationships, charts and tables developed from extensive experimental investigations.

10.7 METHODS OF CONCRETE MIX DESIGN

The methods most commonly used for concrete mix design are:

1. ACI Mix Design Method
2. Indian Standard Concrete Mix Proportioning–Guidelines.
3. British Mix Design Method

Most of these methods follow the basic principles outlined above and only minor variations exist in the process of selecting the mix proportions.

In all the methods, the *water-cement ratio* is selected for the *target mean strength* from empirical relations and the *water content* is chosen for the required workability for the aggregates in a *saturated surface dry condition*. In the ACI method and Indian Standard Guidelines, the volume of dry rodded *coarse aggregate* in the concrete mix is determined first depending on the *maximum size of aggregate* and the *grading of fine aggregate,* whereas in the British method, the proportion of fine aggregate is based to *maximum nominal size of aggregate,* the degree of workability, grading of fine aggregate, and the *water-cement ratio.*

10.8 TESTING

To verify the strength of the designed mix and that of concrete produced at the site, the following tests are usually conducted.

10.8.1 Preliminary Test

The test conducted in the laboratory on the *trial mix* of concrete to verify its strength is termed *preliminary test.* The test helps in determining the adjustments required in *designed mix* to obtain stipulated performance of concrete.

10.8.2 Work Test

The test conducted on the specimens taken out of concrete being used on the work is termed *work lest.* The specimens are usually tested for 28-day compressive strength. However, a quicker idea of the quality of concrete being used can be obtained by testing beams for *modulus of rupture* at seven days or *compressive strength* tests at seven days, in addition to 28-day compressive strength tests. However, in all cases the 28-day compressive strength shall alone be the criterion for acceptance of concrete. Based on the preliminary tests conducted on the trial mix the proportions are adjusted, if necessary as follows:

1. If the *workability* is to be changed without affecting the strength, the *water-cement ratio* must remain unaltered and *aggregate-cement ratio* or *grading of the aggregate* can be modified to obtain the required workability.
2. If the strength is to be changed without affecting the *workability,* the *water-cement ratio* must be modified with the *water-content* of the mix unaltered. The change in the water-cement ratio must be accompanied by a corresponding change in *aggregate-cement ratio* so that the ratio: $\frac{water}{water + cement + aggregate}$ approximately remains constant.

EXPERIMENT NO. 1: ACI Concrete Mix Design

Objective

To design a concrete mix by ACI method for crushing strength of 150 mm cubes at 28 days is 20 MPa and slump is 50 mm.

Theory and Scope

The absolute volume procedure as recommended by the ACI mix proportioning method is used for determining the proportions of the ingredients for the concrete mixture. The method is *suitable for normal and heavy weight concretes* having maximum *28-day cylinder compressive strength* of 45 MPa and workability (slump) range of 25 to 100 mm; the values generally used in the applications are listed in Table 10.1. The ACI method presumes that the *workability* of a mix with given *maximum size of well-graded aggregate* (i.e., an aggregate with suitable particle shape and the grading) is dependent upon the *water-content*, the *amount of entrained air* and certain *chemical admixtures*, but is largely independent of mix proportions, particularly the amount of cementing material. Therefore, ACI has provided a table relating nominal maximum aggregate size, air entrainment and desired slump to the required mixing water quantity.

In ACI method, the bulk volume of coarse aggregate per unit volume of concrete is estimated for the maximum size of coarse aggregate and fineness modulus of sand. The water-cement ratio is determined as in other methods to satisfy both strength and durability requirements. The air content in concrete is taken into account in calculating the volume of fine aggregate.

Apparatus

Sieve sets for finding maximum nominal size and fineness modulus of coarse and fine aggregates respectively; Weighing balance; Trowels; Tamping bar; Moulds, Universal compression testing machine; Graduated cylinder; Slump cone apparatus and Buckets.

Procedure

Step 1: Perform the sieve analysis of both the fine and coarse aggregates to determine the maximum nominal size of coarse aggregate and fineness modulus of fine aggregate. Determine the unit weight, specific gravities, and absorption capacities of both the aggregates.

Step 2: If the workability in terms of slump is not specified for a particular job; select an appropriate value from Table 10.1.

Table 10.1 *Slump ranges for specific applications (after ACI, 2000)*

Types of construction	Maximum Slump, mm	Minimum Slump, mm
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25

(continued)

Table 10.1 *contd.*

Types of construction	Maximum Slump, mm	Minimum Slump, mm
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

Maximum slump may be increased 25 mm for consolidation by hand, i.e., rodding, etc.

Step 3: Estimate the mixing water required for non-air-entrained concretes and entrapped air content from Table 10.2.

Table 10.2 *Approximate requirements of mixing water for non-air-entrained concrete (after ACI 211.1 and ACI 318)*

Slump, mm	Mixing water quantity[1], kg/m^3							
	Specified nominal maximum size of aggregate (after CSA A23.1) (mm)							
	10	14	20	28	40	56[2]	80[2]	150[2]
25 – 50 (Stiff-plastic)	207	199	190	179	166	154	130	113
75 – 100 (Plastic)	228	216	205	193	181	169	145	124
150 – 175 (Flowing)	243	228	216	202	190	178	160	-
Approximate amount of entrapped air, per cent								
All	3.0	2.5	2.0	1.5	1.0	0.5	0.3	0.2

[1] Table gives the maximum water content for reasonably well-shaped crushed aggregate.
[2] The slump values are based on the slump made after removal of particles larger than 40 mm by wet screening.

Step 4: Determine the target mean compressive strength of concrete at 28 days, f_t by using the

$$f_t = f_{ck} + k\ (=1.65)\mathrm{S}$$

where f_{ck} is the characteristic compressive strength at 28 days, and S is the standard deviation.

Step 5: Determine the water–cement ratio from Table 10.3 or Fig. 10.1 for the target mean strength computed in Step 4.

Table 10.3 *Relationship between water–cement ratio and compressive strength of concrete*

Compressive strength at 28 days,MPa	Water-cement ratio by weight
40	0.42
35	0.47

(continued)

Table 10.3 *contd.*

Compressive strength at 28 days, MPa	Water–cement ratio by weight
30	0.54
25	0.61
20	0.69
15	0.79

Maximum permissible water–cement ratios for concrete under severe exposure

Type of Structure	Continuously wet structure exposed to frequent freezing and thawing	Structure exposed to sea water or sulphates
Thin section (railings, curbs, sills, ledges, ornamental work) and sections with less than 25 mm cover over steel	0.45	0.40
All other structures	0.50	0.45

Step 6: Calculate cement content from the water content and water-cement ratio determined in Steps 3, 4 and 5, respectively, for the required strength and durability.

Step 7: Estimate the coarse aggregate content from Table 10.4 for the maximum nominal size of the coarse aggregate and fineness modulus of sand.

Step 8: Determine the content of fine aggregate by subtracting the sum of volumes of the coarse aggregate, cement, water and entrained air from unit volume of concrete.

Step 9: Fix the concrete mix proportions for the first trial mix or trial mix no. 1. Make suitable adjustment for moisture in the aggregates.

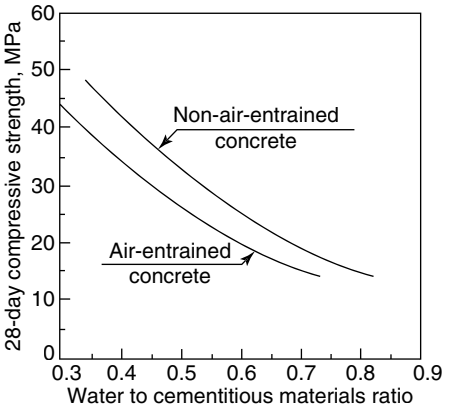

Fig. 10.1 *Relation between water–cement ratio and compressive strength of concrete*

Table 10.4 *Bulk volume of coarse aggregate per unit volume of concrete for different fineness moduli of fine aggregate (Adapted from ACI 211.1)*

Nominal maximum size of aggregate (after CSA A23.1), mm	Bulk volume of oven-dry-rodded coarse aggregate, m^3 Fineness modulus of fine aggregate			
	2.40	2.60	2.80	3.00
10	0.50	0.48	0.46	0.44
14	0.59	0.57	0.55	0.53
20	0.66	0.64	0.62	0.60

(continued)

Table 10.4 *contd.*

Nominal maximum size of aggregate (after CSA A23.1), mm	Bulk volume of oven-dry-rodded coarse aggregate, m^3 Fineness modulus of fine aggregate			
	2.40	**2.60**	**2.80**	**3.00**
28	0.71	0.69	0.67	0.65
40	0.75	0.73	0.71	0.69
56	0.78	0.76	0.74	0.72
80	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

Notes:

1. The values are for aggregate of specific gravity $S_{ca} = 2.68$. For an aggregate having specific gravity of S'_{ca} the value should be multiplied by the ratio S_{ca} / S'_{ca}.
2. Since concrete pavements are, in general, stiffer and less workable, above values can be increased by up to about 10 per cent.
3. Coarse aggregate volumes are based on oven-dry-rodded weights obtained in accordance with ASTM C 29.

Step 10: Measure the workability of the trial mix in terms of slump using only as much water as is needed to reach the desired slump (but not exceeding the permissible w/c ratio). Carefully observe the mix for freedom from segregation and bleeding and its finishing properties. Use the fresh concrete for unit weight, yield and air content.

Step 11: Recalculate the mix proportions keeping the free water–cement ratio at the pre-selected value; this will comprise trial mix no. 2. In addition, design two more trial mixes no. 3 and 4 with the water content same as trial mix no. 2 and varying the free water–cement ratio by ±10 per cent of the preselected value.

Step 12: Cast three 150 mm cubes for each trial mix and test them after 28 days of moist curing. If required, similar number of cubes may be prepared and tested for early strength,.

Step 13: Analyse mix nos. 2 to 4 for relevant information, including the relationship between compressive strength and water–cement ratio. Using this information compute water cement ratio required for the mean target strength. Recalculate the mix proportions for the changed water–cement ratio taking water content as the same as that determined in trial no. 2.

For field trials, produce the concrete by actual concrete production method used in the field.

Observations and Calculations

Type of cement			
Specific gravity of cement			
Characteristic strength of concrete f_{ck},	MPa		
Mean target strength of concrete f_t,	MPa		
Water-cement ratio			
Desired workability in terms of slump,	mm		
Maximum nominal size of coarse aggregate,	mm		
Fineness modulus of sand			

Entrained air,					per cent	
Water content per cubic metre of concrete,					kg	
Cement content per cubic metre of concrete,					kg	
Bulk volume of cement per cubic metre of concrete,					m^3	
Bulk volume of dry rodded coarse aggregate per cubic metre of concrete,					m^3	
Bulk volume of sand,					m^3	
Mix proportions (by volume)						
Trial mix specimens		1	2	3	Age	Average
Crushing load,	kN				28 days	
Crushing strength,	MPa					

Compressive strength of concrete is……. MPa.
This mix is suitable/it needs revision.
The mix proportion is……..

Precautions

1. For calculating the water-cement ratio, the surface moisture should be added to the water mixed in concrete.
2. In choosing the strength required for particular purpose, allowance must be made for the inevitable variation in strength of the test cubes. From the specified minimum strength, the target mean strength is estimated according to the degree of control to be exercised, using information obtained from experience.
3. Slump test should be completed within 30 minutes.
4. Contents should be weighed accurately.
5. The inside of cube should be oiled to prevent the mortar from adhering to the sides of the mould.
6. The ambient temperature at which cubes are prepared should be between 25 and 29°C.

Discussion

The method assumes that the workability of a concrete mix is dependent only on the water content in the mix. The water content decreases with the increase in the maximum nominal size of the coarse aggregate. The fraction of coarse aggregate itself decreases with the increase of fineness modulus of fine aggregate, i.e., coarser the sand lower will be the bulk volume of dry coarse aggregate required for the mix. However, the coarse aggregate content increases with the increase in the maximum nominal size of aggregate.

Viva-Voce Questions

1. What is meant by mix proportioning?
2. What does mix proportions 1: 2: 4 represent?
3. What are the basic principal variables used in the proportioning of concrete mix for the given materials by ACI method of mix proportioning?
4. What is the characteristic strength?

5. Explain target mean strength and how is it obtained?
6. How do you define maximum nominal size of a coarse aggregate?
7. Describe the factors influencing choice of nominal maximum size of a coarse aggregate.
8. What is meant by the fineness modulus of sand?
9. Does a broken stone coarse aggregate require a large percentage of fine aggregate than does a rounded coarse aggregate?
10. How is the batch mass of materials per unit volume of concrete obtained?

Notes and Comments

EXPERIMENT NO. 2: IS Concrete Mix Proportioning – Guidelines

Objective

To design a concrete mix in accordance with Indian Standard mix proportioning – Guidelines.

Theory and Scope

The concrete mix design method uses the Indian Standard mix proportioning guidelines to achieve specified characteristics, i.e., workability of fresh concrete, and strength and durability requirements of hardened concrete at specified age. The guidelines are applicable to ordinary and standard concrete grades only. All the requirements of IS 456-2000 are also satisfied in the mix design process.

Based on the guidelines, the preliminary or trial mixes are made and desired properties of the trial mixes are checked; suitable adjustments are made to produce concrete possessing specified properties both in fresh and hardened states with the maximum overall economy. The design of plastic concrete mixes of medium strength can be based on the following two criteria:

1. The compressive strength of concrete is governed by its water-cement ratio.
2. For the given aggregate characteristics, the workability of concrete is governed by its water content.

Apparatus

Sieve sets for finding maximum nominal size, and gradings of coarse and fine aggregates; Weighing balance; Trowels; Tamping bar; Moulds, Universal compression testing machine; Graduated cylinder; Slump cone apparatus and Buckets.

Procedure

Step 1: Perform sieve analyses of both the fine and coarse aggregates available to determine:

(a) the maximum nominal size of coarse aggregate,
(b) the gradings of fine and coarse aggregates and
(c) the grading zone of fine aggregate.

If necessary, combine two or more different size coarse aggregate fractions so that the overall grading of coarse aggregate conforms to Table 2 of IS 383 for the particular nominal maximum size of aggregate.

Step 2: Determine the unit weight, specific gravities, and absorption capacities of both the coarse and fine aggregates.

Step 3: Determine the target mean compressive strength f'_{ck} in MPa from the specified characteristic compressive strength at 28-day f_{ck} in MPa and the level of quality control.

$$f'_{ck} = f_{ck} + 1.65S$$

where S is the standard deviation in MPa obtained from Table 10.5.

Table 10.5 *Assumed standard deviation*

Group No.	Grade of concrete	Assumed standard deviation, MPa	Quality control
1.	M10 M15	3.5	The values correspond to the site control having proper storage of cement; weigh batching of all materials; controlled addition of water; regular checking of all materials, aggregate grading and moisture content; and periodical checking of workability and strength. Where there is deviation from the above, values given in this table shall be increased by 1.0 MPa.
2.	M20 M25	4.0	
3.	M30 M35 M40 M45 M50 M55	5.0	

Step 4: Determine the water–cement ratio using the relationship between strength and free water–cement ratio established for the materials to be used in the job. In the absence of such data, select the preliminary free water–cement ratio (by mass) corresponding to the target mean strength at 28 days using the empirical relationship between compressive strength and water–cement ratio given in Fig. 10.1. Check the selected water–cement ratio against the limiting water–cement ratio for the requirements of durability given in Table 10.6; the lower of the two values is adopted.

Table 10.6 *Minimum cement content and maximum water–cement ratio of concrete with normal weight aggregates of 20 mm nominal maximum size subjected to different exposures (Adapted from IS 456-2000)*

Sl. No.	Exposure condition	Plain Concrete			Reinforced Concrete		
		Minimum cement content, kg/m^3	Maximum free water-cement ratio	Minimum grade of concrete	Minimum cement content, kg/m^3	Maximum free water-cement ratio	Minimum grade of concrete
1	Mild	220	0.60	-	300	0.55	M20
2	Moderate	240	0.60	M15	300	0.60	M 25
3	Severe	250	0.50	M20	320	0.45	M30
4	Very severe	260	0.45	M20	340	0.45	M35
5	Extreme	280	0.40	M25	360	0.40	M40

Adjustments to Minimum cement contents for Aggregates other than 20 mm Nominal Maximum Size

	Nominal Maximum Size, mm	Adjustments to Minimum cement contents, kg/m^3
1	10	+40
2	20	0
3	40	-30

Notes:

(i) Cement content prescribed is irrespective of the grades of cement and it is inclusive of all supplementary cementitious materials. The additions such as fly ash or ground granulated blast furnace slag may be taken into account in the concrete composition with respect to the cement content and water-cement ratio if the suitability is established and as long as the maximum amounts taken into account do not exceed the limit of pozzolana and slag specified in IS 1489 (Part I) and IS 455 respectively.

(ii) Minimum grade for plain concrete under mild exposure condition is not specified.

Step 5: Determine the water content per unit volume of concrete, for the required workability and maximum size of aggregates (for aggregates in saturated surface dry condition) from Table 10.7 for computing cementitious material contents for trial batches.

Table 10.7 *Maximum water content for nominal maximum size of aggregate*

Sl. No.	Nominal maximum size of aggregate, mm	Maximum water content, kg	Validity conditions
1.	10	208	1. Applicable to angular coarse aggregate
2.	20	186	2. Water content corresponds to saturated surface dry aggregate,
3.	40	165	3. Applicable to slump range of 25 to 50 mm
Adjustments in the water content for the change in type of aggregate and workability			
Change in condition stipulated above			**Adjustment required in water content**
1. Shape of aggregate			
(a) Sub-angular aggregates			–10 kg
(b) Gravel with some crushed particles			–20 kg
(c) Rounded gravel			–25 kg
2. Workability			
(a) For each additional 25 mm slump. Alternatively, required water content may be established by trial			+ 3 per cent
(b) Use of chemical admixtures conforming to IS 9103.			Water reducing admixtures and Superplasticizers usually decrease water content by 5 to 10 per cent and 20 per cent and above, respectively, at appropriate dosages.

Step 6: Calculate the cement and supplementary cementitious material content per unit volume of concrete from the free water–cement ratio and the water content per unit volume of concrete. Check the cementitious material content so calculated against the minimum content for the requirements of durability; adopt the greater of the two values.

Step 7: Estimate the volume of coarse aggregate of given nominal maximum size from Table 10.8 for the reference water–cement ratio of 0.5 and grading zone of fine aggregate used; adjust it suitably for the selected water–cement ratios.

For more workable concrete, e.g., pumpable or concrete mixes to be placed around congested reinforcing steel the estimated coarse aggregate content may be reduced up to 10 per cent subject to slump, water-cement ratio and strength properties of concrete remaining consistent with the provisions of IS 456 and project specifications.

Table 10.8 *Proportion of coarse aggregate to total aggregate for different zones of fine aggregate*

Sl. No.	Nominal maximum size of aggregate, mm	Volume proportion of coarse aggregate to total aggregate for different zones of fine aggregate			
		Zone IV	*Zone III*	*Zone II*	*Zone I*
1.	10	0.50	0.48	0.46	0.44
2.	20	0.66	0.64	0.62	0.60
3.	40	0.75	0.73	0.71	0.69

Step 8: Estimate the volume of total aggregate by subtracting the sum of absolute volumes of cementitious material, water and the chemical admixture; and entrained air (if considered) from unit volume of concrete.

Step 9: Divide the volume of total aggregate so obtained into coarse and fine aggregate fractions by volume in accordance with coarse aggregate proportion already determined in Step 7. Determine the coarse and fine aggregate contents by multiplying with their respective specific gravities and multiplying by 1000. Alternatively, determine the volume of coarse and fine aggregate fractions as follows.

$$V = \left[W + \frac{C}{S_c} + \frac{1}{p}\frac{C_a}{S_{ca}} \right] \times \frac{1}{1000}$$

$$V = \left[W + \frac{C}{S_c} + \frac{1}{(1-p)}\frac{f_a}{S_{fa}} \right] \times \frac{1}{1000}$$

and

V = absolute volume of fresh concrete,
= gross volume (1.0 m^3) minus the volume of entrapped air,
S_c = specific gravity of cement,
W = Mass of water per cubic metre of concrete, kg
C = mass of cement per cubic metre of concrete, kg
p = ratio of coarse aggregate to total aggregate by absolute volume,
f_a. C_a = total masses of fine and coarse aggregates, per cubic metre of concrete, respectively, kg
and
S_{fa}, S_{ca}= specific gravities of saturated surface dry fine and coarse aggregates, respectively.

Step 10: Determine the concrete mix proportions for the first trial mix or trial mix no. 1. Measure the workability of the trial mix in terms of slump; carefully observe the mix for freedom from segregation and bleeding and its finishing properties. If the slump of first trial mix is different from the stipulated value, adjust the water and/or admixture content suitably to obtain the correct slump.

Step 11: Recalculate the mix proportions keeping the free water–cement ratio at the pre–selected value; this will comprise trial mix no. 2. In addition formulate two more trial mixes no. 3 and 4 with the water content same as trial mix no. 2 and varying the free water–cement ratio by ±10 percent of the preselected value.

Step 12: Test the fresh concrete for unit weight, yield and air content. Prepare trial mix and cast three 150 mm cubes and test them after 28 days of moist curing.

Step 13: Analyse mix nos. 2 to 4 for relevant information, including the relationship between compressive strength and water–cement ratio. Compute water–cement ratio required for the mean target strength using the relationship. Recalculate the mix proportions for the changed water–cement ratio keeping water content at the same level as that determined in trial no. 2.

For field trials, produce the concrete by actual concrete production method used in the field.

Observations and Calculations

Characteristic strength of concrete,	f_{ck}	
Early age strength requirements, if required;	MPa	

Workability in terms of slump,					mm	
Admixture details, if to be used Exposure conditions						
Standard deviation, Mean target strength,					S f'_{ck}	
Water-cement ratio	for mean target strength value for durability requirements		Adopt the lower value			
Type and grade of cement Grading zone of fine aggregate Type of coarse aggregate						
Maximum nominal size of aggregate, Specific gravity of cement, Specific gravity of saturated surface dry fine aggregate, Specific gravity of saturated surface dry coarse aggregate, Entrapped air (if considered),					mm S_c S_{fa} S_{ca} per cent	
Water content per cubic metre of concrete,		W kg	before adjustment after adjustment			
Ratio of coarse aggregate in total aggregate by absolute volume,		p	before adjustment after adjustment			
Cement content per cubic metre of concrete,		C kg	from w/c ratio from durability requirements			
Total coarse aggregate per cubic metre of concrete, Total fine aggregate per cubic metre of concrete,					C_a kg f_a kg	

Specimen number	1	2	3	4	age	average
Mix proportions (by mass)						
Load, kN Strength, MPa						

The compressive strength of concrete mix is……..
The designed mix is suitable/it needs further revision.
The mix proportions are……

Precautions

1. The water content and the proportion of coarse aggregate should be adjusted for any difference in workability, water–cement ratio and the grading zone of fine aggregate from the reference values used in Table 10.7 and 10.8.

2. The slump test, cube casting, curing and testing should be done according to the specifications.
3. The fresh concrete should be carefully observed for freedom from segregation and bleeding, and finishing properties.

Discussion

The mix design is really a process of making an initial guess at the optimum combination of ingredients and the final mix proportion is obtained only on the basis of further trial mixes. The IS guidelines envisage that the design of concrete mix be based on the following factors:

1. **Grade designation** giving the characteristic strength requirement of the concrete. The term *characteristic strength* means that value of strength of material below which not more than five per cent of test results are expected to fall. Depending upon the level of quality control available at the site, the concrete mix has to be designed for a *target mean strength* which is greater than the characteristic strength by a suitable margin. The target mean strength is expressed as

$$f_t = f_{ck} + 1.65\ S$$

where f_t = target mean strength,
f_{ck} = characteristic strength, and
S = standard deviation.

2. **Maximum nominal size of aggregates** to be used in concrete may be as large as possible within the limits prescribed by IS: 456-2000 and IS: 1343-1980. In general, an increase in the maximum nominal size of aggregate helps in increasing the workability and reducing the cement requirement for a particular water-cement ratio. However, the size of aggregates also influences the compressive strength of concrete in that, for a particular volume of aggregate, the compressive strength tends to increase with decrease in the size of aggregate. This is due to fact that smaller size of aggregates provide a larger surface area for binding with mortar matrix. Moreover, an increase in maximum size of aggregate increases the stress concentration in the mortar-aggregate interface. For high strength concrete 10 or 20 mm size of aggregate is preferable.
3. The **cement content** is to be limited from shrinkage cracking and creep considerations. In thick concrete sections restrained against movements, high cement content may give rise to excessive cracking by differential thermal stresses due to hydration of cement in young concretes. However, the cement content should not be less than the minimum content prescribed for the requirements of durability.

   For high strength concrete increasing cement content beyond a certain value, of the order of 550 kg/m^3 or so may not help in increasing the compressive strength. From overall economic considerations the maximum cement content in concrete mixes is limited to 530 kg/m^3 for prestressed concrete.
4. The **workability** of concrete for satisfactory placing and compaction is related to the size and shape of the section to be concreted, the quantity and spacing of reinforcement and the technique used for transportation, placing and compaction of concrete.

   In case of fly ash cement concrete of comparable workability, the water-cement ratio can be reduced by about 3 to 5 per cent and proportion of fine aggregate is reduced by 2 to 4 per cent points.
5. As the compressive strength of concrete for the same free water-cement ratio vary with type of cement and supplementary cementitious materials, maximum size, grading, surface texture, and shape of aggregate. Therefore, the relationship between strength and free water-cement ratio should preferably be established for the materials actually to be used. In the absence of such data, the preliminary free water–cement ratio (by mass) corresponding to the target strength at 28 days may be selected from the established relationship, if available, e.g., from Fig. 10.2. This relationship is applicable to both ordinary Portland and Portland pozzolana cements. If the 7-day compressive strength of concrete is considered as an additional parameter influencing the relationship between water-cement ratio and 28-day compressive strength the Fig. 10.3 can be used to make more precise estimate of water-cement ratio. Alternatively

the water-cement ratio given in Table 5 of IS 456 for respective environment exposure conditions may be used as starting point. The supplementary cementitious materials, i.e., mineral admixtures are included in water–cement ratio calculations in accordance with Table 5 of IS 456.

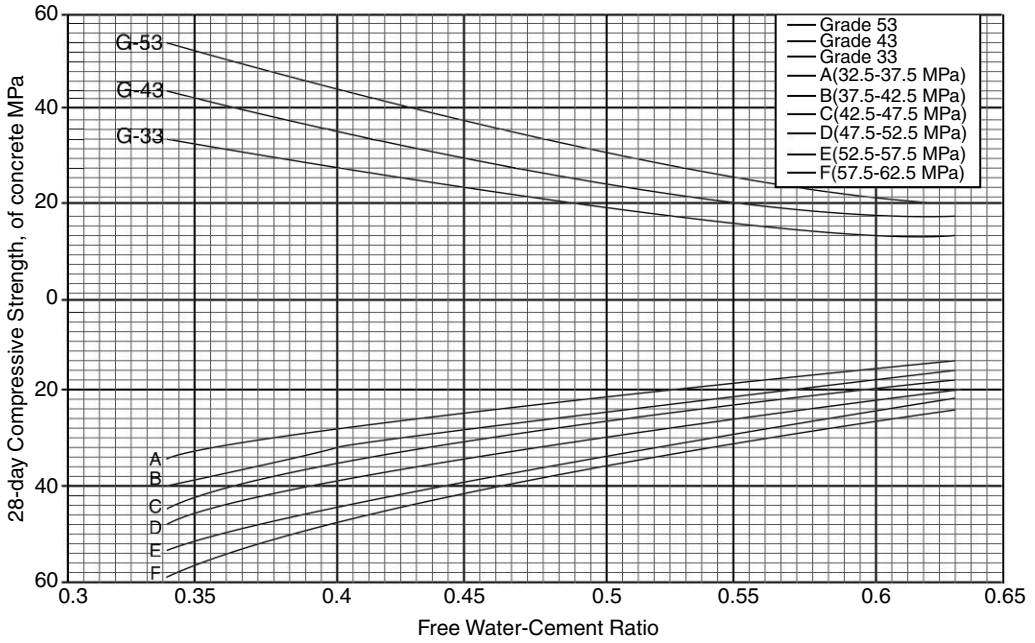

Fig. 10.2 *Relationship between the free water-cement ratio and 28 day compressive strength of concrete*

As in ACI method, the volume of coarse aggregate in concrete mix is first determined depending upon the maximum nominal size of coarse aggregate and grading of fine aggregate. Both the methods use the absolute volumes of the ingredients in mix proportioning.

The method can use the aggregate available at the work site of any grading so long as they are within the grading limits specified by IS 383, i.e., conform to standard grading. For example, consider the case where the fine and coarse aggregates available at work site (given in the table) are to be combined so as to approximate to the standard grading also listed in the table. This can be done conveniently by analytical calculations.

Type of aggregate	**Percentage passing the IS sieve**							
	20 mm	**10 mm**	**4.75*mm**	**2.36 mm**	**1.18 mm**	**600 μm**	**300 μm**	**150 μm**
Coarse aggregate grading (*c*)	100	31	7	-	-	-	-	-
Fine aggregate grading (*f*)	100	100	100	92	76	48	20	3
Specified/selected grading (*s*)	100	45	30	23	16	9	2	1
Combined aggregate grading, $(f + k\,c)/(1 + k) \approx$	100	48	30	23	19	12	5	1

*Reference sieve size

If fine and coarse aggregates are combined in proportion 1: k, then using IS: 4.75 mm sieve size as criteria, the value of k is given by: $k = \dfrac{f-s}{s-c}$

The grading of the resulting combined aggregate is determined by multiplying the grading of fine and coarse aggregates by 1.0 and k, respectively, and dividing the sum of corresponding products of percentages passing the particular sieve size by $(1 + k)$, the values being rounded off to nearest percentage. For this case

$$k = \frac{f-s}{s-c} = \frac{100-30}{30-7} = 3.043$$

Therefore, fine and coarse aggregates are to be combined in a mass proportion of 1: 3.043.

Viva-Voce Questions

1. What is the objective of mix design?
2. What are the basic principal variables considered in proportioning of concrete mix using given materials?
3. Explain the basic assumptions made in the design of plastic concrete mixes of medium strength.
4. Why is mix design really a process of making initial guess at the optimum combination of ingredients and the final mix proportions a basis of further trial mixes?
5. What are the factors influencing the choice of mix design?
6. What is characteristic strength?
7. How is the target mean strength calculated?
8. What is standard deviation?
9. What is the importance of type of cement in the mix design?
10. What is nominal maximum size of coarse aggregate?
11. What are the factors influencing the choice of nominal maximum size of coarse aggregate?
12. How is the batch weight of materials per unit volume of concrete obtained?
13. How is the entrapped air content estimated?
14. With the known quantities of water and cement per unit volume of concrete and proportion of coarse aggregate in total aggregate, how are the coarse and fine aggregates per unit volume of concrete calculated?
15. How is the variability in the results of laboratory trials accounted for to arrive at the final mix proportions?

Notes and Comments

EXPERIMENT NO. 3: British DoE Concrete Mix Design

Objective

To design a concrete mix in accordance with British DoE mix design method.

Theory and Scope

The British DoE method can be applied to produce designed concrete, using cements and aggregates which conform to the relevant British Standards. The method is suitable for the design of normal concrete having 28-day compressive strength as high as 75 MPa for non-air-entrained concretes. The method is also suitable for the design of concretes containing fly ash and GGBFS.

The mixes are specified by the mass of the different materials contained in a cubic metre of fully compacted fresh concrete. The method is based on the following four criteria:

1. The *volume of freshly mixed concrete* equals the sum of the absolute volumes of its constituent materials, i.e., the water, cement, air content and the total aggregate. The method therefore requires that the absolute densities of the materials be known in order that their absolute volumes may be calculated.
2. The compressive strength class of a concrete depends on
   (a) The *free water–cement ratio*.
   (b) The type of coarse aggregate, i.e., whether the aggregate is crushed or uncrushed (gravel).
   (c) The type of cement, i.e., whether the cement is normal (ordinary) Portland cement or combined cement.
3. The *consistence* (workability) of concrete depends primarily on
   (a) The *free water content*.
   (b) The type of fine aggregate and, to a lesser degree, type of coarse aggregate.
   (c) The nominal upper (maximum) size of coarse aggregate.
4. The *consistence* (workability) depends secondarily on
   (a) The fraction of the fine aggregate as a proportion of the total aggregate content.
   (b) The grading of the fine aggregate.
   (c) The free water–cement ratio.

Based on the method, the preliminary or trial mixes are made and desired properties of the trial mixes are checked; suitable adjustments are made to produce concrete possessing specified properties both in fresh and hardened states with the maximum overall economy.

Apparatus

Sieve sets for finding maximum nominal size, and gradings of coarse and fine aggregates; Weighing balance; Trowels; Tamping bar; Moulds; Universal compression testing machine; Graduated cylinder; Slump cone apparatus and Buckets.

Procedure

Step 1: Perform sieve analyses of both the fine and coarse aggregates available to determine:

(a) The *nominal upper (maximum) size of coarse aggregate* The designations of coarse aggregate are established from the nominal lower and upper sieve sizes for the particular aggregates, the

lower size being stated first. For example an aggregate of maximum nominal size of 10 mm is designated as 4/10. The maximum aggregate sizes recommended are: 10 mm; 20 mm and 40 mm.

(b) Gradings of fine and coarse aggregates.

(c) Gradings zone of fine aggregate.

If necessary, combine two or more different size coarse aggregate fractions so that the overall grading of coarse aggregate conforms to desired grading for the particular nominal maximum size of aggregate.

Step 2: Determine the absolute densities, specific gravities, and absorption capacities of both the coarse and fine aggregates. Also determine the specific gravity of overall aggregates in the saturated surface dry condition.

Step 3: Select the target consistence (workability) of fresh concrete in terms of slump class for the normal working range of zero to 200 mm. Where consistence other than slump is specified it is recommended that a relationship between the two is established.

Step 4: Estimate the *strength margin factor* and the *standard deviation* for calculation of the *target mean* corresponding to the 28 day characteristic strength specified. The margin takes in to account the degree of safety required for the strength; it is either specified or calculated for a given proportion of defectives. The statistical standard deviation takes in to account the conformity rules (quality control) during production. These quantities are different for cylinders or cubes.

Note: EN:206 classifies concrete strength in terms of 28 day characteristic strengths on the basis of cylinders and cubes, e.g., C25/30, where the first number is the strength of 150 mm (diameter) × 300 mm (high) cylinder and the second number is the 150 mm cube strength. However, it should not be presumed that by giving both cube and cylinder strengths, a particular relationship is being assumed for purposes of conversion for concrete design or control.

Step 5: Obtain the target mean strength by adding a margin to the stipulated characteristic strength and statistical standard deviation.

If air entrainment is specified, calculate the artificially raised modified target mean strength.

Table 10.9 *Approximate compressive strength of concrete with water-cement ratio as 0.5*

Type of cement	*Type of coarse aggregate*	*Compressive strength (MPa) Age (days)*			
		3	7	28	91
Ordinary (CEM 1) or sulphate resisting cement (SRPC)	Uncrushed	22	30	43	49
	Crushed	27	36	49	56
Rapid hardening Portland cement	Uncrushed	29	37	48	54
	Crushed	34	43	55	61

Step 6: Select the *maximum free water–cement ratio* which will provide the target mean strength for concrete made from the given types of coarse aggregate and cement as follows:

For the given type of cement and aggregate, the compressive strength at the specified age corresponding to the reference water-cement ratio of 0.50 is obtained from Table 10.9. For example, when normal Portland cement and uncrushed aggregate are used, the compressive strength is 43 MPa at 28 days. With this pair of data (43 MPa and water-cement ratio = 0.50) as a controlling or reference point, a strength versus water-cement ratio curve is located in Fig. 10.3. In this particular case, it is

the fourth (dotted) curve from the top of Fig. 10.3 passing the controlling point. Using this curve, water–cement ratio is determined corresponding to the computed *target mean strength.* In case an existing curve is not available which passes through the controlling point, the curve is interpolated between two existing curves in Fig. 10.3.

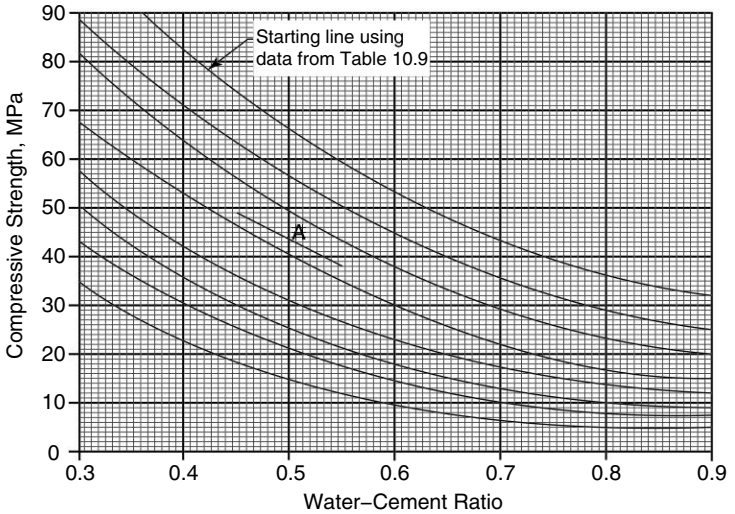

Fig. 10.3 *Variation of compressive strength with water–cement ratio (DoE)*

Compare this water-cement ratio with the maximum water–cement ratio specified for the durability from the Table 10.10 and adopt the lower of the two values. The maximum water–cement ratio based on durability considerations includes a set of exposure classes related to different mechanisms of deterioration. Exposure class XO exists on its own and there are no requirements for the water–cement ratio or the minimum cement content.

Table 10.10 *Minimum cement content and maximum water–cement ratio for different exposures*

Exposure classes (environmental effects, i.e., attacks)				Provisions for resistance		
Class designation		***Type and degree of exposure***		***Maximum water–cement ratio***	***Minimum cement***	***Strength class***
XO		No risk of any attack	No concrete attack	No requirement	No requirement	C8/10
XC	1	Corrosion by carbonation	Dry	0.75	240	C16/20
	2		Constantly wet	0.75	240	C16/20
	3		Moderately moist	0.65	260	C20/25
	4		Wet / dry	0.60	280	C25/30
XD / XS	1	Corrosion by Chlorides	Moderately moist	0.55	300	C30/37
	2		Constantly wet	0.50	320	C35/45
	3		Wet / dry	0.45	320	C35/45

(continued)

Table 10.10 *contd.*

Exposure classes (environmental effects, i.e., attacks)				Provisions for resistance		
Class designation		*Type and degree of exposure*		*Maximum water-cement ratio*	*Minimum cement*	*Strength class*
XF	1	Freeze-thaw /+ salt	Moderate water saturation (wo.s.)[1]	0.60	280	C25/30
	2		Moderate water saturation (w.s.)	0.55 + LP 0.50	300 320	C25/30 C35/45
	3		High water saturation (wo.s.)	0.55 + LP 0.50	300 320	C25/30 C35/45
	4		High water saturation (w.s.)	0.50 + LP	320	C30/37
XA	1	Chemical attack	Weakly corrosive	0.60	280	C25/30
	2		Moderately corrosive	0.50	320	C35/45
	3		Strongly corrosive	0.45	320	C35/45
XM	1	Abrasion (Wear) [2]	Moderate wear	0.55	300	C30/37
	2		Severe wear	0.45	320	C35/45
	3		Very severe wear	0.45	320	C35/45

[1]Abbreviations: w = with; wo = without; s = de-icing salt
[2] BS EN:2306-1 does not contain abrasion classes

Note: For a concrete designed using EN: 206 specifications for durability, the EN:206 specifications allow to count the proportion (k) of addition in the combination with cement towards satisfying specified limits for minimum cement content and maximum water–cement ratio, rather than just the cement content. Since generally the presence of Type 2 (pozzolanic or latent hydraulic) addition reduces the heat of hydration and improves the durability of a mix. Here, the factor k called the efficiency or strength factor of the addition, refers to relative strength of addition with respect to the cement.

Table 10.11 *Approximate water content required for target consistence (Workability)*

Consistence class		S1 / F2	S2 / F3	S3 / F4	S4 / F5
		(Very low)	(Low)	(Medium)	(High)
Slump (S) class	Class range, Slump (mm)	10 to 40	50 to 90	100 to 150	160 to 210
Flow (F) class	Class range, Flow diameter range (mm)	350-410	420-480	490-550	560-620
I. Water content					
Size of aggregate	Type of aggregate	Water content (kg/m^3)			
4/10	Uncrushed	150	180	205	225
	Crushed	180	205	230	250
10/20	Uncrushed	135	160	180	195
	Crushed	170	190	210	225

(continued)

Table 10.11 *contd.*

Consistence class		S1 / F2 (Very low)	S2 / F3 (Low)	S3 / F4 (Medium)	S4 / F5 (High)
20/40	Uncrushed	115	140	160	175
	Crushed	155	175	190	205
II. Reduction in water content when additives are used					
Percentage of additive in combination with cement		**Reduction in water content (kg/m^3)**			
10		5	5	5	10
20		10	10	10	15
30		15	15	20	20
40		20	20	25	25
50		25	25	30	30

Step 7: Select the approximate free water content from Table 10.11, which will provide the target consistence (specified in terms of slump or flow diameter or Vee-Bee time) for the concrete made with the given fine and coarse aggregate types and nominal upper size of coarse aggregate.

When the coarse and fine aggregates used are of different types, the water content is estimated by the expression given by Eq. (10.1).

$$W = (2W_f / 3) + (W_c / 3) \tag{10.1}$$

where

W_f = water content appropriate to type of fine aggregate.
W_c = water content appropriate to type of coarse aggregate.

If the free water content has been determined for target consistence, adjust it for the specified air entrainment, and further adjust if a water reducing admixture is specified.

Step 8: Determine minimum cement content by dividing the *free water content* obtained in Step 7 by the *free water–cement ratio* obtained in Step 6.

$$\text{Cement content (kg/m}^3) = \frac{\text{Water content}}{\text{Water}-\text{cement ratio}} \tag{10.2}$$

(a) Compare the computed cement content with the maximum cement content which is permitted. If the calculated cement content is higher than the specified maximum, then the *target strength* and *target consistence* (workability) cannot be achieved simultaneously with selected materials. In such a situation, the process is repeated by changing the type of cement, the type and upper size of the aggregate.

(b) Compare the computed cement content required for target strength with the minimum cement content which is specified for durability; adopt the greater of the two in the concrete.

Thus the cement content is the minimum given by a free water-cement ratio that is low enough to provide the target strength and durability.

Step 9: Determine the free water content which is available to react with the cement; it is the ***sum*** of (a) the added water; (b) the surface water of the aggregates and (c) the water content of admixtures ***less*** (d) the water absorbed by the aggregate during the period between the mixing and the setting of the concrete.

Step 10: Divide the free water content by the cement content used in the concrete to obtain a modified free water–cement ratio.

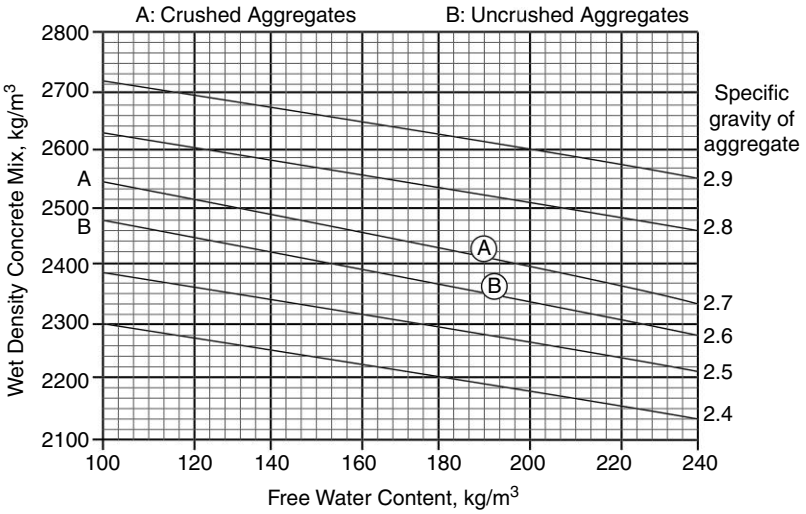

Fig. 10.4 *Estimated wet density of fully compacted concrete (DoE)*

Step 11: Compute the total absolute volume of aggregates as follows:

(a) The total aggregate content (kg/m^3) can be computed from the wet density of concrete obtained from Fig, 10.4. The wet density of concrete depends on the specific gravity of overall aggregates in the saturated surface dry condition.

(b) Alternatively, the absolute volume fraction of the aggregate is calculated by subtracting the proportional volumes of the free water and cement from a unit volume of concrete using Eq. (10.3).

$$\text{Absolute volume of aggregates} = 1 - \frac{C}{1000\,S_c} - \frac{W}{1000} \tag{10.3}$$

where C and W are the cement and water contents, respectively, and S_c is the specific gravity of cement particles. Therefore,

$$\text{Total aggregate content (kg/m}^3) = (1000\,S_a) \times \text{absolute volume of aggregates} \tag{10.4}$$

where S_a is the specific gravity of aggregate particles. If no information is available S_a may be taken 2.6 for uncrushed aggregate and 2.7 for crushed aggregate i.e. curves A and B can be used.

Step 12: Determine the fine and coarse aggregate contents as follows:

(a) Obtain the percentage of fine aggregate from Fig. 10.5 expressed as a percentage of total aggregate that will provide the target consistence of the fresh concrete to be made with the

given grading of fine aggregate, the nominal upper size of coarse aggregate and the free water-cement ratio obtained in Step 10.

(b) Calculate the content of coarse aggregate from the total aggregate content obtained in Step 8 as follows:

$$\text{Coarse aggregate content (per cent)} = 100 - \text{content of fine aggregate (per cent)}$$

(c) Divide the coarse aggregate further in to different size fractions. Coarse aggregate fractions listed in Table 10.12 can be used as a general guideline.

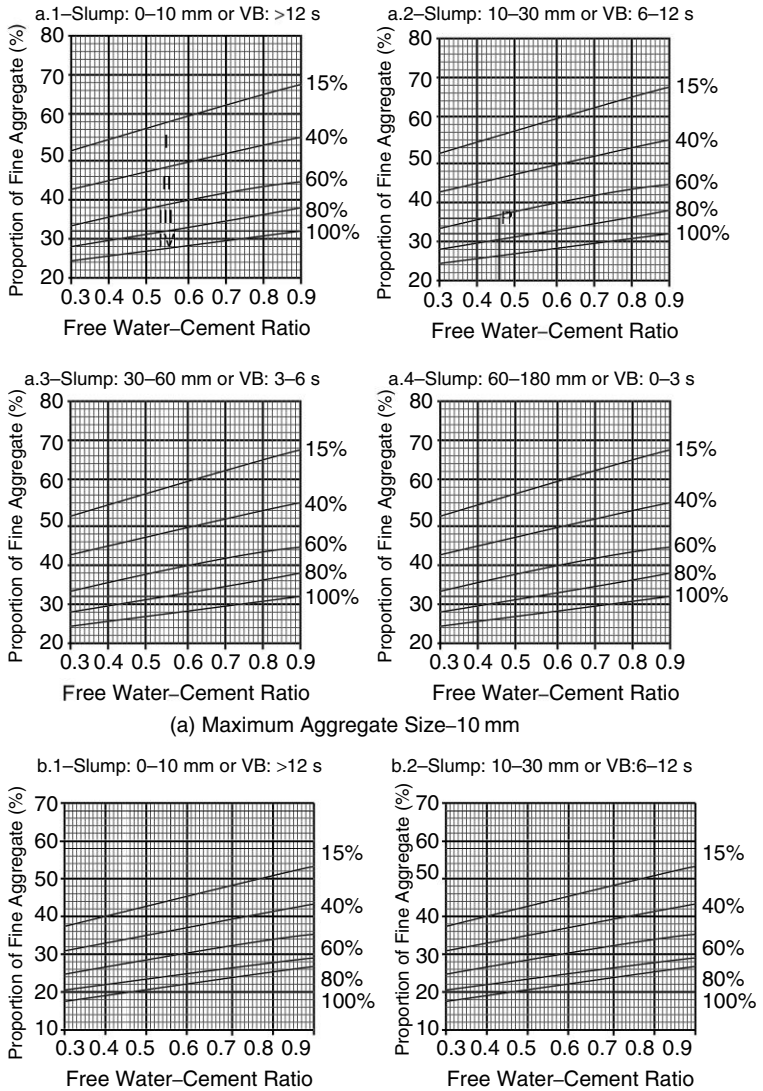

Fig. 10.5 *contd.*

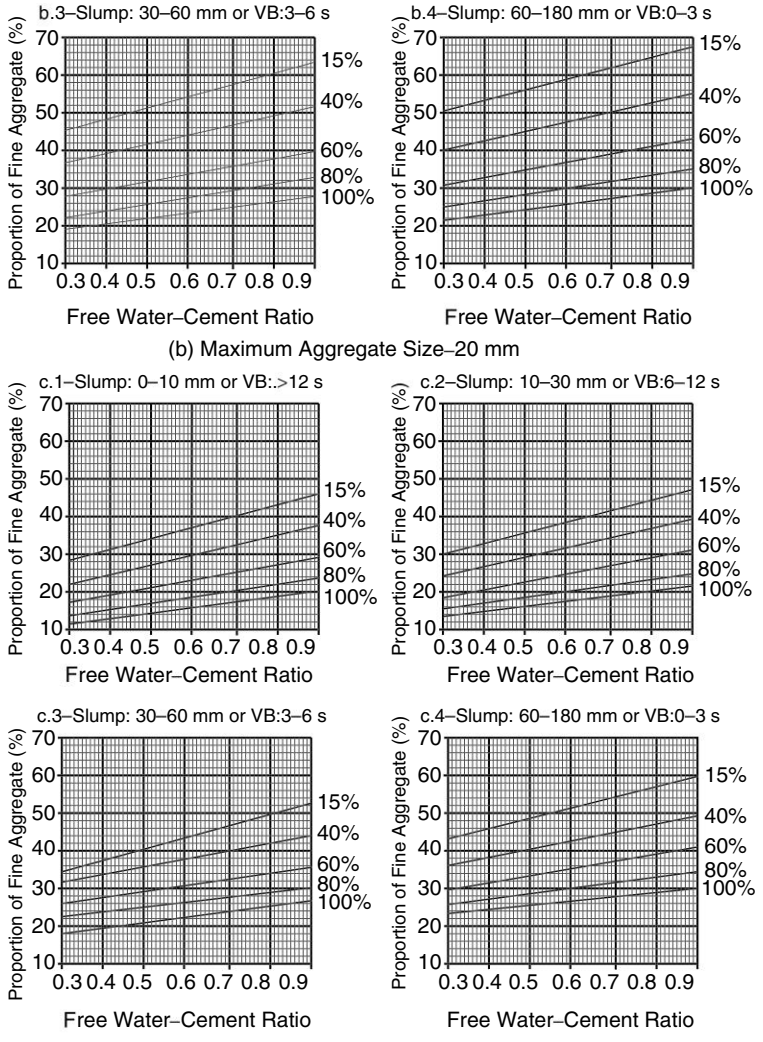

Fig. 10.5 *Recommended proportions of fine aggregate for different grading zones (DoE)*

Table 10.12 *Proportions of different sizes of coarse aggregates*

Aggregate size range (mm)	(2.36 /4) - (4 /10)	(4 /10) - (10 /20)	(10 /20) -(20 /40)
Type-I	33	67	–
Type-II	18	27	55

Step 13: Determine the concrete mix proportions for the first trial mix or trial mix no. 1. Measure the workability of the trial mix in terms of slump; carefully observe the mix for freedom from segregation and bleeding and its finishing properties. If the slump of first Trial mix is different from the stipulated value, adjust the water and/or admixture content suitably to obtain the correct slump.

Step 14: Make adjustments for aggregate moisture and determine final proportions. Since aggregates are batched on actual weight basis, adjust the amount of mixing water to be added to take in to account the aggregate moisture.

Step 15: Recalculate the mix proportions keeping the free water-cement ratio at the pre-selected value; this will comprise Trial mix no. 2. In addition formulate two more trial mixes no. 3 and 4 with the water content same as Trial mix no. 2 and varying the free water-cement ratio by ±10 per cent of the preselected value.

Step 16: Test the fresh concrete for unit weight, yield and air content. Prepare trial mix and cast three 150 mm cubes and test them after 28 days of moist curing.

Step 17: Analyse mix nos. 2 to 4 for relevant information, including the relationship between compressive strength and water–cement ratio. Compute water-cement ratio required for the mean target strength using the relationship. Recalculate the mix proportions for the changed water–cement ratio keeping water content at the same level as that determined in trial no. 2.
For field trials, produce the concrete by actual concrete production method used in the field.

Observations and Calculations

<table>
<tr><td colspan="3">28 day characteristic strength of concrete,</td><td>f_{ck}</td><td rowspan="8"></td></tr>
<tr><td colspan="3">Early age strength requirements, if required;</td><td>MPa</td></tr>
<tr><td colspan="3">Target consistence (workability) in terms of slump,</td><td>mm</td></tr>
<tr><td colspan="3">Admixture details, if to be used</td><td></td></tr>
<tr><td colspan="3">Exposure class</td><td></td></tr>
<tr><td colspan="3">Strength margin factor,</td><td>MPa</td></tr>
<tr><td colspan="3">Standard deviation,</td><td>S MPa</td></tr>
<tr><td colspan="3">Mean target strength,</td><td>f'_{ck} MPa</td></tr>
<tr><td rowspan="2">Water-cement ratio</td><td>for mean target strength value</td><td></td><td rowspan="2">Adopt the lower value</td><td rowspan="2"></td></tr>
<tr><td>for durability requirements</td><td></td></tr>
<tr><td colspan="5">Type and grade of cement</td></tr>
<tr><td colspan="3">Grading zone of fine aggregate
Type of coarse aggregate
Nominal upper (maximum) size of coarse aggregate,
Specific gravity of cement,
Specific gravity of saturated surface dry fine aggregate,
Specific gravity of saturated surface dry coarse aggregate,</td><td>mm
S_c
S_{fa}
S_{ca}</td><td rowspan="3"></td></tr>
<tr><td colspan="3">Specific gravity of saturated surface dry combined aggregate,
Entrapped air (if considered),</td><td>per cent</td></tr>
<tr><td colspan="2">Water content per cubic metre of concrete, W kg</td><td>before adjustment
after adjustment</td><td></td></tr>
</table>

Ratio of fine aggregate in total aggregate by absolute volume, p				before adjustment after adjustment	
Cement content per cubic metre of concrete, C kg				from w/c ratio from durability requirements	
Total aggregate per cubic metre of concrete, A kg Total coarse aggregate per cubic metre of concrete, C_a kg Total fine aggregate per cubic metre of concrete, f_a kg					
Mix proportions (by mass)					
Specimen number	1	2	3	Age	Average
Load, kN					
Strength, MPa					

The compressive strength of concrete mix is……..
The designed mix is suitable/it needs further revision
The mix proportions are……

Precautions

1. The slump test, cube casting, curing and testing should be done according to the specifications.
2. The fresh concrete should be carefully observed for freedom from segregation and bleeding, and finishing properties.

Discussion

EN:206 exerts relatively little influence directly on the process of design of concrete mixtures which is a key part of concrete production. However, it does of course have considerable indirect effect through the requirements for specification and conformity.

An exposure class which requires the greatest resistance in the form of the lowest water-cement ratio along with the highest minimum cement content and the highest concrete strength class is selected. However, the minimum cement contents are independent of the type of cement used. EN:206 specifies design margins in the minimum cement content of minus 10 kg and in maximum water-cement ratio plus 0.02 in trial batch tests.

The free water content which is available to react with the cement is the sum of: (a) the added water; (b) the surface water of the aggregates and (c) the water content of admixtures less (d) the water absorbed by the aggregate during the period between the mixing and the setting of the concrete.

Target air content of fresh concrete For non-air entrained concrete, air content is not specified but entrapped air is as usual considered in design for EN:206 concrete. For air entrained concrete, EN: 206 specifies minimum total air content with a maximum total air content being 4 per cent higher than the specified minimum.

Viva-Voce Questions

1. What is the objective mix design?
2. On what criteria is based British DoE method for proportioning of concrete mixes?
3. What is the basic difference between designs of plastic concrete mixes by IS proportioning-guidelines and British mix design method?
4. Which one is superior?
5. Why is mix design considered a process of making initial guess at the optimum combination of ingredients and the final mix proportions a basis of further trial mixes?
6. What is characteristic strength and how is it expressed?
7. What is consistence of fresh concrete?
8. How is the target mean strength calculated?
9. What is standard deviation?
10. What is nominal upper size of coarse aggregate and how is it expressed?
11. What is exposure class?
12. With the known quantities of water and cement per unit volume of concrete, how is total aggregate per unit volume of concrete calculated?
13. How is the percentage of fine aggregate calculated in total aggregate?

NATIONAL STANDARDS

1. IS 383-1970 (2nd revision, reaffirmed 2011): *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*.
2. IS 456-2000 (4th revision, reaffirmed 2011): *Code of Practice for Plain and Reinforced Concrete*.
3. IS 2386 (Part 3) -1963 (reaffirmed 2011): *Methods of Test for Aggregates for Concrete*: Part 3: *Specific Gravity, Density, Voids, Absorption and Bulking*
4. IS 3812 (Part 1)-2003 (2nd revision, reaffirmed 2007): *Specification for Pulverized Fuel Ash*: Part1: *For Use as Pozzolana in Cement, Cement Mortar and Concrete*.
5. IS 8112-1989 (1st revision, reaffirmed 2009): *Specification for 43-grade Ordinary Portland Cement*.
6. IS 9103-1999 (1st revision, reaffirmed 2008): *Specification for Admixtures for Concrete*.
7. IS 10262-2009 (1st revision): *Concrete Mix Proportioning-Guidelines*.

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PAVEMENT MATERIALS-I

Section 11

This section describes tests performed on aggregates used in bituminous surfacing, hot mix asphalt, Portland cement concrete, aggregate bases, and various soil-aggregate mixtures of base and sub-base materials. The physical characteristics of aggregates as determined using these procedures are critical for ensuring a quality product.

11.1 INTRODUCTION

Aggregate is a collective term for the mineral materials such as sand, gravel, and crushed stone that are used with a binding medium such as bitumen, Portland cement, lime, etc., to form composite materials such as bituminous concrete and Portland cement concrete. By volume, aggregate generally accounts for 92 to 95 per cent of Bituminous concrete and about 70 to 80 percent of Portland cement concrete. They provide volume stability to the mix. Aggregate is also used for base and sub-base courses for both flexible and rigid pavements. Aggregates can either be natural or manufactured. Natural aggregates are generally extracted from larger rock formations through an open excavation called *quarrying*. Extracted rock is reduced to usable sizes by mechanical crushing. Manufactured aggregate is often a by-product of other manufacturing industries. The requirements of the aggregates for the use in pavement are discussed in this section.

11.2 DESIRABLE CHARACTERISTICS

11.2.1 Strength

The aggregates used in top layers are subjected to (i) forces due to traffic wheel load, (ii) wear and tear, (iii) crushing. For a high quality pavement, the aggregates should possess high resistance to crushing under traffic wheel load.

11.2.2 Hardness

The aggregates used in the surface course are subjected to abrasion or grinding under moving traffic. The aggregates should be hard enough to resist the abrasive action caused by the movements of traffic.

11.2.3 Toughness

Resistance of the aggregates to impact is termed as toughness. Aggregates used in the pavement should be able to resist the impact caused by the jumping of the wheels, especially steel rimmed wheels, from one particle to another at different levels.

11.2.4 Shape of Aggregates

Aggregate particles may have rounded cubical, angular, flaky or elongated shape. The flaky and elongated particles of an aggregate provide lesser strength and durability as compared to cubical, angular or rounded particles of the same rock. Hence too flaky and too much elongated aggregates are avoided as far as possible.

11.2.5 Adhesion with Bitumen

The aggregates used in bituminous pavements should have lesser affinity to water as compared to bituminous materials; otherwise the bituminous coating on the aggregate will strip off in presence of water.

11.2.6 Durability

The property of aggregates to withstand adverse action of weather is called soundness. The aggregates are subjected to the physical and chemical actions of rain water and sub-base water containing impurities; it is therefore, desirable that the road aggregates should be sound enough to withstand the weathering actions.

11.2.7 Freedom from Deleterious Particles

The materials whose presence may adversely affect the strength, workability and long-term performance of pavement are termed deleterious materials. These are considered undesirable as constituent because of their intrinsic weakness, softness, fineness or other physical or chemical characteristics harmful to the pavement behaviour.

In addition to strength properties, the aggregates used in bituminous mixes should be clean and free from excess amount of flat or elongated particles, dust, clay lumps, organic impurities and other objectionable materials.

11.3 AGGREGATE TESTS

Aggregates influence, to a great extent, the load transfer capability of pavements. The strength of pavement cannot exceed that of the bulk of aggregate contained therein. Therefore, so long as the strength of aggregate is of an order of magnitude stronger than that of the pavement made with them, it is sufficient. In addition to strength and durability, the aggregates must possess proper shape and size to make the green or fresh mix workable and cured or hardened pavement act as an integral unit. Hence it is essential that they should be thoroughly tested before using for construction.

In order to decide the suitability of the aggregate for use in pavement construction, following tests are generally carried out. Though these tests may not be performed on routine basis, they are used for quality control.

11.3.1 Shape Factors Test [IS: 2386 (Part I)-1963]

The aggregate which is elongated or flaky may break during compaction and under traffic loads. They are detrimental to higher workability and stability of mixes, and result in a lower strength. The flakiness index is defined as the percentage by weight of aggregate particles whose least dimension is less than 0.6 times their mean size. It is measured by a flakiness gauge of the type shown in Fig. 11.1.

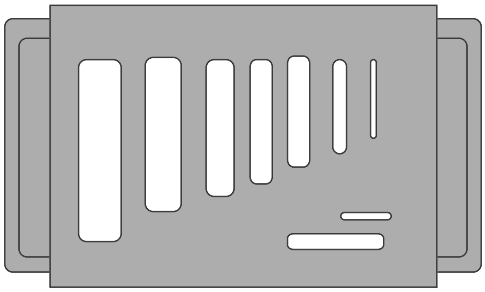

Fig. 11.1 *Flakiness gauge*

According to IS: 2386 Part-I, the elongation index of an aggregate is defined as the percentage by weight of particles whose greatest dimension (length) is 1.8 times their mean dimension. This test is applicable to aggregates larger than 6.3 mm and no limits for the elongation index are specified.

11.3.2 Crushing Strength Test [IS: 2386 (Part IV) -1963]

Of the four tests prescribed for the determination of strength of aggregate, namely, aggregate crushing value, aggregate abrasion, aggregate impact value and ten per cent fines value, the crushing value test is more popular and the results are reproducible.

The aggregate crushing value provides a measure of resistance to degradation of small-size coarse aggregate under gradually applied compressive load. The test consists of subjecting the representative sample of aggregate in a standard mould to compression under specified load conditions. The test sample consists of dry aggregates passing through 12.5 mm sieves and retained 10 mm sieves.

An aggregate crushing value less than 10 per cent signifies an exceptionally strong aggregate whereas above 35 per cent would normally be regarded as weak aggregates.

11.3.3 Ten Per Cent Fines Value Test

This test is a measure of force required to cause specified degradation of coarse aggregate. The method consists in subjecting the standard aggregate specimen to the load gradually applied at a uniform rate for the specified time to achieve specified penetration. The weight of fines in crushed aggregate passing the test sieve is expressed as a percentage of the weight of test sample.

The test is repeated till the load for the fines in range 7.5 to 12.5 is attained. For wearing surface the load shall not be less than 100 kN.

11.3.4 Aggregate Impact or Toughness Test [IS: 2386 (Part 4)-1963]

The aggregate impact test is carried out to evaluate the resistance to impact of aggregates. Aggregates passing 12.5 mm sieve and retained on 10 mm sieve is filled in a cylindrical steel cup and is subjected to standard repetitive impact force by a metal hammer. The impact value is measured as percentage of aggregates degraded or reduced below a certain size.

Aggregates to be used for wearing course, the impact value should not exceed 30 per cent. For bituminous macadam base course the maximum permissible value is 35 per cent and for water bound macadam base course is 40 per cent.

11.3.5 Abrasion or Hardness Test [IS: 2386 (Part V)-1963]

Los Angeles abrasion test is generally carried out to evaluate the hardness property of aggregates and to decide its suitability for different pavement construction works. The principle of Los Angeles abrasion test is to find the percentage wear due to the rubbing action between the aggregate and steel balls used as abrasive charge. The loss in materials expressed as percentage total weight of the sample is called Los Angeles abrasion value.

A maximum value of 40 per cent is allowed for WBM base course. For bituminous concrete, a maximum value of 35 pre cent is specified.

11.3.6 Bitumen Adhesion Test [IS: 6241-1971]

Bitumen normally adheres well to all commonly used types of road aggregates provided they are dry and dust free. In the absence of water there is practically no adhesion problem of bituminous construction. Adhesion problem occurs when the aggregate is wet and cold. This problem can be dealt with by removing moisture from the aggregate by drying and increasing the mixing temperature. Moreover, the presence of water causes stripping of binder from the coated aggregates. Static immersion test is the one specified by IRC and is quite simple. The principle of the test is by immersing aggregate fully coated with binder in water maintained at 40°C temperature for 24 hours. IRC has specified maximum stripping value of aggregates should not exceed 5 per cent.

11.3.7 *Specific Gravity* and Water Absorption [IS: 2386 (Part 3)-1963]

Specific Gravity The specific gravity and water absorption of aggregates are important properties that are required for the design of concrete and bituminous mixes. The specific gravity of a solid is the ratio of its mass to that of an equal volume of distilled water at a specified temperature. Due to the presence of water-permeable voids in the aggregates, two specific gravities of aggregates are defined: namely the *apparent specific gravity* and *bulk specific gravity*.

The apparent specific gravity is computed on the basis of the net volume of aggregates, i.e., the volume excluding water-permeable voids; whereas the bulk specific gravity is based on the total volume of aggregates including water permeable voids.

Water absorption The difference between the apparent and bulk specific gravities is nothing but the water permeable voids of the aggregates. The volume of water permeable voids can be measured by weighing the aggregates dry and in a saturated surface dry condition, i.e., with all permeable voids filled with water. The difference between these two weights is the amount of water absorbed by the aggregate. Water absorption is expressed as the percentage by weight of dry aggregate. Aggregate should have small water absorption characteristic as this may adversely affect the bonding. Also, highly absorptive aggregate may result in higher bitumen consumption.

The specific gravity of aggregates normally used in road construction ranges from about 2.5 to 2.9. Usually the value should not be more than 2 per cent for high quality construction such as B.C. and 1 per cent for other types.

11.3.8 *Soundness Test* [IS: 2386 (Part 5)-1963]

The soundness indicates the ability of the aggregate to resist excessive changes in volume due to changes in environmental conditions, i.e., temperature variations, moisture and alternating wetting and drying. Soundness test is carried out to determine the durability of suspected aggregate against weathering action by subjecting the specimen of specified size to cycles of alternate wetting in a saturated solution of either sodium sulphate or magnesium sulphate for 16–18 hours and then drying in oven at 105–110°C to a constant weight. After five cycles, the loss in weight of aggregates is determined by sieving out all undersized particles and weighing. The loss in weight should not exceed 12 per cent when tested with sodium sulphate and 18 per cent with magnesium sulphate solution. The Porous aggregates subjected to freezing and thawing are likely to disintegrate prematurely.

11.3.9 Stone Polishing Value

Stone Polishing value (SPY) is determined to find out ability of aggregate to sustain the smoothening due to abrasive action over a period of time. The aggregate should not get smooth in order to provide adequate friction. The stone polishing value test apparatus is quite expensive.

Test procedures for first six tests are given in this Section and the ones in serials 7 and 8 in the Section on Concrete Technology.

EXPERIMENT NO. 1: Flakiness and Elongation Indices of Coarse Aggregate

Objective

To determine the flakiness and elongation indices of coarse aggregates.

Theory and Scope

An aggregate having least dimension less than 0.6 times its mean dimension is termed *flaky.* Where the *mean dimension* is the average of the sieve sizes through which the particles pass and the sieve size on which these are retained. On the other hand, the particles having the largest dimension (length) greater than 1.8 times the mean size are termed elongated.

The presence of excess of flaky and elongated particles may have adverse effects on concrete and bituminous mixes. In concrete mix, the flaky and elongated particles decrease the workability appreciably for a given *water-cement ratio*; thus requiring larger amounts of sand, cement and water. The flaky and elongated particles tend to orient in one plane and cause laminations which adversely affect the durability of the concrete. For bituminous mix, flaky particles are liable to break up and disintegrate during the pavement rolling process. The percentage of flaky or elongation index should be limited to 10 to 15. The percentage of combined flaky and elongation indices should be limited to 30.

Apparatus

Balance; A Set of 10 sieves ranging from 63 mm IS sieve to 6.3 mm IS sieve; Thickness gauge and Length gauge shown in Figs. 11.2 and 11.3, respectively.

Procedure

Part 1: To determine the flakiness index

Step 1: Take a sufficient quantity W_1 of coarse aggregate by quartering so as to provide at least 200 pieces of any fraction.

Step 2: Carry out sieving by hand. Shake each sieve in order: 63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm and 6.3 mm, over a clean dry tray for a period not less than 2 minutes. The shaking is done with a varied motion: backward and forward, left to right, circular, clockwise and anticlockwise and with frequent jarring, so that the material is kept moving over the sieve surface in frequently changing directions.

Step 3: Each piece of the separated aggregate fractions as retained on the sieves in Step 2 is tried to be passed through the corresponding slots in the thickness gauge shown in Fig. 11.2, e.g., the material passing through 50 mm sieve and retained on 40 mm sieve is passed through $\frac{1}{2}$ $(50 + 40) \times (3/5) =$ 27.0 mm slot.

Step 4: Determine the mass of aggregate passing though each of the slots.

Step 5: Find the total mass W_2 of the materials passing through the slots of the thickness gauge.

Step 6: Calculate the *flakiness index* as defined below:

The *flakiness index* is an empirical factor expressing the total material passing through the slots of the thickness gauge as the percentage of the mass of sample taken for testing.

Part 2: To determine the elongation index

Step 1: Take a sufficient quantity W_3 of coarse aggregate by quartering so as to provide at least 200 pieces of any fraction.

Step 2: Carry out sieving by hand. Shake each sieve in order: 63 mm, 50 mm, 40 mm, 31.5 mm, 25 mm, 20 mm, 16 mm, 12.5 mm, 10 mm, and 6.3 mm (IS: 2386, Part 1-1963) as explained in the Part (a) so that the material is kept moving over the sieve surface in frequently changing directions.

Step 3: Each piece of the separated aggregate fractions as retained on the sieves in Step 2 is tried to be passed through the corresponding length gauge shown Fig. 11.2 with its longest side, e.g., the material passing through 50 mm sieve and retained on 40 mm sieve is passed through $\frac{1}{2}$ (50 + 40) $\times$ (9/5) = 81.0 mm slot. A particle of length which cannot pass through the corresponding gauge size is taken as retained by the length gauge. Determine the mass of aggregate retained on each of the length gauge sizes.

Step 4: Find the total mass W_4 of the material retained on the length gauges.

Step 5: Determine the elongation index as percentage material retained by the length gauges of the total material taken for testing.

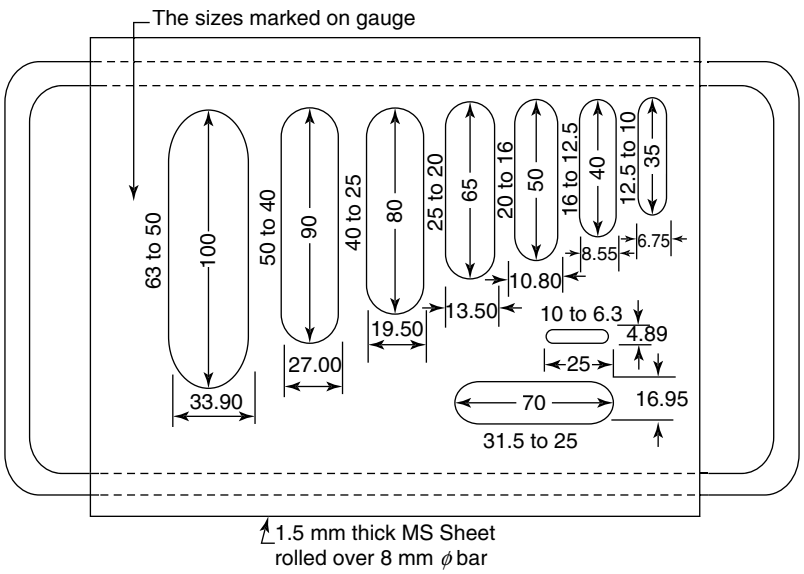

Fig. 11.2 *Thickness gauge*

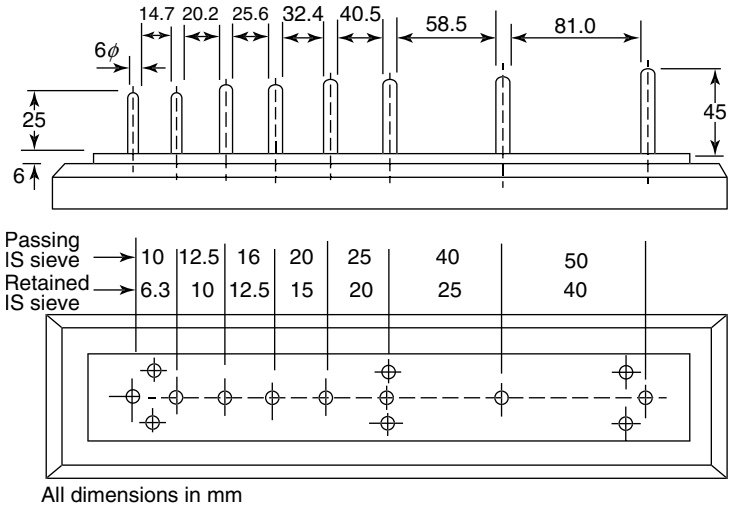

Fig. 11.3 *Length gauge*

Observations and Calculations

1. Flakiness index of coarse aggregate				
Mass of aggregate, W_1 =…….g				
Sl. No.	**Size of Aggregate**			**Mass of aggregate passing through the slot, g**
	Passing through IS: sieve, mm	**Retained on IS: sieve, mm**	**Thickness gauge size, mm**	
1.	63	50	33.90	
2.	50	40	27.00	
3.	40	31.5	19.50	
4.	32.5	25	16.95	
5.	25	20	13.50	
6.	20	16	10.80	
7.	16	12.5	8.55	
8.	12.5	10	6.75	
9.	10	6.3	4.89	
$\Sigma W = W_2$				

Flakiness index of coarse aggregate $= \frac{W_2}{W_1} \times 100$ = ……..per cent.

2. Elongation index of aggregate				
Mass of aggregate, W_3 = …… g.				
Sl. No.	**Size of Aggregate**			**Mass of aggregate retained on the length gauge, g**
	Passing through IS: sieve, mm	**Retained on IS: sieve, mm**	**Length gauge size, mm**	
1.	63	50	—	
2.	50	40	81.0	
3.	40	31.5	58.5	
4.	31.5	25	—	
5.	25	20	40.5	
6.	20	16	32.4	
7.	16	12.5	25.6	
8.	12.5	10	20.2	
9.	10	6.3	14.7	
$\Sigma W = W_4$.				

Elongation index of coarse aggregate $= \frac{W_4}{W_3} \times 100$ = …… per cent.

Precautions

1. The representative sample should be taken by quartering. For quartering, the sample is thoroughly mixed and spread out evenly on the clean surface; it is then cut into four equal parts by a trowel. Two opposite quarters are taken and mixed to make the sample. If any further quantity reduction is required, the process may be repeated.
2. The particles of length which cannot pass through the length gauge size are taken to be retained by the length gauge. They should not be forced to pass through an opening.

Discussion

The main objective of this test is to determine the relative amounts of flaky and elongated particles which when present in large quantity may results in more voids in the concrete, thus requiring larger amounts of sand, cement and water for a particular workability. These particles tend to be oriented on one plane which affects the durability. Generally, elongated or flaky particles in excess of 10 to 15 per cent are not desirable. The tests are not applicable to sizes smaller than 6.3 mm.

Combined flakiness and elongation index of aggregate To determine the combined proportion of the two types of particles, the test is performed in two parts. In the first part, the flaky particles from the representative sample are sorted out and flakiness index determined. In the second part, elongated particles are separated out

from the remaining non-flaky portion of the aggregate and elongation index is determined as the ratio of the weight of elongated particles to that of total non-flaky portion. The combined flakiness and elongation index of aggregate is the total sum of the two indices.

Viva-Voce Questions

1. What are the flaky and elongated aggregates?
2. Define flakiness and elongation indices. What is their significance?
3. How are the results expressed?
4. What is meant by the size of slot of the thickness gauge and that of a length gauge?
5. Describe the process of quartering an aggregate. Why is it done?
6. What precautions do you take while performing the experiment?
7. How do the flaky and elongated aggregates affect the resulting concrete?
8. How are the sizes of the thickness gauge and length gauge related to the sizes of the sieves through which a fraction has passed and retained, respectively?
9. How does the percentage wear change if the aggregate used in abrasion test is flaky or elongated?

Notes and Comments

EXPERIMENT NO. 2: Aggregate Crushing Value

Objective

1. *To determine crushing value of given aggregates.*
2. *To assess suitability of aggregates for use in different types of concrete and pavements.*

Theory and Scope

The road aggregate is generally manufactured to a specified grading and stockpiled at a site. Before being used in the pavement it undergoes certain operations as loading and transporting in trucks, tipping, spreading and compacting which may result in a change in grading and/or the production of excessive and undesirable fines. Significant degradation may take place when the aggregate is weak. Thus, an aggregate complying with a specification at the production site may fail to do so when it is in the pavement.

The aggregate crushing value is a numerical index of the resistance of an aggregate to crushing under a gradually applied compressive load. It is expressed as the percentage by mass of the crushed (or finer) material obtained when the test sample is subjected to a specified load under standardised conditions. Aggregate with lower crushing value indicate a lower crushed fraction under load or higher strength and would provide a longer service life to the structure. Weaker aggregates if used in road pavements would get crushed under traffic loads and produce smaller pieces not coated with binder and these would be easily loosened out resulting in loss of the surface/layer. The aggregate crushing test is conducted as per IS: 2386-1963 (Part IV).

Apparatus

Compression testing machine; Test mould; Tamping rod; Balance; IS test sieves of sizes 12.5 mm, 2.36 mm; Cylindrical measure; Oven.

Description of Apparatus

Compression testing machine of 500 kN capable of loading at uniform rate of 40 kN per minute.

Case hardened test mould consists of a 152 mm diameter open-ended steel cylinder with square base plate; plunger having a piston of diameter 150 mm, with a hole provided across the stem of the plunger so that a rod could be inserted for lifting or placing the plunger in the cylinder.

Tamping rod of 16 mm in diameter, 450 to 600 mm long and rounded at one end.

Metal cylindrical measure having internal diameter of 115 mm and height 180 mm.

Balance of capacity 5 kg, readable and accurate unto 1 g.

The concept of aggregate crushing value test and details of apparatus are illustrated in Fig. 11.4.

Procedure

Part 1: Test of standard sizes of aggregates

The material for the standard test consists of aggregates of size 10.0 mm to 12.5 mm. The aggregates should be in surface dry condition before testing. The aggregates may be dried by heating at 100°–110° C for not more than 4 hours and cooled to room temperature before testing, if necessary.

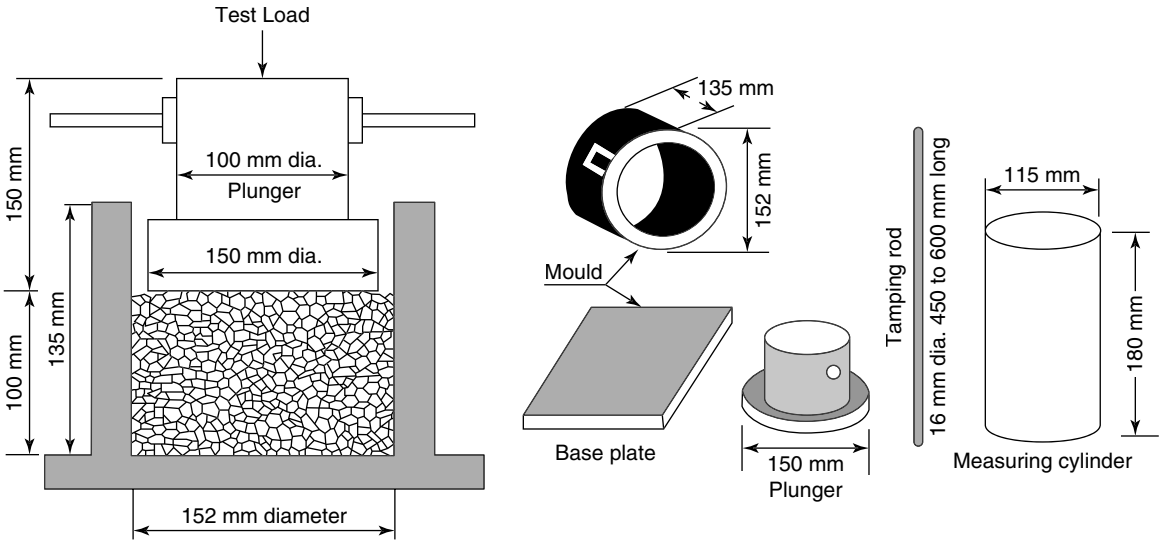

Fig. 11.4 *Concept and apparatus of aggregate crushing value test*

Step 1: Sieve the material through 12.5 mm and 10 mm IS sieves. The aggregates passing through 12.5 mm sieve and retained on 10.0 mm sieve comprise the standard test aggregate.

Step 2: Take about 3.25 kg of aggregate prepared in Step 1 and fill the measuring cylinder with aggregate in three layers, each layer being tamped with 25 strokes of the rounded end of the tamping rod, distributing the strokes gently and evenly over the surface. The measuring cylinder is finally filled to overflow.

Step 3: Strike off the surplus aggregate using tamping rod as straight edge.

Step 4: Weigh the container full of aggregate.

Step 5: Calculate the net mass of aggregate in the measuring cylinder to an accurate of 1 g; this quantity of aggregate constitutes the test specimen.

Step 6: Transfer the whole of this weighed specimen to the test mould by filling it in three layers as explained in Step 2. The total depth of the sample is then about 100 mm and the surface a little below the top of mould.

Step 7: Level off the surface and place the plunger over it so that it rests horizontally on the surface of the aggregates.

Step 8: Place this assembly on the pedestal of compression testing machine.

Step 9: Apply the load at a uniform rate of 40 kN per minute until the total applied load is 400 kN.

Step 10: Release the load and take the crushed aggregate out of the mould.

Step 11: Sieve the crushed aggregate through 2.36 mm IS sieve and weigh the fraction passing through it to an accuracy of 0.1 g. This fraction is a measure of loss of material due to crushing. The mean value of two samples, rounded to nearest whole number is taken as the *aggregate crushing value*.

Observations and Calculations

1. Type condition of aggregate: Dry
Type of drying: Air dried/Oven dried
Size of aggregate: standard size: 12.5 mm
IS sieve used for separating fines: 2.36 mm

Maximum force applied,	kN	400	400
Mass of oven dried sample,	W_1, g		
Mass of sample passing 2.36 mm sieve,	W_2, g		
Mass of sample retained on 2.36 mm sieve,	W_3, g		
Aggregate crushing value, $P = \frac{W_2}{W_1} \times 100$	per cent		

The average Aggregate crushing value =…….per cent.

Part 2. Test of non-standard sizes of aggregates

If the standard size aggregate is not available, test may be conducted with different specifications conforming to those given in the Table 11.1.

Table 11.1 *Test details for the aggregate of non-standard grading*

Aggregate grading/size		Quantity of material, apparatus and procedure	IS sieve for separating fines
Passing through, mm	*Retained on, mm*		
25	20	Standard	4.75 mm
20	12.5	Standard	3.35 mm
10	6.3	Test cylinder: 75 mm diameter	1.70 mm
6.3	4.75	Cylindrical measure: 60 mm diameter and 90 mm height	1.18 mm
4.75	3.35	Tamping rod: 8 mm diameter and 300 mm length	850 μm
3.35	2.36	Depth of material in test cylinder after tamping: 50 mm Total load applied:100 kN uniformly in 10 minutes Quantity of material: 1 kg for two samples	600 μm

Average aggregate crushing value =……..per cent.

Precautions

1. The plunger should be placed centrally and rest directly on the aggregates. Care should be taken that it does not touch the walls of the cylinder so as to ensure that the entire load is transferred onto the aggregates.
2. During sieving the aggregates through 2.36 mm IS sieve and weighing care should be exercised to avoid loss of fines. The sum of weights of fractions retained and passing the sieve should not differ from the original weight of the sample by more than 1.0 g.
3. The aggregate should be gently tamped by dropping the tamping rod and not forcing it in to the aggregate. The blows should be uniformly distributed over the surface of the aggregates taking care that the tamping rod does not frequently strike against the walls of the mould.

Discussion

The values of aggregate crushing test agree in general with that of aggregate impact test. The crushing strength test is more significant as far as the conditions to which the aggregate is likely to be subjected in practice are concerned.

The suitability of aggregate in the pavement layers is dependent upon the type of road construction. The specified limits of aggregate crushing value for different types of road construction are listed in Table 11.2.

Table 11.2 *Limits of aggregate crushing value for different types of road construction*

Type of road construction	Limits for aggregate crushing value, per cent
1. Flexible pavements	
(a) Soling	50
(b) Water Bound Macadam, Bituminous Macadam	40
(c) Bituminous Surface Dressing or thin Premix Carpet	30
(d) High Quality Surface courses	30
2. Rigid pavements	
(a) Surface or wearing course	30
(b) Other than wearing course	45

For the aggregate to be used in concrete the aggregate crushing value should not be greater than 45 per cent (by mass).

Viva-Voce Questions

1. What is the significance of this test?
2. How is a representative sample of aggregate obtained?
3. Which property of aggregate is measured by this test?
4. How is aggregate crushing value expressed?
5. In what respects this test is superior to aggregate abrasion test?
6. Distinguish between 10 percent fines value and aggregate crushing value.
7. What are the aggregate crushing values of aggregate if it is to be used in (a) concrete, and (b) concrete wearing surface?
8. List the various factors which affect the aggregate crushing values.
9. What variation in the results is expected if the smaller size aggregate are used in test?
10. What are the requirements of aggregate crushing testing machine?

Notes and Comments

EXPERIMENT NO. 3: Ten Percent Fines Test

Objective

To assess the resistance of an aggregate to mechanical degradation by the 10% Fines Aggregate Crushing Test (10% FACT).

Theory and Scope

Granular base layers and surfacing are subjected to repeated loadings from truck tyres and the stress at the contact points of aggregate particles can be quite high. The crushing tests can reveal aggregate properties subject to mechanical degradation of this form.

This test is very similar to Aggregate Crushing Test in which a standard force 400 kN is applied and fines material produced by crushing expressed as a percentage of the original mass is the aggregate crushing value. Whereas, the ten percent fines value is the load in kN required to crush a sample of 12.5 – 10 mm aggregate to produce a specified level of mechanical degradation, i.e., to produce 10 per cent fines of the original mass of aggregates (or weight of fine aggregate/weight of all aggregates = 10 per cent). Fine aggregates are defined as those passing 2.36 mm sieve. Ten percent fines value test is applicable to all types of aggregates.

Thus, the 10 per cent Fines Aggregate Crushing Value as defined is determined by measuring the load required to crush a prepared aggregate sample to give 10 per cent material passing a specified sieve after crushing. The test can be conducted in wet or dry condition of aggregates.

Apparatus

Compression testing machine; Case hardened steel cylinder with plunger and base plate; steel tamping rod; metal measuring cylinder;

Description of Apparatus

Compression testing machine capable of applying a force of up to 500 kN and which can be operated to give a uniform rate of loading so that this force is reached in 10 minutes.
Case hardened steel cylinder of 150 mm diameter and 130 mm high together with a plunger.
Steel tamping bar of 16 mm diameter and 450–600 mm length.
Metal measuring cylinder of 115 mm diameter and 180 mm depth.
The concept and detailed apparatus for the 10 per cent fines test and aggregate crushing test are illustrated in Fig. 11.4.

Procedure

The test can be conducted in dry and wet conditions of aggregate, for each test (wet and dry) at least three test specimens (each of mass about 3 kg) are required.

Part 1: Dry test

Step 1: The material used for test is aggregate passing a 12.5 mm sieve and retained on a 10 mm sieve. It shall be clean and dry (washed if necessary) but it must not be dried for longer than 4 hours nor at a temperature higher than 110°C, otherwise certain aggregates may be damaged.

Step 2: The required volume is obtained by filling the measuring cylinder in three layers, each tamped 25 times with the tamping rod and the top struck off level. The weight of the sample is recorded to the nearest 0.1g (say mass W_1).

Step 3: The material from the measuring cylinder is placed in the test cylinder in three layers, each tamped 25 times with the tamping rod. The depth of the sample will then be about 100 mm. The plunger is lowered onto the sample and rotated gently to seat it and level it.

Step 4: Place the cylinder, plunger and sample assembly centrally on the bearing platen of the compression testing machine. Load is gradually applied at a uniform rate so that the total penetration in 10 minutes is about: 15 mm for uncrushed gravel; 20 mm for normal crushed aggregates; 24 mm for honeycombed aggregates (e.g., some slag and volcanic rocks).

Step 5: After specified penetration is reached note the maximum force applied and then release the load.

Step 6: Remove all the material from the cylinder and sieve it on 2.36 mm sieve until no further significant quantity passes through the sieve in one minute. As this is a fairly fine sieve, it is preferable to pass the whole sample over a larger sieve (say 4.75 mm) first.

Step 7: Determine to the nearest 5 g the material passing 2.36 mm sieve (i.e., the fines), let this mass be W_2 and express as a percentage of the original mass of the specimen

$$y = \frac{W_2}{W_1} \times 100$$

Step 8: If the percentage of fines lie between 7.5 per cent and 12.5 per cent, then the force that will be required to produce 10 per cent fines,

$$\text{F} = \text{Load to produce 10 per cent fines} = \text{TFV} = \left(\frac{14}{y+4}\right)x$$

where

x = maximum load for causing 7.5 to 12.5 per cent fines, kN,

y = mean percentage of fines from two test at x kN load, and

The result should be reported to the nearest whole number.

Step 9: Repeat the test using the force as calculated in Step 8 above. If the percentage of fines so obtained is not 10, then again apply the above formula with the force used in this test, and take the re-adjusted force as the final result.

Step 10: If the percentage of fines lies outside the range 7.5 to 12.5, the test must be repeated. Test two more specimens in the same way but with the rate of application of force (and the distance that the plunger is forced into the cylinder) in the light of the above result as to obtain, ideally, three forces that give, respectively, a percentage fines value (i) of less than 7.5 per cent, (ii) in the range 7.5–12.5 per cent and (iii) of over 12.5 per cent.

Plot the percentages so obtained against the forces, in kN, required for each, and from the curve determine the force that would give 10 per cent fines.

Part 2: Wet test

Step 1: After the 24 hour soaking, take a specimen out of the water and allow it to drain for about 5 minute, and then surface dry it by rolling it in a damp cloth.

Step 2: Proceed as in the case dry test but before sieving for fines, dry the material taken from the mould for 24 hours at 105–110 °C.

In general, the rate of loading must be reduced for the material tested in wet condition.

Observations and Calculations

Type of aggregate: Uncrushed gravel/ Normal crushed aggregate/Honeycombed aggregate
Type condition of aggregate: Dry
Type of drying: Air dried/oven dried
Size of aggregate: standard size: 12.5 mm
IS Sieve used for separating fines: 2.36 mm

Mass of sample + Mould + Base plate			
Mass of mould + Base plate			
Mass of (saturated surface dry) sample			
Penetration required,	mm		
Mass of oven dried sample,	W_1, g		
Mass of sample retained on 2.36 mm sieve,	W_3, g		
Mass of sample passing 2.36 mm sieve,	W_2, g		
Percentage fines, y,	$\frac{W_2}{W_1} \times 100$		
Average Load for causing 7.5 – 12.5 percent fines, x	kN		
Force required to produce ten per cent fines, F,	$\left(\frac{14}{y+4}\right)x$		
Ten percent fines value of wet/ dry aggregate, TFV (nearest 10 kN for forces of 100 kN) (nearest 5 kN for forces less than 100kN)	kN		

The average ten per cent fines value (TFV) of aggregate =…….kN.

Precautions

1. The plunger should be placed centrally and rest directly on the aggregates. Care should be taken that it does not touch the walls of the cylinder so as to ensure that the entire load is transferred onto the aggregates,
2. During sieving the aggregates through 2.36 mm IS sieve and weighing care should be exercised to avoid loss of fines. The sum of weights of fractions retained and passing the sieve should not differ from the original weight of the sample by more than 1.0 g.
3. The aggregate should be gently tamped by dropping the tamping rod and not forcing it into aggregate. The blows should be uniform distributed over the surface of the aggregates taking care that the tamping rod does not frequently strike against the walls of the mould.

Discussion

This test is a measure of force required to cause specified degradation of coarse aggregate. If the percentage of fines in the crushing test exceed 30, the result may be anomalous as broken pieces of aggregate tend to fill the voids and prevent further crushing. In this case, the Ten Per cent Fines Test is more appropriate. The aggregate crushing values generally recommended are:

1. For normal concrete, not less than 50 kN.
2. For wearing surface, not less than 100 kN.
3. For granolithic concrete in buildings, not less than 150 kN.

Viva-Voce Questions

1. What is the significance of this test?
2. How is a representative sample of aggregate obtained?
3. Which property of aggregate is measured by this test?
4. How is the ten per cent fines value of aggregate reported?
5. In what respects, this test is superior to aggregate impact and abrasion tests?
6. What is the ten per cent fines value of aggregate if it is to be used in (a) concrete, and (b) concrete wearing surface?
7. What is the difference between ten per cent fines value test and aggregate crushing value test?

Notes and Comments

EXPERIMENT NO. 4: Aggregate Impact Value

Objective

To determine the impact test value of an aggregate.

Theory and Scope

The property of a material to resist impact is known as *toughness*. This situation is typically encountered on highways where due to the movement of vehicles on the road the aggregates are subjected to impact. The aggregates should therefore have sufficient toughness to resist their disintegration due to impact. This characteristic is measured by *impact value test*. The aggregate impact value is a measure of resistance to impact or shock, which may differ from its resistance to gradually applied compressive load.

However, this test may also be considered as an alternative to the aggregate crushing test. The special apparatus needed for aggregate impact test is simple and relatively cheap and is portable while the crushing test requires a 500 kN testing machine, which is expensive. The test does not require any cutting and shaping of special test pieces.

Apparatus

Impact testing machine; riffle box (sample splitter); electric oven; standard rammer; 12.5 mm, 10 mm and 2.36 mm IS Sieves; shovel; pans and a measure of standard dimensions.

Description of Apparatus

Impact testing machine [IS: 2386 (Part IV)-1993] The testing machine weighing 45 to 60 kg consists of a heavy metal base of not less than 300 mm in diameter supporting two heavy vertical metal columns (called guides). Within these two guides a hammer weighing 13.5 to 14 kg with a 50 mm long cylinder, lower end of 100 mm diameter is arranged to slide and fall under its own weight. The hammer falls on to the aggregate placed in a cylindrical steel cup of 105 mm internal diameter and 50 mm deep which is fixed concentrically with the hammer. The free fall of the hammer is 375 ± 5 mm and it should be fitted with an automatic mechanism for raising and releasing it as illustrated in Fig. 11.5. It should also have a catch to hold it in its upper position while fixing and filling the cup. A device for automatically counting the number of blows is generally provided.

Riffle Box It is a stationary sample divider which splits the sample in two parts. As shown in Fig. 4.4 in Section 4, it consists of a number of sloping narrow chutes discharging alternatively on opposite sides where the split aggregate is collected in boxes placed under the chutes. The sample to be splitted is poured evenly over the top hopper and the sample is received by the two boxes (or pans) at the bottom. The chutes of riffle should have a steepest possible slope so that the material may get rapid flow. The distance between two chutes should be three times the size of the particles.

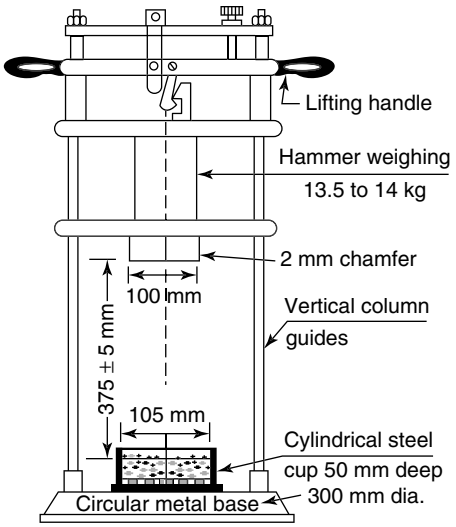

Fig. 11.5 *Aggregate impact test set up*

Procedure

Step 1: Obtain the aggregate sample from the bin or stock pile in such a way as to represent the whole aggregate. This can be done by riffle box or by quartering. The sample must be poured evenly over the top of the box, and the aggregate is collected in the boxes at the bottom. Now reject one half of the sample and the other half is again poured, the process is repeated until the desired quantity of the sample is obtained.

Step 2: Obtain about 350 g of aggregate of size passing through 12.5 mm IS sieve and retained on 10 mm IS sieve.

Step 3: Dry the aggregate sample for 4 hours in an oven at a temperature of 100–110°C.

Step 4: Weigh and pour the aggregate in the cylinder of the impact testing machine, level the surface and give 25 strokes with standard rammer.

Step 5: Release the falling hammer and repeat the procedure until 15 blows are given to the aggregate at 2 seconds interval.

Step 6: Remove the sample from the cylinder and\sieve the material on 2.36 mm IS sieve.

Step 7: Weigh the sample passing through 2.36 mm IS sieve, and express this fraction as the percentage of the total mass of the aggregate.

Step 8: Perform three tests and average of the three is taken.

Observations and Calculations

Specimen no.	Mass of sample of aggregate, W_1, g	Quantity of sample passing 2.36 mm IS sieve, W_2, g	Percentage passing, $= \frac{W_2}{W_1} \times 100$ per cent
1			
2			
3			

Average impact value = ……..per cent.

Precautions

1. As the hammer is heavy, be cautious to keep away from falling mass, to avoid accidents; as a measure of safety the hammer should be locked in position before carrying out any operation at the base of the impact testing machine.
2. Place the plunger centrally so that it falls directly on the aggregate sample and does not touch the walls of the cylinder in order to ensure that the entire load is transmitted on to the aggregates.
3. The sample should be subjected to 15 blows of the hammer at not less than 1 second interval.
4. The fraction passing and retained on the 2.36 mm IS sieve should be weighed and sum should agree within 1 g with the original mass of the sample taken.
5. The tamping is to be done gently by dropping the tamping rod and not by hammering action. Also the tamping should be uniform distributed over the surface of the aggregate taking care that the tamping rod does not frequently strike against the walls of the mould.
6. Check whether the counter is working.

Discussion

The results of aggregate impact test depend to some extend on the elastic properties of the aggregate as well as on the strength. The test does not clearly indicate the property of aggregate it really does measure. However, the values of impact test tend to agree in general with that of aggregate crushing test. The brittle rocks give poorer results in aggregate impact test. Gravel and quartzite tend to have higher impact value than the crushing value. Aggregate impact value which indicates the toughness property can be used to judge the suitability of the aggregate for a particular construction. Aggregate is generally classified in terms of its aggregate impact value as given in Table 11.3.

Table 11.3 *Classification of the aggregate in terms of aggregate impact value*

Aggregate impact value, per cent	Classification
< 10	Exceptionally strong
10–20	Strong
10–30	Satisfactory for road surfacing
> 35	Weak for road surfacing

The crushing strength test is more significant as far as the conditions to which the aggregate is likely to be subjected in practise in the concrete structures. For the aggregate to be used in concrete the impact value should not be greater than 45 per cent (by mass) and 30 per cent for aggregate used in concrete wearing surfaces.

The Indian Road Congress has recommended the following values for different types of road construction as given in Table 11.4.

Table 11.4 *Values for different types of Indian road construction*

Sl. No.	Type of pavement	Aggregate impact value, max, per cent
1.	Bituminous Concrete	24
2.	Dense bituminous macadam, Semi-dense bituminous concrete, Surface dressing, Penetration macadam, Bituminous carpet and Cement concrete wearing course.	27

(continued)

Table 11.4 *contd.*

3.	Wet mix macadam, Bituminous macadam, Lean Bituminous macadam, Premix Carpet, Mix Seal surfacing, W.B.M., Surface Dressing	30
4.	Cement Concrete base course	45

Viva-Voce Questions

1. What is the significance of this test?
2. In what respects this test is superior to aggregate crushing test?
3. How is the representative sample of aggregate obtained?
4. What is riffle box and how is it used in reducing the sample to the required size?
5. What are the impact values of aggregate if it is to be used in (a) concrete, and (b) concrete wearing surface?
6. How may the wear resistance of concrete be improved?
7. List the various factors which affect the aggregate impact values.
8. What are the requirements of impact testing machine?

Notes and Comments

EXPERIMENT NO. 5: Los-Angeles abrasion value of aggregate

Objective

To test the coarse aggregate for its resistance to abrasion in the Los-Angeles testing machine.

Theory and Scope

The aggregate used in surface course of the highway pavements are subjected to wearing due to movement of traffic. The vehicles with pneumatic tyres, steel reamed wheels and animal driven carts cause considerable abrasion of the road surface. Therefore, the road aggregates should be hard enough to resist the abrasion.

In *Los Angeles abrasion test* an abrasive consisting of standard cast iron balls is mixed with the aggregates which rotated in a drum for specific number of revolutions. The percentage wear of the aggregates due to rubbing action with steel balls is determined and is known as *Los Angeles Abrasion Value*. However, it should be noted that the steel balls also cause impact on aggregates.

Abrasion testing of aggregate is of more direct application to the testing of stone aggregate for wearing. The aggregate which shows a low loss in this test is generally be hard, tough, resistant to abrasion and strong; these are also the desirable and necessary qualities for *durability* of concrete.

Apparatus

Los-Angeles abrasion testing machine; 1.7 mm IS sieve; Balance of capacity 5 kg or 10 kg; Drying oven and Trays, etc.

Description of Apparatus

Los-Angeles abrasion testing machine It conforms in all its essential characteristics to the design specifications laid down by AASHO designation T: 96-51 and IS:2386 (Part IV)-1993.

The Los Angeles Machine consists of a hollow steel cylinder closed at both the ends with an internal diameter of 700 mm and length 500 mm, mounted longitudinally on a horizontal shaft. The horizontal axle is so arranged that it does not pass right through the drum. The drum is provided with a firm, rigid 88 mm removable steel shelf projecting radially 88 mm into cylinder, and extending for the full length, i.e., 500 mm. The shelf is placed at a distance 1250 mm minimum from the opening in the direction of rotation. The standard speed of revolution is 30 to 33 rpm. For fine grading the standard number of revolutions are 500, but for coarser grading it is 1000. The cover to the opening for inserting and removing the sample should be arranged so that it flush with inside of the drum.

Abrasive charge The abrasive charge consists of cast iron balls approximately 47.5 mm in diameter and each weighing between 390 g and 445 g conforming to the composition requirement stipulated in AASHO Designation 7-31. Depending upon the grading of test samples six to twelve balls are required.

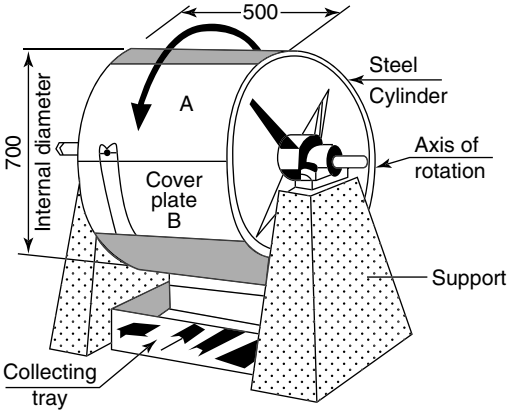

Fig. 11.6 *Los Angeles machine*

Table 11.5 *Abrasive charge for various grades of the sample*

Sieve size: square openings		Grading and mass of test samples, g				
Passing	Retained on	A	B	C	D	E
80 mm	63 mm	...	...	...	...	2500
63 mm	50 mm	...	...	...	...	2500
50 mm	40 mm	...	...	...	...	5000
40 mm	25 mm	1250	...	...	...	...
25 mm	20 mm	1250	...	...	...	...
20 mm	12.5 mm	1250	2500	...	...	...
12.5 mm	10 mm	1250	2500	...	...	...
10 mm	6.3 mm	...	...	2500	...	...
6.3 mm	4.75 mm	...	...	2500	...	...
4.75 mm	2.36 mm	...	...	...	5000	...
Number of spheres		12	11	8	6	12
Number of revolutions		500	500	500	500	1000

Procedure

Step 1: Select the grading to be used in the test. In practice the grading(s) used shall be those most nearly representing the aggregate to be used in construction of the work.

Step 2: Determine the abrasive charge corresponding to the grading selected in Step 1.

Step 3: Collect 25 kg of representative sample for gradings A, B, C or D and 50 kg for gradings E.

Step 4: Calculate mass of test sample of aggregate from Table 11.5. Reduce the representative sample obtained in Step 3 to the desired quantity by riffle box or by quartering.

Step 6: The test sample (5 kg for gradings A, B, C or D and 10 kg for gradings E) shall consist of clean aggregate which has been dried in an oven at 105 to 110°C to a substantially constant mass and shall conform to one of the grading shown in Table 4.2.

Step 7: Place the test sample and the abrasive charge in the Los Angeles abrasion testing machine and replace the cover securely.

Step 8: Rotate the cylinder at a speed of 30 to 33 rpm. For grading *A*, *B, C* and *D* the machine shall be rotated for 500 revolutions and for grading *E* it shall be rotated for 1000 revolutions.

Step 9: At the completion of the required revolutions, discharge the material carefully from the machine to a tray.

Step 10: Remove the cast iron balls and make a preliminary separation of the sample on a sieve coarser than 4.75 mm sieve.

Step 11: Sieve the finer portion on a 1.7 mm IS sieve.

Step 12: The material retained on 1.7 mm IS sieve shall be washed, dried in an oven at 105–110°C to a substantially constant mass and accurately weighed to the nearest gram.

Step 13: Determine the loss in mass, represented by the material passing the 1.7 mm IS sieve, by difference and express it as a percentage of the original mass of sample.

Step 14: Repeat the experiment with another sample and determine the mean of two values to obtain Los Angles Abrasion Value.

Note: If this value is less than 40 per cent, the aggregate can be used in concrete for road surfacing.

Observations and Calculations

Speed of drum in rpm			
Number of required revolutions			
Sieve used for fine fraction			
Original mass of the test sample,	W_1 g		
Final mass of the test sample,	W_2 g		
Loss in mass,	$(W_1 - W_2)$ g		
Percentage of wear,	$P = \frac{W_1 - W_2}{W_1} \times 100$		

Los Angeles Abrasion Value =…… per cent.

Precautions

1. The sieving operation should be conducted by means of a lateral and vertical motion of the sieve, accompanied by the jarring action so as to keep the sample moving continuously over the surface of the sieve. In no case shall the fragments of the sample be turned or manipulated though the sieve by hand.
2. Use a coarser sieve first in order to minimise wear of 1.7 mm IS sieve.

Discussion

Los Angeles abrasion test is preferred because the resistance to abrasion and impact is determined simultaneously. Depending upon the abrasion values of aggregates Indian Road Congress has provided guidelines regarding the suitability of aggregate for different road constructions.

Sl. No.	Type of pavement course	Max permissible L.A. abrasion value, per cent
1.	Water bound macadam; Wet mix macadam; Surface dressing: Premix carpet; Mix seal surfacing; Penetration macadam	40
2.	Dense bituminous macadam, Semi-dense bituminous concrete	35
3.	Bituminous concrete surface course	30

The percentage of wear depends upon the grading, the number of steel balls forming the abrasive charge, the number of revolutions of drum and the mass of sample. These all are variables according to the grading. The number of steel balls used is adjusted for each grading so as to make the result independent of the grading of test sample.

The percentage of wear is increased if the stone is flat and elongated. The same effect is obtained if soft material is present in the sample, but if the stone is of uniform quality, the percentage loss is proportional to the number of revolutions. For the aggregate used in concrete the Los Angeles abrasion value of 40 per cent is the highest acceptable but lower values should be specified for concretes to be used in wearing surfaces.

Viva-Voce Questions

1. What is the utility of this test?
2. What is the function of the shelf provided inside the cylinder?
3. How should an aggregate behave, if it is hard, tough and abrasion resistant?
4. If two aggregates samples have L.A. abrasion values of 20 and 30 respectively, which sample is harder?
5. If an aggregate sample has L.A. abrasion value of 34, for which type of road construction it may be used?
6. What is the abrasive charge? What are the requirements of abrasive charge?
7. On what factors does the abrasive charge depend?
8. How is wear calculated? What should be the limiting percentage of wear, if the aggregate is to be used in concrete for road surfacing?
9. What precaution do you take in the sieving operation?
10. List the factors which affect the percentage of wear in this test?
11. How the results may be made independent of the grading of the test sample?
12. How does the percentage wear change if stone is flat and elongated?
13. How may the wear resistance of concrete be improved?

Notes and Comments

EXPERIMENT NO. 6: California Bearing Ratio Value

Objective

To determine the California Bearing Ratio (CBR) of the subgrade soil by conducting a load penetration test in the laboratory.

Theory and Scope

California Bearing Ratio (CBR) test originally developed by California Division of Highways (U.S.A.) is one of the most commonly used methods to evaluate the strength of subgrade soil for the design of pavement thickness. CBR value as defined by IS: 2720 (Part XVI)-1979 is the ratio of the force per unit area required to penetrate a soil mass with a circular plunger of 50 mm diameter at the rate of 1.25 mm/minute, to that required for corresponding penetration of a standard material. Standard load is that load which has been obtained from tests on a crushed stone whose CBR value is taken to be 100 per cent. The ratio is usually determined for penetrations of 2.5 mm and 5.0 mm. The results of this empirical test cannot be related accurately with fundamental properties of the material but are useful in design of flexible pavements.

Apparatus

Apparatus conforming to the essential requirements of IS: 2720 (Part XVI) with the mould as per of IS: 9669. The field CBR apparatus meets the requirements of IS: 2720 (Part XXXI).

A metallic cylinder mould; Loading machine; Perforated swell plate; Proving ring of 10 kN capacity; Two dial gauges reading to 0.01 mm; 4.75 mm and 20 mm IS sieves; Steel cutting collar; Penetration plunger; Metal rammers; Mixing bowl, Spacer disc; Surcharge weights; Straight edge; Scales; Soaking tank; Drying oven; Filter paper; Dishes and Calibrated measuring jar.

Description of apparatus as per IS: 9669-1980

Mould consists of a gun metal or steel cylinder of 150 mm internal diameter and 175 mm height; provided with a detachable metal extension collar 50 mm in height. It also has a detachable perforated base plate of 10 mm thickness. The perforations in the base plate do not exceed 1.5 mm in diameter.

Loading machine with a capacity of at least 50 kN and equipped with a movable head or base that can travel vertically at an uniform rate of 1.25 mm/minute. Complete with load indicating device. There are two types of test frames:

1. Hand operated load frame of capacity 50 KN.
2. Motorised press or load frame of capacity 50 KN.

In place of dial gauge and proving ring assembly, electronic instrumentation is also available. Typical CBR test loading machines are illustrated in Figs. 11.7 and 11.8.

Spacer disc is a metal disc of 148 mm diameter and 47.7 mm in height. The spacer disc has groove on one side so that a handle can be screwed to facilitate its lifting.

Metal rammer of 2.6 kg weight with a drop of 310 mm (or) 4.89 kg weight with drop of 450 mm.

Steel cutting collar of 60 mm total height which can fit flush with the mould; Penetration plunger having a diameter of 50 mm and at least 100 mm length.

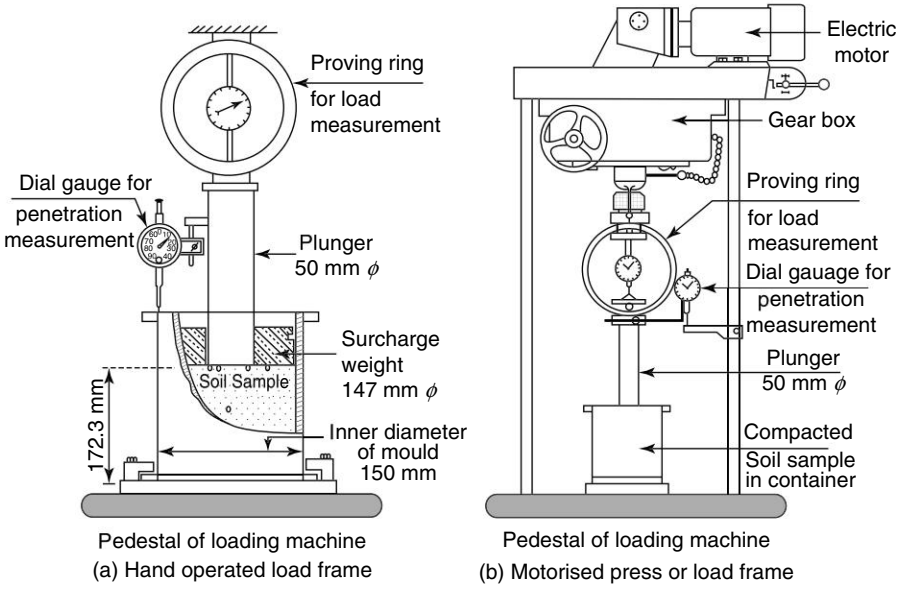

Fig. 11.7 *CBR test set up with loading machine/press*

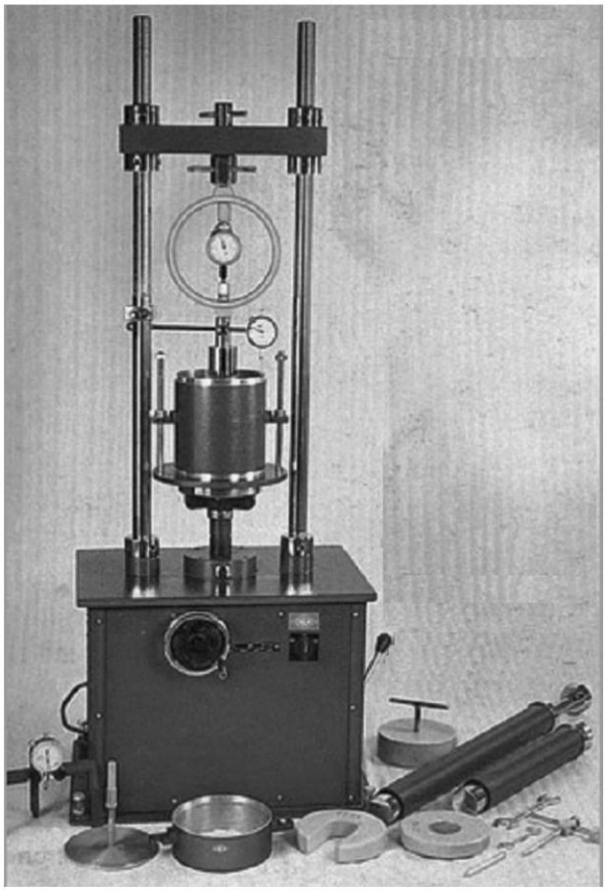

Fig. 11.8 *CBR test loading machine*

Surcharge weights One annular metal weight and several slotted weights 2.5 kg each and 147 mm in diameter with a 53 mm diameter central hole.
Penetration plunger having a diameter of 50 mm and at least 100 mm length.

Procedure

The method can be used for the determination of CBR of undisturbed and remoulded/compacted soil specimens in soaked as well as in unsoaked states. In case of remoulded soil test the specimens may be compacted either statically or dynamically.

Part 1: Preparation of test specimen

Prepare two specimens of the required type as follows:

Step 1: Undisturbed or natural soil specimen Attach the steel cutting edge to the mould and push it gently into the ground till the mould is full of soil. Remove the soil from sides and bottom. Trim the excessive soil from top and bottom; weigh the soil with the mould and determine its density.

Step 2: Remoulded or compacted specimen Prepare the remoulded specimen at Proctor's maximum dry density or any other density at which CBR is required. Maintain the specimen at optimum moisture content or the field moisture as required. The material taken for remoulded specimen should pass 20 mm IS sieve and retained on 4.75 mm IS sieve. In case the soil contains larger than 20 mm size particles, it should be replaced by equal amount of material passing 20 mm sieve but retained on 4.75 mm sieve. The remoulded samples are compacted either statically or dynamically.

(a) Statically compacted specimen

i. Calculate the weight of the soil at the required water content for the desired density after compaction such that it fills the mould (excluding collar);

$$W = \text{desired dry density} \times (1+w)\, V$$

where W = Weight of the wet soil
w = desired water content
V = volume of the specimen in the mould = 2250 cm^3 (as per the mould available in laboratory)

ii. Fix the extension collar to the mould and clamp it to the base plate. Take the weight W (calculated as above) of the soil mixed thoroughly with water and place it in the mould.
iii. Fill the mould with soil, gently pressing it with hands so that it does not spill out of the mould.
iv. Place a coarse filter paper over the leveled soil surface and then insert the spacer disc.
v. Place the mould assembly on the pedestal of static loading machine and compact the soil by pressing the displacer disc till the disc is flush with the top of the mould. Keep the load for some time and then release the load and remove the displacer disc.

(b) Dynamically compacted specimen

i. Take about 4.5 to 5.5 kg for granular soils sieved through 20 mm IS sieve in a mixing pan and add water to the soil in the quantity such that the moisture content of the specimen is either equal to field moisture content or OMC (Optimum Moisture Content) as desired. Mix together the soil and water uniformly.
ii. Clamp the mould along with the extension collar to the base plate. Insert the spacer disc over the base with hole on the bottom side. Place a coarse filter paper on the top of the spacer disc.

iii. Compact the soil-water mix in the mould using either light compaction or heavy compaction. For light compaction, compact the soil in three equal layers, each layer being given 55 blows with the rammer weighing 2.6 kg dropping through 310 mm. For heavy compaction compact the soil in five layers, 56 blows to each layer by the 4.89 kg rammer dropping through 450 mm. After each layer compacted surface should be scratched before adding soil for subsequent layer.
iv. Remove the extension collar and trim off the excess soil by a straight edge.
v. Turn the mould upside down and remove the base plate, the displacer disc and the filter paper.
vi. Weigh the mould with compacted soil and determine the bulk and dry densities.
vii. Invert the mould and place a coarse filter paper on the top of the compacted soil (collar side) and clamp the perforated base plate on to it so that the soil is in contact with the filter paper in the base.

The test may be conducted for both soaked as well as unsoaked conditions.

Part 2: For the CBR test on specimen soaked in both cases of compaction, soak the prepared specimen as described in Step 1 as follows; in case of unsoaked test move to Step 3.

Step 1: Weigh the sample excluding base plate and spacer disc; put a filter paper on the top of the soil and the perforated plate on the top of filter paper.
Step 2: Place annular weights to produce a surcharge equal to weight of base material and pavement expected in actual construction; the surcharge weight may vary from 2.5 to 5 kg. Immerse the mould assembly and weights in a water tank for 4 days. Each 2.5 kg weight is equivalent to 70 mm construction. A minimum of two weights should be placed.
Step 3: Remove the mould from tank and drain off the water from the sample hold it in vertical position for about 15 minutes.
Step 4: Weigh the sample again to calculate the percentage of water absorbed.

Part 3: Test the specimen following the normal procedure

Step 1: Place the mould assembly containing the specimen along with base plate and surcharge weight of 2.5 kg on the top surface of soil on the penetration test machine.
Step 2: Install the proving ring assembly and penetration plunger on to the loading machine. Seat the plunger at the center of the specimen with the smallest possible load, but in no case in excess of 4 kg so that full contact of the plunger on the sample is established as shown in Fig. 11.7.
Step 3: Place the remainder surcharge weight (slotted weight) so that total surcharge weight equals to 5 kg. This should be treated as zero load position.
Step 4: Mount the dial gauge with the tip of its stem resting on the collar to measure the penetration; set the dial gauges to read zero.
Step 5: Apply load so that penetration rate is 1.25 mm/minute. Record the load at penetrations of 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 4.0, 5.0, 7.5, 10.0 and 12.5 mm. In case the load starts decreasing before 12.5 mm penetration, record the maximum load and the corresponding penetration value.
Step 6: Detach the mould from the loading assembly and take about 20 to 50 g of soil from the top 30 mm layer and determine the moisture content.

At least three specimens should be tested on each type of sample. The maximum permissible variation should be within limits given below.

CBR, per cent	Maximum permitted variation, per cent
< 10	3
10–30	5
30–60	10
> 60	Not Significant

Part 4: Computation of test results

Step 1: Plot the load penetration curve with load as ordinate and penetration as abscissa. Generally, the initial portion of the curve is concave upwards due to surface irregularities. In such a case apply a correction. Draw tangent at the point of greatest slope. The point where this tangent meets the abscissa is the corrected zero reading of penetration as illustrated in Fig. 11.9.

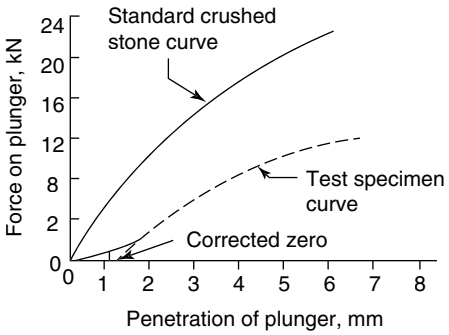

Fig. 11.9 *Typical load penetration curve*

Step 2: From the load penetration curve, determine the load value corresponding to the penetration value at which the CBR is desired.

Step 3: The CBR value is computed from

$$\text{CBR value} = \frac{\text{Test pressure corresponding to chosen penetration in MPa } (p_T)}{\text{Standard pressure for the same penetration in MPa } (p_S)} \times 100 \text{ per cent}$$

where p_T = corrected test pressure corresponding to the chosen penetration from the load penetration curve in MPa.

p_S = pressure to achieve equal penetration on standard soil in MPa

In most cases, CBR decreases as the penetration increases. The CBR values are usually calculated for penetrations of 2.5 mm and 5 mm, and the greater of the two is adopted for design purposes. Generally the CBR value at 2.5 mm is greater than that at 5 mm. However, if CBR for 5 mm penetration exceeds that for 2.5 mm, then the test is to be repeated for checking. If the check test gives similar results, the CBR value corresponding to 5 mm penetration is taken as the design value.

The standard loads adopted for different penetrations for the standard material with a CBR value of 100 per cent are given in Table 11.6.

Table 11.6 *Standard load for different penetration values*

Penetration, mm	Unit standard load, kgf/cm^2	Total standard load, kgf
2.5	70	1350
5.0	105	2055
7.5	134	2630
10.0	162	3180
12.5	183	3600

Observations and Calculations

1. Details of the sample

Sample details	Location		
Type of sample	Undisturbed/Remoulded		
Compaction of specimen	Static/Dynamic		
Type of compaction	Light / Heavy		
Condition of soaking	Soaked / Un-soaked		
Period of soaking	96 hours		
Surcharge weight,			
Dry unit weight			
Weight of material coarser than 20 mm replaced			
Water content of compacted sample	per cent		

(a) For dynamic compaction

Optimum water content = ……per cent
Weight of mould + compacted specimen = ……g
Weight of empty mould = ……g
Weight of compacted specimen = ……g
Volume of specimen = ……mm^3
Bulk density = ……g/mm^3
Dry density = ……g/mm^3

(b) For static compaction

Dry density = ……g/mm^3
Moulding water content = ……per cent
Wet weight of the compacted soil, *W* = ……g

2. Details of penetration test

Calibration factor of the proving ring, 1 Division = 1.176 kg
Surcharge weight used @ 2.0 kg per 60 mm construction = ……..kg
Water content after penetration test = ……..per cent
Least count of penetration dial, 1 Division = 0.01 mm

Penetration, mm	Number of divisions on proving ring, *n*	Corresponding load, kN	Corrected load, kN
0.0			
0.5			
1.0			
1.5			
2.0			
2.5			
4.0			
5.0			
7.5			
10.0			
12.5			

CBR at 2.5 mm penetration =……..
CBR at 5 mm penetration =……..
CBR of sample (design value) =……..
The average CBR value of three test specimens is reported as the CBR value of the sample.

Precautions

1. The holes of the base plate of the mould should not be blocked.
2. The surcharge weight should be aligned with plunger so that the plunger penetrates freely into the soil sample.

Discussion

California Bearing Ratio is an empirical value which can be used in design of flexible pavements. Tests are carried out on natural or compacted soils in water soaked or unsoaked conditions and the results so obtained are compared with the curves of standard test to have an idea of the soil strength of the sub grade soil.

The CBR is a measure of resistance of a material to penetration of standard plunger under controlled density and moisture conditions. The test procedure should be strictly adhered if high degree of reproducibility is desired.

The harder the surface, the higher will be the CBR value. A CBR of 3 may represent tilled farmland, a CBR of 4.75 the turf or moist clay, while moist sand may have a CBR of 10. High quality crushed rock has a CBR over 80. The standard material for this test is crushed California limestone which has a value of 100.

Design curves developed by Road Research Laboratory, UK have been adopted by Indian Road Congress IRC: 37. Depending upon the estimated traffic volume the thickness of base course and sub-base course can be determined from their respective CBR values. The range of CBR values for various types of soils are listed in Table 11.7.

Table 11.7 *Range of CBR values for various types of soils*

Sl. No.	Soil type	CBR value, per cent	Sl. No.	Soil type	CBR value, per cent
1.	Well Graded Gravel (GW)	40 – 80	7	Silt-Sand Mix (SM)	10 – 40
2.	Poorly Graded Gravel (GP)	30 – 60	8	Clayey Sand (SC)	5 – 20
3.	Silt-Gravel Mix (GM)	40 – 60	9	Silt of Low to Intermediate Plasticity (SL, SI)	< 15
4.	Clayey Gravel (GC)	20 – 40	10	Clay of High Plasticity (CH)	< 15
5.	Well Graded Sand (SW)	20 – 40	11	Silt of High Plasticity (SH)	< 10
6.	Poorly Graded Sand (SP)	10 – 40	12	Organic Soil	< 5

Viva-Voce Questions

1. Define the CBR value.
2. What is the significance of surcharge weight and how is it determined?
3. What are the different test conditions?
4. Under what conditions would one recommend to conduct CBR test on soaked specimen?
5. What are the field applications of CBR test results?
6. When is it necessary to apply correction to CBR value?
7. What are the reasons for the concavity of load penetration curve?

Notes and Comments

NATIONAL STANDARDS

1. IS: 460 (Parts 1 and 2)-1985; *Specification for Test Sieves*.
2. IS: 2386 (Part 1)-1963; *Methods of Test for Aggregates for Concrete: Part-I Particle Size and Shape (with Amendment No. 2)*.
3. IS: 2386 (Part 3)-1963; *Specific Gravity, Density, Voids, Absorption and Bulking*.
4. IS: 2386 (Part 4)-1966: *Methods of Test for Aggregates for Concrete: Part-IV- Mechanical Properties (Crushing Value, Aggregate Impact Value, Abrasion, Polished Stone, Crushing Strength) (with Amendment No. 3)*.
5. IS: 2386 (Part 50) – 1963; *Soundness*.
6. 2430–1996 (1st Revision): *Methods for Sampling of Aggregates for Concrete*.
7. IS: 2720 (Part-XVI)-l 979; *Methods of Test for Soils (Lab determination of CBR)*.
8. IS 5640–1970: *Method of Test for Determining Aggregate Impact Value of Soft Coarse Aggregate*.
9. IS : 6241- 1971; *Method of Test for Determining Stripping Value of Road Aggregates*.
10. IS : 6579-1981 (1st Revision); *Specifications for Coarse Aggregate for Water Bound Macadam* (Amendment No.1)

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PAVEMENT MATERIALS-II

Section 12

This section describes the tests generally performed on bitumen binder, hot mix bitumen, etc. The physical characteristics of bitumen as determined using these tests are critical for ensuring a quality pavement that is safe, durable and economical.

12.1 INTRODUCTION

Bitumen is the black or dark coloured solid or viscous residue or by-product obtained when the crude petroleum or natural asphalt is refined by fractional distillation. This residual (bottom) fraction left after removal of volatile components like gasoline (petrol), kerosene, light gas oil, etc., has the highest boiling point of 525°C. It has adhesive properties, and is soluble in carbon disulphide or toluene. Tars are residues from the destructive distillation of organic substances such as coal, wood, or petroleum and are more temperature sensitive than bitumen. Bitumen dissolves in petroleum oils unlike tar.

Bituminous materials are extensively used for roadway construction, primarily because of their excellent binding characteristics, water proofing properties and relatively low cost.

12.2 DIFFERENT FORMS OF BITUMEN

The viscosity of the straight-run or hot bitumen is reduced before they can be used. Based on the method of application they can be grouped into three main categories:

1. **Hot bitumen** Normal practice is to heat bitumen to reduce its viscosity before application.
2. **Cutback bitumen** In this category, bitumen is liquid binder of lower viscosity obtained by dissolving it in a volatile mineral solvent such as naphtha, kerosene, diesel oil, and furnace or fuel oil. From the environmental point of view, cutback bitumen is generally preferred. The solvent from the bituminous material evaporates after the application and the bitumen binds the aggregate. Cutback bitumen is used for cold weather bituminous road construction and maintenance. There are different types of cutback bitumen like rapid curing (RC), medium curing (MC), and slow curing (SC). RC is recommended for surface dressing and patchwork. MC is recommended for premix with less quantity of fine aggregates. SC is used for premix with appreciable quantity of fine aggregates.
3. **Bitumen emulsion** Bitumen emulsion is a liquid product obtained by dispersion or suspension of bitumen in an aqueous (soap water base) medium and stabilised by suitable material. Normally, cationic-type emulsions are used in India. The charge on droplets decreases the viscosity and renders the emulsion easy to handle and apply. The bitumen content in the emulsion is around 60 per cent and the remaining is water.

   When the emulsion is applied on a surface it breaks down resulting in release of water; on evaporation of water bitumen coat is obtained. The time of setting depends upon the grade of bitumen. The viscosity of bituminous emulsions can be measured as per IS: 8887-1995. Three types of bituminous

emulsions are available, which are Rapid setting (RS), Medium setting (MS), and Slow setting (SS). These emulsions have good bonding qualities even on damp and wet surfaces. The bitumen emulsion is commonly used for road and floor surfacing, painting the pipes and waterproofing the concrete walls.

4. **Modified bitumen** The properties of bitumen and bituminous mixes can be improved by using selected polymers, rubber or blend of polymers called *bitumen modifiers*. Bitumen treated with these modifiers is known as *polymer modified bitumen* (PMB). They can be used in the same variety of applications as unmodified bitumens.

Bitumen is always applied hot, cutbacks are applied either hot or cold and emulsion is always applied cold.

12.3 PROPERTIES OF BITUMEN

The requirements of bitumen depend on the mix type and construction. In general, bitumen should possess the following desirable properties:

1. The bitumen should not be temperature susceptible. During hot weather, the mix should not become too soft or unstable, and during cold weather, the mix should not become too brittle causing cracks.
2. The bitumen should provide adequate bond between the bitumen and aggregates used in the mix.
3. The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by heating the bitumen and aggregates prior to mixing or by use of cutbacks or emulsions of suitable grades.

The specifications of paving grade bitumen are listed in the Tables 12.1 and 12.2.

12.4 TESTS ON BITUMEN

As discussed above, bitumen is a visco-elastic material, whose properties are affected by both the temperature and the time during which a force is applied to it (loading time). Different grades of bitumen reflect differing (visco-elastic) resistance to deformation.

To measure this resistance, many generic characterisation tests have been devised including measures of brittleness, temperature susceptibility (penetration index), softening point, penetration value and viscosity. Additionally, more fundamental tests have been developed such as kinematic viscosity and direct tension testing. These are all used to characterise the relative performance of the bitumen at different temperatures.

The following tests are usually conducted on bituminous materials to assess the basic properties related to consistency, gradation, viscosity, temperature susceptibility and safety:

1. **Penetration test (IS: 1203-1978)** It measures the hardness or softness of bitumen at a specified temperature by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds.
2. **Ductility test (IS: 1208-1978)** Ductility is the property of bitumen that permits it to undergo great deformation or elongation. It is defined as the distance in mm, to which a standard sample of the material can be elongated at specified rate without breaking at specified temperature.
3. **Softening point test (IS: 1205-1978)** Softening point denotes the temperature at which the bitumen attains a particular degree of softening under the specifications of test. Generally, higher softening point indicates lower temperature susceptibility and is preferred in hot climates.
4. **Specific gravity test (IS: 1202-1978)** Increase in aromatic-type mineral impurities cause an increase in specific gravity of bitumen and its density is greatly influenced by its chemical composition. Thus, the specific gravity is good indicator of quality of binder and hence used in grading the binder. In pavement construction, the bitumen is generally measured by mass, but when used with aggregates density is used to convert the bitumen content from mass to volume basis.

5. **Viscosity test (IS: 1206-1978)** Viscosity is a fluid stability index of bituminous material and is a measure of its resistance to flow. At the application temperature, this characteristic greatly influences the strength of resulting paving mixes.
6. **Flash and fire point test (IS: 1209-1978)** The flash point is the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions. Whereas, the fire point is defined as the lowest temperature under specified test conditions at which the bituminous material gets ignited and burns. These are the safety tests.
7. **Float test (IS: 1210-1978)** Generally, the consistency of bituminous material can be measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and float test is used. The apparatus consists of an aluminum float and a brass collar filled with bitumen to be tested. The specimen in the mould is cooled to a temperature of 5°C and screwed in to float. The total test assembly is floated in the water bath at 50°C and the time required for water to pass its way through the specimen plug is noted in seconds and is expressed as the float value.
8. **Water content test (IS: 1211-1978)** Water content in bitumen should be the minimum to prevent foaming of the bitumen when it is heated above the boiling point of water. The water content in bitumen is determined by mixing known weight of sample in a pure petroleum distillate free from water, heating and distilling of the water. The weight of the water condensed and collected is expressed as percentage by weight of the original sample. The allowable maximum water content should not be more than 0.2 per cent by weight.
9. **Loss on heating test (IS: 1212-1978)** When the bitumen is heated it loses its weight due to the volatility and gets hardened. Bitumen used in pavement mixes should not generally indicate more than 1 per cent loss in weight.

   In addition, **solubility tests** are conducted to assess the purity (lack of contamination) of the product. Matter soluble in trichloroethylene is primarily aimed to determine the useful binder content or the impurities. Minimum of 99 per cent bitumen should be soluble in trichloroethylene when tested as per prescribed procedure.

   Paraffin wax content test is applicable for bitumen used in the pavements subject to critical usage like airports or industrial purpose where pavement temperature may go high due to jet blast or other factors.

12.5 COLLECTION OF MATERIAL SAMPLE

Materials shall be sampled according to the specified protocols to ensure that correct sampling procedures are followed and that test results provide the required information on consignment quality. The purpose of sampling is to enable subsequent testing to

1. represent, as nearly as practicable, an average of a consignment or batch or
2. detect any variation within a consignment or batch.

12.6 SAFETY PRECAUTIONS WHILE TESTING BITUMENOUS BINDERS

The following precautions should be taken while handling hot bituminous binders:

1. Eye protection, such as safety glasses and/or face shields, shall be worn.
2. Heat-resistant gloves with close-fitting cuffs, and other suitable protective clothing, shall be worn.
3. There shall be no smoking or the presence of other ignition sources in close proximity of test set up
4. Bituminous binders heated in the presence of small quantities of water may foam excessively and splatter or overflow the sample containers. Samples should be checked for the presence of water while the material is still cold.

   Loosen the lid of the sample container, if necessary, by gently heating the container lid, and examine the cold sample for the presence of water. If the presence of water is noticed, drain off as much water as possible and dry the sample at room temperature or blow-dry with clean compressed air.

Standard test procedures on bitumen are covered in this section.

Table 12.1 *Requirements for paving bitumen Type-1*

Sl. No.	Characteristics	Requirements for grades						Reference for test method
		S-35	S-45	S-55	S-65	S-90	S-200	
1.	Specific gravity at 27°C, min	0.99	0.99	0.99	0.99	0.99	0.99	IS:1202:1978
2.	Water per cent by mass, max	0.2	0.2	0.2	0.2	0.2	0.2	IS: 1211 :1978
3.	Flash point, Cleveland open cup, °C, min	175	175	175	175	175	175	IS:1209:1978
4.	Softening point , °C	50 to 65	45 to 60	45 to 60	40 to 55	35 to 50	30 to 45	IS:1205:1978
5.	Penetration at 25°C, 100 g, 5 sec. 1/10 mm	30 to 40	40 to 50	50 to 60	60 to 70	80 to 100	175 to 225	IS:1203:1978
6.	Penetration ratio, min	35	35	35	35	35	35	-
7.	Ductility at 27°C, mm, min	500	750	750	750	750	–	IS:1208:1978
8.	Paraffin wax content, percent by mass, max.	4.5	4.5	4.5	4.5	4.5	4.5	IS:10512:1983
9.	Frass breaking point, °C min	-4	–4	–6	–6	–8	–10	IS:9381 :1979
10.	Loss on heating, thin film oven test, per cent by mass, max	1	1	1	1	1	2	IS:1212:1978
11.	Retained penetration after thin film oven test, 25°C, 100g, 5 sec. 1/10mm. per cent of original, min	55	55	52	52	47	42	IS: 9382 : 1979
12.	Matter soluble in trichloroethylene, per cent by mass, min	99	99	99	99	99	99	IS:1216:1978
13.	Viscosity at: (a) 60°C, Poises, min (b) 135°C, cst, min	2500±500 220	2000±400 210	1500+300 180	1000±200 150	500+100 110	2500±500 220	IS:1206(Part2): 1 978 IS206(Part3): 1978

Table 12.2 *Requirements for paving bitumen Type-2*

Sl. No.	Characteristics	Requirements for Grades				Reference for test method
		A 35	A 55	A 65	A 90	
1.	Specific gravity at 27°C, min	0.99	0.99	0.99	0.98	IS:1202:1978
2.	Water percent by mass, max	0.2	0.2	0.2	0.2	IS: 1211 :1978
3.	Flash point, Cleveland open cup, °C, min	175	175	175	175	IS:1209:1978
4.	Softening point , °C	55 to 70	45 to 60	45 to 60	35 to 50	IS:1205:1978
5.	Penetration at 25°C, 100 g, 5 sec. 1/10 mm	30 to 40	50 to 60	60 to 70	80 to 100	IS:1203:1978
6.	Penetration ratio, min	25	25	25	25	–
7.	Ductility at 27°C, mm, min	10	15	15	15	IS:1208:1978
8.	Paraffin wax content, percent by mass, max.	10	10	10	10	IS:10512:1983
9.	Frass breaking point, °C min	–4	–6	–8	–10	IS:9381 :1979
10.	Loss on heating, thin film oven test, per cent by mass, max	1	1	1	1	IS:1212:1978
11.	Retained penetration after thin film oven test, 25°C, 100g, 5 sec. 1/10mm. per cent of original, min	57	57	47	42	IS: 9382 : 1979
12.	Matter soluble in trichloroethylene, per cent by mass, min	99	99	99	99	IS:1216:1978
13.	Viscosity at: (a) 60°C, Poises, min (b) 135°C, cst, min	1000+ 300 250	400+300 100	300±10 70	200+50 50	IS:1206(Part2):1 978 IS:1206(Part3):1978

$$\text{Penetration ratio} = \frac{\text{Penetration at 4°C , 200g, 60s}}{\text{Penetration at 25°C, 100g, 5s}} \times 100$$

EXPERIMENT NO. 1: Penetration Value of Bitumen

Objective

To determine the consistency of bituminous material and assess its suitability for its use under different climatic conditions and types of construction.

Theory and Scope

Penetration test measures the hardness or consistency (softness) of bituminous material by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically into a sample of the material under standard conditions of temperature, in five seconds. The concept of Penetration test is illustrated in Fig. 12.1(a). The test helps in establishing and verifying the grade of bitumen. This test is conducted as per IS: 1203-1978.

Apparatus

Penetrometer; A cylindrical container and a needle; Water bath and Bath thermometer, transfer dish or tray.

Description of Apparatus

Penetrometer calibrated to give accurate results in one tenth of a millimeter shown in Fig. 12.1(c) allows the needle to penetrate without much friction. The penetrometer has levelling screws and spirit level to make the base horizontal. The needle is secured in vertical position and total weight of needle assembly is 100 g. A knob is used to release or lock the needle assembly. The needle penetration is measured on a dial graduated in 1/10th of mm. An automatic-type penetrometer is provided with an electric timer that releases the needle exactly for 5 seconds.

Container is a flat bottomed cylindrical metallic dish 55 mm in diameter and 35 mm in depth. If the penetration is of the order of 25 mm or more, deeper dish of 70 mm diameter and 45 mm depth is used.

Needle consists of a straight, highly polished, cylindrical hard steel rod, as per dimension given in Fig. 12.1(b).

Water bath maintained at 25°± 0.1 °C containing not less than 10 litres of water, the sample being immersed to a depth not less 100 mm from the top and supported on a perforated shelf not less than 50 mm from the bottom of the bath.

Bath thermometer of range 0 to 44°C with 0.2°C graduations.

Time measuring device with an accuracy of ± 0.1 seconds.

Transfer dish or **tray** for supporting the container and should not rock the container. It should be of such capacity as to completely immerse into container during the test.
Penetration test set up is illustrated in Fig. 12.1(c). Automatic digital readout equipment is also available.

Procedure

Step 1: Soften the material to a pouring consistency by heating it at a temperature not more than 90°C for bitumens and 60°C for tars above the approximate softening point; stir it thoroughly until it is homogeneous and is free from air bubbles and water.

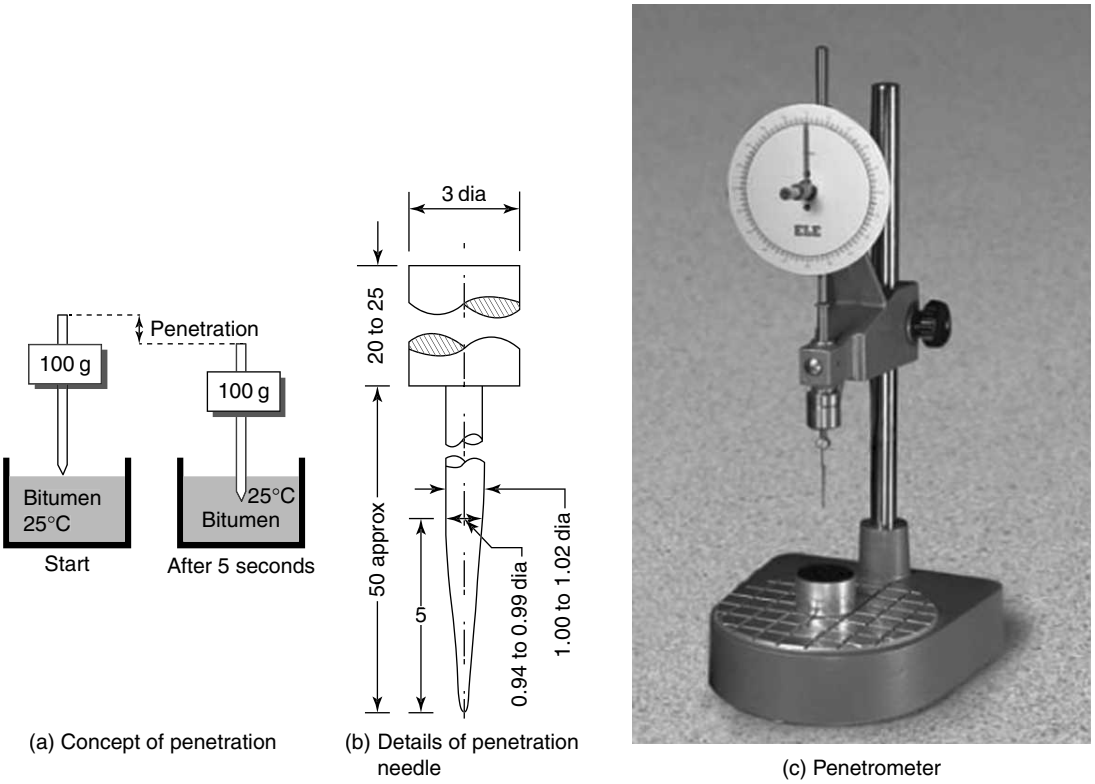


Fig. 12.1 *Penetration test concept and penetrometer assembly (all dimensions in mm).*

Step 2: Pour the melted bitumen into the container to a depth at least 15 mm in excess of expected penetration at 25°C.

Step 3: Protect the sample from dust and allow it to cool in an atmospheric temperature between 15° to 30°C for 1½ hours. Then place it in a transfer dish in the water bath at 25 ± 0.1°C for 1 to 1½ hours.

Step 4: Fill the transfer dish with water from the water bath to depth sufficient to cover the container completely, place the sample in it and keep the container on the stand of the penetration apparatus.

Step 5: Clean the needle with benzene, dry it and load with the weight. The total moving load required is 100 ± 0.25 g, this includes the weight of the needle, carrier and super-imposed weights.

Step 6: Adjust the needle to make contact with the surface of the sample. This may be done by placing the needle point in contact with its image reflected by the surface of the bituminous material.

Step 7: Adjust the pointer of the dial to read zero or note the initial dial reading.

Step 8: Release the needle for exactly 5 seconds. Release of needle can be secured with the help of automatic electric timer. The needle is locked after 5 seconds; use of timer minimises the human error.

Step 9: Adjust the rack of penetration dial to measure the distance penetrated in 1/10th of mm.

Step 10: Repeat the above procedure at least thrice at points on the surface of the sample not less than 10 mm apart and not less than 10 mm from the side of the dish. After each test return the sample and transfer dish to the water bath and wash the needle clean with benzene and dry it. In case of material of penetration greater than 25 mm, three determinations on each of the two identical test specimens using a separate needle for each determination should be made, leaving the needle in the sample on completion of each determination to avoid disturbance of the specimen.

The value of penetration should be the mean of not less than three determinations expressed in tenths of a millimetre.

Observations

Test temperature			
Penetrometer dial reading (a) Initial (b) Final			
Penetration value			
Mean penetration value			

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.
4. There should be no movement of the container while needle is penetrating into sample.
5. Bitumen sample should be just sufficient to fill the container to a depth of at least 15 mm in excess of the expected penetration.
6. The needle should be cleaned with benzene and dried before each penetration.
7. It is important to maintain the test temperature at the specified level during testing.

Discussion

It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature.

Penetration test is a commonly adopted test on bitumen to grade the material in terms of its hardness or consistency. For example, S-90 (80/100) grade bitumen indicates that its penetration value lies between 80 and 100. The grading of bitumen helps to assess its suitability for use in different climatic conditions and types of construction. For bituminous macadam and penetration macadam, IRC suggests 35, 65 and 90 bitumen grades. For semi dense bituminous concrete (SCDC) with bitumen emulsion and bitumen concrete (BC), usually 65 grade is used. For mastic asphalt, harder grade is used. In hot climates, a lower penetration grade is preferred to avoid softening whereas higher penetration grades are used in colder regions so that excessive brittleness does not occur. Highest penetration grade is used in spray application work. The penetration value of various grades are listed in Table 12.3.

Table 12.3 *Penetration range for various grades of bitumen*

Bitumen grade: S	S–35	S–45	S–55	S–65	S–90	S–200
Bitumen grade: A	A–35	-	A–55	A–65	A–90	-
Penetration range	30 – 40	40 – 50	50 – 60	60 – 70	80 – 100	175 – 225

Viva-Voce Questions

1. Which property of bitumen is related to penetration value?
2. What is meant by the term 40/50 bitumen?
3. What are the applications of penetration test?
4. The penetration value of a binder is 65; what is the distance in mm which the needle has penetrated through? What variations are expected in the test results if: (a) the time of penetration is increased? (b) The actual test temperature is below the standard temperature?
5. What are the precautions to be taken while conducting a penetration test?
6. What does 90-grade bitumen indicate?
7. Which bitumen grades are commonly used in warmer regions and why?

Notes and Comments

EXPERIMENT NO. 2: Ductility of the Bitumen

Objective

To measure the ductility of a given sample of bitumen and assess its suitability for its use in road construction.

Theory and Scope

Ductility is the property of bitumen that permits it to undergo large deformation or elongation. The Ductility test gives a measure of adhesive property of bitumen and its ability to stretch. In a flexible pavement design, it is necessary that binder should form a thin continuous ductile film around the aggregates so that the physical interlocking of the aggregates is improved. Binder material having insufficient ductility when subjected to repeated traffic loads makes pavement surface impervious.

The ductility values of bitumen vary from 50 to over 1000 mm; often minimum value of 500 mm is specified for bituminous pavement construction.

Ductility of a bituminous material is measured by the distance in millimeters to which it will elongate before breaking when two ends of standard briquette specimen of the material are pulled apart at a speed and temperature as illustrated in Fig. 12.2(a).

Apparatus

Apparatus required for the standard ductility test as per IS: 1208-1978:
Standard Briquette mould; Water bath; Testing machine and Thermometer.

Description of Apparatus

Standard briquette mould is made up of brass with the shape, dimensions and tolerances as specified by IS: 1208-1978. The ends *b* and *b′* are known as *clips* and parts *a* and *a′* are sides of the mould as shown in Fig. 12.2(b). The circular holes are provided in the clips to grip the fixed and movable ends of the testing machine. The mould when properly assembled form a briquette specimen of following dimensions:

Total length	75.0 ± 0.5 mm
Distance between clips	30.0 ± 0.3 mm
Width at mount of slip	20.0 ± 0.2 mm
Width at minimum cross section (halfway between clips)	10.0 ± 0.1 mm
Thickness throughout	10.0 ± 0.1 mm

Testing machine is used for pulling the briquette of bituminous material apart horizontally at a uniform speed of 50 ± 2.5 mm per minute with specimen continuously submerged in water while being pulled apart.
Water bath A bath maintained within ± 0.1°C of the specified test temperature, containing not less than 10 litres of water, the specimen being submerged to a depth not less than 100 mm and supported on a perforated shelf not less than 50 mm from the bottom of the bath.

Generally, water bath is combined with the testing machine to form single equipment. It is provided with an electric immersion heater and a pump to circulate water such as to obtain uniform temperature in the tank. The tank is lined with copper or steel strip. The machine may have a provision to test two or more specimens simultaneously as illustrated in Fig. 12.2(c).

Thermometer with the range 0°C– 44°C and readable up to 0.2 °C.

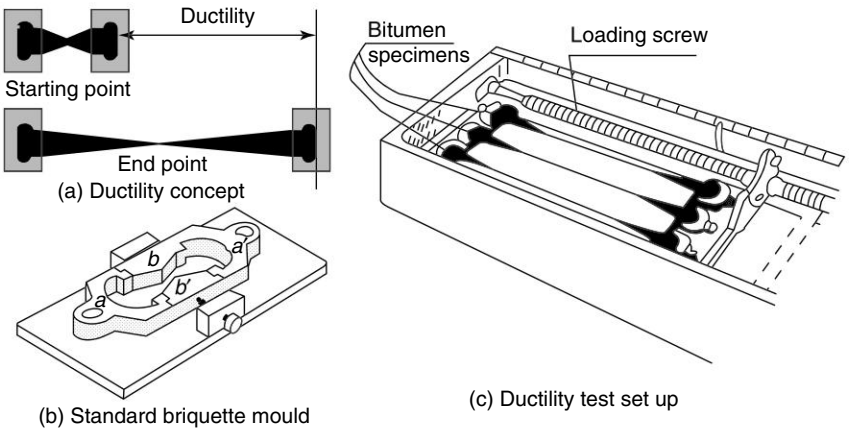


Fig. 12.2 *Ductility test concept, briquette mould and test set-up*

Procedure

Step 1: Assemble the standard briquette mould on a brass plate; in order to prevent the material under test from sticking to the mould, coat the surface of the plate and the interior surfaces of the sides of the mould with either mercury or by a mixture of equal parts of glycerine and dextrine.

Step 2: Heat the bituminous material to be tested to a temperature of 75 to 100°C above the approximate softening point until it attains fluid consistency. Strain the fluid through IS sieve 30.

Step 3: After stirring the fluid bitumen thoroughly, pour it in the coated mould assembly placed on a brass plate. While filling, pour the material in a thin stream back and forth from end to end of the mould until it is more than full level.

Step 4: Cool the filled mould assembly at room temperature for 30 to 40 minutes and then place it in a water bath maintained at the specified temperature (27°C) for 30 minutes.

Step 5: Remove the sample and mould assembly from the water bath and cut off the excess bitumen by means of a hot, straight-edged putty knife or spatula, so that the mould is just level full.

Step 6: Replace the brass plate and mould with briquette specimen in water bath maintained at 27°C for 85 to 95 minutes.

Step 7: Remove the briquette from the brass plate; detach the side pieces from the briquette immediately.

Step 8: Attach the two clips to the pins or hooks in the testing machine without causing any initial tension and adjust the pointer to read zero.

Step 9: Start the machine and pull the two clips apart horizontally at a uniform speed of 50 mm per minute; in the process one end remains fixed and other end is pulled apart until the specimen briquette ruptures.

Step 10: Measure the distance in mm through which the clips have pulled the bitumen thread to rupture.

The test may be stopped if the specimen does not break beyond 500 mm distance for S-35 grade and 750 mm for other grades from the same source.

Observations and Calculations

1. Bitumen grade =
2. Pouring temperature, °C =
3. Test temperature, °C =
4. Period of cooling, minutes =
   (a) In air =
   (b) In water bath before trimming =
   (c) In water bath after trimming =

Measurement	Briquette No.		
	1	2	3
(a) Initial reading			
(b) Final reading			
Ductility = $(b - a)$, mm			

The average of three normal test values is considered as the ductility of the sample, provided the three determinations are within ±0.5 per cent of their mean value. If the values of the three determinations do not lie within ±0.5 per cent of their mean, but the two higher values are within ±0.5 per cent of their mean, then the mean of the two higher values is taken as the test result. The mean of test values is rounded to nearest whole number as the ductility value.

Average ductility value of the sample = ……

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. Check the samples for the presence of water while the material is still cold; if water is present, drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.
4. The standard briquette mould should be filled with molten bitumen uniformly by pouring the material in a thin stream back and forth from end to end of the mould until it is more than level full.
5. During the test, it should be ensured that the water in the tank of the testing machine covers the specimen both above and below by at least 25 mm and the temperature is maintained continuously within ± 0.5°C of the specified temperature.

Discussion

A normal test is one in which the material between the two clips pulls out to a point or to a thread and rupture occurs where the cross-sectional area is minimum. The ductility value is affected by factors such as pouring temperature, test temperature, rate of pulling, etc. This test can also be conducted to determine the ductility of distillation residue of cutback bitumen, blown type bitumen and other bituminous products. The suitability of bitumen is judged, depending upon its type and proposed use. Bitumen with low ductility value may get cracked especially in cold weather.

Like the penetration test, ductility test has limited use since it is empirical and conducted at only one temperature (27°C). The minimum ductility values for various grades of Bitumen specified by IS: 1208–1978 are listed in Table 12.4.

Table 12.4 *Ductility of various grades of bitumen*

Source of paving bitumen	Bitumen from Assam petroleum				Bitumen from sources other than Assam petroleum			
Penetration grade	A-25	A-35	A-45	A-65	S-35	S-45	S-65	S-90
Minimum ductility value, mm	50	100	120	150	500	750	750	750

Viva-Voce Questions

1. What do you understand by ductility of bitumen?
2. Why ductility of bitumen needs to be determined?
3. Explain the significance of ductility test. Give its significance in a flexible pavement construction.
4. How is ductility value expressed? Give the dimensions of the standard briquette mould.
5. What are the factors which affect the ductility of test specimens?
6. Why is water used in this experiment?
7. What is the test temperature and standard rate of pull?
8. How will be the ductility value affected if the test temperature is more than the specified one?
9. What do the terms repeatability and reproducibility stand for?
10. Why is it necessary to add either methyl alcohol or sodium chloride in the testing bath?

Notes and Comments

EXPERIMENT NO. 3: Softening Point of Bituminous Material

Objective

To determine the softening point of bitumen/tar.

Theory and Scope

Softening point is the temperature at which the bitumen attains a particular degree of softening under specified condition of the test. The binder should have sufficient fluidity before its use in road works. The determination of softening point indicates the temperature up to which a bituminous binder should be heated for various road applications. Softening point is determined by ring and ball apparatus. According to IS: 334-1982, it is the temperature (in Celsius) at which a standard ball passes through a sample of bitumen in a mould heated under water or glycerin at specified conditions of test and falls through a height of 25 mm. The concept of softening point is illustrated in Fig. 12.3(a).

Apparatus

Pensky–Martens ring and ball apparatus; Bath; Low and high range thermometers, Stirrer and Heating system.

The ring and ball apparatus consists of

Steel balls Two steel balls of 9.5 mm diameter and 3.5 ± 0.05 g weight.

Brass rings Two tapered brass rings having depth of 6.4 mm, and inside bottom and top diameters of 15.9 mm and 17.5 mm, respectively.

Supports Supports to hold rings in position and also allows for suspension of a thermometer. The distance between the bottom of the rings and the top surface of the bottom plate of the support is 25 mm.

Bath A heat resistant glass beaker not less than 85 mm in diameter and 1220 mm in depth.

Thermometers:

(a) Low range from (–) 7 to 110°C with an accuracy of 0.5°C.
(b) High range from 90 to 370°C with an accuracy of 2°C.

Digital thermometer may be used to minimise the visibility error.

A heating system An electric plate with energy regulator is quite suitable.

Procedure

Part 1: Preparation of test sample

Step 1: Heat the bituminous material to a temperature between 75°–100°C above its softening point to obtain fluid consistency; stir until it is completely free form air bubbles and water. Filter it through IS sieve 30, if necessary.

Step 2: Heat the rings to a temperature approximately equal to that of the molten material. Place the rings on a metal plate; coat the plate and inner surfaces of rings with a mixture of equal parts of glycerine and

dextrine. Fill the material in the rings. After cooling, the rings filled with material for 30 minutes in air, level the material in the ring by removing the excess with a warmed sharp knife.

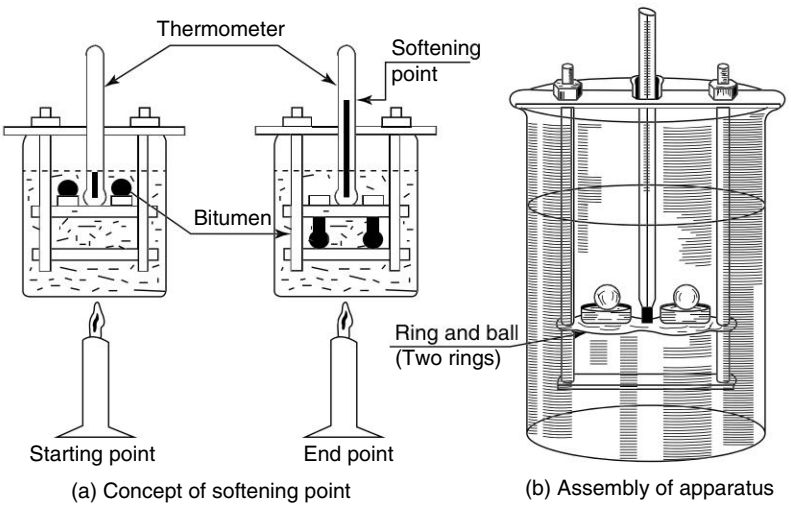


Fig. 12.3 *Concept of softening point and test set up for determining softening point of bitumen/tar*

Part 2: Test procedure

(a) Materials of softening point below 80°C

Step 1: Assemble the apparatus with the rings, thermometer and ball guides in position. Fill the bath with distilled water to a height of 50 mm above the upper surface of the rings. The starting temperature should be 5± 0.5 °C.

Step 2: Apply heat to the bath and stir the liquid with the help of a stirrer so that the temperature rises at a uniform rate of 5 ± 0.5°C per minute.

Step 3: Apply heat until the bituminous material softens with the increase in temperature and the ball sinks through the ring, carrying a portion of the material with it.

Step 4: Note down the temperature when any of the steel ball with bituminous coating touches the bottom plate. This temperature at which the ball touches the bottom is the softening point of that material.

Some specifications consider the temperature when the second ball also touches the bottom plate. The average of the two readings to the nearest 0.5°C is reported as the softening point.

(b) Materials of softening point above 80°C

The procedure is the same as described above. The only difference is that instead of distilled water, glycerine is used to fill the bath and the starting temperature of the test is 35°C.

Binder tested		
Test set up	1	2
Temperature when (a) first ball touches bottom, °C (b) second ball touches bottom, °C		
Average		

Softening point =……°C.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.
4. Distilled water should be used as the heating medium.
5. During the conduct of test the apparatus should not be subject to vibrations.
6. The bulb of the thermometer should be at about the same level as the rings.

Discussion

Softening point indicates the temperature at which binders possess the same viscosity. Bituminous materials do not have a definite melting point. Rather the change of state from solid to liquid is gradual and over a wide range of temperature. Softening point has particular significance for materials that are to be used as joint and crack fillers. Generally, higher softening point indicates lower temperature susceptibility. Bitumen with higher softening point may be preferred in hot climates as they will not flow during service. Softening point for various grades should lie within the range listed in Table 12.5.

Table 12.5 *Softening point for various grades of bitumen*

Source of bitumen	Bitumen from sources other than Assam petroleum						Bitumen from Assam petroleum			
Grade	S-35	S-45	S-55	S-65	S-90	S-200	A-35	A-55	A-65	A-90
Softening Point, °C	50-65	45-60	45-60	40-55	35-50	30-45	55-70	45-60	45-60	35-50

Viva-Voce Questions

1. What is softening point? If material A has softening point of 56°C and B has 42°C, which binder is good and why?
2. What is the objective of the softening test and application of test results?
3. What is the importance of determination of softening point in road construction operations?
4. What is the concept of determination of softening point by ring and ball apparatus?
5. What is the criterion of selection of medium in bath used for heating the specimen?
6. What will happen to softening point if: (a) aluminium balls are used in place of steel balls? (b) The distance between rings and the bottom plate is increased?
7. Do the softening point and penetration values for particular bitumen vary at different places and in different climate?
8. What are the factors which affect the ring and ball test results?

Notes and Comments

EXPERIMENT NO. 4: Specific Gravity Test for Bitumen

Objective

To determine the specific gravity of given bituminous material.

Theory and Scope

The specific gravity of bitumen is defined as the ratio of mass of given volume of bitumen of known content to the mass of equal volume of water at 27°C. The specific gravity can be measured using either pycnometer or preparing a cube specimen of bitumen in semi-solid or solid state. The specific gravity of bitumen is greatly influenced by its chemical composition; it increases with the increase in aromatic-type mineral impurities. Thus, the property of specific gravity is of importance in classifying or grading the binders.

In pavement construction works, the bitumen is measured by weight, but when used with aggregates bitumen content is converted to volume using its density.

Apparatus

Specific gravity bottles; Water bath; Bath thermometer with range 0 to 44° C and least count 0.2°C; Balance and Distilled water.

Description of Apparatus

Specific gravity bottle of 50 ml capacity, it may be either Ordinary or Wide-mouthed capillary type as per IS: 1202-1978 as shown in Fig. 12.4.

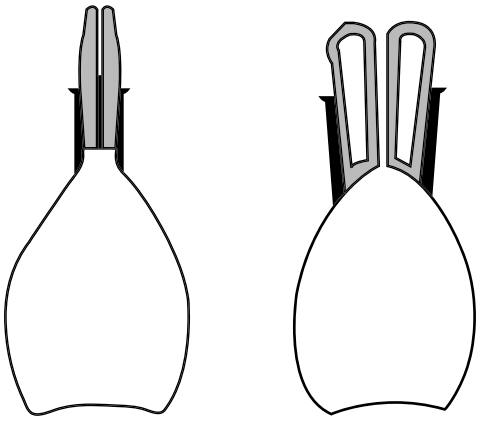


Fig. 12.4 *Capillary type specific gravity bottles*

The method using specific gravity bottle is called *pycnometer method*.

Procedure

Step 1: Weigh the clean, dried specific gravity bottle along with the stopper.

Step 2: Fill the specific gravity bottle with freshly boiled distilled water and insert the stopper firmly. Place the filled gravity bottle in the water bath having a temperature of 27 ± 0.1°C for not less than 30 minutes.

Step 3: Remove bottle from the water bath and clean it from outside. Weigh the specific gravity bottle containing distilled water.

Step 4: Empty and clean the specific gravity bottle.

Step 5: Heat the bituminous material to the pouring consistency and approximately half fill the empty cleaned specific gravity bottle, by taking care to prevent entry of air bubbles.

Step 6: Weigh the specific gravity bottle with the material.

Step 7: Fill the remaining space in specific gravity bottle with distilled water at 27°C.

Step 8: Weigh the specific gravity bottle about half-filled with the material and the other half with distilled water.

Observations and Calculations

Type of measurement			
Weight of empty specific gravity bottle,	W_1 g		
Weight of specific gravity bottle filled with water,	W_2 g		
Weight of the specific gravity bottle with material,	W_3 g		
Weight of the specific gravity bottle with material and water,	W_4 g		
Specific gravity, $s = \dfrac{(W_3 - W_1)}{(W_2 - W_1) - (W_4 - W_3)}$			

Average specific gravity of given bituminous material =…….

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.
4. Care should be taken to prevent entry of air bubbles while pouring the bitumen in specific gravity bottle.
5. The specific gravity bottle should be held in a constant temperature water bath sufficiently long to ensure same temperature before each weighing is made.
6. Duplicate determination of specific gravity should agree within 0.01.

Discussion

The test is based on the principle that specific gravity is the ratio of mass of a given volume of bitumen to the mass of an equal volume of water, both taken at a specified temperature. This test can also be used to determine the specific gravity of road tars, creosote and anthracene oils as per IS: 1202-1978. The specific gravity of bitumen varies from 0.97 to 1.02. The specific gravity of any grade of bitumen to be used in pavements should not be less than 0.99.

Viva-Voce Questions

1. Define specific gravity.
2. What is the significance of specific gravity?
3. Is it necessary to determine the specific gravity of water or other liquid used when all the measurements are made entirely by mass?
4. Is it permissible to use kerosene in this experiment, if not, why?
5. What are the sources of error in the experiment?

Notes and Comments

EXPERIMENT NO. 5: Viscosity of Bituminous Materials

Objective

To determine the viscosity of bitumen.

Theory and Scope

Viscosity represents the fluid property of bituminous binder; it is a measure of its resistance to flow or workability. The lower the viscosity of bitumen, the faster it will flow under the same stress; and conversely the more viscous a fluid is, the more it will resist the flow. At the application temperature, viscosity greatly influences the strength of resulting paving mixes. Low or high viscosity during compaction or mixing results in lower stability. At high viscosity, it requires the more compacting effort and results in a heterogeneous mix having lower stability. On the other hand, at low viscosity instead of providing a uniform film over aggregates, it will lubricate the aggregate particles.

Viscosity is defined as the ratio between the applied shear stress and induced shear rate of a fluid and is measured either as absolute viscosity or kinematic viscosity. When shear rate is expressed in units of 1/sec. and shear stress in units of Pascal, viscosity will be in units of Pascal-seconds (Pa-sec). In c.g.s. units the shear stress is expressed in Dynes/cm^2, the viscosity will be in units of Dyne-sec/cm^2 called poise. Thus, poise = Dyne-sec/cm^2 = (N-sec/m^2)/10. Therefore, Pa-sec = (N/m^2)-sec = N-sec/m^2 = 10 poise, i.e., one Pascal-second is equal to 10 Poises. However, for bituminous materials a smaller unit called centi-poise which is 1/100 of poise is used. For a Newtonian fluid, the relationship between shear stress and shear rate is linear, and thus the viscosity is constant at different shear rates or shear stress. However, for a non-Newtonian fluid, the relationship between shear stress and shear rate is not linear, and thus the apparent viscosity will change as the shear rate or shear stress changes.

Absolute or *dynamic viscosity* is internal friction measured in poises; whereas, the *kinematic viscosity* of a liquid is the absolute (or dynamic) viscosity divided by the density of the Newtonian liquid at the temperature of measurement. When viscosity is in units of Poise and density in units of g/cm^3, the kinematic viscosity will be in c.g.s. units of Stokes. For binders such as bitumen, etc., a smaller unit called centi-stoke which is 1/100 of Stoke is adopted.

The basic absolute viscosity test measures the time taken by a fixed volume of asphalt binder to be drawn up through a capillary tube by means of vacuum, under closely controlled conditions of vacuum and temperature as illustrated in Fig. 12.5.

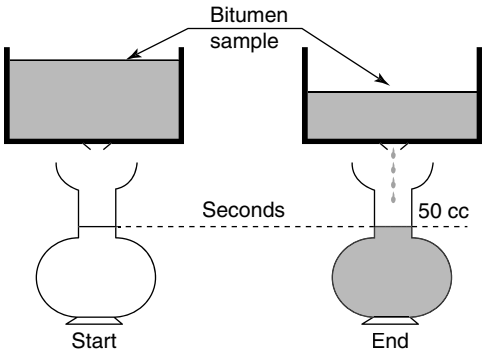


Fig. 12.5 *Concept of viscosity apparatus*

The basic kinematic viscosity test measures the time taken by a fixed volume of asphalt binder to flow through a capillary viscometer under closely controlled conditions of head and temperature.

Apparatus

Measurement of absolute viscosity

Absolute viscosity of bitumen is measured by vacuum capillary viscometers of the types: (a) Cannon–Manning Capillary Viscometer, (b) Asphalt Institute Capillary Viscometer and (c) Modified Koppers Vacuum Capillary Viscometer.

The Cannon–Manning vacuum viscometer conforming to IS: 1206 (Part II) is generally used for determination of absolute viscosity of bitumen.

Components equipment constant temperature bath; Silicone bath oil suitable up to 150°C; Vacuum system; Thermometer for bath; Timing device; Viscometer stand and Cannon-Manning vacuum viscometers.

Description of Apparatus

Constant temperature bath A bath for immersion of at least six vacuum capillary viscometer tubes with a digital temperature controller to maintain the temperature in the bath at accuracy of ± 0.1°C.

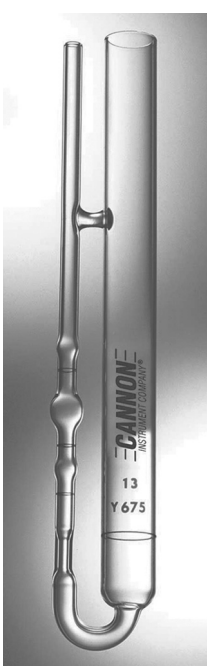
Vacuum system Capable of maintaining a vacuum within ±0.5 mm of the desired level up to and including 300 mm of mercury. The system shall consist of all accessories as needed to complete the vacuum system.

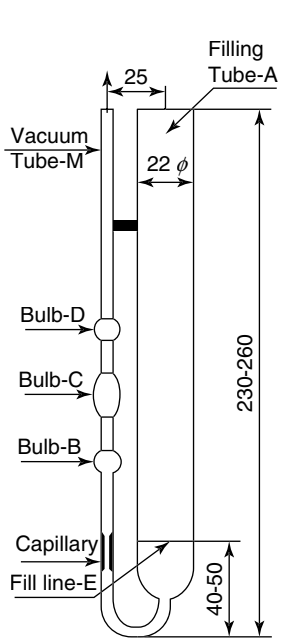
Thermometer for bath Thermometer with range of 37.8 to 82° C, and least count of 0.2°C.

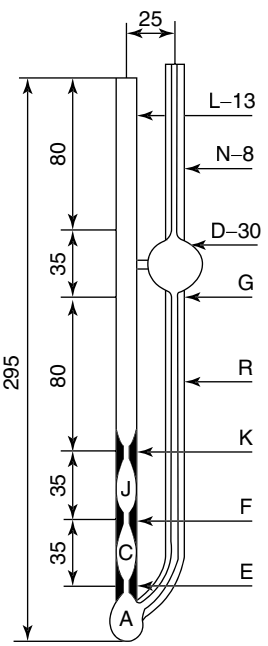
Timing device A stop watch or stop clock capable of reading up to ½ second.

Cannon–Manning vacuum viscometers The viscometer has a measuring bulb, filling tube and carries some markings as illustrated in Fig. 12.6. It should be provided with manufacturers' calibration certificate, viscometer holder and silicone cork of sizes 12 and 13 (one each).

Viscometer stand for holding six viscometers.







Cannon–manning viscometer Cannon–Fenske opaque viscometer

Cannon–Manning Cannon–Manning viscometer Cannon–Fenske opaque viscometer

Fig. 12.6 *Cannon–Manning vacuum capillary viscometer (all dimensions are in mm)*

Procedure

Part 1: Measurement of absolute or dynamic viscosity

Step 1: Calibrate the viscometer against a liquid of known viscosity or manufacturers' calibration certificate.

Step 2: Preparation of sample.

(a) Heat the bitumen to a temperature not more than 90°C above its approximate softening point until it has acquired pouring consistency or fluidity like motor oil.

(b) Transfer about 20 ml into a suitable container and keep it in bath maintained at a temperature of 135 ± 5.5°C for 30 minutes, stirring occasionally to allow entrapped air to escape.

Step 3: Pour the hot bitumen in the Canning–Manning vacuum viscometer through the larger diameter filling tube A so that bitumen is within 2 mm of the fill line E.

Step 4: Place the charged viscometer in an oven or bath maintained at 135 ± 5.5°C for a period of 10 ± 2 minutes to allow larger air bubbles to escape.

Step 5: Place the charged viscometer vertically in the test bath with the help of a holder so that the uppermost timing marks is at least 20 mm below the surface of the bath liquid.

Step 6: Establish a vacuum of 300 ± 0.5 mm of mercury in the vacuum system and connect it to the viscometer with the valve closed.

Step 7: After the viscometer has been in the bath for 30 ± 5 min, open the stop cock and allow the bitumen to flow in the viscometer.

Step 8: Note the time taken (to within ± 0.5 sec) for the leading edge of the meniscus to pass between successive pairs of timing marks, the predetermined path length.

Step 9: Record the first flow time which exceeds 60 seconds along with the identification of the sample.

Part 2: Measurement of kinematic viscosity

Equipment For this test, either Cannon–Fenske Opaque Viscometer or BS U-tube reverse flow Viscometer can be used for the viscosity measurement.

Procedure The principles of working are quite similar to that of the measurement of absolute viscosity.

First a calibration constant is determined using a standard liquid and then measurement is done with the sample under prescribed conditions of temperature and other parameters. As specified in IS: 1206 (Part 3) -1978.

Observations and Calculations

Identification of the sample			
Calibration factor K, poise/s			
Time taken to pass the pre-determined path length, t in seconds			
Viscosity of sample, $K \times t$, poise			

Average absolute viscosity =…….. Poises.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.
4. Care should be taken to prevent entry of air bubbles while pouring the bitumen in viscometers.

Discussion

Although absolute viscosity is an improvement over the penetration test, it still only measures viscosity at one temperature and thus does not fully characterise bitumen binder's consistency over the expected range of construction and service conditions. The 135°C measurement temperature was selected to simulate the mixing and lay down temperatures for the typical pavement construction. To convert from kinematic viscosity (in units of Stokes) to absolute viscosity (in units of Poises), the number of Stokes is multiplied by the density in units of g/cm^3.

A Newtonian liquid is the liquid in which shear strength (resistance) is directly proportional to rate of shear strain. This test method applies to bitumens and multigrade bitumens with repeatability of 7 per cent, and reproducibility of 12 per cent.

To measure absolute viscosity of viscosity graded paving bitumen (IS:73-1992) at 60°C in accordance with IS:1206 (Part 2) a vacuum capillary viscometer is used. It should be noted that any other viscometer such as rotational viscometer cannot be used to measure the absolute viscosity at 60°C since the bitumen is non-Newtonian in nature at this temperature.

Orifice-type viscometers are used to indirectly find the viscosity of liquid binders like cutbacks and emulsions. The viscosity expressed in seconds is the time taken by the 50 ml bitumen material to pass through the orifice of a cup, under standard test conditions and specified temperature. Viscosity of a cutback can be measured with either 4 mm orifice at 25°C or 10 mm orifice at 25°C or 40°C.

Viscosity values as specified by IS: 73 -1992 are listed in Table 12.6.

Table 12.6 *Values for viscosity for different grades of bitumen*

Viscosity	Grade of bitumen					
	S-35	S-45	S-55	S-65	S-90	S-200
135 °C, cst, min	220	210	180	150	110	20
60 °C, Poises	2500 ± 500	2000 ± 400	1500 ±300	1000 ±200	500 ± 100	250 ±50

Viva-Voce Questions

1. Explain the term viscosity. What are the uses of viscosity test?
2. What is the difference between test procedures for measuring the absolute viscosity and kinematic viscosity?
3. How are the units of absolute viscosity or kinematic viscosity related to each other?
4. Why is 135°C measurement temperature chosen for determination of dynamic viscosity of bitumen?
5. What are the precautions to be taken during viscosity test using orifice viscometer?
6. How does low or high viscosity influences the stability bituminous mix?
7. What is the viscosity of conventional hot-rolled asphalt wearing course binder?

Notes and Comments

EXPERIMENT NO. 6: Flash and Fire Points of Bituminous Material

Objective

To determine flash point and fire point of the bituminous material.

Theory and Scope

At high temperatures, bituminous materials emit hydrocarbon vapour which are susceptible to catch fire and may create hazardous conditions. For safety reasons it is, therefore, essential to qualify or restrict the heating temperature of bituminous material for each grade. IS:1209-1978 has defined the flash point as the temperature at which the vapour of bitumen momentarily catches fire in the form of flash under specified test conditions. Whereas, the fire point is defined as the lowest temperature at which the application of test flame causes the bituminous material to ignite and burns at least for 5 seconds under specified test conditions. Flash point and fire point tests used to determine the temperature to which bituminous material can safely be heated.

Flash and fire points can be determined by Cleveland open cup tester conforming to IS: 1209-1972 for petroleum products and other liquids. It is not used for fuel oils and the material having flash point above 79°C.

Apparatus

Cleveland open cup apparatus; Shield; Low and high range thermometers.

Description of Apparatus

Cleveland open cup apparatus has the following major components:

(*a*) *Brass test cup* internal diameter of 63–64 mm and height of 32.5 to 34.0 mm. A filling mark is engraved at a distance 9-10 mm below to surface. It also has a circular plate on outside near top. The cup is provided with a wooden handle.

(*b*) *A brass or cast iron or steel heating plate* with a 69.5 to 70.5 mm diameter centre hole. A sheet of hard asbestos board covers the metal plate except over the hole. The central hole allows mounting of the test cup.

(*c*) *Test flame applicator*, for applying the test flame, having the tip at the end of about 1.6-mm diameter with an orifice of 0.8 mm diameter. The device swings such that the centre of orifice is not more than 2 mm above the rim of the cup. A bead having a diameter of 3.2 to 4.8 mm is mounted in a convenient position on the apparatus so that the size of the test flame can be controlled by comparison to it. Domestic LPG Gas in smaller cylinder can be used.

(*d*) *An electric heater* controlled by a variable voltage transformer. Flame heater or burner using a gas can also be used.

(*e*) *Thermometer support* to hold the thermometer in a specified position.

A shield 460 mm square and 610 mm high and having an open form is recommended,

Thermometers of specifications:

For low range values, measurement range:–7 to 110°C and readable to 0.5°C.

For high range values, measurement range: 90 to 370°C and readable to 2°C.

Semi-automatic and automatic Cleveland open cup apparatus are generally used.

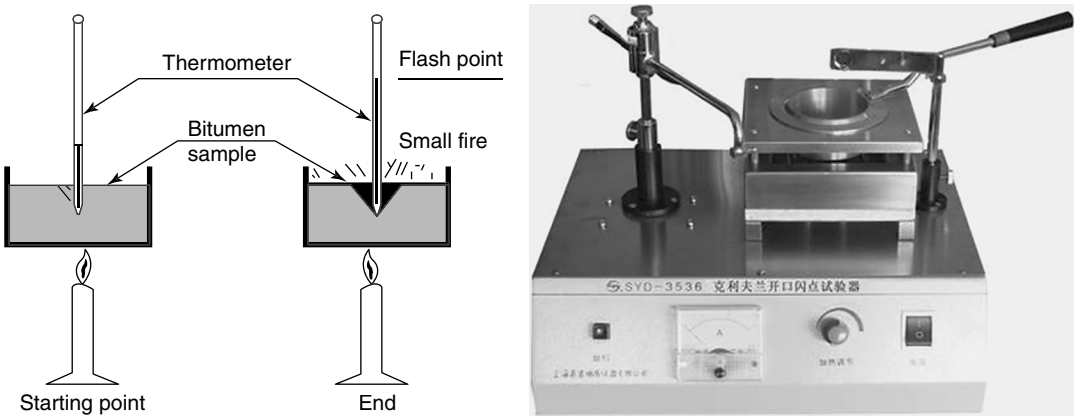


Fig 12.7 *Concept of flash point determination and Cleveland open cup test apparatus*

Procedure

Part 1: Flash point

Step 1: Clean the test cup with an appropriate solvent to remove any deposits; wash with water and dry over an open flame or hot plate. Allow it to cool.

Step 2: Assemble and support the apparatus.

Step 3: Insert the thermometer of high or low range as per requirement in a vertical position with the bottom of bulb 6.4 mm from the bottom of the test cup. It should be positioned at a point halfway between the centre and side of the cup on diameter perpendicular to the arc of sweep of the test flame and on the side opposite to the test flame's burner arm. Also insert the stirrer, to stir the material.

Step 4: Heat the bitumen to a temperature not more than 100°C above its approx. softening point until it has acquired pouring consistency. Stir molten material thoroughly to remove air bubbles and water.

Step 5: Pour the hot bitumen to fill the test cup up to the filling mark. Light the test flame and adjust it.

Step 6: Apply heat initially at the rate so that the temperature rise of sample is 14 to 17°C per minute. When the sample temperature has reached approximately 56°C below expected flash point, supply heat at such a rate that the temperature increase as recorded by the thermometer is neither less than 5°C nor more than 6°C per minute for the last 28°C before the flash point.

Step 7: Light the test flame and adjust it to a diameter of 3.2 to 4.8 mm.

Step 8: Start application of the test flame when the temperature is at least 28°C below the expected flash point; apply the test flame at 2°C intervals. Pass the test flame across the centre of the cup with a smooth continuous motion. Pass the flame in one direction first, then in the opposite direction, the time spent in passing the test flame across the cup should be about one second,

Step 9: When a flash first appears at any point on the surface of the material in the cup, note the temperature on thermometer and record it as flash point,

Step 2: Fire point

Step 1: After flash point has reached, heating should be continued at a rate of 5° to 6°C per minute.

Step 2: The test flame should be adjusted so that it is of the size of a bead 4 mm in diameter.

Step 3: Continue application of the test flame at 2°C intervals until the vapors ignite and continue to burn for at least 5 seconds. Record the temperature at this point as the fire point.

Step 4: The duplicate results should not differ by more than 8°C for both flash point and fire point.

Observations and Calculations

Flash point =……°C.
Fire point =……..°C.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow dry with clean compressed air.
4. While using a gas burner or other such device for heating the cup, the free flame should not be allowed to come up around the cup.
5. During the last 17°C rise in temperature prior to the flash point, care must be taken to avoid disturbing the flash point; care must be taken to avoid disturbing the vapours in test cup by careless movement or breathing near the cup.
6. The bluish halo that sometimes surrounds the test flame should not be confused into the true flash.
7. Discontinue stirring during the application of the test flame.

Discussion

Flash point should be taken as the temperature read on the thermometer at the time when the vapour of bitumen momentarily catches fire. Flash Point information required for safety in handling the bituminous materials. This test can also be conducted to determine the flash and the fire points of fluxed native asphalt, cutback bitumen and blown type bitumen, etc.

Viva-Voce Questions

1. Define flash and fire points.
2. What is the significance of flash and fire point test?
3. What are the parameter that affects the result of flash and fire point tests?
4. What is the consistency of bitumen in this test?
5. What is the minimum value of fire point specified by the Code?
6. Can methods used for determining the flash point of bitumen used for gasoline, kerosene, etc.? Is fire point same as ignition point?

Notes and Comments

EXPERIMENT NO. 7: Float Test for Bituminous Materials

Objective

Determine the consistency of bitumen by the float test.

Theory and Scope

The float test characterizes the flow behavior or consistency of bituminous materials, including asphalts and tar products. The measure of consistency of bitumen is useful in establishing the uniformity of certain shipments or sources of supply.

Apparatus

Aluminium float; Three brass collars; Thermometer; Water bath; 75×50 mm brass plate and stop watch.

Description of Apparatus

Float is made of aluminium or aluminium alloy and conforms to IS: 1210-1978.

Brass collar the top of which shall screw up tightly against lower side of the shoulder of float,

Weight of float, 37.90 ± 0.20 g
Weight of collar, 9.80 ± 0.20 g

Fig. 12.9 *Float test apparatus*

Low softening point thermometer 378 to 384 mm in length containing liquid mercury which is filled above it by nitrogen gas conforming to IS: 1210-1978.

Temperature range (–) 2°C to (+) 80°C with subdivisions 0.2°C.

Water bath of at least 185 mm internal diameter (or 150 mm wide × 300 mm long) containing water at least 185 mm in depth with height of the container above the surface of the water of at least 100 mm maintained at 5.0 ± 1.0 °C.

The assembled float and collar filled flush with the bottom weighing 53.2 g, shall float upon water with the rim 8.5 ± 1.5 mm above the surface of water.

Procedure

Part 1: Preparation of sample

Step 1: Place the brass collar with the smaller end on a brass plate which has been previously coated with equal parts of glycerin and dextrin.

Step 2: Completely melt a suitable quantity of solid bitumen or residue from cutback bitumen at the lowest possible temperature to bring it to a sufficiently fluid condition for pouring. Stir thoroughly until it is homogeneous and free from air bubbles and then pour it into the collar in any convenient manner until slightly more than level with the top.

(*a*) *Asphalt and asphalt products* Cool the material to room temperature for 15–60 minutes; place it in water maintained at 5°C for 5 minutes, and trim the material flush with the top of the collar by means of a warm spatula or steel knife. Place the collar and brass plate in the water bath maintained at 5 ±1°C for not less than 15 minutes and not more than 30 minutes.

(*b*) *Tar products* Immediately immerse tar products for 5 minutes in the water bath at 5°C and trim the material flush with the top of the collar by means of a warm spatula or steel knife. Place the plate and collar in the water bath at 5°C for not less than 15 minutes and not more than 30 minutes.

Step 3: Heat the bath water to the temperature at which the test is to be made. Maintain this temperature accurately without stirring; the temperature at no time throughout the test shall be allowed to vary by more than 0.5°C from the specified temperature. The temperature is determined by immersing the thermometer with the bottom of the bulb at a depth of 40 ±2 mm below the water surface.

Step 4: After the material to be tested has been kept in the water at 5°C for not less than 15 minutes and not more than 30 minutes, remove the collar with its contents from the plate, screw into the aluminium float and immerse in water at 5 °C for 1 minute. Remove the water, if any, from the inside of the float and immediately float the latter in the warm bath, making sure that the collar fits tightly into the float and that there is no seepage of water between the collar and float during the test.

Step 5: Determine, by means of a stop watch, the time in seconds elapsed between placing the apparatus on the water and when the water breaks through the material.

Observations and Calculations

Bituminous material		
Time taken by the water in breaking through material, seconds		
Average time, seconds		

Mean of time =……..seconds.

Precautions

1. Mercury or its vapour may be hazardous to health and corrosive to materials. Caution should be taken when handling mercury and mercury containing products.
2. It shall be ensured that the collar fits tightly into the float and there is no seepage of water between the collar and float during the test.
3. The temperature bath should be accurately maintained at the specified level without stirring to avoid disturbance.

Discussion

The float test is conducted on bitumen to assess its consistency which is a useful parameter in establishing the uniformity of certain deliveries or sources of supply. This property of bitumen is also helpful in assessing its performance characteristics in the various applications. Generally, the consistency of bituminous material is measured either by penetration test or viscosity test. But for certain range of consistencies, these tests are not applicable and Float test is used.

Viva-Voce Questions

1. How is the consistency of bitumen defined?
2. What is the significance of this test?
3. Why is float made of light material like aluminium or aluminium alloy?
4. What principle is used in determination of consistency of bitumen sample by float test?
5. Why is the float test used when the consistency of bituminous material can also be measured either by penetration test or viscosity test?

Notes and Comments

EXPERIMENT NO. 8: Determination of Water Content

Objective

Determine the water content of bituminous material.

Theory and Scope

Water content is defined as the quantity of water present in a material expressed as a percentage by mass of the material. This test uses Dean and Stark method for the determination of water content of asphalt bitumen and fluxed native asphalt, crude coal tar, road tar, cutback-bitumen, Digboi-type cutback bitumen and creosote and anthracene oil.

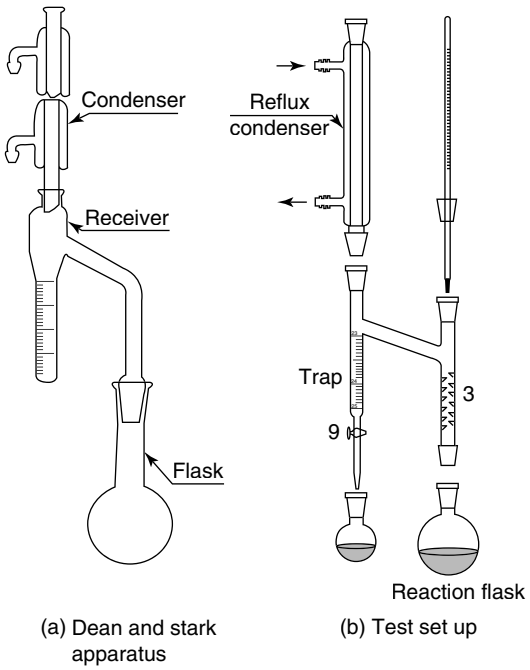


Fig. 12.10 *Dean and Stark apparatus and test set-up*

Apparatus

Heat resistant glass or metal flask; Heat resistant glass condenser; Graduated heat resistant glass receiver; 100 ml Graduated cylinder; Gas burner or electric heater; Spray tube and Solvent.

Description of Apparatus

Flask of 500 ml capacity made of well annealed heat resistant glass with a ground glass socket at top of the neck or a metal flask.

Condenser made of well-annealed heat resistant glass conforming to IS: 1211-1978.

Receiver made of heat resistant well-annealed glass with graduation marks conforming to IS: 1211-1978.

Heater may be any suitable gas burner or electric heater. In the case of a gas burner, a ring burner with ports on inside the circumference and metal still, shall be used. The dimensions shall be such that it may be moved up and down the vessel when testing materials that are likely to foam or solidify in the still.

Solvent, a carrier liquid, shall be any one of the following:

(a) Blend of 20 per cent by volume of industrial grade toluene and 80 per cent by volume of industrial grade xylene.
(b) Petroleum or coal tar naphtha (IS: 213-1968) free from water yielding not more than 5 per cent distillate at 125°C and not less than 20 per cent at 160°C.
(c) Petroleum spirit with a boiling range of 100 to 120°C.

Procedure

Step 1: Place about l00 g of the sample, accurately weighed, in the flask and add 100 ml of solvent.
Step 2: Attach the flask to the Dean and Stark condensing and collecting system, and heat the flask at such a rate that the condensate falls from the end of the condenser at a rate of two to five drops per second. Continue the distillation until condensed water is no longer visible in any part of the apparatus except the bottom of the graduated tube and until the volume of water collected remains constant for a period not less than 5 minutes.
Step 3: Remove the persistent ring of condensed water in the condenser tube, if any, by increasing the rate of distillation by a few drops per second.
Step 4: Wash down the droplets of water which adhere to the lower end of the condenser tube into the receiver with solvent/carrier liquid using the spray tube.
Step 5: Insert a loose plug of cotton wool in the top of the condenser tube to prevent the condensation of atmospheric moisture in the condenser tube.
Step 6: Determine the water content to the nearest 0.05 per cent by weight if 2 ml receiver has been used and to the nearest 0.1 per cent if the 10 ml receiver has been used with 100 g of sample.

Observations and Calculations

Volume of receiver,	ml		
Mass of sample,	gm		
Mass of water,	gm		
Water content,	per cent		

Precautions

1. An air-tight connection between the flask and the receiver shall be ensured.
2. A loose plug of cotton wool should be inserted in the top of the condenser tube to prevent the condensation of atmospheric moisture in the condenser tube.

Discussion

Presence of water in bitumen in excess of the specified amount may cause foaming and adversely affect the coating of aggregate or the adhesion. Water content determination test is based on principle of condensation;

it is carried out on Dean and Stark distillation glassware assembly. This measurement of water in bitumen may also be used to assess quality and related performance characteristics of bitumen in different applications. Water content should not exceed 1 per cent. Duplicate determinations shall not differ by more than that given in Table 12.10.

Table 12.7 *Duplicate determinations as per IS: 1211-1978*

Water collected	Repeatability	Reproducibility
0 to 1.0 ml	0.1 ml	0.2 ml
1.1 to 25 ml	0.1 ml or 2 per cent of the mean whichever is greater	0.2 ml or 10 per cent of the mean whichever is greater

Viva-Voce Questions

1. How is the water content in bitumen defined?
2. What is the significance of this test?
3. What is the function of solvent or carrier?
4. What principle and equipment are used in determination of water content in bitumen sample?

Notes and Comments

EXPERIMENT NO. 9: Test for Loss on Heating of Bitumens

Objective

Determine the loss on heating of asphaltic bitumens.

Theory and Scope

The loss on heating of asphaltic bitumens is defined as the loss in weight (exclusive of water) of oil of a bituminous material when heated to a standard temperature and under specified conditions. Loss on heat is determined by heating the sample for specified period in a special ventilated oven on a rotating platform under specific temperature conditions.

Apparatus

Rectangular oven; Perforated metal shelf; Thermometer; Metal or glass containers.

Description of Apparatus

Oven is a double-walled rectangular chamber with interior height from the top of the heating element to the top of the chamber not less than 292 mm, and width and depth not less than 298 mm. The chamber has a tightly fitting hinged door with a double-glass window, at least 100 mm square, to read the thermometer without opening the door. Ventilation is provided by means of 12 to 16 mm diameter vent holes at different locations. Electric heating is used to maintain the temperature within the specified limits.

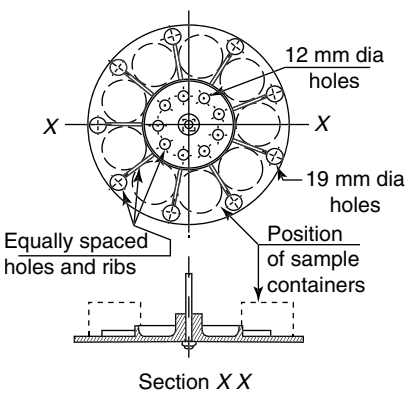


Fig. 12.11 *Perforated aluminium shelf*

Perforated metal shelf is a 250 mm diameter perforated aluminium shelf of the form shown in Fig. 12.11 and dimensions conforming to IS: 1212-1978. The shelf is suspended at the centre of the oven with respect to all interior dimensions of the oven, by a vertical shaft which rotates it at the rate of 5 to 6 revolutions per minute.

Centigrade thermometer of the shape and gradation conforming to IS:1212-1978 with temperature range of 155 to 170°C and subdivisions of 0.5°C.

Cylindrical containers of metal or glass of 55 mm internal diameter and 35 mm depth with flat bottom.

Procedure

Step 1: Stir and agitate thoroughly the material as received, warming if necessary, to ensure a complete mixing before a portion is taken for testing.

Step 2: Heat three containers in an oven at 100 to 110°C for 30 minutes, cool and weigh them. Weigh into the containers 50 ± 0.5 g of the material correct to the nearest 0.01 g.

Step 3: Bring the oven to a temperature of 163±1°C and place the sample containers on the revolving shelf near the circumference or in three of the recesses symmetrically if the recommended shelf is used.

Step 4: Close the oven and rotate the shelf during the entire test period of 5 hours at a rate of 5 to 6 revolutions per minute, the temperature being maintained at 163±1°C for after the sample has been introduced. The 5 hour period is reckoned from the instant temperature reaches 162°C and in no case shall the total time, during which the sample is in the oven, be more than 5 hours 15 minutes.

Step 5: At the end of the specified heating period, remove the containers with material, cool them to room temperature and weigh to an accuracy of 0.01 g.

Step 6: Compute the mean percentage loss in weight to the nearest 0.05 per cent.

Note: Generally, a number of samples having nearly the same degree of volatility may be tested simultaneously, but samples having large variation in volatility shall be tested separately. However, when extreme accuracy is required, only one material, that is, two/three containers shall be placed in the oven at one time.

Observations and Calculations

Weight of sample as received,	g			
Weight of sample after heating,	g			
Loss in weight,	per cent			

Average loss in weight of material =……..per cent.

Precautions

1. While mixing the material by stirring care should be taken to avoid incorporating air bubbles in the material.
2. For accurate results the total time during which the sample is in the oven should not exceed 5 hours 15 minutes, and during this period the temperature should be strictly maintained at 163±1°C.

Discussion

Loss on heating is useful in studying the effect of temperature or environmental deterioration on binder quality with the passage of time. It is basically a measure of durability of bituminous mixes.

If the sample contains water, it is tested in that condition; however, the tests during which samples show evidence of loss by foaming are rejected.

When the penetration test on the sample after heating is to be conducted, the residue in the container is melted at the lowest possible temperature and thoroughly mixed by stirring, taking care to avoid incorporating air bubbles in the material. Pour the residue into the container specified for penetration test; from the stage of pouring follow the test procedure described in IS: 1203-1978.

Duplicate determinations shall not differ by more than that given in Table 12.8. The repeatability figures given in the table and the differences between the duplicate determinations refer to the tests made simultaneously in the same oven.

Table 12.8 *Duplicate determinations as per IS: 1212-1978*

Loss on heating. per cent	Repeatability	Reproducibility
0 to 0.5	0.1	0.2
0.5 to 1.0	0.2	0.4
1.0 to 2.0	0.3	0.6
Above 2.0	10 per cent of mean	20 per cent of mean

Viva-Voce Questions

1. How is the loss in weight of bitumen defined?
2. What is the significance of this test?
3. In what circumstances is the test result rejected?
4. Can the penetration test conducted on the residue of sample obtained after loss in weight test?

Notes and Comments

EXPERIMENT NO. 10: Bitumen Content by Centrifuge Extractor

Objective

To determine quantity of bitumen in hot-mix paving mixture and pavement sample.

Theory and Scope

The centrifuge extractor is used for the quantitative determination of bitumen in hot-mixed paving mixtures and pavement samples. The sample mix is added with a solvent and dissolved bitumen is removed by centrifugal action. The solvent generally used is trichloroethylene; other approved solvents can also be used.

It is essentially a field or laboratory test to exercise quality control and ensure that the specified amount of bitumen has been used. The bitumen content is calculated by difference of the weight of the extract aggregate, moisture content and ash from the weight of the sample taken for the test.

Apparatus

Centrifuge Extractor; Filter ring of outer diameter same as that of the bowl; Filter discs; Balance; Oven; Stainless steel fork or spoon; Aluminium or stainless steel (galvanised) pan; Graduated cylinder (1000 ml); Beaker; Rubber pipe; Evaporating dish (250 ml)and Specified solvents.

Description of Apparatus

Centrifuge extractor

Hand operated model This portable unit consists of a removable revolving bowl inside a metal housing. The bowl is provided with a cap that is secured in position by tightening the nut. The bowl assembly is mounted on a vertical shaft protruding from the gear box enclosed in cast housing. The gears are splash lubricated and the system is operated manually with the handle; the bowl can be revolved to a speed of 0 to 3600 rpm. The housing is provided with an outlet to drain out the dissolved bitumen removed by centrifugal action in the rotating bowl. This model of 1500 gm capacity has generally two speeds i.e. slow and fast, and is provided with brake mechanism. The housing, removable bowl, cover and nut are generally constructed of cast aluminum to resist corrosion.

Electrically operated model In the electrically operated model with speed regulator, the aluminium revolving bowl is coupled directly to a motor through flexible coupling. These are with 3000 g sample capacity in which the bowl may be revolved at controlled, variable speeds up to 3600 rpm. The apparatus should have explosion-proof features.

Filter ring of paper or felt to fit the rim of the bowl.

Balance with a readability and sensitivity of 0.1 g and an accuracy of 0.1 g or 0.1 per cent. The balance must have sufficient capacity to weigh the bowl and its contents.

Thermostatically controlled oven maintained at 111 ± 5 °C.

Stainless steel fork or spoon approximately 300 mm long, grind flat tip for easier manipulation of sample.

Aluminium or stainless steel pan approximately 330×230×60 mm.

Chemicals: Trichloroethylene technical grade or other approved solvent.

(a) Hand operated centrifuge extractor

(b) Electically operated centrifuge extractors

Fig. 12.12 *Bitumen centrifuge extractors*

Procedure

Step 1: Sample preparation

The bituminous mix sample is heated in oven at 110 ± 5 °C until the sample is dry and soft and appropriate sample quartering method is used to obtain an extraction sample of 1000 – 1100 g. The test portion is dried to a constant weight state (moisture free) before testing, i.e., further drying at 110 ± 5 °C does not alter the mass by more than 0.05 per cent.

Step 2: Weigh an empty, clean centrifuge bowl and record its weight to the nearest 0.1 g.

Step 3: With the bowl on the balance tray and the balance reading zero, weigh 1000 g sample into bowl. Break the sample down to small pieces with fork and distribute the sample evenly in the bowl; record the weight to the nearest 0.1 g.

Step 4: Fit the bowl with sample into centrifuge apparatus and add benzene or trichloroethylene or other approved solvent (n-propyl bromide) until the sample is covered.

Step 5: Weigh and record weight of filter ring dried to a constant weight at 110 ± 5 °C to the nearest 0.1 g.

Step 6: Place the filter ring around the edge of the extractor bowl; secure the extractor's lid by tightening the knurled lock nut onto the bowl's cover by hand.

Step 7: Allow the solvent to dissolve the sample for a minimum of 1 hour. The extraction process must be completed within 24 hrs. With aggregates like recycled bituminous, where removal of the asphalt cement is difficult; soaking for a longer period and stirring occasionally may help with this process.

Step 8: Place the assembled bowl inside the housing and firmly tighten the centrifuge cover.

Step 9: Place a suitable container; say a beaker, under the extractor's drain to collect the filtrate.

Step 10: Start the securely anchored centrifuge and slowly increase to the proper speed (2000 – 2500 rpm). Solvent will be rapidly expelled from the drainpipe.

Step 11: Run the centrifuge until the solvent flow slows to a dripping rate. Also keep on watching the colour of extract coming out the drain pipe. Shut the centrifuge down and as the bowl begins to slow down stop the bowl's rotation by applying the manual brake.

Step 12: Add an additional 200 to 400 ml of solvent into the top of the extractor and allow the sample to dissolve the bitumen for 5 to 10 minutes. Run centrifuge until solvent flow slows to a dripping rate. Stop the bowl.

Step 13: Repeat solvent-washing cycle at least 2 more times until the solvent flowing from drainpipe is no longer cloudy; and it is in light straw colour when viewed against a white background. Due to the nature of the extraction process, it is difficult to obtain a perfectly clear extract without using an excessive amount of solvent.

Step 14: At the end of the final solvent rinse cycle, the bowl should be rotated at approximately 3000 rpm for a minute. The purpose of this is to remove as much of the solution as possible from the aggregates.

Step 15: Remove the beaker containing the asphalt/solvent filtrate. Dispose it off in an appropriate manner, unless a determination of mineral matter in the extract is required.

Step 16: Open the centrifuge cover; and place the filter ring and centrifuge bowl with the aggregate under a hood until the chemical fumes dissipate. Then take the centrifuge bowl with the ring and aggregate and place it into an oven.

Step 17: Dry the aggregate in the centrifuge bowl along with the filter ring in the oven maintained at 110 ± 5 °C to a constant weight. Record the weight of assembly to nearest 0.1 g.

Step 18: Carefully brush off any remaining fines from the filter ring into the bowl. The trapped fines in the ring are considered 200 μm material and needs to be accounted for in the extracted aggregate gradation.

Step 19: Record the final weight of the bowl, filter ring and extracted aggregate to the nearest 0.1 g.

Step 20: Extracted aggregate is then tested for gradation and/or other analysis.

Observations and Calculations

Observation	Measurement	Sample		
1. Before test				
Weight of empty bowl	W_1, g			
Weight of bowl + Sample	W_2, g			
Weight of filter ring	W_3, g			
2. After test				
Weight of bowl + Ring + Sample	W_4, g			
Weight of sample	$(W_2 - W_1)$, g			
Weight of aggregate in bowl, W_A	$(W_4 - W_1 - W_3)$, g			
Weight of bitumen, W_B	$(W_2 - W_1) - W_A$			
Bitumen content, per cent	$\frac{W_B}{W_A} \times 100$			
For BM, DBM, SDBC and BC*	$\frac{W_B}{W_2 - W_1} \times 100$			

Note*: Bitumen content is determined w.r.t. total weight of the mix.

Precautions

1. Safety glasses and/or face shields, chemical and heat-resistant gloves with close-fitting cuffs should be worn.
2. Trichloroethylene is a toxic hazardous chemical by ingestion, skin absorption, and vapor inhalation thus requires proper handling procedures of this and any other solvent used. Refer to the literature

supplied with the chemicals for proper handling and disposal procedures.

3. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
4. In addition to good general laboratory ventilation, the extraction work area should be well ventilated. Humidity control is recommended to prevent excessive water absorption by the dried aggregate.
5. The samples is checked for the presence of water while the material is still cold; if water is present it is drained off as much as possible and the sample allowed to dry at room temperature or blown dry with clean compressed air.
6. The particles of the mixture are separated as uniformly as possible taking care not to fracture the mineral particles.
7. The hat or cover plate should be fixed tightly on the bowl.
8. Since dry aggregate absorbs moisture when exposed to air containing moisture, determine the dry mass of the extracted aggregate within 30 minutes after the constant weight has been determined.
9. Filters are oven dried before use.
10. For clear vision transparent tube and glass container should be used.

Discussion

The results of the test are an indication regarding the quantity of bitumen that has been used in a bituminous mix. By performing this field test, a substantial saving in the cost of bitumen can be had by ensuring that the optimum quantity of bitumen has been provided. Also the performance of the road shall be affected if lesser or more quantity of bitumen is used.

In order to derive appropriate conclusions, the bitumen content of mix should be determined without any delay after it is prepared or laid.

Since trichloroethylene used as solvent is a toxic hazardous chemical, alternatives like n-propyl bromide and d-limonene may be used as suitable replacements.

Viva-Voce Questions

1. What is the significance of determination the quantity of bitumen in hot mixed paving mixtures and pavement samples?
2. What is the criterion for specifying benzene or trichloroethane as solvents to be used in the test?
3. How would the road surface be affected in case the test reveals use of (a) lesser quantity of bitumen and (b) more quantity of bitumen than the optimum quantity?
4. What safety precautions should be taken while performing this test?

Notes and Comments

EXPERIMENT NO. 11: Stripping Value of Road Aggregate

Objective

1. *To determine the stripping value of aggregates used in road construction.*
2. *To ascertain the suitability of road aggregates for bituminous road construction.*

Significance

This test is conducted to determine the effects of moisture upon the property of adhesion of the aggregate with different types of bituminous binders. Thus, this test is of significant value to ascertain the suitability of the two materials viz. bitumen (binder) and aggregates, because one particulars aggregate may be satisfactory with one binder and unsatisfactory with another; and the same being true for the binders. Two test methods, based on IS: 6241-1971 (R2003), that can be employed to find stripping value are:

1. Static immersion method
2. Dynamic immersion method

The specifications of Ministry of Transport and Shipping recommend the determination of stripping value by the static immersion method.

Static Immersion Method

Theory and Scope

Static immersion method covers the procedure for determining the stripping value of aggregates when bitumen and tar binders are used. The test is conducted by immersing the aggregate fully coated with binder in water maintained at 40°C temperature for 24 hours. IRC has specified maximum stripping value of aggregates should not exceed 5 per cent.

Apparatus

Water bath; Drying oven; Balance; IS sieves; Riffle box; Beaker; Mixer, miscellaneous equipment as containers for the heating and mixing of materials; and spatula.

Description of Apparatus

Thermostatically controlled **water bath**.

Drying oven capable of heating to a temperature of 175°C.

Balance to weigh up to 500 g with an accuracy of 0.1 g.

Heat resistant glass beaker of 500 ml capacity.

IS sieves 20 mm and 12.5 mm.

Riffle box with 20 mm openings for collecting the sample.

Procedure

Step 1: By means of a riffle box quarter out sufficient material to yield a test sample of 200 g of aggregate of size passing 20 mm sieve and retained on 12.5 mm sieve.

Step 2: Place 200 g of dry clean aggregate test sample in a suitable container and heat in an oven up to 150–175°C (110°C in case of tar).

Step 3: Heat 5 per cent binder by weight of aggregate to 120–160°C (110°C in the case of tar binder) and mix it with aggregate thoroughly till it completely coats the aggregate.

Step 4: Transfer the mixture to a 500 ml beaker and allow it to cool at room temperature for about 2 hours.

Step 5: Add distilled water to immerse the coated aggregates.

Step 6: Cover the beaker and keep it undisturbed in a thermostatically controlled water bath at a temperature of 40°C for a period of 24 hours. It should be ensured that the level of water in the water bath is at least half the height of the beaker.

Step 7: Take out the beaker after 24 hours and cool it at room temperature and estimate the extent of stripping by visual examination while the specimen is still under water. Express as the average per cent area of aggregate surface uncoated.

Step 8: Express the stripping value as the ratio of the uncovered area observed visually to the total area of aggregates in each test as percentage. Three samples are tested simultaneously so as to arrive at an average value. The stripping value is expressed to the nearest whole number.

Observations

The result is reported as the percentage of stone surface that becomes uncoated after the specified periods, the mean value of at least three visually estimated values, being rounded off to the nearest 5 per cent.

Type of aggregate Type of binder Temperature of water bath				
Amount of binder used, per cent Weight of aggregate, gm Weight of binder, gm Stripping observations, per cent				
Average value of stripping, per cent				

Stripping value of aggregate with the given binder = ……per cent.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. The aggregate should be thoroughly dried before mixing with binder.
4. Care should be taken that the level of water in the water bath is at least half the height of the beaker.
5. Distilled water should be used for the test.
6. Mixing of the three separate samples should be uniform.

Dynamic Immersion Method

Theory and Scope

Determination of stripping value by static immersion method requires more than 24 hours for its completion. The dynamic immersion test speeds up the stripping action. The sample is agitated mechanically. Stone screenings for use in seal coats or open graded mixtures are usually subjected to this test. The test is applied to the aggregate fraction passing through 10 mm sieve and retained on the 2.36 mm sieve.

Apparatus

Film stripping device; Water bath; Balance; IS sieves; riffle box; Measuring cylinder; tray; spatula; miscellaneous items such as containers for the heating and mixing of materials, etc.

Description of Apparatus

Film stripping device consists of a circular disc which rotates in a vertical plane at a rate of approximately 100 rpm by an electric motor. It is provided with four glass bottles of approximately 400 cc capacity clamped to the holders positioned equidistant on the disc at an angle of 90° to each other with their mouths towards centre of the disc. The machine with a time switch is mounted over a firm base.

Thermostatically controlled water bath capable of maintaining a temperature of 60°C.

Balance to weigh 200 g with an accuracy of 0.1 g.

IS sieves 10 mm and 2.36 mm.

Riffle box with 10 mm openings for collecting the representative sample.

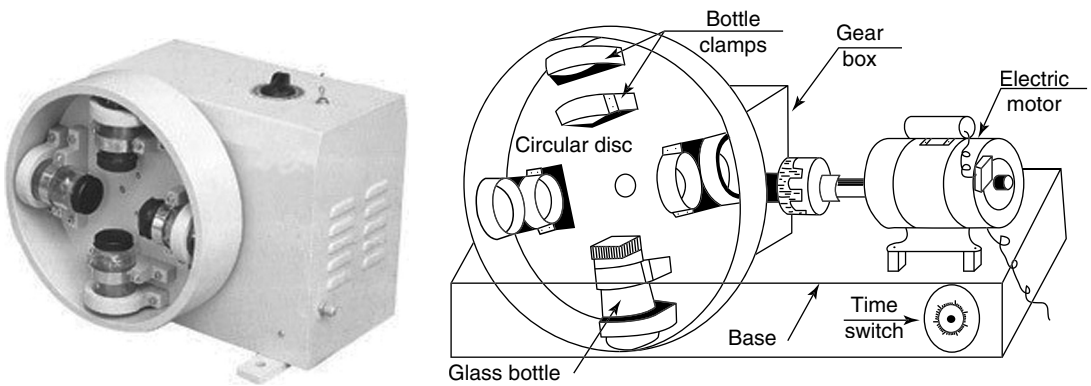


Fig. 12.13 *Film stripping value apparatus*

Procedure

Step 1: Preparation of sample

By means of a riffle box quarter out sufficient aggregate fraction passing 10 mm and retained on the 2.36 mm sieves to yield test samples. Prepare four test specimens as follows:

(a) Unscrew the clamps and clean the holders.
(b) Clean the bottles thoroughly.

(c) Weigh 60 g of representative test sample and place in a suitable container. Coat the sample with the binder of type and quantity to be used in construction.
(d) Transfer the sample to the cleaned bottle.

Step 2: Cure all the four coated specimens for 15 hours at 60°C.
Step 3: Remove the specimens and cool them to room temperature of about 25°C.
Step 4: Add 175 ml of the distilled water in each bottle and screw on the cap to the bottle with the rubber gasket in between the bottle top and the cap.
Step 5: Place the bottles in the holders of the stripping device and clamp the bottles; ensure that each bottle is protected by the cushion.
Step 6: Start the machine and agitate the mixture for 15 minutes.
Step 7: Stop the machine and allow the disc to come to a rest; remove the bottles from the holders.
Step 8: Estimate by visual observation the percentage stripped.

Observations

As in the previous method, the result is reported as the percentage of stone surface that becomes uncoated after the specified periods, the mean value of at least three visually estimated values, being rounded off to the nearest 5 per cent.

Sample in bottle	I	II	III	IV
Area of aggregate uncoated by immersion in water, per cent				
Average stripping value, per cent				

Stripping value of aggregate with the given binder = ……per cent.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. It should be ensured that the bottles are tightly clamped against cushion so as to prevent breakage.
4. When not in use keep the bottles clean.

Discussion

Both the tests are qualitative and provide subjective evaluation of the stripping; to the best they can be considered just capable of discriminating between poor and good performers in regard to stripping. However, the results must still be tied to field performance.

The results of the stripping test give an indication regarding susceptibility of aggregate to the action of water, or moisture. The more the stripping value, the poorer are the aggregate from point of view of adhesion. IRC has specified the maximum stripping value of 25 per cent for aggregate to be used in bituminous road construction.

Viva-Voce Questions

1. What is the significance of stripping value test?
2. What the safety precautions to be exercised while performing the stripping value test?
3. Two aggregates A and B have stripping value of 20 per cent and 30 per cent when used with the same bitumen; which is preferable for use any why?

4. How will the stripping value be affected in case the aggregate are not fully dried?
5. Which method is recommended by specifications of Ministry of Transportation for the determination of stripping value?
6. What are the drawbacks with these methods?

Notes and Comments

EXPERIMENT NO. 12: Bituminous Mix Design by Marshall Method

Objective

1. *To determine the optimum binder content of the bituminous mix by Marshall method of mix design.*
2. *To determine Marshall stability of bituminous mixture.*

Theory and Scope

Bituminous mixes are used in the surface layer of road and airfield pavements. The mix is usually composed of aggregates (coarse, fine and filler) and binder. The design of bitumen paving mix as with the design of concrete is largely a matter of selecting and proportioning constituent materials to obtain the desired properties in the finished pavement structure.

The bitumen mix design consists of two parts namely the *dry mix design* and the *wet mix design*. In the wet mix design, the optimum bitumen content is determined. There are many methods available for wet mix design but Marshall method of mix design is the most popular one. The Marshall stability and flow test provides the performance indices for the Marshall mix design method. The stability portion of the test measures the maximum load supported by the cylindrical test specimen at a loading rate of 50 mm/minute. Load is applied to the specimen till failure, and the maximum load carrying capacity of the mix at 60°C measured in N is designated as stability; it measures the resistance of cylindrical specimen of a bituminous mixture to plastic flow when loaded on the lateral surface. During the loading, an attached dial gauge measures the specimen's plastic flow (deformation) as a result of the loading. The flow value is recorded in 0.25 mm increments at the same time when the maximum load is recorded. This test is performed as per ASTM D 1559.

Apparatus

Marshall Load Frame; Proving ring; Breaking Head Flow Measurement Dial Gauge; Specimen Extractor or Ejector; Compaction Pedestal; Compaction Moulds; and Thermometers. In addition, an oven or hot plate, water bath and balance is required.

Description of Apparatus

Marshall load frame of 50 kN capacity for applying load to cylindrical stability test specimens mounted in a thick-walled stability test mould (breaking head); it is electrically operated automatic loading unit having constant rate of strain at 50 mm/minute.

Proving ring of 30 kN capacity fitted with a dial gauge of least count of 0.002 mm, it is provided with a calibration certificate as per IS: 4169. Load cells with strip chart recorder or digital transducer readout are also available.

Stability breaking head consisting of upper and lower cylindrical segments having inside radius of curvature 50 mm to be used for loading cylindrical specimens for Marshall stability test.

Flow measuring dial gauge of least count of 0.01mm with 25 mm travel for using with Marshall stability breaking head.

Specimen extractor consisting of a thrust plate and loading bar for fast extrusion of specimens from compaction moulds; it can exert maximum forces upto 25 kN.

Compaction pedestal consisting of compacting hammer mounted on wooden block capped with a steel plate.

Compaction hammer with 4.53 kg mass and 457 mm fall.

Specimen moulds of 100 mm diameter with interchangeable collar and base plate used for preparing specimens for Marshall stability testing.

Thermometers of range up to 200°C with sensitivity of 2.5°C.

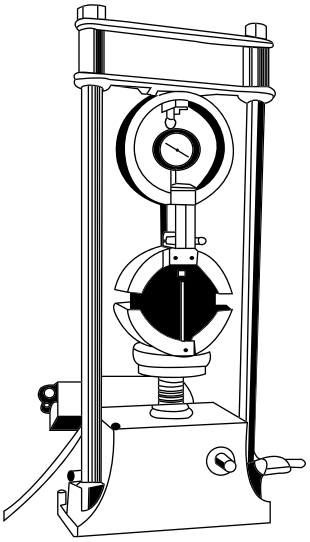
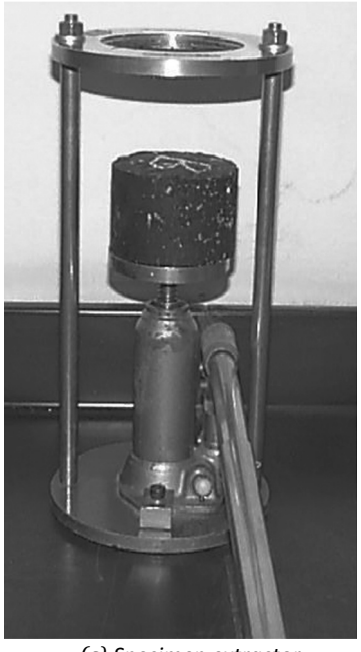


Fig. 12.14 *Typical Marshall stability and flow test frames*

(a) Stability breaking head

(b) Specimen mould



(c) Specimen extractor

Fig. 12.15

Procedure

Part 1: Dry Mix Design

Preparation of sample

Step 1: Usually two or more sizes of coarse aggregate, fine aggregate and mineral filler material are mixed in such a proportion that the grading of combined mix is within specified range. This can be accomplished as explained in this section.

Step 2: The specific gravity values of different aggregates, filler and bitumen used are determined; the theoretical specific gravity of the mix is also computed.

Part 2: Wet Mix Design

Preparation of test specimen

Step 1: The compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C.

Step 2: Approximately 1200 g of aggregates and filler are blended in the desired proportions as obtained in dry mix design and heated in the oven to the mixing temperature of 175°C to 190°C.

Step 3: The bitumen is heated to the mixing temperature of 121°C to 138°C to produce viscosity of 170 ± 30 centi-stokes. The first trial percentage of heated bitumen (say 3.5 or 4.0 per cent by weight of the material aggregates) is added to the heated aggregate and thoroughly mixed using a mechanical mixer or by hand mixing in a heated pan with heated trowel.

Step 4: The mixed material is returned to the oven, and reheated and maintained to the compacting temperature of 150° to 160°C (to produce viscosity of 280±30 centi-stokes).

Step 5: The mixture is then transferred to the preheated compaction mould with a collar and base. The mixture is spaded around the sides of the mould. A filter paper is placed under the specimen and another on its top.

Step 6: The mould is placed on the Marshall Compaction pedestal and compacted by giving 75 blows on the top side (as cast) of the specimen mix with a standard hammer (457 mm, 4.53 kg). The specimen is then inverted and compacted on the other face with 75 blows.

Step 7: After compaction, the mould with the specimen is removed from the compaction pedestal and cooled for a few minutes. The mould is inverted; with collar on the bottom and the base removed the sample is extracted by pushing it out with the help of specimen extractor.

Step 8: Specimens are marked and allowed to stand for a few hours or overnight to cool at room temperature.

The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5±3 mm. A series of trial specimens are prepared by the similar method by varying bitumen content at an increment of 0.5 per cent. Usually, three specimens are cast for each of the bitumen contents. At least four binder contents are to be tested to get the optimum binder content.

Step 9: Soon after the compacted bituminous mix specimen has cooled to room temperature, its average thickness and diameter are noted. The mass (in grams) of the specimen W_a and W_w in air and water, respectively, are recorded.

Step 10: From these measurements following properties are determined:

(a) Theoretical specific gravity G_t of the mix is its specific gravity without considering air voids,

$$G_t = \frac{W_{ca} + W_{fa} + W_{mf} + W_b}{\frac{W_{ca}}{G_{bca}} + \frac{W_{fa}}{G_{bfa}} + \frac{W_{mf}}{G_{bmf}} + \frac{W_b}{G_b}}$$

where W_{ca}, W_{fa}, W_{mf} and W_b are the weights of coarse aggregate, fine aggregate, filler material and bitumen, respectively, in the total mix; G_{bca}, G_{bfa}, G_{bmf} and G_b are the apparent specific gravity of coarse aggregate, fine aggregate, filler and bitumen, respectively.

(b) The bulk specific gravity of the mix G_m takes in to account the air voids,

$$G_m = \frac{W_a}{W_a - W_w}$$

where W_a and W_w are the weight of mix in air and water, respectively.

(c) Air voids V_v is the per cent of air voids by volume in the specimen and is given by

$$V_v = \frac{G_m - G_t}{G_t} \times 100 \text{ per cent}$$

where G_m and G_t are the bulk and theoretical specific gravities of the mix, respectively.

(d) The volume of bitumen V_b is the per cent volume of bitumen in the total volume of mix and given by

$$V_b = \frac{W_b / G_b}{(W_{ca} + W_{fa} + W_{mf} + W_b) / G_m} \times 100$$

where G_b and G_m are the apparent specific gravity of bitumen and bulk specific gravity of mix, respectively.

(e) Voids in mineral aggregate V_{ma} is the volume of voids in the aggregates, and is the sum of air voids V_v and volume of bitumen V_b, thus,

$$V_{ma} = V_v + V_b \text{ per cent}$$

(f) Voids in the mineral aggregate V_{fb} filled with the bitumen,

$$V_{fb} = \frac{V_b}{V_{ma}} \times 100 \text{ per cent}$$

where V_b is per cent bitumen content in the mix and V_{ma} is the per cent voids in the mineral aggregate.

Part 3: Determination Marshall Stability and Flow

Step 1: The specimens to be tested are kept immersed under water in a thermostatically controlled water bath maintained at 60° ±1°C for 30 to 40 minutes or in an oven for minimum of 2 hours.

Step 2: The specimens are removed from the water bath or oven one at a time and placed in lower segment of the breaking head. The upper segment of the breaking head of the specimen is placed in position and the complete assembly is placed in position on the testing machine.

Step 3: The dial gauge or flow meter to measure the vertical deformation is placed over one of the posts and is adjusted to read zero.

Step 4: Load is applied at a constant strain rate of 50 mm/minute until the maximum load reading is reached. The maximum load in Newton is termed as *marshal stability* and *dial gauge reading* measuring the vertical deformation of the specimen at the failure expressed in units of 0.25 mm units is called the Marshall flow value of the mix.

Part 4: Stability Corrections

If the average height of the specimen is not exactly 63.5 mm; the Marshall stability value of each specimen is corrected by multiplying each measured value by a correction factor as given in Table 12.10.

Part 5: Preparation of Graphical Plots

Five graphs are plotted between the binder content against the average values of bulk specific gravity (G_m); percentage of voids in total mix (V_v); voids filled by the binder (V_{ma}) Marshall stability (N) and Marshall flow as illustrated in Fig. 12.16.

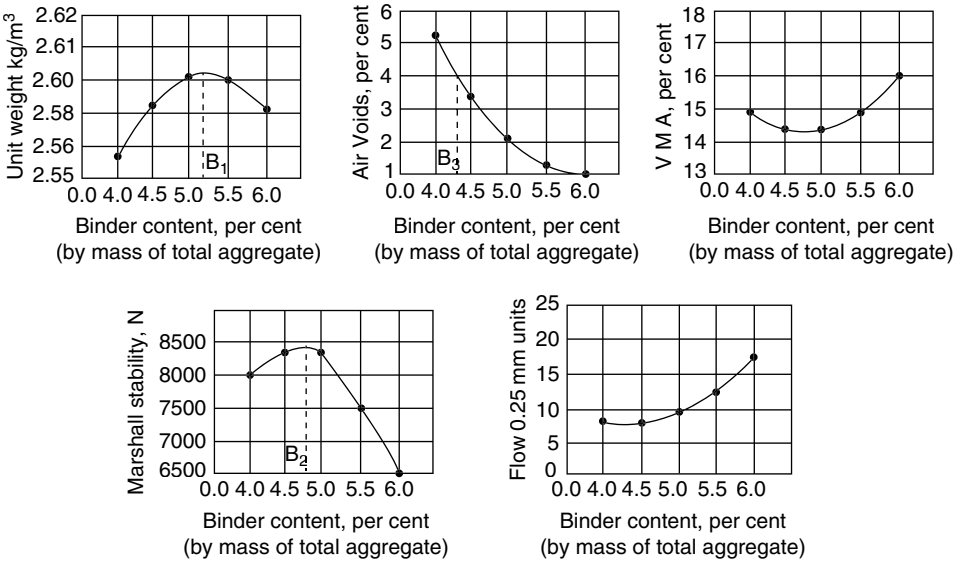


Fig. 12.16 *Curves between binder content against various parameters*

Part 6: Determination of Optimum Bitumen Content

Step 1: Determine the optimum binder content for the designed mix by taking average value of the following three bitumen contents noted from the graphs obtained in the previous step.

(a) Binder content corresponding to maximum bulk density or specific gravity, B_1.
(b) Binder content corresponding to maximum stability, B_2.
(c) Binder content at specified per cent air voids (V_v) in the total mix, B_3, i.e., 4.0 per cent.

Then the optimum bitumen content for mix design is given by

$$B_o = (B_1+B_2+B_3)/3$$

Step 2: Evaluate the suitability of designed mix with the design requirements/parameters.

Observations and Calculations

Type of grading aggregate = ……..
Total weight of aggregate = 1200 g
Grade of bitumen:

(a) Specifications for aggregate selection

Sieve size	Percentage of aggregate passing though the sieve size						
	26.5 mm	19.0 mm	9.5 mm	4.75 mm	2.36 mm	300 micron	75 micron
As per specifications	100	90–100	56–80	35–65	23–49	5–19	2–8
As obtained by blending							

(b) Details of the ingredients

Ingredient	Weight, g	Percentage of total aggregate	Specific gravity
Coarse aggregate			
Fine aggregate			
Filler (aggregate dust)			
Bitumen: 1.			
2.			
3.			
4.			
5.			

(c) Marshall stability test

Number of blows:

Compaction temperature:

Bitumen by weight of total aggregate mix, per cent	Weight of specimen, g						G_{bcm}			Stability			Flow		
	In air			In water											
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3

(d) Results and calculations for various properties

Bitumen by weight of total aggregate mix, per cent	G_{bcm}	Volume	G_{bam}	G_{mp}	V_{ma}	V_v	Stability		Flow
							Observed	*Corrected*	

The optimum binder content of the given mix, B_o = _____ per cent.

Precautions

1. Wear safety glasses and/or face shields, heat-resistant gloves with close-fitting cuffs.
2. There shall be no smoking or the presence of other ignition sources in close proximity of test set-up.
3. Check the samples for the presence of water while the material is still cold; if water is present drain off as much water as possible and allow the sample to dry at room temperature or blow-dry with clean compressed air.

Discussion

The overall objective of the mix design is to evolve an optimum blend of different ingredients that will satisfy the requirements of the given specifications. This mixture should have:

1. Sufficient durability; skid resistance, shear strength; fatigue resistance; air voids; workability and flexibility.
2. Sufficient amount of binder to ensure an adequate film thickness around the aggregate particles.
3. Adequate mix stability to prevent unacceptable distortion and displacement under traffic loads.
4. Adequate voids in the total compacted mixture to permit a small amount of compaction under traffic load without bleeding and loss of stability.
5. Adequate workability to facilitate placement of the mix without segregation.
6. Sufficient flexibility to avoid premature cracking due to repeated bending and to prevent shrinkage cracks at low temperature.
7. Resistance to moisture-induced damage.
8. Fatigue resistance.

Dry Mix Coarse aggregate provides compressive and shear strengths, and ensures good interlocking properties. Fine aggregate (sand, rock dust) fills the voids in the coarse aggregate and stiffens the binder. Whereas, the filler (rock dust, cement, lime) fills the voids, stiffens the binder and the binder fills the voids, cause particle adhesion and reduce permeability.

Well-graded dry mix provides dense bituminous mix and is generally called dense bituminous macadam concrete which offers good compressive strength and some tensile strength and other desirable characteristics. A typical aggregate gradation for BC is given in Table 12.9.

Table 12.9 *Aggregate gradation for BC*

Sieve size	26.5 mm	19.0 mm	9.5 mm	4.75 mm	2.36 mm	300 micron	75 micron
Passing, per cent	100	90–100	56–80	35–65	23–49	5–19	2–8

Wet Mix If the mix design for the optimum binder content does not satisfy all the requirements of specifications. It is necessary to adjust the original blend of aggregates. The trial mixes can be adjusted by using the following guidelines:

1. **If low voids** The voids can be increased by adding more coarse aggregates.
2. **If high voids** Increase the amount of mineral filler in the mix.
3. **If low stability** This condition suggests low quality of aggregates. The quality of aggregates should be improved by using different aggregates or cement coated aggregate.

Sometimes, the thickness of the specimen is slightly different from the standard value of 63.5 mm; in such a case, measured stability values is corrected by multiplying it with a correction factor so that it corresponds to the value which would have been obtained if the specimens had been exactly 63.5 mm. the correction factors are listed in Table 12.10.

Table 12.10 *Stability correction factors or ratios*

Volume of specimen, cm^3	Thickness of specimen, mm	Correction Factor
444–456	55.6	1.25
457–470	57.1	1.19
471–482	58.7	1.14
483–495	60.3	1.09
496–508	61.9	1.04
509–522	63.5	1.00
523–535	65.1	0.96
536–546	66.7	0.93
547–559	68.3	0.89
560–573	69.9	0.86
574–585	71.6	0.83

The stability and flow values, and V_{fb} are checked with Marshall mix design specifications given in Table 12.11. Mixes with very high stability value and low flow value are not desirable as the pavements constructed with such mixes are likely to develop cracks due to heavy moving loads.

Table 12.11 *Marshall mix design specifications*

Test Property	Specified Value
Marshall stability, kg	340 (minimum)
Flow value, 0.25 mm units	8–17
Percent air voids in the mix, V_v per cent	3–5
Voids filled with bitumen, V_{fb} per cent	75–85
Bitumen content, per cent (by mass of total aggregate)	4.5–6.5

Viva-Voce Questions

1. How the Marshall stability and the flow value of a mix are defined?
2. What is the significance of flow value in Marshall test?
3. What is the proper nominal aggregate size to use?
4. What is meant by filler?
5. What are the essential properties of bituminous mixes?

6. What is the recommended air void content for compaction of bitumen pavements?
7. How is air void content controlled?

Notes and Comments

NATIONAL STANDARDS

1. IS: 73-1992 (2nd revision, reaffirmed 2003): *Specification for Paving Bitumen*.
2. IS: 215-1995 (3rd revision, reaffirmed 2000): *Road Tar —Specification.*
3. IS: 217-1988 (2nd revision, reaffirmed 2004): *Specification for Cutback Bitumen*.
4. IS: 334-2002 (3rd revision): Glossary of Terms Relating to Bitumen and Tar
5. IS: 1201 to IS: 1220 (in one volume) (1st revision, reaffirmed 2004): *Methods for Testing Tar and Bituminous Materials.*
6. IS: 1201-1978 (1st revision, reaffirmed 2004): *Sampling of Tar and Bituminous Materials*.
7. IS: 1202-1978 (1st revision, reaffirmed 2004): *Determination of Specific Gravity*.
8. IS: 1203-1978 (1st revision, reaffirmed 2003): *Determination of Penetration*.
9. IS: 1204-1978 (1st revision, reaffirmed 2004): Determination of Residue of Specified Penetration.
10. IS: 1205-1978 (1st revision, reaffirmed 2004): *Determination of Softening Point*.
11. IS: 1206(Part 2)–1978 (1st revision, reaffirmed 2004): *Determination of Viscosity*, Part 2 *Absolute Viscosity*.
12. IS: 1206(Part 3)-1978 (1st revision, reaffirmed 2004): *Determination of Viscosity*, Part 3 *Kinematic Viscosity*.
13. IS: 1208-1978 (1st revision, reaffirmed 2004): *Determination of Ductility*.
14. IS: 1209-1978 (1st revision, reaffirmed 2004): *Determination of Flash Point and Fire Point*.
15. IS: 1210-1978 (1st revision, reaffirmed 2004): *Float Test.*
16. IS: 1211-1978 (1st revision, reaffirmed 2004): *Determination of Water Content* (Dean and Stark method).
17. IS: 1212-1978 (1st revision, reaffirmed 2004): *Determination of Loss on Heating.*
18. IS: 1215-1978 (1st revision, reaffirmed 2004): *Determination of Matter Insoluble in Toluene.*
19. IS: 1217-1978 (1st revision, reaffirmed 2003): *Determination of Mineral Matter* (Ash).
20. IS: 1218-1978 (1st revision, reaffirmed 2004): *Determination of Phenols.*
21. IS: 1219-1978 (1st revision, reaffirmed 2004): *Determination of Naphthalene.*
22. IS: 1220-1978 (1st revision, reaffirmed 2004): *Determination of Volatile Matter Content.*
23. IS: 2386-1963 (Part IV): Methods of Test for Aggregate for Concrete.
24. IS: 2720 (Part-XVI)-l 979: Methods of Test for Soils (Lab Determination of CBR).
25. IS: 6241-1971 (reaffirmed 2003): Methods of Test for Determination of Stripping Value of Road.

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2. AASHTO 245: *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, Washington, 1993.
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5. BS EN 13924-2006: *Bitumen and Bituminous Binders—Specifications for Hard Paving Grade Bitumen*.
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BRICKS AND TILES

Section 13

This section covers procedures for tests generally performed on bricks and tiles. The tests performed on bricks include compressive strength, absorption, saturation coefficient, efflorescence and determination of weight, size and warpage; whereas the tests performed on roofing, flooring and walling tiles include water absorption, breaking strength and abrasion resistance. The physical characteristics of bricks and tiles as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

13.1 BRICKS

A brick is building unit rectangular in shape and of size that can be conveniently handled with one hand. The common brick is composed of inorganic, non-metallic substance of mineral origin (e.g., clay) baked by heat at high temperature. Clay bricks are commonly used largely due to their decorative and load bearing properties, exceptional durability, lightweight, thermal insulation property, easy availability and low cost. In general, a brick should be fairly uniform in size, shape and colour with smooth, rectangular surface and square corners. It shall be thoroughly burnt, so as to give clear ringing sound when struck; deep red, cherry or copper in colour. It should show a fine grained, uniform, homogeneous and dense texture on fracture. It shall be free from cracks, air holes, lumps of lime, soluble salts causing efflorescence or other defects which may impair their strength, durability, and appearance.

The length, width and height of a brick are interrelated as below:

Length of brick = 2 × width of brick + thickness of mortar

Height of brick = width of brick

Size of a standard brick (also known as modular brick) should be 190 × 90 × 90 mm and 190 × 90 × 40 mm. When placed in masonry the 190 × 90 × 90 mm brick with mortar becomes 200 × 100 × 100 mm.

13.1.1 PHYSICAL CHARACTERISTICS OF BRICKS

The properties of bricks which affect their performance during their service life are durability, compressive strength, water absorption, efflorescence, hardness, dimensions, i.e., shape and size, weight, body structure and soundness. These properties depend upon the chemical composition of the clay, and quality of manufacturing process (preparation, moulding, drying) and degree of firing of clay. These properties are explained below.

1. **Durability** The current brick specifications consider *compressive strength* and *absorption values* together with *saturation coefficient* as predictors of durability. For colder regions accepted method for specifying brick durability considers compressive strength, and freeze and thaw resistance as predictors of durability.
2. **Compressive strength** The compressive strength of a brick is considered as an index of its durability and ability in a masonry wall to resist crushing loads. While most of brick types are specified on the

basis of strength, it is important not to sacrifice properties of durability and bond for higher compressive strengths. Most of the bricks currently produced have strength generally ranging from 3.5 MPa to over 10 MPa.

For determination of compressive strength, a prepared test specimen is loaded in compression testing machine with specified rate of loading till the failure of specimen. The failure load divided by the average area of bed face of the specimen gives the crushing or compressive strength of the brick; in a test, an average of five test values is determined. While computing the average value, any single test value which is higher than the specified (nominal) value of the class of brick tested shall be taken as the upper limit of the class. The test values which are below the average by more than 20 per cent shall be discarded. The average value shall not be less than the specified value.

3. **Water absorption** The presence of minute pores in the brick structure results in the porosity of the brick; these bricks absorb water by capillary action. Absorption of a brick is defined as the ratio of the mass of water that is absorbed into its body divided by its dry mass. Absorption can be divided into two distinct categories: *absorption* and *initial rate of absorption* (IRA). Both are important in selecting the appropriate brick for the application under consideration.

   Water absorption is measured in two ways: (i) submerging the test specimen in water at room temperature for a period of 24 hours, and (ii) submerging the test specimen in boiling water for 5 hours. These two are used to calculate the *saturation coefficient* by dividing the 24 hour cold water absorption by the 5 hour boiling water absorption. The saturation coefficient is used to help predict durability.

   Absorption value are used to determine the porosity of bricks which provide an indication of the potential for the development of problems related to the penetration of salts into the bricks causing salt attack and efflorescence.
4. **Potential to efflorescence** Efflorescence is a deposit of salts, usually white, on the surface of bricks after being laid. The salts usually come from ground water or out of the mortar, but may also come from within the bricks themselves. The efflorescence test predicts the likelihood that the masonry units will display such unsightly deposits from salts that they already contain. The specifications limit the efflorescence to be not more than moderate (10–50 per cent) up to class 12.5 and not more than slight (< 10 per cent) for higher classes.
5. **Warpage of the brick** The warpage of a brick is defined as the greatest distance of brick surface from the edge of straightness. Warpage of the brick is measured with the help of flat steel or glass surface and measuring ruler graduated in 0.5 mm divisions or steel wedge of $60 \times 15 \times 15$ mm as illustrated in Fig. 13.1. It is determined as concave warpage and convex warpage, and the higher of the distances measured in these two warpage tests is reported as warpage. For warpage test, the sample consists of 10 bricks from a lot.
6. **Hardness of brick** A good brick should be reasonably hard such that finger nail does not leave any impression on scratching the bricks surface.
7. **Internal body structure** In this test, a brick is broken and its structure is examined. A broken surface which reveals homogeneous and compact texture, and absence of any structural defects such as air holes, lumps, etc., will indicate that the brick is sound.
8. **Soundness** For this test, two randomly selected bricks are taken, one in each hand, and struck lightly against each other. If the bricks produce clear ringing sound without breaking they are sound; and if the sound is dull they will indicate that the bricks are unsound. Alternatively, a brick is dropped from a height of 1 metre to fall flat on a hard ground. If the brick does not break, it is sound brick.

   All the above tests, except the compressive strength, can be carried out in the field.

13.1.2 Indian Standard Classification of Bricks

IS:1077-1992 has classified the bricks according to their compressive strength into four categories as listed in Table 13.1. The general requirements of different classes of burnt clay bricks are compared in the table.

Table 13.1 *Classification of bricks with general requirements of burnt clay bricks.*

Class of brick: general (strength)	Minimum comp. strength, MPa	Maximum absorption, per cent	Efflorescence	Tolerance in dimension, per cent	Shape and other requirements
(10)	10	12–15	nil	±3	Well burnt, uniform colour; compact and uniform texture; perfect flawless surface; sharp edges and corners; ringing metallic sound.
I (7.5)	7.5	20	Slight	±8	Uniform colour; thoroughly burnt but not over-burnt; compact and uniform texture; smooth rectangular surfaces; sharp edges and corners; emit ringing sound on striking.
II (5)	5.0	22	Slight	±8	Uniform colour; slightly over-burnt; fine compact and uniform texture; ringing sound; slight distortion in shape allowed, but should not cause difficulty in laying.
III (3.5)	3.5	25	Moderate	±8	May be slightly under-burnt; non-uniform texture; dull sound; may be distorted and have round corners, but should not cause difficulty in obtaining uniform courses.

Note: In general factory-made, i.e., extruded and wire-cut bricks in India give the strength of the order of 17 MPa in dry state and 12 MPa when wet. The common hand-made bricks generally give the strength of the order of only 3 to 5 MPa when dry.

13.1.3 Tests for Burnt Clay Bricks

The tests covered in this section are:

1. Compressive strength
2. Water absorption and saturation coefficient
3. Efflorescence
4. Warpage of the brick

Sampling for Testing of Bricks

A brick sample shall be representative of the lot of units from which they are to be selected in respect of the range of colours, textures, and sizes and shall be free of or brushed to remove dirt, mud, mortar, or other foreign materials unassociated with the manufacturing process. IS:3495-1992 has stipulated the procedures for

testing the burnt clay bricks. The sample of the brick shall be taken at random and tests listed in Table 13.2 can be carried out for a particular class of brick.

Table 13.2 *Tests and sample size for clay fired bricks*

Class designation	Sample size	Lot size	Tests to be made
10	20 bricks	50,000 or more	1. Compressive strength 2. Water absorption 3. Efflorescence 4. Hardness 5. Dimensional test 6. Soundness
7.5 to 3.5	20 bricks	100,000 or more	Test at the discretion of competent authority

The dimensions shall be measured to the nearest 1 mm.

13.2 TILES

The tiles are thin plates (elements) used for covering building surfaces, namely roofs, walls and floors. These are made from clays and/or other inorganic raw materials, usually shaped by extruding or pressing at room temperature or other processes, then dried and subsequently fired at temperatures sufficiently high to develop the required properties; tiles can be glazed (GL) or unglazed (UGL) and are incombustible and unaffected by light.

Depending upon the types of surface covered, they are called roofing tiles, wall tiles, flooring tiles and partition tiles. However, roofing tiles are generally baked earthenware and their manufacture is more akin to that of bricks. Wall and floor tiles used for interior and exterior decoration/aesthetics belong to a class of ceramics known as *whitewares*. Tiles for walls and floors may be either glazed or unglazed. Generally speaking, wall tile is glazed tile with a thin body used for interior decoration of residential walls.

Flooring tiles, on the other hand, are durable, impervious to water, resistant to abrasion, easy to wash and have aesthetic appeal; they are extensively used in residential and industrial buildings. Surface or wall tiles differ from floor tiles principally in degree of burning. Wall tiles are burned at a relatively low temperature, glazed, and re-fired in muffle kiln at a still lower temperature.

Most types of tiles that are made from clay or a mixture of clay and other materials, then kiln-fired, are considered to be a part of the larger classification called *ceramic tiles*. These tiles can be split into two groups, porcelain tiles and non-porcelain tiles. The non-porcelain tiles are frequently referred to as ceramic tiles by themselves, a category different from porcelain tiles.

1. **Porcelain tiles** Porcelain tile differs from ceramic tile in its manufacture, absorption and breaking strength. These inherent differences in the manufacturing processes and the quality of the raw materials make porcelain tile a superior product in terms of value, durability, color and design.

   The porcelain tile which is manufactured by dust pressing in dyes at high pressure of the order of 40 MPa and fired at a temperature of 1200° C, is very tough and extremely dense (denser than ceramic tile). On the other hand ceramic tile which is fired at much lower temperature of 980°C has a higher rate of water absorption. The international standard for porcelain tile states that for tile to qualify as Porcelain, it must have water absorption of 0.5 per cent or less.

2. **Glazed porcelain tiles** which are obtained by glazing the top of the dense unglazed tile body are extremely durable products. They can have any type of finish. If made correctly a good factory porcelain tile is superior to ceramic.

Quality Control The tiles must meet certain specifications regarding physical and chemical properties. Properties generally measured include mechanical strength, abrasion resistance, chemical resistance, water absorption, dimensional stability, frost resistance, and linear coefficient of thermal expansion.

13.2.1 Test Methods for Tiles

In this section, a number of test procedures are included which are compulsory tests for the given type of tile.

1. **Testing of clay tiles** Burnt clay flat terracing or roofing tiles, which may be machine-pressed/machine extruded or hand-made, are used for flat roof finishing over lime concrete or cement concrete base, and depending on the degree of protection necessary, they are used in two or more courses.

   The *clay roofing tiles* are generally tested for their transverse strength and water absorption. On the other hand in addition to these tests the flooring tiles are tested for impact; the ridge tiles need be tested for water absorption and breaking strength.

   The *impact test* apparatus stipulated by IS:1478 consists of an upright stand fixed to a heavy base with a 35-mm diameter and 170 g steel ball held in the jaws of a clamp fixed to the stand. In this test a representative sample of three tiles is dried in an oven at 105 ± 5°C to a constant weight and the tiles are allowed to cool at the room temperature. The cooled tile is placed horizontally with its face upwards over a 25 mm thick rubber pad which in turn is placed over a rigid horizontal surface. The tile is placed such that the ball when released strikes vertically on its centre. Starting from a height of 75 mm, the steel ball is dropped from different heights in increments of 75 mm until the test specimen fractures. The maximum height of drop of the test ball is recorded.

   As per the test procedure recommended by IS:1464 for determining the breaking strength of *ridge tile*, the two longitudinal edges of a saturated surface wiped dry ridge tile are placed in the normal position over two strips of 25 mm thick rubber pads placed on the testing bed of the machine. The tile is loaded at a uniform rate 2.7 kN/min through a 75 × 100 × 300 mm rubber lined block placed symmetrically over the ridge of the tile parallel to the direction of rubber sheets supporting the bottom edges. The breaking load of each tile divided by its length is recorded. The average result in N/mm gives breaking strength of the ridge tile.
2. **Resistance to salt attack** Salt can cause damage to roof tiles, by chemical attack or by the expansive effect of salt crystals forming in the pores of a tile, or a combination of both. To assess resistance of a tile to salt attack, small pieces are alternately soaked in a salt solution, dried in an oven, soaked again; the process is repeated for 40 cycles. The amount of material that's crumbled or flaked off the surface during this procedure determines whether the tile can be classed as exposure grade. This test is highly relevant in coastal situations.
3. **Testing of ceramics tiles** The important considerations governing the suitability of ceramic tile for an application include hardness and moisture absorption.

   Moisture absorption Since the water absorption rate reflects the density of the tile body apart from the resistance to wear and tear; the ceramic tile is generally classified by the percentage of water absorption.

   Moisture absorption test is actually a procedure to evaluate tile's permeability to water. It consists in saturating the individual tiles by boiling in water and computing the per cent gain in weight from

the original dry state. This per cent gain in weight recorded for the two conditions is referred to as the water absorption value. Based on water absorption the tile is categorized as:

(*a*) *Impervious* (*extremely dense*) Tile with water absorption of 0.5 per cent or less.
(*b*) *Vitreous* (*highly dense*) Tile with water absorption of 0.5 per cent to 3.0 per cent.
(*c*) *Semi-vitreous (medium dense)* Tile with water absorption of 3.0 per cent to 7.0 per cent.
(*d*) *Non-vitreous (low dense)* Tile with water absorption in excess of 7.0 per cent.

For exterior applications, the selected tiles must have a very low water absorption rate, especially in climates subjected to rainfall, freezing and thawing cycles. Some types of tile may crack if the moisture penetration is too high. Smaller the percentage of water absorption, the better will be the performance when placed in water or used in wet application. Non-vitreous tiles are not recommended even for flooring applications.
There are two methods to determine the water absorption of the ceramic tiles:

i. Boiling method, and
ii. Vacuum method

The *boiling method* involves drying the tiles out and then boiling them in water for 2 hours followed by cooling to room temperature over a 4 hour period. The mass of the tiles are determined both before and after immersion in water to determine the percentage of water absorption.

The *vacuum method* evacuates the air from a chamber with the tiles inside and then immerses the tiles in water. Once again the tiles are weighed before and immersion in water to determine the *apparent porosity*, *apparent relative density* and *bulk density*.

In general terms, if the tile has low water absorption, the durability and strength are increased. Low water absorption restricts the amount of water that may cause failure by cyclic salt attack and freeze thaw.

This test is also sometimes used as a good indicator to predict the stain resistance of unglazed tile, the lower the absorption the greater stain resistance.

Hardness rating Material hardness means its resistance to surface scratching. The relative hardness of glazed tile is an important consideration in selecting a tile, particularly in flooring applications, which are subject to deterioration due to wear and scratchings. Resistance is measured on the MOH'S scale. This scale includes ten mineral ores graduated in increasing hardness order, so that each one can scratch the preceding ones and can be scratched by the following ones. The test consists in scratching the surface of the tile with different minerals at the same pressure and assigning subjectively a "MOH'S Scale Hardness" number to the glaze. A value of #5 or greater is suitable for most residential floor applications. A value of #7 or greater is normally recommended for commercial or high traffic applications.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Talc	Gypsum	Calcite	Fluorite	Apatite	Orthoclase	Quartz	Topaz	Corundum	Diamond

Surface abrasion resistance test This test envisages the performance of glazed tiles in a wear test using an apparatus which subjects the tile specimen to the effects of a standard abrasive load, at an increasing number of cycles (from 150 to 1500 rpm).
Breaking strength test Ceramic tile used on floors and walls must be able to support the expected load of various installations. In order to determine the breaking load and flexural strength of the tile a force is applied to an unsupported portion of the tile until breakage occurs. The ultimate breaking strength is then computed in N. Final selection of the tile should be based upon the breaking strength and appropriate installation method.

13.2.2 Application-based Tests

In this section, a number of test procedures are included which are application based tests. These tests are performed on tiles prior to installation.

1. **Impact resistance** The impact resistance as measured by the coefficient of restitution is required only for testing tiles that are used in areas where impact resistance is considered to be of particular importance. The normal requirement for light duty installations is a coefficient of restitution of 0.55. For heavier duty applications a higher figure would be required.
2. **Linear thermal expansion** Most ceramic tiles have low levels of linear thermal expansion. This test is required for tiles that are installed in conditions of high thermal variation.
3. **Resistance to thermal shock** Although all ceramic tiles withstand high temperatures, this test may be applied to any ceramic tile that may be subjected to localised thermal shock.
4. **Moisture expansion** The majority of glazed and unglazed tiles have negligible moisture expansion which does not contribute to tiling problems when tiles are correctly installed. However, with unsatisfactory fixing practices or in certain climatic conditions, moisture expansion in excess of 0.6 mm/m may contribute to problems.
5. **Frost resistance** This test is compulsory only for tiles that are intended to be used where frost action may exist. The test is not required for tiles groups that are generally specified as unsuitable for use where frost may be present.
6. **Chemical resistance** Ceramic tiles are normally resistant to common chemicals. The test for high concentrations of acids and alkalis is intended for ceramic tiles which are to be used in potentially corrosive conditions.
7. **Resistance to stains** This test is compulsory for glazed tiles.
8. **Coefficient of friction** The test is only required for tiles that are intended for use on floors. The coefficient of friction of tiles varies depending on the nature of the surface of the tile, whether the surface is dry or wet, and results differ for different types of shoe material. Requirements also vary depending on the nature of the flooring application and the size of the floor area and its intended use. Coefficient of friction values higher than those needed for many types of domestic applications may be desirable for large flooring areas, industrial and commercial applications and ramps, especially those connected immediately to the outside, than for many types of domestic applications.

13.3 ACCEPTANCE CRITERIA

Table 13.3 *Acceptance criteria for commonly used tiles*

Particulars of test	Sample size	Acceptance criteria	Characteristics envisaged
I. Burnt clay roofing tiles (IS 2690-1993)			
1. Water absorption, per cent	6 tiles / 1000	Shall not be more than 15 per cent	To ensure durability
2. Transverse strength, MPa	6 tiles / 1000	Shall not be less than 2.0 MPa	To support the dead and live loads
II. Cement concrete flooring tiles (IS 1237-1990)			
1. Water absorption, per cent	6 tiles / 2000	Shall not be more than 10 per cent	To ensure dryness of floor and durability

(continued)

Table 13.3 *contd.*

2. Transverse strength, MPa	6 tiles / 2000	Shall not be less than 3.0 MPa	To provide a capacity to withstand load in case of loss in support
3. Abrasion resistance, mm	6 tiles / 2000	Average wear shall not exceed 3.5 mm Wear on any individual specimen shall not exceed 4.0 mm	Lower the abrasion value, higher the durability and lower the maintenance
III. Ceramic tiles: Test methods (IS 13630 -1993) and Acceptance criteria (IS 15622:2006)			
1. Water absorption, per cent	As per tile size	Average shall lie in the range 3.0 to 6.0 per cent Individual maximum shall not exceed 6.2 per cent	To ensure dryness of surface and durability
2. Bending strength, MPa	As per tile size	Average strength shall exceed 30 MPa Strength of any individual specimen shall not be less than 28 MPa	To provide a capacity to withstand load in case of loss in support
3. Scratch hardness, Mohs	As per tile size	Minimum 5	To resist surface scratching
4. Resistance to surface abrasion	As per tile size	To be specified by the manufacturer (a) Home application ≥ II (b) Commercial application ≥ IV	To ensure durability and low maintenance
5. Crazing resistance	As per tile size	Minimum 4 cycles	For specifications and quality control

EXPERIMENT NO. 1: Compressive Strength

Objective

To determine the compressive strength of solid and perforated bricks.

Theory and Scope

This test covers the method of determination of compressive strength of burnt clay building bricks. The crushing strength provides a basis for comparing the quality of bricks, but is of little value in determining the strength of a masonry wall, since the latter depends primarily on the strength of mortar.

Apparatus

A compression testing machine; Balance with weight box; Crucible for mixing cement and sand; Measuring cylinder; Measuring scale; Trowel.

Description of Apparatus

The compression testing machine should be of sufficient capacity which can provide the rate of loading prescribed by Indian Standards. Generally, a testing machine is equipped with two bearing blocks with hardened faces (platens). The upper platen can be raised or lowered by means of a heavy screwed bolt. The upper platen bears on the upper surface of the specimen to which the load is applied.

Procedure

Part 1: For solid bricks

Step 1: Collect a sample of five test bricks at random from a lot and measure their dimensions to 1 mm accuracy.

Step 2: Preconditioning or preparation of specimens.

(a) Remove unevenness, if any, observed in the bed faces, to provide two smooth and parallel faces by grinding.

(b) Immerse the brick in water at room temperature ($27 \pm 2°C$) for 24 hours. Remove the specimen and drain out any surplus moisture after completion of immersion period.

(c) Fill the frog, where provided, and all voids in the bed face flush with cement mortar 1:3 (1 cement, 3 parts clean coarse sand of grade 3 mm and down).

(d) Store the prepared specimen under the damp jute bags for 24 hours followed by immersion in clean water for 3 days. After this period, remove the specimen from water and wipe out any traces of moisture on the surfaces.

Step 3: Place the preconditioned specimen with flat faces horizontal, and mortar filled face facing upwards between two 3-ply plywood sheets each of 3 mm thickness and carefully centered between plates of the testing machine.

Step 4: Apply load axially at a uniform rate of 14 MPa per minute till failure occurs; record the maximum load at failure when the specimen fails to produce any further increase in the indicator reading on the testing machine.

Observations and Calculations

Sl.No.	Dimensions of top bed face			Dimensions of bottom bed face			Average area of bed faces A, mm^2	Failure load F (max.), N	Compressive Strength, $\frac{F}{A}$ MPa
	L, mm	B, mm	$A_1 = LB$, mm^2	L, mm	B, mm	$A_2 = LB$, mm^2			

The average compressive strength is……. MPa.

Part 2: For perforated bricks

Step 1: Collect five test bricks at random and measure their dimensions to 1 mm accuracy.

Step 2: Preconditioning or preparation of specimens: Immerse the specimen in water at room temperature for 24 hours. Remove the specimen from water and drain out any surplus water.

Step 3: Place the perforated faces of the brick between two 3-ply plywood sheets each of 3 mm thickness and carefully centered between plates of the testing machine.

Step 4: Apply load axially at a uniform rate of 14 MPa per minute till failure occurs; record the maximum load at failure when the specimen fails to produce any further increase in the indicator reading on the testing machine.

Observations and Calculations

Sl.No.	Dimensions of top bed face			Dimensions of bottom bed face			Average area of bed faces A, mm^2	Failure load F (max.), N	Compressive Strength, $\frac{F}{A}$ MPa
	L, *mm*	B, *mm*	$A_1 = LB$, *mm*^{2}	L, *mm*	B, *mm*	$A_2 = LB$, *mm*^{2}			

The average compressive strength is……. MPa.

Precautions

1. The specimen must be accurately placed within location marks on the bottom platen so that it is truly concentric with the spherical seat of upper platen. The bearing face should be wiped clean before test specimen is placed on it.
2. The test specimens during the period between their removal from water immersion and testing should be kept moist by wet blanket covering.
3. The surface water and grit should be wiped off the specimens and any projecting fins removed from the surface which is to be in contact with the packing strips.
4. The bearing surfaces of the test machine and of the packing strips shall be wiped clean.
5. The load should be applied uniformly (without shock) at the specified rate.
6. In case of perforated bricks, neither mortar filling in perforations nor mortar capping shall be provided.

Informative Comments

As the specimen nears the failure point in the compression test its rate of yield increases considerably and the movements of the platens of the testing machine must be speeded in order to maintain constant rate of application of the load. If the test machine is not capable of speeding up, the rate of application of load decreases as the failure point is reached and this results in reduction of the load at which failure takes place.

A quicker rate of loading will give an apparent increase in strength of test specimen. A rate of loading of 14 MPa/minute should always be used and the load is increased until specimen fails and maximum load carried by specimen during test should be recorded.

In place of plywood bed sheets, plaster of paris may be used to ensure a uniform surface for application of load.

Viva-Voce Questions

1. What is the purpose of laboratory and field tests?
2. Why has Bureau of Indian Standards laid down rules for performing these tests?
3. What is significance of the compression test of bricks?
4. What is meant by sampling?
5. What are the fundamental tests required to check the quality of brick?
6. What is the rate of loading used in compression testing of bricks?
7. What is the nature of compression failure of brick?
8. Why should the specimens be covered by damp sacks?
9. What precautions are taken during testing of specimens?

Notes and Comments

EXPERIMENT NO. 2: Water Absorption of Bricks

Objective

To determine the water absorption and saturation coefficient of bricks.

Theory and Scope

This test covers the method of determination of water absorption and saturation coefficient of burnt clay building bricks. The percent water absorption provides a valuable indication of degree of compactness which depends on the degree of burning or vitrification. Absorption value can also determine the porosity of bricks which can cause penetration of salts and other materials into the bricks leading to salt attack and efflorescence.

However, water absorption does not necessarily indicate the behaviour of a brick in weathering. The amount of water freezing in the pores of a brick depends upon the proportion of pore space occupied.

The basis of the saturation coefficient, also called the 24 hour cold water to 5 hour boiling water absorption (C24/B5) ratio, is that resistance to freeze-thaw action will be satisfactory if the brick does not become completely saturated under ordinary conditions, that is, some spaces remain empty. The ease of water uptake is assessed by a 24 hour cold water submersion test; the proportion of unfilled volume is determined by the 5 hour boiling test. The reproducibility of test is good, ± 0.015 or less. Thus, the saturation coefficient is considered to be a better criterion of resistance to freezing and thawing of brick than the percentage of absorption after 48 hours.

Apparatus

Ventilated oven maintained at constant temperature of 110 ± 5°C; Boiling water arrangement; A sensitive balance capable of weighing within 0.1 per cent of the mass of the specimen; Water tub; Damp cloth.

1. The dimension shall be measured to the nearest 1 mm.
2. All apparatus and testing equipment shall be calibrated at frequent intervals.
3. The number of specimens for the test shall be selected according to IS 5454: 1976.

Procedure

Part 1: 24-hour cold water absorption

Step 1: Collect a sample of five test bricks at random from a lot.

Step 2: Dry the bricks in an oven maintained at constant temperature of 110 ± 5°C till they attain constant mass; this may take about 48 hours.

Step 3: Cool the oven heated bricks to room temperature; this may typically take about 4 to 6 hours without a fan and 2 to 3 hours with a fan blowing.

Step 4: Weigh each brick and record the mass M_1.

Step 5: Immerse the bricks in clear water in a tub at room temperature (27 ± 2°C) for 24 hours. At the end of this period remove the bricks out of water and wipe dry with a damp cloth.

Step 6: Weigh each brick and record the mass M_2.
Step 7: Compute the water absorption as per cent of dry weight as follows:

$$\text{Water absorption (per cent)} = \frac{M_2 - M_1}{M_1} \times 100$$

Determine the average 24-hour cold water absorption of five test values.

Part 2: 5 hour boiling water absorption and saturation coefficient

Step 1: Submerge the same bricks in water freely circulating around the bricks. The water is heated to boiling in 1 hour, and boiled continuously for 5 hours.
Step 2: Cool the bricks in water to room temperature and wipe dry surfaces with a damp cloth; weigh the bricks again and determine the mass M_3.
Step 3: Compute boiling water absorption by dividing the mass of water absorbed during boiling by the oven dry mass as a percentage.

$$\text{Water absorption (per cent)} = \frac{M_3 - M_1}{M_1} \times 100$$

Determine the average 5 hour boiling water absorption of five test values.

Part 3: Saturation coefficient

Compute the saturation coefficient as the ratio of cold water absorption to boiling water absorption.

Observations and Calculations

Item	Brick specimen number				
	1	2	3	4	5
Weight of the oven dried specimen cooled to air temperature, M_1 g					
Weight of the specimen after immersion in water for 24 hours, M_2 g					
24 hour cold water absorption, C24 $\frac{M_2 - M_1}{M_1} \times 100$ per cent					
5 hour boiling water absorption, B5 $\frac{M_3 - M_1}{M_1} \times 100$ percent					
Saturation coefficient, C24/B5					

1. Average 24 hour cold water absorption of brick sample is……..per cent.
2. Average 5 hour boiling water absorption of brick sample is……..per cent.
3. Saturation coefficient is…….

Precautions

1. Specimen warm to touch shall not be used for the test.
2. Avoid evaporation during surface drying operation.

Informative Comments

A compact brick will not have more than 3 per cent absorption after 48 hours of immersion. Generally, low absorption bricks, i.e., absorption less than 7 per cent, usually show adequate resistance to damage by freezing. The amount of water freezing in the pores of a brick depends upon the proportion of pore space occupied. Saturation coefficient, which is the ratio of the 5 hours boiling absorption value to the 24 hours cold water absorption value, is an approximate indication of the space available in the brick to accommodate the expansive pressure of freezing of water; i.e., the lower the saturation coefficient the more space there is for the freezing pressure to be relieved, thus it is less likely for the brick to be damaged. Thus the saturation coefficient (C24/B5) is considered to be a better indicator of resistance of brick to freezing than the percentage of absorption after 48 hours. The saturation coefficient test method is described in ASTM: C-67; and saturation coefficient is always less than 1.0; the lower the value the lesser absorptive the brick. ASTM: C-62 has set maximum permissible values for brick that will be exposed to freezing and thawing. The value of the saturation coefficient decreases with decreasing specimen size.

Absorption value can determine the porosity of bricks and blocks, which provide an indication of potential for the development of problems related to the penetration of salts and other materials. On the other hand, suction is perhaps the most important physical property to the mason/contractor. Bricklayer productivity is influenced by the suction and the layout of the portion of brickwork being laid.

Viva-Voce Questions

1. What is significance of the water absorption test of bricks?
2. What is meant by sampling of bricks?
3. What is the difference between 24 hour cold water absorption and 5 hour boiling water absorption tests?
4. Which test is a better criterion of resistance of brick to freezing and thawing than the percentage of absorption after 48 hours?

Notes and Comments

EXPERIMENT NO. 3: Efflorescence in Bricks

Objective

Determination of efflorescence in bricks.

Theory and Scope

This test covers the method of determination of efflorescence of burnt clay bricks. The standard test is conducted to determine the capacity of bricks to contribute to efflorescence through soluble salt content. The test consists in placing the bricks on ends in a pan containing distilled water for 7 days; during this period water is drawn upwards through the brick and evaporated from the surface. Soluble salts in the brick are taken into solution by the water and on its evaporation are deposited on the surface.

The test for efflorescence is conducted before the bricks are delivered to the construction site to determine whether the bricks contain salts which will contribute to efflorescence. Although it will not result in a quantitative amount of efflorescence present, it will indicate if the brick effloresces within permissible limit.

Apparatus

Shallow square or cylindrical flat bottom dish made of glass, porcelain or glazed stoneware. The size of square shaped dish should be 180 × 180 × 40 mm depth and for cylindrical shaped 200 mm diameter × 40 mm depth.

Procedure

The test is performed in a warm well ventilated room at 18 to 30°C.

Step 1: Collect a sample of five test bricks at random from the brick lot under consideration.

Step 2: Pour sufficient distilled water in the shallow flat bottom dish to completely saturate the specimens.

Step 3: Place each of the test bricks vertically with end of the brick immersed in water in the dish to a depth of 25 mm.

Step 4: Allow whole water in the dish to be absorbed by the test bricks and the surplus evaporated through them.

Step 5: Cover the dish containing the brick with suitable glass cylinder so that excessive evaporation from the dish may be avoided.

Step 6: When the water has been absorbed and bricks appear to be dry, pour a similar quantity of water in the dish and allow it to evaporate as before.

Step 7: Examine the bricks for efflorescence after the second evaporation and report the results.

Observations and Calculations

The liability of bricks to efflorescence shall be reported as 'nil', 'slight', 'moderate', 'heavy' or 'serious' as a quantitative measure of efflorescence present in accordance with the following definitions:

No perceptible deposit of salt on the brick surface	Nil
Not more than 10 per cent of brick area is covered with salt	Slight
Heavy deposit covering up to 50 per cent of brick area but no sign of powdering or flaking of the surface	Moderate

Heavy deposit covering more than 50 per cent of brick area accompanied by powdering or flaking of the surface	Heavy
Heavy deposit of salts accompanied by powdering and/or flaking of the surface and deposition tends to increase with repeated wetting of specimen	Serious

The specifications limit the efflorescence to be not more than moderate (10–50 per cent) up to class 12.5 and not more than slight (less than 10 per cent) for higher classes. Thus, the bricks for general construction should not have more than slight to moderate efflorescence.

Precautions

1. Water in the dish should be enough to completely saturate the specimens, it is estimated that brick immersion in water to a depth of 25 mm will be adequate.
2. Cover the dish containing the brick with suitable glass cylinder so that excessive evaporation from the dish may be avoided.

Informative Comments

Efflorescence is a crystalline deposit of water-soluble salts (usually white) on the face of brick units in a wall. Its occurrence may result in disfigurement of masonry, and severe defacement of a wall is not uncommon. Its presence indicates excess water, a condition that can damage interiors and encourage the growth of mold. Efflorescence producing salts are usually sodium sulphate, sodium carbonate, magnesium sulphate, calcium sulphate, calcium carbonate and sometimes slight traces of sodium chloride. However, in most of the cases of serious efflorescence, sodium sulphate is generally present, rarely being less than 50 per cent of the total content. Mortar is also a source of efflorescence which generally appeared to be sodium carbonate.

Several factors may influence the occurrence of efflorescence in a particular case, but there must be salts in the masonry to be taken into solution by water and then deposited on the surface as the moisture dries. The movement of the solutions within masonry is controlled to a considerable extent by temperature, humidity and wind. In the summer, even after long rainy periods, moisture evaporates quickly and small amounts of salt or efflorescence are brought to the surface. Usually efflorescence is more common in the winter, when the slow rate of evaporation allows the migration of salts to the surface.

Viva-Voce Questions

1. What is the significance of efflorescence test of bricks?
2. What is meant by sampling?
3. What is efflorescence in bricks and what causes it?
4. Does the test give a quantitative amount of efflorescence present in brick?

Notes and Comments

EXPERIMENT NO. 4: Warpage of Burnt Clay Brick

Objective

To check the dimensional conformity of burnt clay brick as regard to warpage.

Theory and Scope

This test covers the method of estimation of warpage of burnt clay brick which is defined as the deviation from true plane surface. The test is particularly suited for use under field conditions and provides a means to determine whether the brick meets the requirements considered necessary to assure a satisfactory construction.

Apparatus

Steel ruler; Calipers; Steel measuring wedge or taper gauge; Flat sheet of steel or glass.

Description of Apparatus

The steel ruler should be graduated in 0.5 mm divisions.

The measuring steel wedge of 60 mm in length, 15 mm in width and 15 mm in thickness at one end and tapered to zero thickness at the other end. The wedge shall be graduated in 0.5 mm divisions and numbered to show the thickness of the wedge between the base AB and the slope AC as illustrated in Fig. 13.1. A flat surface of steel or glass sheet should not be less than 300 mm × 300 mm in area and plane to 0.02 mm.

Procedure

1. Collect a sample of ten test bricks at random from the lot under consideration.
2. Clean the surface of the brick by removing any dirt adhering to the surface.

Part 1: For Concave Warpage

Step 1: Place the flat surface along the surface to be measured selecting the location that gives the greatest departure from straightness.

Step 2: Measure the greatest distance of the brick surface from the edge of straightness by a steel ruler or calipers or wedge.

Part 2: For Convex Warpage

Step 1: Place the brick on the flat surface with the convex surface in contact with the flat surface.

Step 2: Measure the distance from flat surface to the four corners of the brick with steel ruler or calipers and take the maximum of four measurements as convex warpage.

The higher of the distance measured in concave and convex warpage tests is reported as warpage.

Observations and Calculations

	1	2	3	4	5	6	7	8	9	10
Concave warpage, mm										
Convex warpage, mm										
Average warpage, mm										

The average warpage of the sample is…….mm.

Precautions

1. The surface of the brick should be properly cleaned by removing any dirt adhering to the surface and local projections should be removed as they may affect measurements.
2. While taking measurements for convex warpage, the specimen should not be allowed to move.

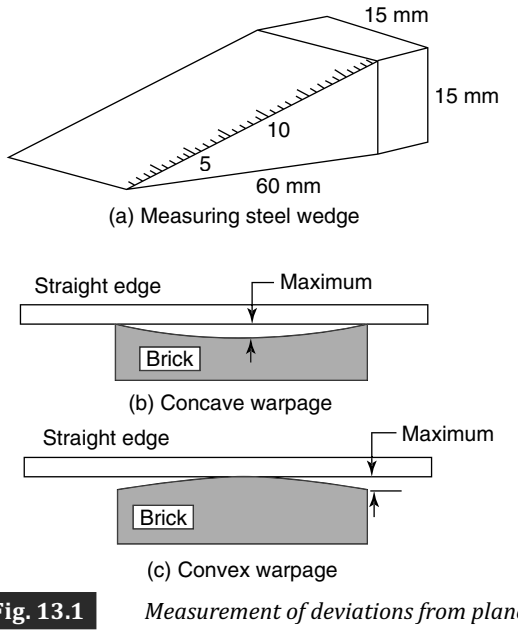


Fig. 13.1 *Measurement of deviations from plane*

Informative Comments

The test method determines the warpage as the maximum deviation from true plane surface. In some standards, the warpage is calculated by dividing the measured amount of deviation from flatness by the length of the edge or diagonal.

Warpage in bricks leads to the following problems:

1. Warpage in bricks results in unbalanced and asymmetric brick courses in masonry walls. Due to curvature in units bending stresses develop in addition to usual axial stresses.
2. **Moisture penetration** It is virtually impossible for significant amounts of water to pass directly through a brick unit. When water passes through brick masonry walls, it invariably does so through separations or cracks between the brick units and the mortar. Therefore, brick units that develop a

complete bond with mortar offer the best moisture resistance. Brick and mortar properties should be compared in order to provide compatible materials that result in more watertight walls. The use of warped bricks develops a poor bond with mortar and thus aids moisture penetration.

Viva-Voce Questions

1. What is the significance of warpage test for bricks?
2. What is procedure for the sampling the bricks for testing?
3. How does use of warped bricks aids the moisture penetration in the brick wall?
4. How does use of warped brick results in bending stress in the unit?
5. What is the acceptance/rejection criterion with regard to dimensional conformity of bricks?

Notes and Comments

EXPERIMENT NO. 5: Water Absorption of Flat Roofing Tiles

Objective

To determine the water absorption of burnt clay flat terracing tiles.

Theory and Scope

Burnt clay flat terracing tiles, which may be machine-pressed/machine extruded or hand-made, are used for flat roof finishing over lime concrete or cement concrete base, and depending on the degree of protection necessary, they are used in two or more courses.

This test covers the method of determination of water absorption of burnt clay terracing tiles. The per cent water absorption provides is a valuable indication of degree of compactness which depends on the degree of burning or vitrification. Absorption value can also serve as an index of porosity of tiles which can cause penetration of salts and other materials into the tiles leading to salt attack and efflorescence. However, water absorption does not necessarily indicate the behaviour of a tile in weathering.

The average water absorption of flat burnt clay terracing tiles to be used in roof finishing shall not exceed 15 per cent.

Apparatus

Ventilated oven maintained at constant temperature of 105 ± 5°C; A sensitive balance capable of weighing to 1 g; Water tub; Damp cloth; Oven gloves.

Procedure

Step 1: Collect a representative sample (according to IS:2690) of at least six tiles at random for every 1000 tiles or fraction thereof in a lot. The number of tiles taken from a lot for test shall not be less than 15 in any one lot. However, for laboratory practice collect a sample of six tiles at random.

Step 2: Dry the tiles in an oven maintained at constant temperature of 105 ± 5°C till they attain constant mass; this may take about 24 hours.

Step 3: Cool the oven dried tiles to room temperature; this may typically take about up to 4 hours without a fan and 2 hours with a fan blowing,

Step 4: Weigh each tile and record its mass M_1.

Step 5: Immerse the tiles in clear water in a tub at room temperature (27 ± 3°C) for 24 hours. At the end of this period remove the bricks out of water and wipe dry with a damp cloth.

Step 6: Weigh each tile of the sample correct to 1g within three minutes of removing the specimen from water and record the mass M_2.

Step 7: Compute the water absorption as per cent of dry weight as follows:

$$\text{Water absorption (per cent)} = \frac{M_2 - M_1}{M_1} \times 100$$

Step 8: Determine the average of water absorption of test tiles in the sample.

Observations and Calculations

Item	Tile specimen number					
Weight of the oven dried specimen cooled to air temperature, M_1 g						
Weight of the specimen after immersion in water for 24 hours, M_2 g						
Water absorption, $\frac{M_2 - M_1}{M_1} \times 100$ per cent						

Average water absorption of tile sample is……..per cent.

Precautions

1. Specimen warm to touch shall not be used for the test.
2. To avoid evaporation during surface drying operation, the specimen shall be weighed within three minutes after removing the specimen from water.
3. While checking each tile weight every four hours and so it should be ensured that a heat proof mat is placed between the tiles and the balances.

Informative Comments

A compact tile generally does not have more than three per cent absorption after 48 hours of immersion. Absorption value can determine the porosity of tiles, which provide an indication of potential for the development of problems related to the penetration of salts and other materials.

If any of the tiles in the sample fails to comply with the requirements of the test, another sample shall be similarly drawn and tested. If any of the tiles in the second sample also fails to comply with requirements of the test, then the whole lot, from where the samples were taken, shall be rejected as not complying with IS 2690 (Part 1)-1993 stipulations.

Viva-Voce Questions

1. What is meant by sampling of tiles?
2. What is significance of the water absorption test for tiles?
3. How do the mechanical properties of tile change with moisture content?
4. When is a sample taken as non-complying with the requirements of the test?
5. What is the permissible limit of water absorption for the burnt clay plain terracing tiles?

Notes and Comments

EXPERIMENT NO. 6: Transverse Strength of Clay Roofing Tiles

Objective

To determine the transverse strength of clay roofing tiles.

Theory and Scope

The transverse strength test is commonly used to measure the flexural strength of clay roofing tiles. The test method provides means for establishing whether or not a lot of tiles meet the strength requirements which may appear in tile specifications.

Bending test is carried out in accordance with IS 2690 (Part 1)-1993 to ensure that a plain burnt clay tile has sufficient bending strength to withstand bending under standard load without fracturing. In the test procedure a standard saturated surface dry specimen at room temperature is subjected to a line load acting through the mid span of the tile; the loaded tile is considered a simply supported beam with a concentrated load applied at its center. Thus, the transverse or flexural strength can be computed as

$$\text{Transverse strength (MPa)} = \frac{M_{\max}}{Z} = \frac{(WS/4)}{(bt^2/6)} = \frac{1.5\ WS}{bt^2}$$

where W = breaking load in N,

S = distance between wood bearers in mm = 3/4 of tile length and

b, t = width and thickness of the tile in mm, respectively.

Apparatus

A compression testing machine (CTM) with a minimum load capacity of 100 kN; Transverse strength test bearer fixture; Three 20×3 mm thick plywood padding of tile length ; Water tub; Damp cloth.

Description of Apparatus

The transverse strength test bearer assembly consists of two parallel self-aligning cylindrical steel bearers, with the bearing surface rounded to 40 mm diameter; these are so placed that the distance between their centres can be adjusted suitably. The assembly is mounted on a rigid mild steel plate. The load is applied through a third central steel bearer of similar shape placed midway between the parallel supports. The lengths of all the bearers exceed the maximum width of the tile under test for square and rectangular tiles.

Procedure

Step 1: Collect a representative sample (according to IS:2690) of at least six tiles at random for every 1000 tiles or fraction thereof in a lot. The number of tiles taken from a lot for test shall not be less than 15 in any one lot. However, for laboratory practice collect a sample of six tiles at random.

Step 2: Insert the appropriate test fixture in the CTM. Adjust the supports for the required distance and clamp to the lower platform of the machine.

Step 3: Measure and record the distance S between the two supports or the span of tile specimen.

Step 4: Immerse the tiles in clear water in a tub at room temperature (27 ± 3°C) for 24 hours. At the end of this period remove the tiles out of water and wipe dry the surface with a damp cloth.

Step 5: Support each of the wet but surface wiped dry tiles along longer face on the rounded edges of bearers as shown in Fig. 13.2. Place plywood padding between tile and supports and wearing surface and rod.

Step 6: Apply the load continuously at constant rate in the range 450–550 N/minute along the centre line at right angles to the length or span of the tile through a specially designed block placed symmetrically.

Step 7: Determine the average of breaking load of test tiles in the sample.

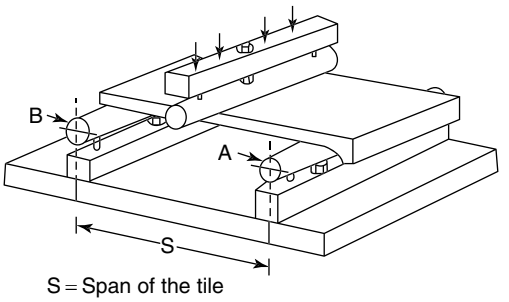


Fig. 13.2 *Typical transverse testing fixture for transverse strength of plain tiles*

Observations and Calculations

Type of tile …….
Source……

Flexural Properties of Tile Specimen

Specimen No.	Size of specimen $b \times t \times L$ and S, mm				Maximum applied load at failure, W N	Flexural strength, MPa $f_{max} = \frac{1.5\,WS}{bt^2}$
	b	t	L	S		
1.						
2.						
3.						
4.						
5.						
6.						
Average flexural strength nearest to 0.5 MPa						
Specified flexural strength, MPa					2.0	

Results

The average transverse breaking load of six tiles is……MPa.
The average breaking load of six tiles is/is not less than as specified in the Code.

Precautions

1. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the supports.
2. The load applying blocks shall be brought in contact with the upper loading beam between the supports.
3. The load shall be applied slowly without shock at the stipulated rate.

Informative Comments

If any of the tiles in the sample fails to comply with the requirements of the test, another sample shall be similarly drawn and tested. If any of the tiles in the second sample also fails to comply with requirements of the test, then the whole lot, from where the samples were taken, shall be rejected as not complying with IS 2690 (Part 1)-1993 stipulations.

Viva-Voce Questions

1. What is the basic difference between burnt clay tile and ceramic tile?
2. How do the mechanical properties of tile change with moisture content?
3. Why is the test performed on saturated surface dry tiles?
4. What is the bending or transverse strength test for a tile?
5. What is the significance of bending test?
6. What are the factors which influence the result of bending test?
7. What is the equation governing simple bending?
8. What is the meaning of flexure equation: $M/I = f/y = E/R$?
9. How is the bending stress calculated in a loaded tile?
10. What is the rate of loading in the bending test?
11. How are bending test results expressed?
12. What is the permissible variation in strength of a specimen while taking the average?

Notes and Comments

EXPERIMENT NO. 7: Transverse Strength of Flooring Tiles

Objective

To determine the breaking strength of concrete flooring tiles.

Theory and Scope

The breaking strength test is commonly used to measure the flexural strength of concrete flooring tiles. The test indicates directly the load carried by an individual tile while remaining unsupported over a specified span; it indirectly provides information on its density, compaction and toughness of wearing layer as well as interlocking of wearing and base course mixes. The test method forms basis for establishing whether or not a lot of tile meets the strength requirements which may appear in tile specifications.

This breaking load test is carried out in accordance with IS 1237-1980 wherein a standard saturated surface dry specimen at room temperature is subjected to a load applied through a steel rod acting at the mid span of the tile. The transverse or flexural strength can be computed as:

Wet transverse strength (MPa), $f_{\max} = \dfrac{3.0\ WS}{bt^2}$

where W = breaking load in N,

S = distance between wood bearers in mm =3/4 of tile length, and

b, t = width and thickness of the tile in mm, respectively.

Apparatus

A compression testing machine (CTM) with a minimum load capacity of 100 kN; Transverse strength test bearer fixture; Three 20×3 mm thick plywood padding of tile length ; Water tub; Damp cloth.

Description of Apparatus

The parallel support bearer assembly consists of two cylindrical self-aligning steel bearers with rounded contact bearing surface of 40 mm diameter. The bearers are so placed that the distance between their centres can be adjusted suitably. The assembly is mounted on a rigid mild steel plate. The load is applied through a 12-mm diameter steel rod with rounded contact surface placed midway between the parallel supports. The lengths of all the bearers exceed the maximum width of the tile under test for square and rectangular tiles.

Procedure

Step 1: Collect a representative sample (according to IS 1237-1980) of at least six full size tiles at random from one uniform lot of supplies.

Step 2: Insert the parallel support bearer assembly in the CTM. Adjust the supports for the required distance as follows and clamp to the lower platform of the machine.

Size of tile (mm)	Span, S (mm)
200×200	150
250×200	200
300×300	200

Step 3: Measure and record the distance S between the two supports, i.e., the span of tile specimen.

Step 4: Immerse the tiles in clear water in a tub at room temperature (27 ± 3°C) for 24 hours. At the end of this period remove the tiles out of water and wipe dry with a damp cloth.

Step 5: Support each of the wet but surface wiped dry tiles along longer face on the rounded edges of bearers as shown in Fig. 13.2. Place plywood padding between tile and supports and wearing surface and rod.

Step 6: Apply the load continuously at constant rate of 2000 N/minute along the centre line at right angles to the length or span of the tile through the steel rod placed symmetrically till the tile breaks. Record the breaking load, *W*.

Step 7: Determine the average thickness *t* of tile by measuring it at 50 mm from edge at broken surface at number of points.

Step 8: Compute wet transverse strength in MPa of the specimens.

Step 9: Determine the average of breaking strength of test tiles in the sample.

Observations and Calculations

Type of tile …….

Source……

Flexural Properties of Tile Specimen

Specimen No.	Size of specimen $b \times t \times L$ and S, mm				Maximum applied load at failure, W N	Flexural strength, MPa $f_{max} = \frac{3WS}{bt^2}$
	b	t	L	S		
1.						
2.						
3.						
4.						
5.						
6.						
Average flexural strength nearest to 0.5 MPa						
Specified flexural strength, MPa						

Results

The average transverse breaking strength of tiles is……MPa.

The average breaking strength of tiles sample is/is not less than as specified in the Code.

Precautions

1. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the supports.
2. The load applying blocks shall be brought in contact with the upper loading beam between the supports.
3. The load shall be applied slowly without shock at the stipulated rate.

Informative Comments

If any of the tiles in the sample fails to comply with the requirements of the test, another sample shall be similarly drawn and tested. If any of the tiles in the second sample also fails to comply with requirements of the test, then the whole lot, from where the samples were taken, shall be rejected as not complying with IS 1237–1980 stipulations.

Viva-Voce Questions

1. What is the basic difference between roofing tile and flooring tile?
2. How do the mechanical properties of tile change with moisture content?
3. Why is the test performed on saturated surface dry tiles?
4. What is the bending or transverse strength test for a tile?
5. What is the significance of breaking test?
6. What are the factors which influence the result of breaking test?
7. What is the meaning of flexure equation: $M/I = f/y = E/R$?
8. How is bending stress calculated in a loaded tile?
9. What is the rate of loading in the breaking test for flooring tile?
10. How are breaking test results expressed?
11. What is the permissible variation in strength of a specimen while taking the average?

Notes and Comments

EXPERIMENT NO. 8: Water Absorption of Ceramic/ Glazed Tile

Objective

To determine the water absorption of ceramic/glazed tiles.

Theory and Scope

The water absorption test provides indication of porosity of tiles, which affects the longevity of tiles, as well as its bonding with backing plaster, appearance of wearing surface and luster. This test covers the method of determination of water absorption of ceramic and glazed tiles.

The average water absorption of ceramic/glazed tiles shall not exceed 6 per cent.

Test Sample

The sample is collected as per one of following criteria:

1. Ten whole tiles of each type selected at random.
2. Five whole tiles selected at random if surface area of each tile is greater than 0.04 m^2.
3. The bigger tiles can be cut up in pieces and all pieces collectively have to be included in the measurement.
4. For irregular shapes, lengths and widths are considered as of enclosing rectangles.
5. Minimum mass of 50–100 g in case of lighter tiles.

Apparatus

Ventilated oven maintained at constant temperature of 110 ± 5°C; Heating apparatus for boiling of tiles; A sensitive balance capable of weighing to an accuracy of 0.01 g; Desiccator (silica gel base) and Chamois leather; Oven gloves.

Procedure

Step 1: Collect a representative sample of tiles at random according to IS 13630 (Part 2) 1992 as outlined under the section scope.

Step 2: Dry the tiles in an oven maintained at constant temperature of 105 ± 5°C till they attain constant mass, i.e., when the difference in mass between two consecutive four hourly weighing is less than 0.1 per cent. This drying process may take about 24 hours.

Step 3: Cool the oven dried tiles to room or ambient temperature in the desiccator; this may typically take about up to 4 hours.

Step 4: Weigh each tile accurately as follows and record its mass M_1.

Mass of each tile, g	Accuracy, g
50–100	0.02
101–500	0.05
501–1000	0.25
1001–3000	0.50
3001 & above	1.00

Step 5: Place the weighed tiles in distilled water in the heating apparatus vertically without any surface contact with each other and with 50 mm water depth below and above tiles throughout the test.
Step 6: Heat the water until boiling and continue to boil for 2 hours.
Step 7: Remove the burner and allow the apparatus to cool for 4 hours.
Step 8: Lightly wipe dry surfaces of the tiles by Chamois leather.
Step 9: Immediately weigh each tile accurately and record its mass M_2.
Step 10: Compute boiling water absorption by dividing the mass of water absorbed during boiling by the oven dry mass as a percentage.

$$\text{Water absorption (per cent)} = \frac{M_2 - M_1}{M_1} \times 100$$

Step 11: Determine the average of water absorption of test tiles in the sample.

Observations and Calculations

Item	Tile specimen number					
	1	2	3	4	5	6
Weight of oven dried specimen cooled to room temperature, M_1 g						
Weight of specimen after immersion in water for 24 hours, M_2 g						
Water absorption, $\frac{M_2 - M_1}{M_1}$ per cent						

Average water absorption of tile sample is……..per cent.

Precautions

1. Specimen warm to touch shall not be used for the test.
2. To avoid evaporation during surface drying operation, the specimen shall be weighed within 3 minute after removing the specimen from water.
3. While checking each tile weight every 4 hours it should be ensured that a heat proof mat is placed between the tiles and the balances.

Informative Comments

The low water absorption ceramic tiles are generally referred to as fully vitrified, impervious and porcelain. These terms synonymously exhibit water absorption of less than 0.5 per cent when tested to AS4459.3.

A compact tile generally does not have more than 3 per cent absorption after 48 hours of immersion. Absorption value can determine the porosity of tiles, which provide an indication of potential for the development of problems related to the penetration of salts and other materials.

If any of the tiles in the sample fails to comply with the requirements of the test, another sample shall be similarly drawn and tested. If any of the tiles in the second sample also fails to comply with requirements of

the test, then the whole lot, from where the samples were taken, shall be rejected as not complying with IS 2690 (Part 1)-1993 stipulations.

Viva-Voce Questions

1. What is meant by sampling of tiles?
2. What is significance of the water absorption test for tiles?
3. How do the mechanical properties of tile change with moisture content?
4. When is a sample taken as non-complying with the requirements of the test?
5. What is the permissible limit of water absorption for the ceramic wall tiles?

Notes and Comments

EXPERIMENT NO. 9: Abrasion Resistance of Flooring Tiles

Objective

To evaluate resistance to wear by observing reduction in thickness of tile's top surface under specific operating conditions of abrasion testing machine.

Theory and Scope

The toughness of top wearing layer of a tile ensures lasting lustre, shine and longer life under service conditions. This test covers the method of measuring wear by observing reduction in thickness of tile's top or wearing surface under specific operating conditions of abrasion testing machine.

The average loss in thickness of tiles in a sample shall not exceed the value listed in Table 13.3.

Apparatus

Abrasion Testing Machine (IS 1237-1980); Abrasive powder (IS 1237-1980); Ventilated drying oven maintained at constant temperature of 110 ± 5°C; Thickness measuring set up to measure thickness to accuracy of 0.01 mm; Oven gloves.

Procedure

Step 1: Collect a representative sample at random (as per IS 1237-1980).

Step 2: Preconditioning or preparation of specimens:

(a) Saw 70.6 × 70.6 (± 2%) mm size (Area = 5000 mm^2) test specimen from each tile, preferably from central part of it.

(b) Smoothen the wearing surface of the specimen by grinding.

Step 3: Dry specimens in an oven maintained at constant temperature of 110 ± 5°C till they attain constant mass; this may take about 24 hours.

Step 4: Cool the oven dried specimens to room temperature; this may typically take about up to 4 hours without a fan and 2 hours with a fan blowing,

Step 5: Weigh each specimen and record its mass M_1.

Step 6: Place the specimen with wearing surface upwards in thickness measuring apparatus and find out average thickness by taking measurements at 5 specified points on specimen.

Step 7: Spread 20 g grinding powder evenly in path of disc of abrasion testing machine.

Step 8: Fix up the specimen in holding device with surface to be ground the disc and load it at centre with 300 N load.

Step 9: Grind the specimen for 22 revolutions of abrasion testing machine at speed of 30 revolutions per minute.

Step 10: Remove grinding powder and ground waste; clean the specimen surface.

Step 11: Turn the specimen clockwise through 90° and clamp.

Step 12: Put 20 g grinding powder and repeat the process for 9 more operations completing 220 revolutions.

Step 13: Remove the specimen and record its weight to an accuracy of 0.01 g. Discard the measurement if specimen chips during the abrasion test.

Step 14: Compute average loss in thickness of a specimen indicating the wear as follows:

$$\text{Average loss in thickness, } \delta t = \frac{(M_1 - M_2) \times V_1}{M_1 \times A} \text{ mm}$$

where

M_1 = Initial mass of specimen in g,

M_2 = Final mass of specimen in g,

V_1 = Initial volume of specimen in mm^3 and

A = Surface area of specimen in mm^2.

Step 15: Determine the average loss in thickness of specimens in the sample. While averaging, minimum of three residual measurements should be ensured.

Observations and Calculations

Type of tile …….

Source……

Flexural Properties of Tile Specimen

Specimen No.	Size of specimen $b \times d$ and t, mm			Surface area, mm^2	Initial volume, mm^3	Mass of specimen, g		$\delta t = \frac{(M_1 - M_2) \times V_1}{M_1 \times A}$
	b	d	t	$A = b\,d$	V_1	M_1	M_2	mm
1.								
2.								
3.								
4.								
5.								
6.								
Average loss in thickness of tiles, mm								
Specified loss in thickness of tiles, mm								

Average loss in thickness of tiles in the sample is……..mm.

Precautions

1. Specimen warm to touch shall not be used for the test.
2. While checking each tile weight every 4 hours or so it should be ensured that a heat proof mat is placed between the tiles and the balances.

Informative Comments

The degree of deterioration of a floor is not adequately determined by the reduction in its thickness, but by the visible difference in appearance between the worn surface and the unworn surface, assessed at a defined distance under standard conditions of lighting. Due to the fact that for the same degree of abrasion, wear is invariably more visible on dark surfaces. For this reason, the PEI value is shown in catalogues as the requirement for the individual article, and not for the series as a whole. The new ISO product standards (Project ISO TC/189) envisage the introduction of a further class of resistance, class PEI V, to which tiles, meeting the following conditions at 12000 rpm will be assigned:

1. Alterations must not be visible at a standard distance.
2. The surface subjected to abrasion must pass a cleaning test (with the staining agents chromium green in light oil, iodine in alcohol solution, and olive oil).

This new class, therefore, also takes into account the effects of abrasion on susceptibility to soiling. The introduction of class PEI V fulfills the need to highlight more clearly, in relation to performance, the superior characteristics of ceramic glazes for technical applications developed in recent years.

An adequately compacted tile generally does not have more than ….mm average loss in thickness.

Viva-Voce Questions

1. What is meant by sampling of tiles?
2. How is a test specimen prepared for abrasion test?
3. What is significance of the abrasion test for tiles?
4. How is the wearing property of a tile affected with moisture content?
5. When is a sample taken as non-complying with the requirements of the test?
6. What is the permissible limit of average loss in thickness of flooring tiles?

Notes and Comments

NATIONAL STANDARDS

A. Burnt Clay Building Bricks

1. IS 1077-1992: *Common burnt clay building bricks*.
2. IS 2180-1988: *Heavy Duty burnt clay building bricks*.
3. IS: 3495 (Parts 1 to 4) 1992 (3rd Revision): *Methods of Tests of Burnt Clay Building Bricks*; Part 1: *Determination of Compressive Strength*; Part 2: *Determination of Water Absorption*; Part 3: *Determination of Efflorescence and* Part 4: *Determination of Warpage*
4. IS 3952-1988: *Burnt Clay Hollow Bricks for Walls and Partitions*.
5. IS 5454-1978: *Method of Sampling of Clay Building Bricks*.
6. IS: 5454-1976 (1st revision): *Method for Sampling of Clay Building Bricks*.

B. Burnt Clay Flat Terracing and Ceiling Tiles

1. IS 1464-1992 (2nd revision): *Specification for Clay Ridge and Ceiling Tiles*.
2. IS 2690(Part 1)-1993 (2nd revision, reaffirmed 2002): *Specification for Machine-made Burnt Clay Flat Terracing Tiles*.
3. IS 2690(Part 2)-1992 (2nd revision, reaffirmed 2002): *Specification for Hand-made Burnt Clay Flat Terracing Tiles*.

C. Cement Concrete Flooring Tiles

1. IS: 1237 -1980 (1st revision, reaffirmed 2006): *Cement Concrete Flooring Tiles*.

D. Ceramic Tiles

1. IS 4457-1982 (1st revision, reaffirmed 1990): *Specifications for Ceramic Unglazed Vitreous Acid Resisting Tiles*.
2. IS 13630 (Parts 1-14)- 1993 (1st revision, reaffirmed 2006): *Ceramic Tiles - Methods of Test, Sampling and Basis for Acceptance*.
3. Part 2: *Determination of Water Absorption and Bulk Density*.
4. Part 3: *Determination of Moisture Expansion Using Boiling Water*.
5. Part 4: *Determination of Linear Thermal Expansion*.
6. Part 6: *Determination of Modulus of Rupture and Breaking Strength*.
7. Part 9: *Determination of Crazing Resistance—Glazed Tiles*.
8. Part 11: *Determination of Resistance of Surface Abrasion—Glazed Tiles*.
9. Part 13: *Determination of Scratch Hardness of Surface According to MOHS.*
10. IS 15622:2006 (SO 13006): *Specification for Pressed Ceramic Tiles* - (Superseding IS 13753, IS 13754, IS 13755 and IS 13756).

REFERENCES

1. ASTM C67-11: *Standard Test Methods for Sampling and Testing Brick and Structural Clay Tile*.
2. ASTM C1314-11: *Standard Test Method for Compressive Strength of Masonry Prisms*.
3. AS4459.3: *Determination of Water Absorption, Apparent Porosity, Apparent Relative Density and Bulk Density of Ceramic Tiles*.

4. BS EN ISO 10545-1: *Sampling and Acceptance Criteria for Ceramic Tiles*.
5. BS EN ISO 10545-4: *Determination of Tensile Strength and Resistance to Bending for Ceramic Tiles*.
6. Gambhir, M. L. and Neha Jamwal, *Building Materials: Products, Properties and Systems*, McGraw-Hill Education (India), 2011.
7. ISO 10545-3:1995: *Ceramic Tiles*: Part 3: *Determination of Water Absorption, Apparent Porosity, Apparent Relative Density and Bulk Density*.
8. ISO 10545-5:1996: *Ceramic Tiles* -Part 5: *Determination of Impact Resistance by Measurement of Coefficient of Restitution.*
9. ISO 10545-6:1995: *Ceramic Tiles* -Part 6: *Determination of Resistance to Deep Abrasion for Unglazed*.
10. ISO 10545-7:1996: *Ceramic Tiles* -Part 7: *Determination of Resistance to Surface Abrasion*.
11. ISO 10545-10:1995: *Ceramic Tiles* - Part 10: *Determination of moisture expansion.*
12. ISO 10545-11:1994: *Ceramic Tiles* - Part 11: *Determination of Crazing Resistance for Glazed Tiles.*
13. ISO 13006:1998: *Ceramic Tiles* - *Definitions, Classification, Characteristics and Marking*.

INFRASTRUCTURAL MATERIALS

Section 14
Metals

This section describes the mechanical tests generally performed on metals. These include Rockwell hardness test; Brinell and Vickers hardness tests; Impact tests (Charpy V-Notch and Izod tests); Tensile test; Compression test; Bend test for metal products; Shear test; flexural bending test; Torsion test and Fatigue test. The physical characteristics of metals as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

14.1 INTRODUCTION

Structural steel is basically combination of iron and carbon. Depending on the purpose for which the material is required, different ratios are formulated for different types of steel. The commonly used structural steel contains less than 2 per cent carbon and less than 1 per cent manganese; it also contains small amounts of phosphorous, silicon, sulphur and oxygen. Iron-carbon combination containing up to 2 per cent carbon is called *carbon steel* while those having more than 2 per cent are called *cast steel*. In carbon steel, the carbon content greatly affects the properties of steel; the strength, hardness, corrosion-resistance of steel increase with the carbon content, while malleability, ductility and weldability decrease.

Stainless steel It is obtained by adding 15–18 per cent chromium and 7–8 per cent nickel contents by mass. Stainless (stains less) steel does not stain, corrode, or rust as easily as ordinary steel, but it is not stain-proof. It is also called corrosion-resistant steel or CRES.

Rolling of cast iron causes its coarse grain structure to recrystallise into a much finer grain structure, giving greater toughness, shock resistance and tensile strength. In addition, rolling is the main process used to shape steel into different products. There are two types of rolling—hot and cold. In hot rolling, the slabs and billets are heated in a furnace to about 1200°C before being rolled in to usable product; whereas, the cold rolling is carried out at the room temperature. Cold rolling increases strength, makes steel thinner and produces a bright smooth surface.

14.1.1 Thermo-Mechanical Treatment (TMT)

Thermo-Mechanical Treatment or TMT consists of the quenching processes, Tempcore and Thermex. However, neither of these two patented processes employs any mechanical treatment whatsoever. Instead they obtain the unique properties in the rebars by quenching and tempering. After rolling, the deformed steel bar is passed through a quenching line whereby the periphery is subjected to intense water quenching in a

short time whereas the core remains largely unaffected. On leaving the quenching system, the core heat is utilised to temper the quenched outer surface. The resulting structure is a concentric tempered martensite periphery with a softer ferrite-pearlite core. Thus, no mechanical treatment is involved in the production of TMT rebars.

Tempcore and Thermex technologies have enabled production of rebars that have far superior properties than the conventional Cold, Twister and Deformed bars (CTD bars); these low cost rebars having high yield strength of about 450 to 500 MPa combined with good ductility result in saving in steel consumption and provide adequate safety when used in high seismic zones. It should be noted TMT bars may be considered as an improvement on the old CTD bars, but it is not a brand name.

Since hot rolling mills for long products undertake thermal and mechanical operations in the normal course of rolling, the manufacturers are exploiting the name TMT and marketing their product the conventional CTD bars as TMT bars; even when they do not employ any Tempcore or Thermex processing or any sort of quenching system. There is nothing in the current laws or regulations which prevent the rolling mill selling untreated and untwisted deformed bars as TMT bars–even though the strength can be as low as only 300 MPa. Thus, it is imperative that all rebars must be purchased based on the properties of yield strength, tensile strength and elongation values to avoid exploitation by unscrupulous elements. Some of the conventional CTD Fe 415 bars being sold as Grade Fe 415 have been found to be of yield stress of about 350 to 390 MPa only as against 415 MPa specified in IS: 1786-1985 for grade Fe 415. To check the use of substandard and improperly quenched TMT Rebars need to be tested.

Because of the safety ramifications associated with steel construction, there are specific standards and regulations established for the steel industry and structural steel design. The codes are written in legal format to enable their adoption by reference to building codes; however, the stipulations are general guidelines having no legal standing of their own.

14.2 MECHANICAL PROPERTIES OF STEEL

14.2.1 Stress-Strain Behaviour

The stress-strain curve for steel is generally obtained from tensile test on standard specimens as shown in Fig. 14.1. The details of the specimen and the method of testing are detailed in IS: 1608-1995. The important parameters in tensile test are the gauge length, L_o and the initial cross section area A_o. The loads are applied through the threaded or shouldered ends. The initial gauge length is taken as $5.65\sqrt{A_o}$ in the case of rectangular specimen and it is 5 times the diameter in the case of circular specimen.

An axially loaded tension member exhibits an *elastic range* (a–b) ending at *yielding* (b), followed by yield plateau (b–c). In the yield plateau, the load almost remains constant as the elongation increases to more than ten times the yield strain. On further loading, the material exhibits a smaller increase in tension due to reorientation of the crystal structure of the metal with *elongation* (c–d). This region is referred to as the *strain hardening* range. After reaching the *ultimate load* (d), the loading decreases as the elongation increases (d–e), until the specimen eventually fractures at (e).

The idealised stress-strain curve for specimen subjected to tension is shown on Fig. 14.1(b); for the specimen in compression, the idealised stress-strain curve is taken to be identical to the one in tension up to the point of maximum stress. However, the difference in actual curves is indicated by reduced yield stress in compression.

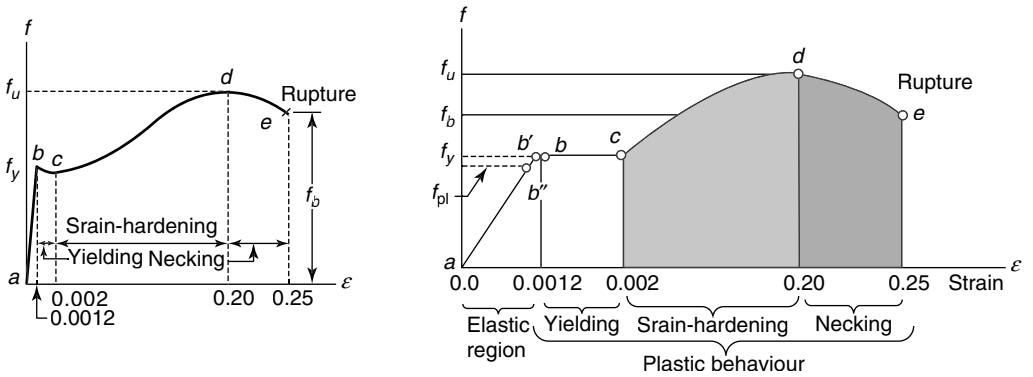
For all structural steels, the modulus of elasticity is usually taken as 205,000 MPa and the tangent modulus at the onset of strain hardening is roughly 1/30th of that value or approximately 6,700 MPa.

High strength steels, due to their specific microstructure, do not show a sharp yield point but rather they yield continuously. For such steels, the yield stress is always taken as the stress at which a line at 0.2 per cent strain, parallel to the elastic portion, intercepts the stress strain curve.

14.2.2 Properties of Steel Determined From Stress-Strain Curve

1. **Yield strength** It is the stress at which the material begins to yield; for mild steel, there is a noticeable increase in deformation with little increase in load. The yield stress is obtained by dividing the load at the yield point by the nominal cross-sectional area of the test specimen. However, for steel and most metals, a 0.2 per cent offset is used to define the yield stress. A strain value of 0.002 is selected and a line parallel to the elastic portion of the stress-strain curve is constructed. The intersection of this line with the stress-strain curve defines the value of the yield stress.

   The minimum specified yield strength is just that the minimum specified value which should be higher than specified. The code specifications only require that the yield stress shall be at least the specified value; it is specified value that can be used in design calculations.



(a) Actual stress-strain curve (b) Idealised stress-stress-strain curve (not to scale)

Fig. 14.1 *Typical stress-strain curve from a tension test on structural steel specimen*

2. **Ultimate or tensile strength** The ultimate or tensile strength of the material which is generally taken as guaranteed ultimate tensile strength is given by

$$f_u = \frac{\text{Ultimate tensile load}}{\text{Original area of cross section}} \tag{14.1}$$

Ideally, the ultimate strength would have been calculated based on reduced area of cross section, but it is not practical to determine reduced area of cross section at various stages of loading. Thus, this stress is also called the *nominal* or the *engineering stress*. Similarly, the engineering strain is taken as the ratio of the change in length to original length. It is the largest value of stress that the material can support. This value is commonly used to determine the maximum or nominal strength of a member.

Elastic constants

1. **Modulus of elasticity**, *E,* is a measure of a material's *axial stiffness*; it does not change with the type of steel and has the value of 2.5×10^5 MPa
2. **Shear modulus**, *G*, is a measure of the *shear stiffness* of the material. It is a constant for all steels and has the value of 0.769×10^5 MPa
3. **Poisson's ratio** is not required in strength and serviceability computations. However, it is often used in structural analysis.

It should be noted that since all steels have the same stiffness, *E*, but not the same strength, f_y and/or f_u thus, the use of high strength steel is advantageous only if the limiting criteria are strength related instead of stiffness related.

14.2.3 Ductility of Steel

The *ductility* of steel, defined as its capacity to undergo large inelastic deformations without significant loss of strength, is an important consideration in analysis and design of steel structures. It is one of the founding pillars of limit state design approach. The amount of permanent strain from proportionality limit to the point of rupture or fracture is a measure of ductility. Thus, the ductility of steel can be measured by computing the percentage elongation of the test specimen over the specified or standard gauge length given by, $5.65\sqrt{A_o}$ where A_o is the cross sectional area of the specimen

$$\text{Elongation} = \frac{\text{Elongated length } (L_f) - \text{Gauge length } (L_o)}{\text{Gauge length } (L_o)} \times 100 \text{ (per cent)} \tag{14.2}$$

The minimum required *percentages of elongation* for various grades of steel are given in the Table 14.1.

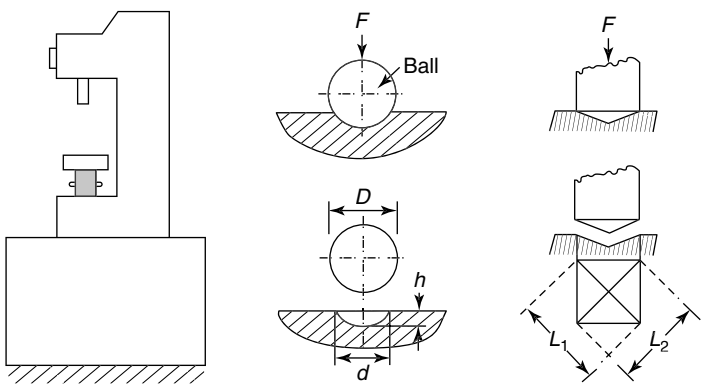
14.2.4 Toughness

The toughness is the ability of a material to resist fracture or to absorb large amounts of energy under impact loading; it involves both strength and ductility. The toughness of structural steels enables the steel members to be subjected to large deformations when they are bent, hammered, and sheared, and holes are punched during fabrication and erection without fracture. This is an important consideration in steel construction where impact loads are significant and structures subjected to earthquake loading which is dynamic in nature. For low toughness cases it is determined from the area under-stress curve.

14.2.5 Hardness

In general, hardness implies to the resistance to deformation which is both elastic and plastic. For metals the hardness is a measure of their resistance to permanent or plastic deformation. Depending upon the form of the indenter forced on to the surface and the manner in which the test is conducted, the methods for determining the hardness of a metal are classified as follows.

1. **Brinell hardness** This is widely accepted and standardised indentation-hardness test involving ball penetrators of different diameters which are pressed with a certain load onto a smooth and even surface for a certain amount of time (10 to 15 seconds) as illustrated in Fig. 14.2. For metal surface, a 10 mm diameter steel ball is used with a load of 3,000 kgf (29,400 N). For soft metals, the load is reduced to 500 kgf to avoid too deep an impression, and for very hard metals, a tungsten carbide ball is used to minimise distortion of the indenter. The load is applied for a standard time, usually 20 second, and the diameter of the indentation is measured with an eyepiece or a low power microscope after removal of the load.



(a) Hardness testing machine (b) Brinell method indent (c) Vickers method indent

Fig. 14.2 *Concept of hardness testing indentation*

Hardness is expressed as a number obtained as the ratio of the applied load in N to the surface area of the indentation formed in mm^2. Thus, the units of the Brinell hardness are MPa (N/mm^2). As a typical example, Brinell hardness number (BHN) is given by the ratio of the applied load to the spherical area of the indentation, i.e.,

$$BHN = \frac{F}{\pi\left(\frac{D}{2}\right)\left[D - \sqrt{D^2 - d^2}\right]}$$

where F is the load, D and d are the ball and indent diameters, respectively.

2. **Vickers hardness** Vickers method is similar to the Brinell method, but it uses a *diamond penetrator in the shape of a pyramid with a square base* and an angle of 136° for the entire hardness range. Thus, the indentation looks like a concave (negative) pyramid with a square base. The average length L of the two diagonals of the indentation is measured with an accuracy of ± 0.002 mm. As in the case of Brinell method, the Vickers hardness value VH (V = Vickers, H = hardness) is the ratio between the applied test load and the surface of the indentation. Thus, the Vickers test hardness value (VHN) as given by

$$VHN = 0.102 \times \frac{F}{A} = \frac{0.189\ \mathrm{F}}{L^2}$$

Vickers hardness is reported in a format which includes test conditions. For example, reported Vickers test hardness value of 190 VH50/30 means that Vickers hardness number is 190, at test load 490.5 N (50 kgf = 50 × 9.81= 490.5 N) and test time 30 seconds. The BHN and VHN for steel lie in the range from 150 to 190.

The Vickers method is especially suitable for tests of small and thin parts or components with any kind of surface treatment. The Vickers method is also suitable for materials with different layers. Increasing test loads are applied subsequently to determine the thickness of certain surface layers, e.g., after nitration hardening. However, the Vickers method should not be used for heterogeneous materials, like cast iron.

3. **Rockwell hardness** Principally Rockwell hardness testing is similar to Brinell hardness testing, but Rockwell hardness tester provides direct reading of hardness number on a dial provided with the machine. It differs only in diameter and material of the indentor and the applied force. The test method consists of applying a specific load and then measure the depth of the resulting impression. The indenter may either be a steel ball of some specified diameter or a spherical diamond-tipped cone of 120° angle and 0.2 mm tip radius. A minor load of 10 kg is first applied, which causes a small initial penetration to seat the indenter and remove the effects of any surface irregularities. Then, the dial is set to zero and the major load is applied. Upon removal of the major load, the depth of indent is measured while the minor load is still on. The hardness number may then be read directly from the relevant scale.

There are many scales having different combinations of load and size of indentor. In testing harder materials, hard cast iron and many steel alloys, an indentor having 120° diamond cone at the tip is used with load up to a 150 kgf and the hardness is read on the "C" scale and is reported as RHC which means Rockwell Hardness measured on scale C. For soft materials such as copper alloys, soft steel, and aluminium alloys a 1/16 "(1.6 mm) diameter steel ball is used with a 100 kgf load and the hardness is read on the "B" scale. For still softer materials, the test load may be 60 kgf. For example, consider the test report 50 RHB; this report indicates that the material has a hardness reading of 50 on the B scale. *Rockwell hardness testing is not normally used for structural steels*.

The important mechanical properties of steel produced in India are summarised in Table 14.1. The UTS listed in the table represents the minimum guaranteed ultimate tensile strength.

Table 14.1 *Mechanical properties of some typical structural steels*

Type of steel	Designation	UTS (MPa)	Yield strength (MPa) *Thickness (mm)*			Percentage Elongation, at Gauge Length, $L_o = 5.65\sqrt{Ao}$, mm	Internal Bend Diameter, mm
			<20	20–40	3*t*		
Ordinary structural steel	E 165	290	165			23	2t
	E 170	330	170			23	3t
	E 215	370	215			23	3t
Standard structural steel	Fe 410 A, B, C	410	250	240	230	23	–
	Charpy V-notch values for quality grade B and C, Joules (min):						27
Micro alloyed high strength steel			<16	16–40	41–63		
	Fe 440	440	300	290	280	22	–
	Fe 540	540	410	390	380	20	–
	Fe 590	590	450	430	420	20	–

Notes: (i) *t* is the thickness of the test piece and (ii) MPa = N/mm^2 = MN/m^2 = 0.102 kgf/mm^2 = 144.4 psi

The ordinary or low tensile structural steel, also called general-purpose steel, referred in Table 14.1 is normally used for door and window frames, window bars, grills, steel gates, hand railing, building hardware, fencing post and tie bars. The below test procedures may be used for plain round, square and flat bar of all sizes, angles up to 50 × 50 × 10 mm, tee section up to 100 × 100 × 12 mm, channels up to 100 × 60 × 12 mm.

14.3 TEST PROCEDURES

For product design, it is necessary that the basic mechanical properties of material to be used in product are known in advance. To this end, the producers or supplier need to specify the minimum requirements which their products meet. The tests are conducted to ensure that products conform to the material's specified properties and meet grading requirements.

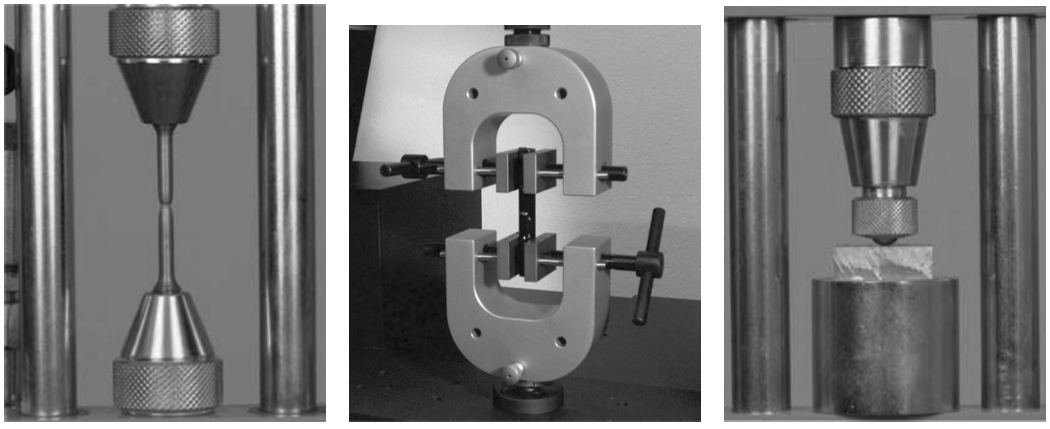
14.3.1 Testing Equipment

Tension testing of material validates tensile properties such as yield and proof strength, reduction of area and elongation. Testing systems need to ensure accurate and consistent results. The test machine, its gripping and measurement systems must be unaffected by contamination from the oxide scale on the surface of hot rolled specimens. Software used to control testing must incorporate sophisticated algorithms to determine test results from a wide variety of stress/ strain curves.

For mechanical tests on materials, it is preferable to have a single test platform universal test machine (UTM) with top-mounted hydraulic actuator (this will enable provision of loading area at ground level) of capacity of 1500 kN which can accommodate rebar specimens ranging in length from 400 mm to 700 mm. This machine will be adequate for testing rebar samples up to 60 mm rebars (all grades). These universal testing machines can perform tension, compression and bend tests on the material samples simply by adding compression adapters and bend fixture to the tension grips. A typical universal testing machine is shown in Fig. 14.3.

For the tension test hydraulic Vee-shaped wedge grips are preferable because the initial clamping force will reduce the grip slippage on the uneven surface of the rebar with ribs. Currently, machines with automatic extensometer to measure strain over adjustable gauge length from 10 mm to 300 mm (required for most rebar applications) are available. Typical attachments for universal testing machine are shown in Fig. 14.4.

Fig. 14.3 *Typical universal testing machine*



(a) Tensile test attachments (b) Hardness test attachments

Fig. 14.4 *Typical attachments for universal testing machine*

14.3.2 Gauge Length for Test Specimen

For specimens that have the same cross-sectional area throughout such as tubes, rods and rectangles, the gauge length is determined by simply measuring the distance between the grip faces. For the most commonly used dog-bone specimens illustrated in Fig. 14.5, the non-uniform shape often introduces errors in the gauge length measurement. However, in a dog-bone specimen, most of the stretching occurs within the narrow region and not in the tabs because they have a larger cross-sectional area; the narrow length is taken as the gauge length. For accurate strain measurement an extensometer can be used.

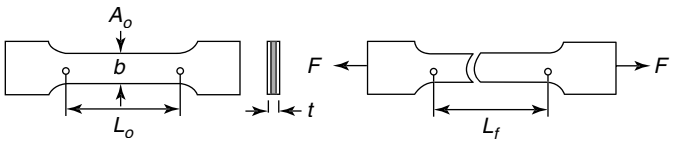


Fig 14.5 *Standard tensile test specimen*

14.3.3 Preparation of Test Samples

The test samples are cut from the locations in the product so as to provide the clearest possible information regarding properties in the cross section. The recommended locations for cutting the test specimens for plates, sections and bars are given in IS: 2062-2006. Alternatively, in case of sections, the samples may preferably be taken from the web. The following codal guidelines shall be followed:

1. Wherever practicable, the rolled surface of the steel shall be retained on the two opposite sides of the test samples.
2. In case of flat samples for tensile test, both surfaces are normally retained on the test specimen for strips up to 32 mm thick. At least one rolled surface shall be retained on rectangular specimen taken from plate exceeding 32 mm in thickness. Round test samples are permitted, but should only be adopted for thickness exceeding 28 mm.
3. In case of flats up to 16 mm thick, the test specimen shall undergo, if possible, no machining whatever, prior to use as a test piece. If this is not possible, the test sample shall undergo the minimum amount of machining.
4. Bars below 28 mm shall be tested without machining. In case of bars having diameters or thickness between 28 mm and 71 mm, the bars may be symmetrically reduced by machining.
5. In case of strips, sections and flats, bend tests shall be carried out on rectangular test samples which as far as possible should be of the full thickness of the product. In case of plates, sections and flats exceeding 28 mm in thickness, it is permissible to remove metal from one side of the test sample before using it as a test piece. The rolled surface of the test piece shall be on the outer side of the bend during the test.
6. Test samples shall be cut in such a manner that the deformation is avoided as far as possible. If shearing or flame-cutting is employed, an adequate allowance shall be made for removal by machining.
7. Test samples shall not be subjected to heat treatment unless the material from which they are cut is similarly and simultaneously treated with the material before testing. Any slight straightening of test samples which may be required shall be done cold.

Number of Tensile Tests

1. Plates, Sections (Angles, Tees, Beams, Channels, etc.) and Flats

   (a) For lot/heat size up to 100 tonnes—2 samples
   (b) For lot size between 100-200 tonnes—3 samples
   (c) For lot size over 200 tonnes—4 samples

   One additional tensile test shall be made from the material in each class of product for each variation in thickness of 6 mm.
2. Bars (Round, Square and Hexagonal)
   One tensile test shall be made from finished product for every 40 tonnes or part thereof.
   One additional tensile test shall be made for each variation of 3 mm above or below the diameter or thickness of the bar ordered.

14.3.4 Cross-Sectional Area and Mass of Deformed Bars

The nominal size (diameter) of a deformed bar is equal to that of a plain round bar having the same mass per meter length. For the purpose of checking the nominal mass, the density of steel shall be taken as 0.00785 kg/mm^2 of cross-sectional area per meter run.

Table 14.2 *Cross-sectional area and mass of deformed bars of nominal diameter*

Nominal size ,	mm	8	10	12	16	18	20	22	25	28	32	36
Sectional area,	mm^2	50.3	78.6	113.1	201.2	254.6	314.3	380.3	491.1	616.0	804.6	1018.3
Mass per metre run,	kg	0.395	0.617	0.888	1.58	2.00	2.467	2.985	3.855	4.836	6.31	7.99

14.4 TORSION TEST OF MATERIALS

Torsion is a variation of pure shear wherein a component is twisted; the torsional force produces a rotating displacement about the longitudinal axis at one end of the member relative to the other end. The stress distribution in a torsion member is non-uniform; it varies from zero at the centroidal longitudinal axis to a maximum at the outer fibers.

In many engineering applications, such as torque transmission shaft, twisted drills and springs, the torsional behavior critically governs the design. In many cases, the maximum torsional stress is the limiting factor in design while in others; it may be the maximum permissible angle of twist. Moreover, structural applications such as bridges, vehicle parts, airplane fuselages and boat hulls are randomly subjected to torsion.

In order to study the response of materials under a torsional force, the torsion test is performed by mounting the specimen onto a torsion testing machine typically shown in Fig. 14.5, and then applying the twisting moment till failure. Normally, the test specimens used are of a cylindrical rod type since the stress distribution across the section of the rod is of the simplest geometry, which facilitates the calculation of the stresses.

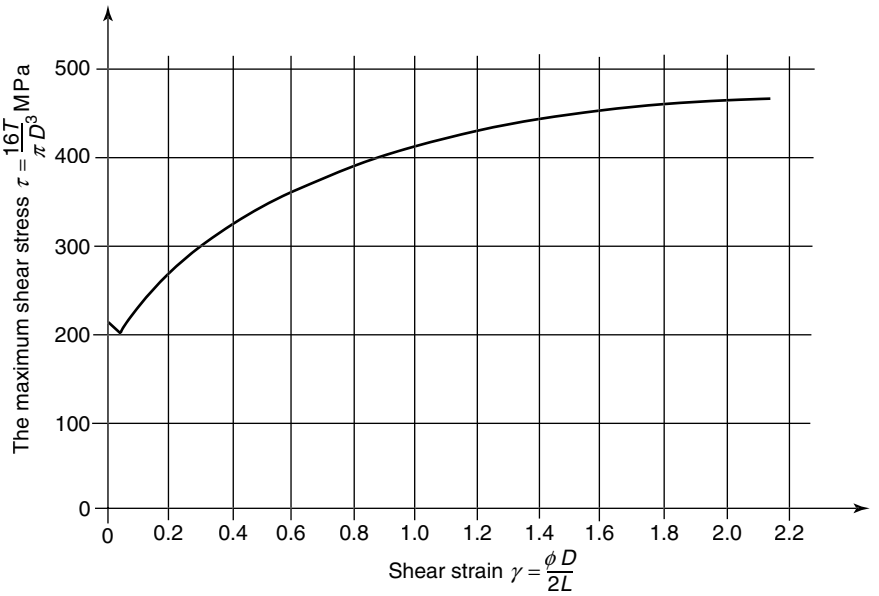


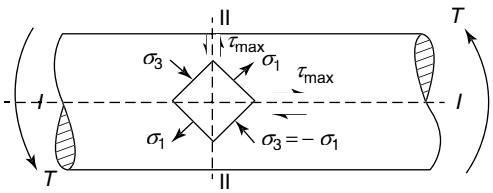
Fig. 14.6 *Relationship between shear stress and shear strain*

The shear stress due to the applied torque and resulting shear strain are measured and plotted as shown in Fig. 14.6. It should be noted that initially the test specimen deforms elastically and then plastically similar to the case of the tension test specimen. During the initial stage of elastic behavior there is a linear relationship between torque and twist with its slope representing the shear modulus, the modulus of rigidity, G. Beyond the proportional limit, specimen deforms in a plastic manner and the relationship between the torque and the twist is no longer linear. However the determination of the proportional limit carried out using a torsional specimen of a thin-wall tube type will provide a more accurate value in comparison to that obtained from a cylindrical rod-type specimen. Since the stresses vary across the section of the specimen from the center toward the peripheral of the specimen, the reduced effect of stress distribution in the thin-walled specimen is therefore beneficial for the calculation of the stress.

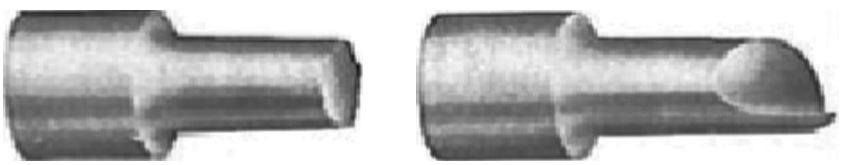
14.4.1 Types of Torsion Failures

Torsion failures are different from tension failures and normally occur with little deformation or elongation. The characteristic of the fracture surface in torsion is related to the state of stress at the point on the surface of specimen. The state of stress at the point on the surface of specimen can be represented as shown in Fig. 14.7. It can be seen that the maximum shear stresses exist along two planes, which are perpendicular to each other. One is perpendicular to the longitudinal axis I-I and another is aligned parallel to the longitudinal axis I-I. The principle stresses σ_1 and σ_3 are inclined at 45° to the longitudinal axis and have their magnitudes equal to those of the shear stresses. The principle stress σ_1 is tensile while the principle stress σ_3 is compressive. The intermediate stress σ_2 is zero under torsion.

Depending upon the relative magnitude of principle stresses, the torsion failures can be (a) ductile failure due to the shear stresses and (b) brittle failure due to the tensile stresses. The former produces the fracture surface along the plane of the maximum shear stress and more frequently normal to the longitudinal axis as seen in Figs. 14.7(a) and (b). The later exhibits the fracture planes normal to the directions of the tensile stresses, which are 45° to the longitudinal axis. However, the fracture characteristic is reported to be associated with the hardness of the material.



(a) State of stress at the point on the surface



(b) Ductile shear failure (c) Brittle shear failure

Fig. 14.7 *Types of failure of rod specimens under torsion*

14.5 COMPRESSION TEST OF MATERIALS

Stress-strain curves for specimens subjected to compression have different shapes from those for specimen under tension. Ductile materials such as steel, aluminum, brass, etc., have proportional limits in compression

very close to those in tension; hence the initial regions of their compression stress-strain diagrams are similar to the tension diagrams. However, when yielding begins, the behaviour is quite different. In a tensile test, the specimen is stretched, necking may occur, and specimen ultimately fractures after strain hardening. When a small specimen of ductile material is compressed, it begins to bulge outward laterally and assumes barrel shape. With further increase in load, the specimen flatten outs resulting in increased cross sectional area, thus offering increased resistance to further shortening, i.e., the stress-strain curve shifts upward. These characteristics are typically illustrated in Fig. 14.8 for a ductile material. Brittle materials in compression typically have an initial linear region followed by a region in which the shortening increases at a higher rate than does the load. Thus, for the specimen under compression the stress-strain curve has a shape that is similar to the shape of the tensile curve. However, brittle materials usually reach much higher ultimate stresses in compression than in tension. Also, unlike ductile materials in compression, brittle materials actually fracture or ruptures at the maximum load. The tension and compression stress-strain diagrams for a particular type of cast iron are illustrated in Fig. 14.9.

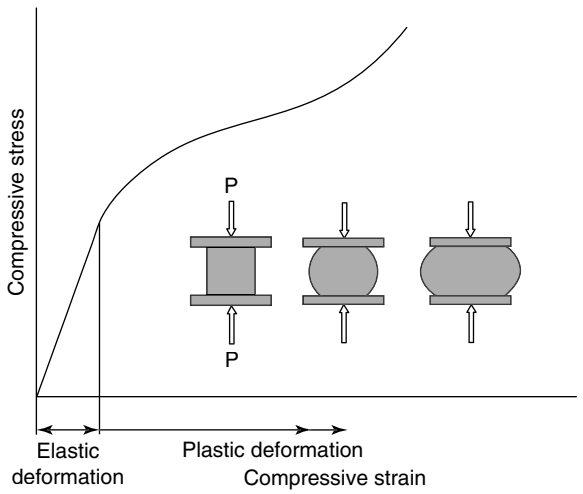


Fig. 14.8 *Typical stress-strain curve for ductile materials in compression*

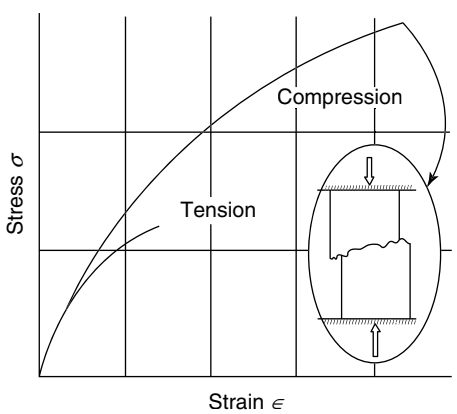


Fig. 14.9 *Tensile and compressive stress-strain curves for brittle materials*

14.6 BENDING TEST

Bend or flexure testing is generally performed on spring steels and brittle materials whose behaviour are linear just before the failure such as concrete, stone, wood, plastic, glass and ceramic. Smooth rectangular specimens are generally used for bend testing under three-point or four-point bend arrangements as illustrated in Figs. 14.10(a) and (b), respectively. Within the elastic range, brittle materials show a linear relationship between load and deflection where yielding occurs on a thin layer of the specimen surface at the mid-span. This in turn leads to crack initiation and finally to specimen rupture.

A ductile material on the other hand provides load-deflection curve which deviates significantly from a linear relationship before failure takes place. Therefore, the bend test to failure is not suitable for ductile materials due to difficulties in determining the yield point of the material in bending and the obtained stress-strain curve in the elastic region may not be linear. As a result, the bend test is appropriate for testing of brittle material whose stress-strain curve show approximately linear elastic behaviour just before its failure.

The elastic modulus of a material obtained from the bend test is generally close to the elastic moduli obtained from tension and compression tests. There are several factors that affect the elastic moduli, which include the following:

1. Elastic and plastic deformation at the rollers at the supports or the loading points might not be sufficiently small in comparison to the beam deflection to qualify as point loads.
2. In short specimen tested in bending, deformation due to shear stress may be insignificant which is neglected in the beam theory.

Materials might have different elastic moduli under bending, tension and compression. Therefore, the elastic moduli in bending should be identified to avoid any confusion in the interpretation of the mechanical behaviour of the material.

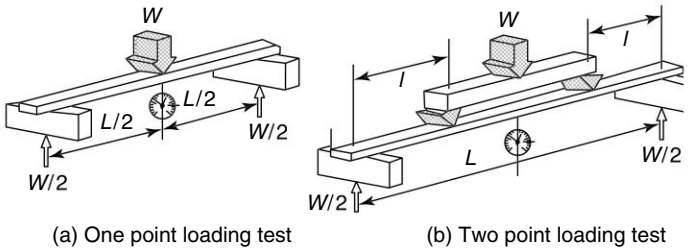


Fig. 14.10 *Three-point and four-point bending test arrangements*

14.6.1 Applications

The bending tests are generally

1. Used as a direct means of investigation of the behaviour under bending loads, particularly for determining limits of structural stability of structural beams of various shapes and sizes.
2. Performed to determine bending strength, yield strengths and bending stiffness of beams.
3. Used to determine resilience and toughness of materials in bending.
4. Used as quality control measure for brittle materials and not suitable for determining ultimate strength of ductile materials.

14.6.2 Failure Modes

1. A beam may fail by yielding of extreme fibres.
2. In long span beams compression fibres act like those of a column and may fail by buckling.
3. In webbed members, excessive shear stress may occur and stress concentrations may build up in parts of beam adjacent to supports.

14.7 FATIGUE TEST

14.7.1 Fatigue

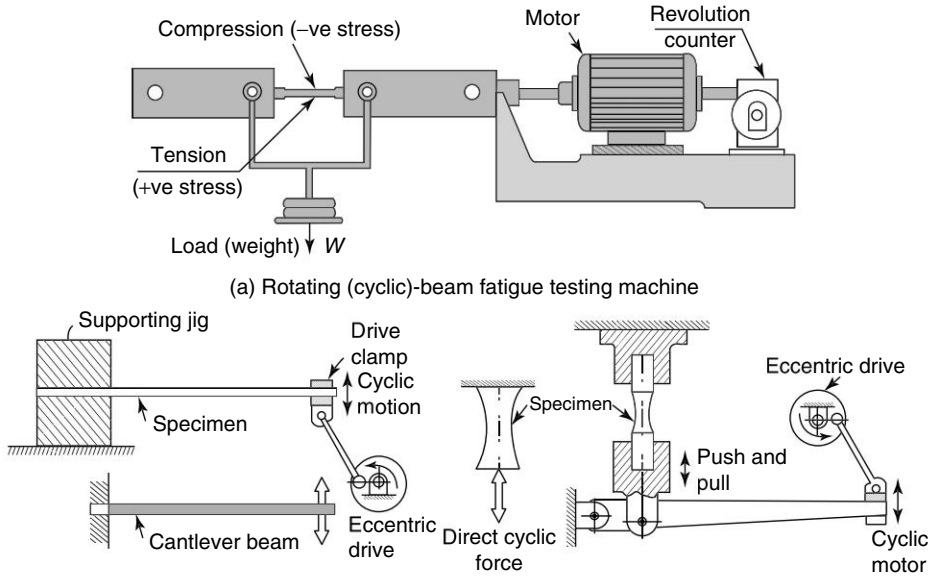
In many applications, materials are subjected to vibrating or oscillating forces. The behaviour of materials under such load conditions differs from the behaviour under a static load. When a material product is subjected to repeated load cycles (fatigue) in service, it cracks or fails as a result of application of repeated stress cycles of magnitude less than the ultimate strength of the material. The product designers are generally faced with problem of predicting *fatigue life*, which is defined as the total number of cycles to failure under specified loading conditions. Fatigue failures generally involve three stages namely (i) *crack initiation*, (ii) *crack propagation* and (iii) *sudden fracture*. Fatigue failures are brittle in nature even in normally ductile materials with little gross plastic deformation occurring prior to fracture. The failure occurs by the initiation and propagation of cracks and the fracture surface is ordinarily close to perpendicular to the direction of maximum tensile stress. Fatigue failures often occur suddenly with catastrophic results. Commonly used industrial materials such as the metals, polymers and ceramics are all susceptible to sudden fatigue failures.

Fatigue testing provides data required to predict the in-service life of materials; it consists in applying a cyclic loading to the test specimen till failure and examining its performance under test conditions. The load application is either a repeated application of a fixed load or simulation of in-service load condition. The load application may be repeated millions of times at the rate up to several hundred times per second.

Servo-hydraulic fatigue testing machines are available for conducting fatigue tests. This fatigue testing machine consists of a hydraulically operated actuator fitted into a high stiffness load platform to apply the load to the specimen. A hydraulically operated system can provide both high loads and high cyclic frequencies.

14.7.2 Types of Fatigue Test

Applied stresses may be axial (tension-compression), flexural (bending) or torsional (twisting) in nature; typical machines are illustrated in Fig. 14.11. Reciprocating (cyclic) bending machines are illustrated in Figs. 14.11(a) and (b); whereas, the reciprocating direct force generating mechanism is shown in Fig. 14.11(c). The reciprocating motions to achieve a non-zero mean stress are developed by rotating crank with respect to the motor.



(a) Rotating (cyclic)-beam fatigue testing machine

(b) Cyclic bending (hogging and sagging bending) (c) Cyclic axial force (tension and compression)

Fig. 14.11 *Reciprocating (cyclic) bending and direct-force fatigue testing machines*

In general, there are three possible fluctuating stress-time modes. The simplest is completely *reversed constant amplitude* where the alternating stress varies from a maximum tensile stress to a minimum compressive stress of equal magnitude. The second type, termed as *repeated constant amplitude*, occurs when the maxima and minima are asymmetrical relative to the zero stress level. Lastly, the stress level may vary randomly in amplitude and frequency which is merely termed as *random cycling*. There are two types of fatigue tests:

1. **Low cycle fatigue** Low Cycle Fatigue (LCF) simulates the service environment of many critical metal components subjected to low frequency and large loads/strains. LCF typically involves large deformations, thereby results in an accumulation of damage on the specimen. The LCF environment is typically encountered in turbine blades (heat-up/cool down cycling) and other power generation equipment subject to thermal and/or mechanical cycling (i.e., pressure vessels, piping, etc.).
2. **High cycle fatigue** High Cycle Fatigue (HCF) environment results from vibratory stress cycles at frequencies which can reach thousands of cycles per second and can be induced from various mechanical sources. It is typical of aircraft gas turbine engines and has led to the premature failure of major engine components (fans, compressors, turbines). While LCF involves bulk plasticity where stress levels are usually above the yield strength of the material, HCF is predominantly elastic, and stress levels are below the yield strength of the material.

14.7.3 Fatigue Test Specimens

Component testing and/or full-scale prototype tests are sometimes carried out on fatigue-critical structures. For fatigue testing at the basic material level the commonly used test specimen types are shown in Fig. 14.12.

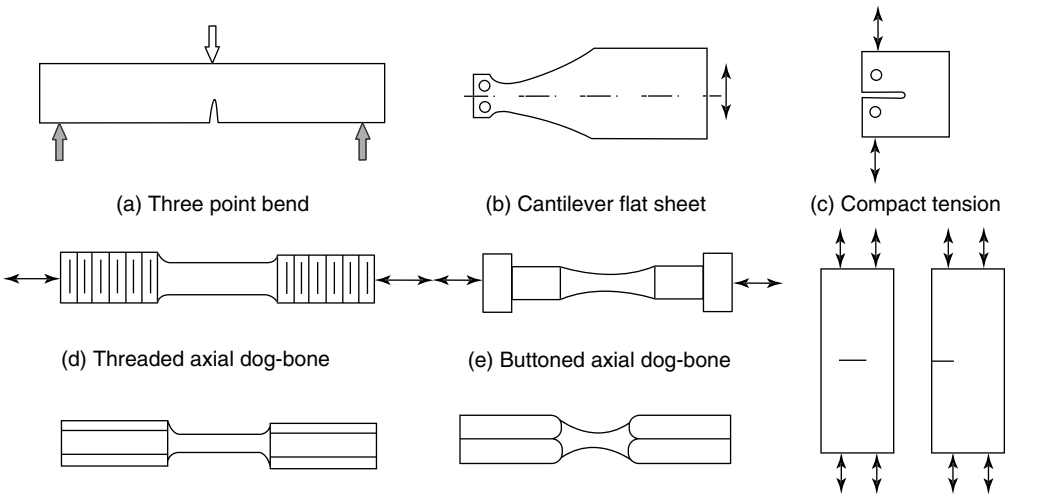


Fig. 14.12 *Commonly used fatigue specimens for testing of basic materials*

14.7.4 S-N Curve

Most fatigue tests are conducted at 'Constant Amplitude Stress Level', i.e., the maximum and minimum stresses are constant for each cycle of a test. The data of fatigue testing are expressed as curves applied stress, S, versus number of cycles to failure, N, generally referred to as a material's S-N curve. S-N curves are generally plotted on semi-log or log-log graph paper where each plotted point represents the results of a single test specimen. The fatigue test is normally conducted using at least 8–12 specimens in order to provide sufficient information for the interpretation of fatigue behaviour of the tested material.

The S-N curve can be used to determine the fatigue life of the material subjected to cyclic stress. Higher the applied cyclic stress, lower is the number of cycles to failure. At the fatigue endurance limit, there will be a certain value of the cyclic stress where specimen failure will not occur. This cyclic stress level is called the fatigue strength. Thus the endurance limit is the stress level below which the material will theoretically withstand an infinite number (~10^8) of stress cycles without fracture. The most important part of the curve is often the portion to the right of the bend (or 'knee') in the curve that identifies the *endurance limit* or the *fatigue limit*. Fatigue tests tend to be time consuming and expensive; each data point represents many hours of testing.

The non-ferrous alloys such as some alloys of aluminium, magnesium and copper normally do not indicate the fatigue endurance limit. The slope can be found gradually downwards with increasing number of cycles to failure and unlike ferrous alloys no horizontal line is seen. In such a case, the fatigue strength is generally defined at a stress level where the number of cycles to failure reaches 10^7 or 10^8 cycles.

14.7.5 Fatigue Testing Methods

A number of fatigue test data formats have been developed to achieve specific objectives namely: (i) Life distribution at a constant stress level, (ii) Strength distribution at a constant life and (iii) Design data at a minimal cost and time, etc.

The specific procedure followed should be carefully selected based on the data requirements. The most commonly used Standard Method of fatigue testing is followed when only a few test specimens are available. In this method a low number of tests (1 to 3) are conducted at a set of stress amplitudes that span the expected stress range of the material; σ_a and N are recorded for each specimen. Run-outs specimens which do not fail after 10^8 cycles are rerun at a higher stress level to maximize the data obtained from the limited specimen set.

14.7.6 Analysis of Results

Although most fatigue is not actually of constant amplitude, but methods have been developed for utilising constant amplitude S-N results to predict failure under varying load histories. This approach to fatigue assessment is referred to as '**Linear Cumulative Damage**' approach.

The basic cumulative damage approach is based on *Miner's Law* which states that damage is cumulative, and that each stress cycle contributes to damage as a function of the number of cycles to failure for that cycle amplitude. Linear cumulative damage approach neglects any sequence effects, (e.g., low amplitude followed by high amplitude vs. high amplitude followed by low amplitude) that may change fatigue life.

Thus, the damage (D) caused by one cycle is expressed as; $D = 1/N$

The damage produced by "n" cycles at a given stress level is given by, $D = n/N$

The cumulative damage for a set of cycles over a range of stress levels can be expressed as

$$D = \sum D_i = \sum n_i / N_i$$

where n_i represents the number of cycles at stress level 'i' and N_i represents the number of cycles that will cause failure at stress level 'i'.

14.7.7 Factors Influencing Fatigue Properties of Materials

In addition to the characteristics of the applied stresses such as maximum stress, mean stress and stress ratio, the factors like stress concentration, size of specimen, surface condition, combined stresses, cumulative fatigue and change in stress level, metallurgical variables, corrosion and temperature, significantly affects the fatigue behaviour of the materials. The fatigue crack initiation generally starts near the surface; rough surfaces are therefore undesirable due to stress concentration which accounts for further fatigue crack propagation and eventually lead to global failure. Corrosive environment and high service temperatures are reckoned to have

negative effects on fatigue properties of the materials as they accelerate faster rates of both fatigue initiation and propagation.

14.8 CODES FOR TEST PROCEDURES

The tests described in this section are:

1. Rockwell hardness test (IS: 1586-2000)
2. Brinell and Vickers hardness tests (IS: 2281-2005 RA-2011)
3. Impact tests (Charpy V-Notch and Izod tests) (IS: 1757-1988 and IS: 1598-1977 RA-2009))
4. Tensile Test (IS: 1608-2005 RA-2011)
5. Compression test (IS: 13780-1993 /ISO 4506-1979)
6. Bend test for metal products (IS: 1599-1985 RA-2011)
7. Shear test (IS: 5242-1979 RA-2006)
8. Beam or flexural bending test
9. Torsion test and
10. Fatigue test (S: 5074-1969 RA-2001 and IS: 5075-1985 RA-2001)

For all the tests described in this section, the method as specified in relevant ISO standard may also be followed as an alternate method. The final value, observed or calculated, expressing the result of a test or analysis, is rounded off in accordance with IS: 2-1960. The number of significant places retained in the rounded off value should be the same as that of the specified value in the code.

14.8.1 Retests

If any of the test specimens does not give specified results, additional tests shall be carried out at random on the same lot as per the relevant code. The retests shall conform to the requirements of the relevant standard; otherwise, the lot shall be rejected.

EXPERIMENT NO. 1: Rockwell Hardness Test

Objective

To measure the Rockwell hardness of ferrous and non-ferrous metals such as hard alloy, carbon steel, alloy steel, cast iron, brass, aluminium, etc.

Theory and Scope

Hardness may be defined as resistance to penetration or resistant to abrasion. The test involves determination of the depth of dent on the specimen caused by the penetration of certain indenter under certain standard load.

In Rockwell hardness test, an indenter is forced into the surface of a test specimen in two operations. In the first operation, a small initial or datum (minor) load of 10 kg is applied to the penetrator to take care of the roughness of the surface of the specimen; whereas in the second operation a major or standard load (60,100,150 kg) is added. The permanent increase in the depth of penetration from the depth reached under the datum load due to the standard load is measured after removing it. The reading on dial which is inversely proportional to the depth of penetration represents the hardness of the material; so that the greater the penetration, the lower the hardness number and vice versa. The indenter used is either a steel ball or diamond cone having an angle of 120 degrees made of black diamond. The indentor is selected depending on the nature and condition of the material. This indentation test which is used on smaller specimens and harder materials is conducted as per IS 1586:2000.

Rockwell hardness testing machine is more extensively used because of its simple testing procedure, direct reading of hardness number. This machine can be used to test materials like hard steel, mild steel, aluminum, cast iron, brass, etc. The indentator or penetrator is either a steel ball or diamond cone with slight rounded point. A steel ball is used with a load of 100 kg to test softer materials like brass and hardness number is found on B scale. A diamond cone is used with a load 150 kg to test harder materials like hard steel and hardness number is found on C scale.

Apparatus

Rockwell hardness testing machine; Ball and Brale (diamond) Indentors; 0.0 Emery paper.

Description of Apparatus

Rockwell hardness testing machine Rockwell hardness testing machine impacts a standard load on a steel ball or Brale (diamond) indentor. The depth of indentation is recorded on a dial gauge in terms of Rockwell hardness numbers. The dial gauge of the machine is provided with red and black scales with a long pointer. Red scale is used for hardness readings obtained with Ball indentor and black scale is used for Diamond indentor. Hardened steel is tested on C scale with diamond indentor and 150 kg major load. Softer materials are tested on the B scale with 1.5875 mm diameter steel ball and 100 kg major load. Application of major load is preceded by the minor load of 10 kg. Typical Rockwell hardness testing machines are shown in Fig. 14.13.

Indentors Brale indentor also called *black diamond indenter*, a conical-shaped diamond penetrator with 120 degrees apex angle and 0.2 mm radius tip is used for hard steel and cast iron. A hardened steel ball 1.5875 mm diameter is used for non-ferrous metals.

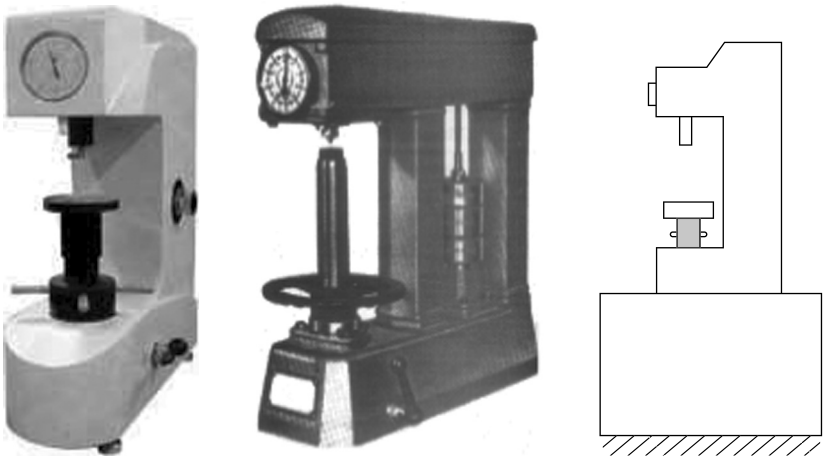


Fig. 14.13 *Typical Rockwell hardness testing machines*

Procedure

Step 1: Select standard load of 100 kg or 150 kg to be applied to the specimen depending on the nature of the material to be tested.

Step 2: Select the penetrator to be used corresponding to the load selected in Step 1.

Step 3: Remove any oxide scale and foreign materials from the surface of the specimen by rubbing with Emery paper.

Step 4: Place the specimen on the hardened anvil of the machine and turn the hand wheel to move the anvil upwards till the surface of specimen just touches the indentor.

Step 5: Apply the datum or minor load of 10 kg to the specimen by rotating the hand wheel slowly until the smaller needle (pointer) on the dial reaches the red mark (dot); in some machines at this point the pilot lamp goes off.

Step 6: Actuate the lever or handle to apply major load of 100 kg for scale B and 150 kg for scale C to the specimen by rotating the hand wheel in about 5 to 8 seconds.

Step 7: On completion of penetration, remove the major load by pulling backward the loading handle to the original position; the initial load 10 kg will still be on the specimen.

Step 8: Read the position of the pointer on the C or B scale dial which gives Rockwell Hardness Number (RHN) of the specimen; record the hardness number read from the dial of the machine.

Step 9: Release the minor load of 10 kg by rotating the hand wheel anticlockwise and lowering the screw.

Step 10: Repeat the Steps 4 to 9 for five times on the same specimen selecting different points for indentation.

Step 11: Take average of five values of indentation of each specimen to obtain the hardness number of the material sample. Plot the bar charts separately for B and C Scales.

Step 12: Compare the results obtained from other hardness tests and draw conclusions.

Observations and Calculations

For different materials guidelines for selecting indentor, major load and hardness scale are listed in the observation table itself.

Material of the specimen is ……

Sr. No.	Material	Type of Indentor	Applied load, kg	Scale (S)	Rockwell Hardness (RH) No.		
					Trial No.	*RHN*	*Average RHS*
1.	Hard Steel	Diamond-Cone (120°)	150	RC	1 2 3 4 5	…. …. …. …. ….	
2.	Mild Steel	Steel ball 1.5875 mm radius	100	RB	1 2 3 4 5	…. …. …. …. ….	
3.	Brass	Steel ball 1.5875 mm radius	100	RB	1 2 3 4 5	…. …. …. …. ….	

Result

Rockwell hardness number for material is……

Precautions

1. Surface of the specimen should be well polished, free from oxide scale and any foreign materials.
2. Thickness of the specimen should not be less than eight times the depth of indentation to avoid the deformation to be extended to the opposite surface of specimen.
3. Indentation should not be made nearer to the edge of a specimen to avoid unnecessary concentration of stresses. In such a case, distance from the edge to the centre of indentation should be greater than 2.5 times diameter of indentation.
4. Rapid application of load should be avoided. Sudden application of load on the ball may increase the effective indentation force. Also rapidly applied load will restrict plastic flow of a material, which produces effect on size of indentation.
5. Give at least 10 seconds after the lever comes to rest position before recording the reading.

Informative Comments

The Rockwell hardness test utilises the depth of penetration of a test indenter under a standard load as a measure of hardness. The indentor is selected depending on the nature and condition of the material. The standard load of 100 kg is applied in about 5 to 6 seconds whereas the 50 kg load is applied in about 6 to 8 seconds.

Rockwell hardness test is also commonly used to determine the hardness of ceramic materials, plastics such as nylon, polycarbonate, polystyrene, and acetyl. The dial gauge indicates the hardness based on the difference in depth of indentation produced by the datum and standard loads.

For general reference, the combinations of major load and indentor for some materials are given in Table 14.3.

Table 14.3 *Selection of combination of major load and indentor for some materials*

Scale	Major load, kg	Indentor	Application materials
A	60	Cone	Cemented carbide, thin steel, hardened steel
B	100	Steel ball	Brass, copper alloys, soft steels, aluminum alloys, malleable iron
C	150	Cone	Mild steel, cast iron, malleable iron, deep case hardened steel

Viva-Voce Questions

1. What is hardness?
2. What are the different forms of hardness?
3. What are the uses of hardness test?
4. What are the different types of hardness test?
5. What are the indentors used in RB and RC scales?
6. Why is hardness test conducted instead of tension test?
7. Why major and minor load is used in Rockwell hardness test?
8. What precautions are taken in Rockwell hardness test?
9. What physical properties of a material can be estimated from a hardness test?
10. Why is Rockwell test preferred over Brinell Test?
11. How is the hardness values converted from one scale to another?
12. Where are the Vickers and Rockwell hardness test employed?
13. Why is a minor load applied before setting the Rockwell measuring dial?

Notes and Comments

EXPERIMENT NO. 2: Brinell and Vickers hardness Tests

Objective

To determine the Brinell and Vickers hardness for the given steel samples.

Theory and Scope

Hardness is the resistance of a material to localised deformation. The term can apply to deformation from indentation, abrasion, scratching, cutting or bending. The deformation considered is plastic or permanent deformation of the surface and is subject to different interpretations. The lack of a fundamental definition indicates that hardness is not a basic property of a material, but rather a composite one with contributions from the yield strength, work hardening, true tensile strength, modulus, and others factors. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be non-destructive tests when the marks or indentations produced by the test are in low stress areas.

Brinell hardness test provides the only possibility of determining the tensile strength of steel non-destructively as there is a close relationship between the Brinell hardness and the tensile strength (with a ratio of 3.53 for carbon steel, chromium steel and chromium-manganese steel; for chromium-nickel steel the ratio is 3.33). However, the Brinell method cannot be used for hardened steel, as it does not allow the use of diamond penetrator.

In Brinell hardness testing, steel balls are used as indentor. Diameter of the indentor and the applied force depend upon the thickness of the test specimen, because for accurate results depth of indentation should be less than 1/8th of the thickness of the test pieces. According to the thickness of the test piece increase, the diameter of the indentor and force are changed.

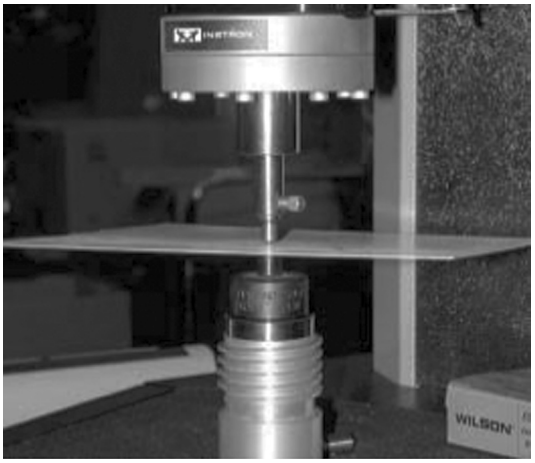


Fig. 14.14 *Vickers cum Brinell hardness testing machine*

Apparatus

Brinell cum Vickers hardness testing machine; Metal specimen and Brinell microscope.

Description of Apparatus

Hardness testing machine and indentors A hardness test can be conducted on Brinell testing machine using a cylindrical, cubical/prismatic, thick or thin metallic sheet specimens. The concept of Brinell hardness testing machine and types of indentation are illustrated in Fig.14.14. Configuration of typical hardness testing machine:

1. Ability to determine hardness up to 500 BHN.
2. Diameter of ball (as indentor), D = 1 mm, 2.5 mm, 5 mm, 10 mm.
3. Maximum application load = 3000 kgf.
4. Method of load application = Lever type
5. Capability of testing the lower hardness range = 1 BHN on application of $0.5D^2$ load.

Procedure

Step 1: Select suitable indenter; ensure that the indenter and anvil are clean. Insert the indenter in the indent holder of the machine.
Step 2: Clean the specimen surface by removing dust, dirt, oil and grease, etc., and place it on the anvil of the machine.
Step 3: Adjust the jack by hand operated wheel so that the specimen surface just touches the indenter.
Step 4: Press the loading button.
Step 5: Pull the load release lever so that the load is automatically applied gradually for minimum of 15 seconds.
Step 6: Remove the specimen from the anvil and locate the indentation so made.
Step 7: View the indentation through microscope and measure the diameter d by micrometer fitted on microscope.
Step 8: Repeat the test three times.
Step 9: Determine the Brinell hardness number (BHN) by dividing the applied testing load with the surface area of the spherical cup. This results in the formula:

$$BHN = (0.102)\frac{2F}{\pi\, D(D - \sqrt{D^2 - d^2})} = (0.102)\frac{F}{\pi Dh}$$

where F is the test load in N, D is the diameter of the ball penetrator in mm and d is the diameter of the indentation in mm, h is the depth of impression in mm. The units of BHN are MPa.

Observations and Calculations

Reporting Brinell Test Results

The test conditions should be reported along with the Brinell hardness number. In Brinell test report, the abbreviation BHN (Brinell hardness) follows the Brinell hardness number and is followed by the ball diameter in mm, the test load as per specification and the testing time in seconds, if it differs from the standard time (10–15 seconds). For example, a value reported as 60 BHN 10/14710/30 means that a Brinell hardness of 60 was obtained using a 10 mm diameter ball with a 14710 N load applied for 30 seconds.
Test piece material = ……

Sr. No.	Ball diameter, *D* mm	Load applied, *F* N	Diameter of indentation, *d* mm	F/D^2	BHN
1					
2					
3					

Average hardness of the material: …..BHN…./…../……

Precautions

1. The indenter and anvil should be clean and well seated.
2. The surface of specimen to be tested must be well prepared, clean and dry.
3. The surface should be flat and perpendicular to the indenter.
4. The thickness of the specimen should be such that a mark or bulge is not produced on the reverse side of the piece. It is generally recommended that the thickness be at least 10 times the depth of the indentation. The spacing between indentations should be three to five times the diameter of the indentation.
5. The speed of application of the load should be standardised. Variations in hardness can be appreciable in very soft materials unless the rate of load application is carefully controlled.
6. As far as possible F/D^2 should be maintained constant; the BHN generally will vary with the load. Over a range of loads the BHN reaches a maximum at some intermediate load.
7. When there is large number of indentations covering the surface; the surface should be not ground to re-use the specimen. The structure of the layers below the indentations (approximately eight times the indentation depth) are usually altered because of the load application and thus, measured results would not be accurate.

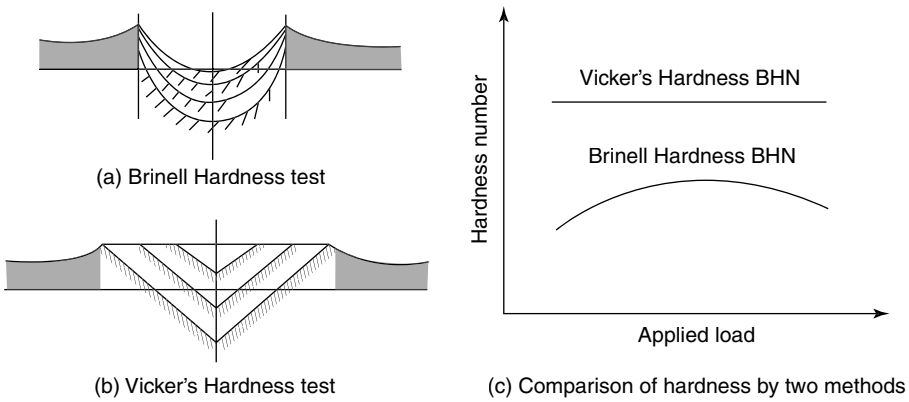


Fig. 14.15 *Comparison of Brinell and Vickers hardness test methods*

Informative Comments

In the Brinell Test, the ball diameter and applied load are constant and are selected to suit the composition of the metal. Further, the hardness of the ball should be at least 1.7 times than the test specimen to prevent permanent set in the ball.

As discussed earlier, Vicker's hardness test follows a procedure exactly an identical with that of Brinell test, but the steel ball is replaced by a diamond, having the form of a square—based pyramid with an angle of 136° between opposite faces. This is pressed into the flat surface of the test piece using a specified force, and the diagonals of the resulting indentation measured are using a microscope. the use of pyramidal or conical shape indenters overcomes the disadvantage which is faced in Brinell test, i.e., as the load increases, the geometry of the indentation's does not change.

Advantages

1. The Brinell method uses very high test loads generated by relatively simple and robust devices. Furthermore, the indentation can be measured with the help of a simple microscope or even with a measuring magnifier.
2. The Brinell value can be multiplied with a certain coefficient, which is specific for every material, to determine the material's tensile strength.
3. Vicker's test is advantageous as it is relatively convenient and can test harder material with smaller indentation which is less obtrusive or damaging.

Disadvantages

1. The Brinell main disadvantage of the Brinell hardness test is that the Brinell hardness number is not independent of the applied load; as the ball is pressed into the surface under increasing load the geometry of the indentation changes; however, size of impression may change as illustrated in Fig. 14.15(a).
2. In the Brinell method, the indentation is measured optically, which is liable to measuring errors. However, modern, automatic image evaluation computer systems are available which reduce this source of errors significantly.
3. Although high test loads are used, the surface must be well prepared in order to achieve the high accuracy needed for the measurement of the indentation.

Thus, Brinell testing is not a quick procedure and not suitable for routine tests. To avoid this disadvantage, the Rockwell method is often used with Brinell penetrators and Brinell test loads.

However, Rockwell method which is relatively quick method cannot be considered a genuine Brinell test; the converted results are not the same for each material (for instance, the conversion for steel is not the same as that for cast iron). Rockwell method should be preferred for routine tests or when there is no possibility for optical measurements. It also offers the advantage that the surface must not be prepared as well for optical analysis.

Table 14.4 *Brinell abbreviations, ball diameter and standard test loads (ISO 6506-1) Ball diameters: 10 mm, 5mm, 2.5mm and 1 mm*

Abbreviation	Ball diameter	Test load, N	Abbreviation	Ball diameter	Test load N
BHN 10/3000	10 mm	29420	BHN 2.5/ 187.5	2.5 mm	1839
BHN 10/1500	10 mm	14710	BHN 2.5/ 62.5	2.5 mm	612.9
BHN 10/1000	10 mm	9807	BHN 2.5/ 31.25	2.5 mm	306.5
BHN 10/500	10 mm	4903	BHN 2.5/ 15.625	2.5 mm	153.2

(continued)

Table 14.4 *contd.*

Abbreviation	Ball diameter	Test load, N	Abbreviation	Ball diameter	Test load N
BHN 10/250	10 mm	2452	BHN 2.5/ 6.25	2.5 mm	61.29
BHN 10/100	10 mm	980.7	BHN 1/30	1 mm	294.2
BHN 5/750	5 mm	7335	BHN 1/10	1 mm	98.07
BHN 5/250	5 mm	2452	BHN 1/5	1 mm	49.03
BHN 5/125	5 mm	1226	BHN 1/2.5	1 mm	24.52
BHN 5/62,5	5 mm	612.9	BHN 1/1	1 mm	9.807
BHN 5/25	5 mm	245.2			

Viva-Voce Questions

1. Define hardness. Why is hardness not a basic property of the material?
2. What are the different forms of hardness?
3. What are the units of Brinell hardness and Vickers hardness?
4. What are the limitation of Brinell hardness test and why?
5. What is the difference between Brinell hardness test and Vickers hardness test methods?
6. Why is the Rockwell hardness test not preferred for structural steel? Which is the hardest material and why?
7. Can the tensile strength of a material predicted if its hardness in known?
8. Which ball size is generally recommended for Brinell test?
9. What is difference between two test reports: 300 BHN 2.5/187.5 and 300 BHN 2.5/187.5/20? (*Hint:* In the first report load application time is 10–15 seconds).
10. For steel having Brinell hardness of 195 BHN x /3000, what is the tensile strength? (*Ans*: $195 \times 3.53 = 688.3$ MPa)

Notes and Comments

EXPERIMENT NO.3: Impact Tests (Charpy V-Notch and Izod Tests)

Objective

1. *To examine the energy absorbing characteristics of metal at a specified temperature using the Charpy, Izod, and Tension impact methods.*
2. *To evaluate the toughness or impact strength of structural steel by Notch-toughness or Charpy V-notch impact test as per IS: 1598 and IS: 1499 at room temperature.*

Significance

The Charpy impact test or Charpy V-notch test is a standardised high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. But a major disadvantage is that all results are only qualitative or comparative.

The apparatus consists of a pendulum hammer (swinging through a fixed distance) which fractures a standard size machined, notched specimen of material with one blow. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after fracture of specimen. The Charpy impact test results are expressed in kilo joules as an assessment of TOUGHNESS or energy absorption.

Theory and Scope

The test is performed with a pendulum-type single blow impact apparatus in which the specimen usually V-notched at the centre is supported at both ends as a simple beam and broken by a falling pendulum. The energy absorbed, as determined by the subsequent rise of the pendulum, is a measure of impact strength or notch toughness. A typical set-up for the test and standard specimens are shown in Fig. 14.16.

The Charpy test is most commonly used to evaluate the relative toughness or impact toughness of materials and is often used in quality control applications as it is a fast and economical test. It is used more as a qualitative or comparative test rather than a definitive test. However, this test can be used to determine the ductility of a material. If the material breaks on a flat plane, the fracture is brittle, and if the material breaks with jagged edges or shear lips, then the fracture is ductile. Usually a material does not break in either way; thus comparing the jagged to flat surface areas of the fracture will give an estimate of the percentage of ductile and brittle fracture.

Apparatus

Pendulum-type single blow impact testing machine; Vernier caliper, specimen setting fixture.

Description of Apparatus

Specifications of a typical Pendulum-type impact testing machine:
Impact capacity = 300 joule, scale readable to 2 joule;
Weight of striking hammer = 18.7 kg with striking velocity of 5.6 m/sec;
Swing diameter of hammer = 1600 mm;
Angle of hammer before striking = 160°;
Distance between supports for test specimen = 40 mm.

Specimens

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain which is the basis of energy computation.

Impact tests Impact tests are designed to measure the resistance to fracture of a material specimen to a suddenly applied force. Impact energy is a measure of the work done to fracture a test specimen. Different types of notched bar impact tests are carried out to determine the tendency of a material to behave in brittle manner. The most common methods of measuring impact energy are the Charpy and Izod tests.

The **V-notch specimen** geometry for the Charpy and Izod impact tests are shown in Fig. 14.16.
Size of specimen = $55 \times 10 \times 10$ mm
Type of notch = V-notch
Angle of notch = 45°
Depth of notch = 2 mm
Radius along the base = 0.25 mm

U-notch or keyhole notch A 5 mm deep notch with 1 mm radius at the base of the notch.

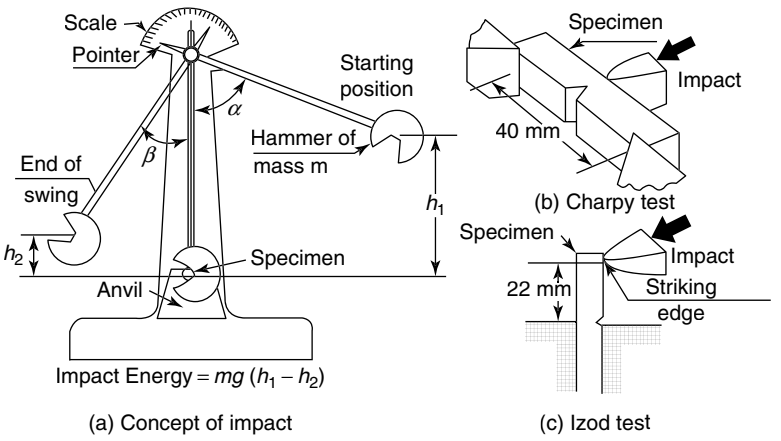


Fig. 14.16 *Schematic of Charpy Impact machine for (a) Charpy V-Notch and (b) Izod Tests*

Procedure

Step 1: Measure the dimensions of the specimen; and record the mass *m* of striker marked on its surface and length of the pendulum.
Step 2: Set the latching mechanism in the upper position.
Step 3: Lift the pendulum to its upper position and secure it with the safety latching mechanism.
Step 4: Release the pendulum with no specimen on anvil; record the reading which gives friction at the bearings, and air resistance offered to striker and pendulum.
Step 5: Using positioning gauge place the Charpy V-notch test specimen horizontally across supports on the anvil in the path of a pendulum with the notch facing away from the hammer. Make sure the specimen is centered within the anvil jaws and tightened firmly in the position.
Step 6: Slide the indicator pointer to the left until it indicates the maximum energy range on the upper Charpy-tension scale.

Step 7: Raise the pendulum arm to the right until it is firmly supported by the latching mechanism. *Caution: Make sure the safety latch is in the clear when raising the pendulum arm into this test position.*

Step 8: The test conductor shall then release the pendulum by pushing up on the release knob. The hammer will drop and attain a striking velocity of 16.8 ft/s, striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator will move and stop when peak swing through is registered, providing a direct reading of the energy absorbed by the specimen.

Step 9: Read the indicated value from the Charpy scale and record.

Step 10: Apply the hand brake when the pendulum has returned to its stable hanging vertical position.

Step 11: Remove the specimen from the testing area and examine the failure surface.

Step 12: Leave pendulum in the down hanging vertical position until another test is to be performed.

Step 13: Compute modulus of rupture and notch impact strength as follows:

Modulus of rupture = Rupture / effective volume of specimen

Notch impact strength = Energy absorbed/ effective cross-section area

Observations and Calculations

Type of material……
Source……
Date of sampling……..
Mass of striking hammer, m = ……. kg
Swing diameter of hammer, $2r$ = ……. mm
Angle of fall of hammer before striking, α = ……. °
Breath of cross section, b = ……. mm
Depth of cross section, d = ……. mm

Test condition		Angle of fall $\alpha°$	Angle of rise β^o	Computed absorbed energy, mgr (cos β – cos α)	Recorded absorbed energy (Scale reading)
(1) Test without specimen (2) Actual test with specimen					
Energy absorbed, E = (2) - (1)	joules				
Impact velocity $= \sqrt{2gr(1-\cos\alpha)}$	m/sec				
Notch impact strength $= \frac{\text{Energy absorbed}}{\text{effective sectional area}}$	joule/mm2				

Note: (i) Angle of fall α^o gives initial energy and (ii) Angle of rise β^o gives residual energy

The impact strength of given specimen = ……..joule/mm^2

Precautions

Since the impact tester is hazardous with the potential for injury, following safety considerations should be observed:

1. Prior to performing any operations, such as placement of specimens, pull the pendulum arm back and engage the safety latch restraining the movement of the pendulum arm.
2. All participants should remain behind the caution tape during the actual test.
3. It should be ensured that the safety latch is in the clear when raising the pendulum arm into the test position.
4. The test operator shall apply brake upon breakage of the test specimen. All other participants shall remain clear until the brake has brought the pendulum to a complete stop.
5. Safety glasses shall be worn by all participants.
6. The specimen should be prepared properly to the specified dimensions and placed firmly in its test position.
7. Ensure that the movable pointer in engaged with the fixed pointer after setting the pendulum.

Informative Comments

When the striker (pendulum hammer) hits the specimen, the material is subjected to elastic deformation, plastic deformation and finally, fracture in rapid succession. When the striker impacts the specimen, the specimen absorbs energy until it yields; at this point, the specimen begins to undergo plastic deformation at the notch. The test specimen continues to absorb energy and work hardens at the plastic zone at the notch. When the specimen cannot absorb more energy it fractures.

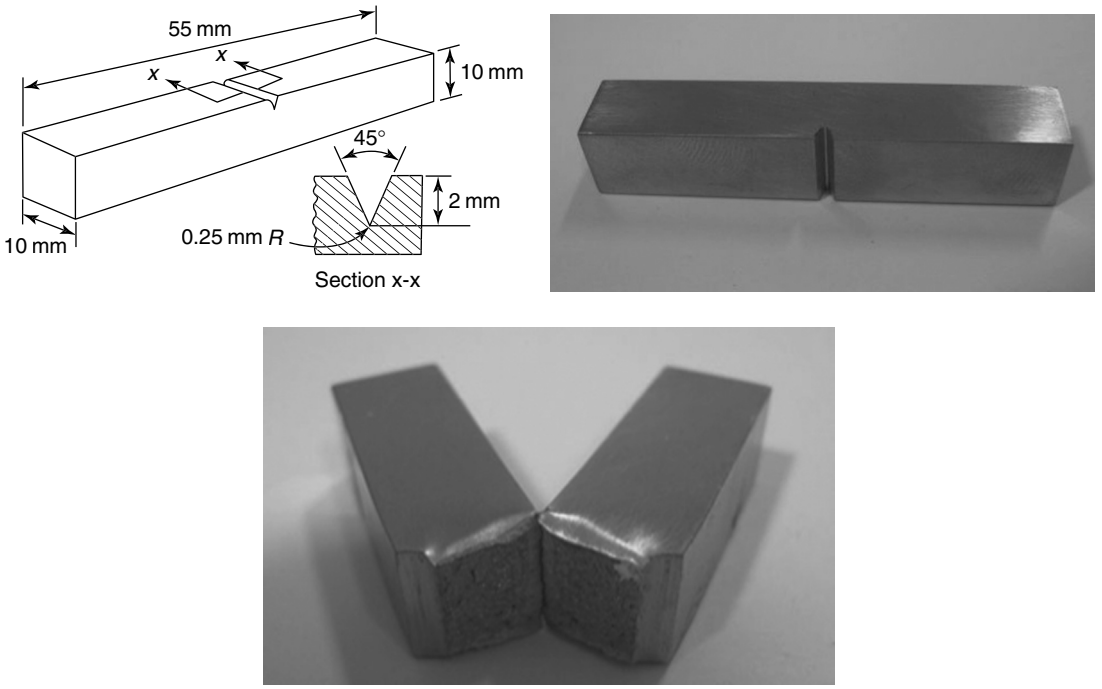


Fig. 14.17 *Details of Charpy V-Notch test and fractured specimen*

When the striker is at its highest point, h_1, before its release, the energy is only potential (mgh_1). The striker transforms its potential energy to kinetic energy when it swings through and breaks the specimen. In the process striker loses a part of its energy, and consequently swing up (rises) to a lesser height after the impact, h_2 with potential energy (mgh_2). Thus, the energy used to fracture the specimen is therefore, $E = mg\ (h_1 - h_2) = mgh$ as illustrated in Fig. 14.16; where, m is the mass of the hammer at the end of the pendulum, g is the

acceleration due to gravity and h is the vertical distance between the highest and the lowest positions of the pendulum. In terms of angle of pendulum before and after striking, α and β respectively, the energy used to fracture the specimen can be expressed as, $E = mgr$ (cos β – cos α); where r is the length of pendulum. A tougher material absorbs more energy; consequently the striker attains smaller height after the impact; whilst brittle materials tend to absorb very little energy on fracture.

Factors that affect the Charpy impact energy of a specimen include: yield strength and ductility of material, type of notches, temperature and strain rate.

Most of the impact energy is absorbed by means of plastic deformation during the yielding of the specimen. Therefore, factors that affect the yield behaviour and hence ductility of the material such as temperature and strain rate will affect the impact energy. For a given material, the impact energy is seen to decrease if the yield strength is increased, i.e., if the material undergoes some process that makes it more brittle and less able to undergo plastic deformation. Such processes may include cold working or precipitation hardening.

Increasing the temperature of metals generally increases the ductility and hence impact energy absorbed increases. However, in materials with a body centered cubic structure, lowering of temperature reduces ductility more markedly than face centered cubic materials.

Some materials such as carbon steels undergo what is known as a *ductile-to-brittle transition*; which results in a rapid dropping off of impact energy as the temperature decreases. If the impact energy drops off very sharply, a transition temperature can be determined. This is often a good indicator of the minimum recommended service temperature for a material.

The notch serves as a stress concentration region and some materials are more sensitive towards notches than others. The notch geometry, i.e., depth and tip radius are therefore very important factors.

Indian Standard Requirements

Impact test shall normally be carried out on products having thickness/diameter greater than or equal to 12 mm. The test sample shall be taken from the thickest product meeting the specified requirements, because the toughness of the product will be dependent on the rolling direction as well as on the section size. The test specimen is taken parallel to the direction of rolling and the notch axis shall be perpendicular to the rolled surface.

If the average of values obtained on three Charpy impact standard test specimens shown in Fig. 14.17 taken side by side from the same product meets the stipulated requirements, the product is acceptable provided no individual value shall be less than 70 per cent of the specified value. If this average fails to comply by an amount not exceeding 15 per cent of the specified minimum average value, three additional test pieces from the same sample shall be tested and the results added to those previously obtained and a new average calculated. Provided this new average complies with the specified requirement, the material represented shall be deemed to comply with the standard.

A test sample shall be taken from each 50 tonnes or part thereof from the same lot.

Viva-Voce Questions

1. What is Notch-toughness or Charpy V-Notch impact test?
2. What is the significance of this test?
3. What is impact energy?
4. What is resilience? How is it different from proof resilience and toughness?
5. What are factors affecting Charpy impact energy?
6. How will impact strength of two specimens differ; when one is having smooth surface and the other with scratches on its surface?
7. Why is it necessary to make a notch in impact test specimen?
8. How does V-notch differ from U-notch?

9. How does the sharpness of V-notch affect the test result?
10. What is the effect of temperature on the values of notch impact strength and rupture energy?

Notes and Comments

EXPERIMENT NO. 4: Tensile Test

Objective

1. *To examine the constitutive behaviour of the steel tested to failure in tension.*
2. *Determine the tensile strength, yield strength (by 0.2 per cent offset), modulus of elasticity, modulus of resilience, modulus of toughness and percentage elongation, per cent reduction in area and weight per metre (for rebars only).*

Theory and Scope

The tensile test of a standard steel specimen to failure provides the important basic properties of steel, viz., the proportional or elastic limit of the material, the yield strength, the ultimate stress, the elongation (strain) at fracture and the material stiffness, i.e., Young's modulus of elasticity. This data enables in setting the required performance level, checking the suitability of the product for a particular application and to control the quality of production.

The percentage elongation test is one of the methods for evaluating ductility which is considered as a quantitative means of predicting service performance of structure subjected to axial and bending actions. This property forms the basis of limit state design of steel structures.

Apparatus

Universal Testing Machine (UTM) with applicable tensile grips; Mechanical extensometer; Calipers; Mechanical dividers; Machinist scale; Gauge length punch and hammer.

Procedure

Specimen Requirements

Two test specimens that are approximately 900 mm in length of each size and each lot are required for testing. One specimen is normally tested for tensile strength while the other is tested for bend.

Step 1: Prepare standard specimens as per IS 1608 requirements.
Tensile test specimen The tensile strength, yield strength and percentage elongation of steel shall be determined from standard test pieces cut crosswise from plates and strips; and lengthwise from sections, flats and bars. The test shall be carried out on the standard test pieces prepared in accordance with IS 1608, using a proportional gauge length.

$L_o = 5.65\sqrt{A_o}$, where L_o is the gauge length and A_o is the cross-sectional area of the test piece. Test pieces with a non-proportional gauge length, may be used; in this case, the elongation values shall be converted in accordance with IS 3803 (Part 1).

Step 2: Determine the mean diameter or cross-sectional dimensions of the specimen.

Step 3: Mark a 200 mm gauge length near the middle of the specimen using a centre punch and hammer. *The gauge mark will provide reference points for determination of the per cent elongation. Punch marks shall be light, sharp, and accurately spaced* (200 ± 1.5 mm).

Step 4: Insert the specimen in the UTM such that the centres of the grips are in alignment with the axis of the specimen at the beginning and during the test; the grips to the section should remain outside the gauge length. Attach the extensometer carefully.

Step 5: Select a load range for the UTM that will accommodate the maximum anticipated load during the test. Apply the load at such as rate that the load and behavior of the specimen can be monitored properly. Record simultaneously the readings of load from the UTM and elongation from the extensometer. Remove the extensometer when it nears its range. Then continue monitoring the elongation of the specimen using the mechanical dividers and machinist scale in 1.5 mm increment until fracture occurs. Attempt to obtain the load at fracture.

Step 6: After failure, fit the broken halves together and measure the final 'gauge' length, L_f and the smallest diameter.

Step 7: Draw the following x-y plots of stress vs. strain:

(a) A complete stress vs. strain curve for the entire test to fracture.
(b) A stress vs. strain curve to the yield point (by the 0.2% offset method).
(c) A stress vs. strain curve just past the proportional limit stress

Step 8: Clearly mark and record the following values on the stress vs. strain curves plotted in Step 7:

(a) Proportional limit stress,
(b) Modulus of elasticity
(c) Yield stress (by 0.2% offset)
(d) Ultimate tensile stress
(e) Per cent elongation in 50 mm gauge length
(f) Per cent reduction in area
(g) Modulus of resilience
(h) Modulus of toughness (use trapezoidal integration)

Step 9: Discuss and compare the experimental values to known theoretical values for the given grade of steel and compute the per cent errors for all required values.

Observations

Type of material…….
Source ……
Date of sampling……
Use of material……

Size, diameter, etc.,		mm		
Weight per metre (rebar only),		kg/m		
Proportional limit stress,		MPa		
Modulus of elasticity,		MPa		
Yield stress,		f_y MPa		
Ultimate tensile strength,		MPa		
Elongation,	$\frac{L_f - L_o}{L_o} \times 100$	per cent		
Reduction of area,	$\frac{A_f - A_o}{A_o} \times 100$	per cent		
Modulus of resilience				
Modulus of toughness				

Precautions

1. It is the function of the gripping or holding device of the machine to transmit the load from the heads of the machine to the specimen under test. The essential requirement is that the load shall be transmitted axially. This implies that the centers of the action of the grips shall be in alignment, sofar as practical, with the axis of the specimen at the beginning and during the test, and that bending or twisting be held to a minimum.
2. For proper working, the extensometer should be attached carefully as per manufacturer's directions.
3. Rebar specimens often break violently (with considerable recoil) and at high loads. Such failures can be problematical for fragile test equipment.

Informative Comments

Yield stress is the stress at which the material begins to *yield*; this is indicated by a halt or hesitation of the load indicating pointer; the pointer value is termed the *yield point*. The stress at this point is computed and termed as *yield stress*. The yield stress is obtained by dividing the load at the yield point by the nominal cross-sectional area of the test specimen.

The tensile strength of the deformed bar is determined by dividing the maximum load sustained by the specimen during the test by the original (nominal) cross-sectional area of the specimen as specified in IS.

After the failure the fractured surface between two pieces appears in the form a cup and cone. This cup and cone fracture is considered to be an indication of ductile fracture. The percentage of elongation is determined by fitting the ends of the fractured specimen together carefully and measuring the distance between the gauge marks to the nearest 3 mm. The increase in the gauge length is expressed as a percentage of the original gauge length provides per cent elongation. In reporting elongation values, give both the percentage increase and the original gauge length.

If any part of the fracture takes place outside of the middle half of the gauge length or in the punched or scribed mark within the reduced section, the elongation value obtained may not be representative of the material. If the elongation measured meets the minimum requirements specified, no further testing is needed. However, if the elongation is less than the minimum requirements, the specimen is discarded and the test is repeated with new specimen.

Resilience is the amount of energy (or work) that can be absorbed during the linear behaviour of the specimen. This is the area under the linear portion of the stress strain curve up to the yield point. *Modulus of resilience* the amount of energy stored per unit volume at the elastic limit.

Toughness is the amount of energy the specimen can absorb until failure. This is represented by the area under the stress-strain curve up to the failure point and can be easily obtained by counting the squares under the curve on graph paper. Alternatively, trapezoidal integration may be used for computing the area under the curve. The dimensions and units of the squares are to be correctly determined. *Modulus of toughness* is the amount of energy stored per unit volume at fracture of the material; this is a measure of the ductility of the material.

Percent Area Reduction Reduction in area at fracture in necking region with respect to original cross-section area; this is a measure of the ductility of the material.

Strain hardening Portion of the stress-strain curve between the elastic limit and the ultimate stress.

The irregular surface of rebar makes gripping difficult as the teeth of the grip jaws are initially clamped onto the ridges of the specimen. Without a uniform gripping surface, the specimen can easily slip within the jaws. When strain data is needed for yield and modulus characteristics, specimen slippage can significantly affect test results and ultimately, pass/fail criteria. Moreover, the irregular surface of rebar also makes it more difficult to obtain consistent and accurate strain data; thus necessitate rebar testing at extended gauge lengths where the elongation (strain) is averaged over a long distance.

Viva-Voce Questions

1. What is a tension test? What is the significance of this test?
2. What is the importance of the mechanical properties determined in tensile test to engineering design?
3. How is the gauge length determined?
4. What mechanical properties of the material represent its ductility?
5. Why is alignment important in tensile testing?
6. When testing some specimens, why do the strain values appear to go backwards?
7. What is the effect extensometer slippage?
8. Why is sometimes upper yield point not seen?
9. What are the problems encountered in testing rebars?

Notes and Comments

EXPERIMENT NO. 5: Compression Test

Objective

1. *To examine load-deformation behaviour of the materials tested to failure in compression.*
2. *To determine mechanical properties of the materials namely the compressive strength, yield strength (by 0.2 per cent offset), modulus of elasticity, modulus of resilience, modulus of toughness and percentage compression.*
3. *To observe failure behaviour of the materials subjected to compression load.*

Theory and Scope

Several machine and structural products are subjected to compressive load in applications. These components are made of high compressive strength materials. Brittle materials, such as cast iron and concrete, are often weak in tension because of the presence of submicroscopic cracks and faults. However, these materials can prove to be quite strong in compression, due to the fact that the compression test tends to increase the cross sectional areas of specimens, preventing necking to occur. In general, the average compressive strength to tensile strength ratio of brittle materials is approximately 8/1.

Simple tensile testing usually yields sufficient data to determine the mechanical properties of ductile materials. In these materials, the yield limits under tension and compression are generally the same. Therefore, it is not necessary to perform the compression test on highly ductile materials such as mild steel or most Al-alloys. However, in brittle and fibrous materials, the tensile strength is considerably different from compressive strength; therefore, it is necessary to test them under tension and compression separately.

The compressive test of a material specimen to failure provides the important basic properties of material, viz., the proportional or elastic limit of the material, the yield strength, the ultimate stress, the compression (strain) at fracture and the material stiffness, i.e., Young's modulus of elasticity. This data enables in setting the required performance level, checking the suitability of the product for a particular application and to control the quality of production.

Apparatus

Universal Testing Machine (UTM) or Compression Testing Machine (CTM); Mechanical compressometer or Dial gauge; Vernier Calipers; Compression shackles; Mechanical dividers; Machinist scale; Safety Goggles.

Description of Apparatus

Machines used for compression testing are basically similar to those used for tensile testing; generally the same machine can be used to perform both tests.

Shape of the specimen The shapes of the compression specimen to be used for the different materials are as follows:

1. For metals and certain plastics, the specimen may be cylindrical in form.
2. For building materials such as concrete, bricks or stone or timber, the shape of the specimen may be a cube or prism.

Procedure

Step 1: Prepare standard compression test specimens.

Surface finished cylindrical test specimen with $h/d = 2$ of the given material (cast iron, aluminium, mild steel and copper) are prepared for each test. The ends of the test specimen should be plane and normal to its longitudinal axis. Prism test specimen can also be used.

Step 2: Measure the initial height h_i and average initial diameter d_i or initial cross-sectional dimensions of the test specimen measured at three different locations along its height by vernier calipers.

Step 3: Place the specimen centrally on lower compression anvil or platen of the UTM or CTM such that the centre of moving head is in alignment with the axis of the specimen.

Step 4: Bring down the movable intermediate cross head or anvil manually until it touches the specimen's top surface without moving the specimen.

Step 5: Select a load range for the UTM that will accommodate the maximum anticipated load during the test.

Step 6: Apply the load gradually by operating the load control wheel at such increments (say 5 or 10 kN) that the load and behaviour of the loaded specimen can be monitored properly.

Step 7: Record simultaneously the magnitude of load from the UTM and corresponding contraction or decrease in height from the scale of compresometer. Continue the experiment till the specimen attains a barrel shape on reaching the maximum load for ductile materials or fractures at maximum load for brittle materials.

Step 8: Remove the compresometer when it nears its range. Then continue monitoring the contraction of the specimen using the mechanical dividers and machinist scale in 1.0 mm increment until the specimen fails. Attempt to obtain the load at failure.

Step 9: Measure final height h_f and largest diameter of the specimen d_f using vernier calliper.

Step 10: After failure, examine the failure pattern of specimen and sketch it with observations like broken into pieces without appreciable reduction in height or turned to barrel shape with appreciable reduction in height with or without cracks on outer surface, etc.

Step 11: Calculate stresses and corresponding strains. Plot the following stress vs. strain plots in compression:

(a) A complete stress vs. strain curve (σ-ε) for the entire test to fracture.
(b) A stress vs. strain curve to the yield point (by the 0.2 per cent offset method).

Step 12: Calculate the following parameters from the stress-strain curves plotted in Step 11.

(a) Proportional limit stress.
(b) Modulus of elasticity from the graph, i.e., slope of the graph with in elastic limits.
(c) Yield stress (by 0.2 per cent offset).
(d) Ultimate or the maximum compressive stress.
(e) Per cent reduction in length or height of the specimen.
(f) Modulus of resilience.
(g) Modulus of toughness (use trapezoidal integration).

Step 13: Discuss and compare the experimental values to known theoretical values for the given material and compute the per cent errors for all required values.

Observations and Calculations

Least count of vernier calipers =……..mm.

1. Basic detail of the specimen

Sr. No.	Different measurements of the specimen		Material of the specimen		
			I	II	III
1.	Initial height of the specimen h_i,	mm			
2.	Initial diameter of the specimen d_i,	mm			
3.	Final height of the specimen h_f,	mm			
4.	Final diameter of the specimen d_f,	mm			
5.	Initial area, $A_i = \pi d_i^2/4$	mm^2			
6.	Final area, $A_f = \pi d_f^2/4$	mm^2			
7.	Increase in area $(A_f - A_i) \times 100 / A_i$	per cent			
8.	Decrease in height $(h_f - h_i) \times 100 / h_i$	per cent			
9.	Compressive strength W_{max} / A_i,	MPa			

2. Applied load and resulting stress and strains

Material					
Sr. No.	Applied load W, kN	Scale reading, mm	Shortening of specimen δ, mm	Strain, $\varepsilon = \delta / h_i$	Stress, $\sigma = W / A_i$ MPa
0.	0.0		-	-	-
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					
11.					
12.					

Results

Proportional limit stress,	MPa		
Modulus of elasticity,	MPa		

Yield stress, f_y	MPa		
Ultimate compressive strength,	MPa		
Modulus of resilience			
Modulus of toughness			

The compressive strength of given specimen is ……MPa.

Precautions

1. The specimen should be prepared as per laid down standards. The ends of the test specimen should be plane and normal to its longitudinal axis.
2. The essential requirement of the test is that the load shall be transmitted to the specimen under test axially. This implies that the centers of the action of the platens, insofar as practical, should align with the axis of the specimen.
3. For proper working, the compressometer should be attached carefully as per manufacturer's directions.
4. Specimens of some materials often break violently (with considerable recoil) and at high loads. Such failures can be problematical for fragile test equipment.
5. Hands or any part of body must not be placed between the platens/grips of operating machine.

Informative Comments

In a compression specimen, it is essential to keep $h/d \leq 2$ to avoid lateral instability due to buckling tendency. The basic difference in behaviour of ductile and brittle materials in compression is given below.

1. *Ductile materials such as steel, aluminium and copper*

(a) The ductile materials have stress-strain curves similar to ones for the tensile test, there is an elastic range followed by a plastic region.
(b) The ductile materials have proportional limits in compression test and are very much close to those in tension.
(c) In tension test, a specimen is being stretched, necking may occur, and ultimately fracture takes place. On the other hand, when a small specimen of the ductile material is compressed, it begins to bulge on sides and becomes barrel shaped. With increasing load, the specimen is flattened out, thus offering increased resistance to further shortening consequently stress-strain curve moves upward.

2. *Brittle materials*

(a) Brittle materials in compression typically have an initial linear region followed by a region in which the shortening increases at a higher rate than does the load. Thus, the compression stress-strain diagram has a shape that is similar to the shape of the tensile diagram.
(b) Brittle materials usually reach much higher ultimate stresses in compression than in tension.
(c) Brittle materials in compression behave elastically up to certain load, and then fail suddenly by splitting or by cracking. The brittle fracture occurs by separation and is not accompanied by noticeable plastic deformation.

Wood is a commonly used engineering material showing different mechanical behaviour under tensile and compressive loadings. However, contrary to cast iron or concrete, it does not show brittle characteristics

under tensile loading and surprisingly, it is considerably stronger in tension than compression. The fact that the cell structures in the material are stronger in the longitudinal than transverse direction is the major factor leading to this unusual mechanical behaviour of wood.

The compressive modulus of elasticity of typical materials is given in Table 14.5.

Table 14.5 *Compressive modulus of elasticity of typical materials*

Material	Steel	Cast iron	Brass	Aluminium
Modulus of elasticity, MPa	0.85×10^5	0.45×10^5	0.55×10^5	0.35×10^5

Determination of mechanical properties

Yield stress is the stress at which the material begins to yield; this is indicated by a hesitation of the load indicating pointer; the pointer value is termed the yield point. The stress at this point is computed and termed the yield stress. The yield stress is obtained by dividing the load at the yield point by the nominal cross-sectional area of the test specimen.

Resilience is the amount of energy (or work) that can be absorbed during the linear behaviour of the specimen. This is the area under the linear portion of the stress strain curve up to the yield point. Modulus of resilience: the amount of energy stored per unit volume at the elastic limit.

Toughness is the amount of energy the specimen can absorb until failure. This is represented by the area under the stress-strain curve up to the failure point and can be easily obtained by counting the squares under the curve on graph paper. Alternatively, trapezoidal integration may be used for computing the area under the curve. The dimensions and units of the squares are to be correctly determined. Modulus of toughness is the amount of energy stored per unit volume at fracture of the material; this is a measure of the ductility of the material.

Viva-Voce Questions

1. What is a compression test? What is the significance of this test?
2. What is the importance of the mechanical properties determined in compression test to engineering design?
3. Why compression test is performed generally on brittle materials?
4. How does the *h/d* ratio of specimen affect the test result?
5. What mechanical properties of the material represent its ductility?
6. How do the ductile and brittle materials behave in compression test?
7. What is the difference between the failure patterns of cast iron and copper specimen tested in compression test?
8. Why is alignment important in compression test?
9. What are bi-modular materials? Give examples.
10. When testing some specimens, why do the strain values appear to go backwards?

Notes and Comments

EXPERIMENT NO. 6: Bend Test for Metal Products

Objective

1. *To ascertain the qualitative degree of formability or ductility of steel products, typically reinforcing steel, by bend test.*
2. *To ascertain the aging effect on rebar by rebend test.*

Significance

The bend test relates to the mechanical testing of steel products; it is performed by subjecting a specimen of the material to a measured deformation to which it is likely to be subjected in service/ application. The test indicates the adequacy or otherwise of the material to undergo required deformation without fracturing or yielding.

Rebar is bent into different shapes to reinforce concrete structures. To ensure that the material is capable of being bent without significant strength loss, bend test is conducted by bending the specimen around a mandrel or a forming pin to 90° or 180° angles. Sometimes, three-point bend test is used as a quality control check to ensure the bar's formability.

Theory and Scope

Bending tests are carried out in accordance with IS: 1599-1985 to ensure that a metal has sufficient ductility to stand bending without fracturing. A standard specimen at room temperature is bent to an inside diameter, as designated by the applicable product specifications, and examined for major (specified) cracking on the outside of the bent portion. In the case of metal strip the direction of grain flow is noted whether the bend is with or across the grain. The speed of bending is ordinarily not an important factor.

Apparatus

Rebar bending test jig or fixture: The mechanism for a typical Bend Test Fixture is shown in Fig. 14.18.

Procedure

Preparation of test specimen

Bend test is carried out on a specimen made from finished steel product from each lot. The number of tests is one for every 20 tonnes of material or part thereof, rolled continuously.

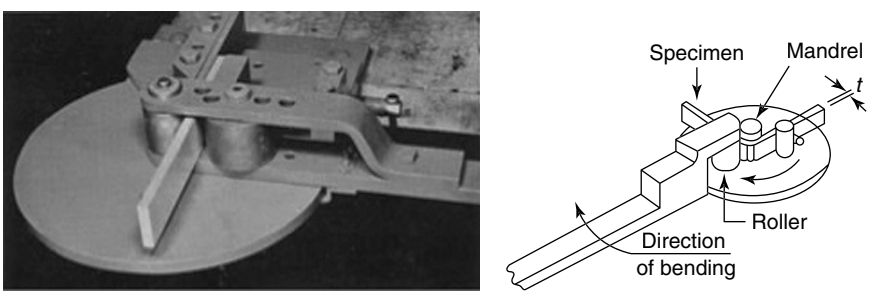


Fig. 14.18 *Typical bend testing fixture with a test specimen loaded and ready to be tested*

The test pieces are cut lengthwise or widthwise from plates and strips, and lengthwise from sections, flats and bars. When section permits, these shall be not less than 40 mm wide. If so desired the round, square, hexagonal, flat bars and structural sections shall be bent in the full section as rolled.

In all bend test pieces, the rough edge arising from shearing is removed by filing or grinding or machining but the test pieces shall receive no other preparation. The test pieces shall not be annealed or otherwise subjected to heat treatment unless the material from which these are taken is similarly treated.

Bend Test

Procedure

Step 1: Select mandrel of required diameter as per Table 14.6 for the bend test and install it on the testing jig.

Table 14.6 *Mandrel diameter for bend test (Adapted from IS: 1599-1985)*

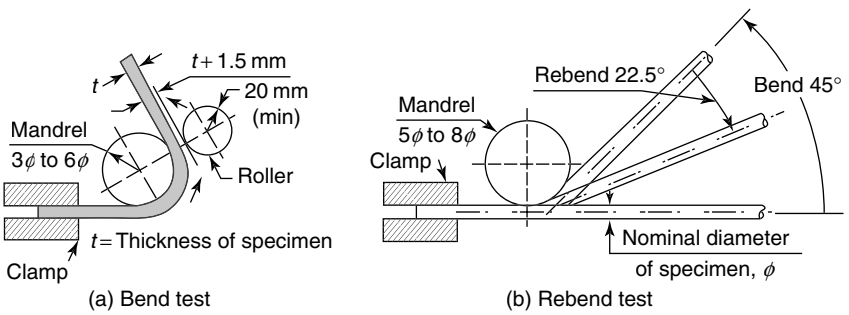
Nominal size of bar		Mandrel diameter for different grades		
		Fe415	*Fe500*	*Fe550*
Up to and including	22 mm	3ϕ	4ϕ	5ϕ
Over	22 mm	4ϕ	5ϕ	6ϕ

Note: ϕ is the nominal size of test specimen in mm

Step 2: Bend the specimen first by 90° about the mandrel of appropriate diameter selected in Step 1; examine the specimen for cracks in the bent portion.

Step 3: Bend the specimen by additional 90° about the mandrel to make total bend angle of 180°C.

Step 4: Examine the specimen carefully for cracks in the bent portion.



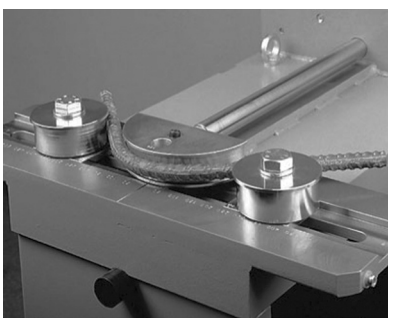


Fig. 14.19 *Bend test zig and concept of rebend test*

Observations

Source……..
Date of sampling…….
Use of material……

Specimen details		Test specimen	Retest specimens	
Grade of reinforcing bar				
Nominal diameter of the bar,	mm			
Weight of the specimen,	kg/m			
Diameter of mandrel,	mm			

Result

Test specimen……Passed/ failed.

(To pass the bend test, the test specimen at room temperature shall withstand bending through 180^{o} to an internal diameter not greater than that of mandrel without cracking).

Re-bend Test

Theory and Scope

The purpose of re-bend test is to measure the effect of strain ageing on steel. Strain ageing has embrittlement effect which takes place after cold deformation by diffusion of nitrogen in steel. Hence, there is limitation stated in some design codes to restrict the nitrogen content of steel to 0.012 per cent.

Procedure

Step 1: Select mandrel of required diameter as per Table 14.7 and install it on the testing jig. Bend the specimen by 45°, i.e., to an included angle of 135° using mandrel of appropriate diameter.

Table 14.7 *Approximate mandrel diameter for re-bend test*

Nominal size of bar		Mandrel diameter for different grades	
		Fe415 and Fe500	*Fe550*
Up to and including	10 mm	5ϕ	7ϕ
Over	10 mm	7ϕ	8ϕ

Note: ϕ is the nominal size of test specimen in mm

Step 2: Keep the bent test specimen in boiling water, i.e., 100°C for 30 minutes.
Step 3: Remove the test specimen from boiling water and allow it to cool to room temperature.
Step 4: Bend back the test specimen by 22½° to have an included angle of 157½° as illustrated in Fig. 14.19(b).
Step 5: Examine the specimen carefully for cracks in the bent portion.
Step 6: Discuss the experimental results and give conclusions.

Observations

Specimen details		Test specimen	Retest specimens	
Grade of reinforcing bar				
Nominal diameter of the bar,	mm			
Weight of the specimen,	kg/m			
Diameter of mandrel,	mm			

Result

Test specimen……Passed/ failed.

(The sample specimen is considered to have passed the test if there is no fracture in the bend portion).

Precautions

1. For correct results, the preparation of test samples prior to bend testing and selection of appropriate mandrel should be done carefully.
2. The force for bending should be applied to the test specimen to bend it progressively (continuously) around the pin or mandrel without jerks.

Informative Comments

This test typically requires the sample to be bent around a forming pin to 90° or 180° angles, and visually inspected for development of any surface cracks. International standards specify requirements for the diameter of the forming pin, the degree of the bend, and the support span. In addition, most rebar standards require that the bend test be completed in one continuous test stroke.

This test helps in determining the formability or ductility, but it cannot be considered as a quantitative means of predicting service performance in bending operations. The severity of the bend test is primarily a function of the angle of bend and inside diameter to which the specimen is bent, and of the cross section of the specimen. These conditions are varied according to location and orientation of the test specimen and the chemical composition, tensile properties, hardness, type, and quality of the steel specified.

Bend testing is commonly performed to measure the flexural strength and modulus of all types of materials and products.

Viva-Voce Questions

1. What is the bend test?
2. What is the significance of bend test?
3. What are the factors which influence the result of bend test?
4. What is the draw back with these methods?
5. What is the purpose of conducting re-bend test of steel reinforcement?

Notes and Comments

EXPERIMENT NO. 7: Shear Test

Objective

To determine the shear strength (ultimate shear stress) of the mild steel specimen using double shear method.

Theory and Scope

A type of force which results in sliding or tends to slide two contiguous parts of the body relative to each other in a direction parallel to their plane of contact is called the shear force. If the shear force is resisted through one plane, i.e., single area then the material is said to be in single shear. If two sections (areas) resist the load then the material is said to be in double shear. The shear stress at failure is called the *shear strength* of the material. Figure 14.20 illustrates single shear and double shear applied on the given specimen. Ultimate shear strength = W/A for single shear where W is fracture load and A is the area of cross section of the given specimen. In double shear, ultimate shear strength = $W/2A$.

Typical examples of product that are subjected to shear forces are rivets, bolts, screw threads, and cotter pins and structural beams.

The method for determining the shear strength consists of loading the material specimen in full cross section to single shear or double shear, using a suitable test rig, in a testing machine. The test load is a compressive load or tensile pull applied perpendicular to the axis of test specimen of suitable length; the load W at fracture gives the required shear load. The test is conducted as per the provisions of IS 5242:1979.

Apparatus

Universal Testing Machine; Shear test device; Shear dies; Sliding Vernier calipers or screw gauge.

Description of Apparatus

Shear test device The typical steel device for double shear testing illustrated in Fig. 14.20 is based upon fork and eye plate principle, wherein the test specimen is inserted as a connecting pin in the bush housing between the shackles; the fork plates of the shackle held rigidly together by bolts for avoiding any bending tendency of the specimen under high loads.

Shear attachment shall be mounted on UTM such that the holes provided in shackles for inserting the specimen in the shear attachment are in line to enable the specimen to be inserted through the holes centrally. The inner diameter of the hole in the shear test attachment shall be slightly greater than that of the specimen. This arrangement makes the specimen to shear off at two cross sections due to the applied load and the test performed is known as *double shear test*.

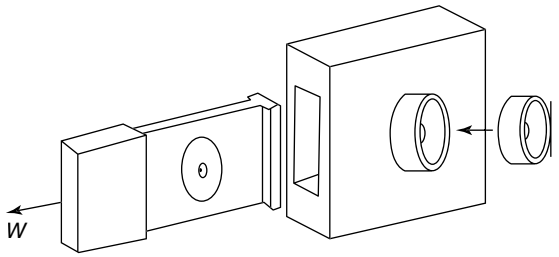


Fig. 14.20 *Typical steel device for double shear testing*

Two coupling shackles are also used to provide either a single-shear or double-shear connection. Both shackles have parallel pieces, but while the single-shear block is routed out so that there is only one shear plane, the double-shear block has a hole through each bar.

Specimen Mild steel specimen

Load range of machine The load range to which the machine is to be set for the test is selected based on the expected maximum load W to be applied on the specimen for shear failure. This can be calculated from the yield stress f_y and the factor of safety *FOS*, as follows:

Permissible shear stress τ for mild steel as per IS 800, $\tau = 0.45 f_y$

and therefore, $\tau_{\max} = 0.45 f_y \times FOS$

Consider suitable factor of safety (Say 4), then

Load range for double shear, $W = \tau_{\max} \times 2A = 0.45 f_y \times FOS \times 2A$ (14.1)

For mild steel specimen, $f_y = 250$ MPa and $FOS = 4$

Expected maximum load to be applied on the specimen, $W_{max} = 4 \times 0.45 \times 250 \times 2A$

Select the suitable load range for the UTM before starting the experiment.

Procedure

Test procedures for single shear and double shear tests are similar except that specimen holding fixtures are different.

Step 1: Measure the diameter *d* of the specimen using sliding vernier calipers taking the average of three readings taken at different points along the length of the specimen.

Step 2: Calculate the maximum load expected to be applied on the specimen using Eq. (14.1) select the load range to be used.

Step 3: Set the universal testing machine for the selected load range.

Step 4: Select appropriate set of shear shackles to assemble the double shear device. Mount the top part of the shear attachment on the middle adjustable cross-head and the bottom part of the shear attachment shall be mounted on the lower compression crosshead by the mechanism provided for the purpose so that the holes provided for inserting the specimen in the shear attachment are in line.

Step 5: Insert the specimen in to the shear device to pass through the holes centrally so that it projects equally on either side. The inner diameter of the hole in the shear test devise is slightly greater than that of the specimen. Thus, the arrangement is made so that the specimen will be sheared off at two cross sections due to the applied load and the test performed is known as double shear test.

Step 6: Move down the intermediate cross slide till it makes contact with the top of the centre plate, through which the load is applied on the specimen.

Step 7: Set the load pointer to zero.

Step 8: Start the machine and apply the load gradually till the specimen ruptures by shearing at two cross sections completely. Ensure that the load remains within the range without any need for alteration. At this point record, the load applied on the specimen as indicated on the dial gauge.

Step 9: Remove the load to take out the shear attachment and broken pieces of specimen.
Step 10: Examine the nature of failure of sheared surface, sketch and note down the salient features.
Step 11: Calculate the shear strength of the given material specimen.
Step 12: Discuss the results obtained by the test.
Repeat the experiment with other specimens.

Observations and Calculations

Material of the specimen is……..
Least count of vernier caliper = ……..mm

Diameter of the specimen, d	mm		
Sectional area of the bar, $A = \pi d^2/4$	mm^2		
Load at failure, W_f	kN		
Double shear strength = $W_f/2A$	MPa		

Result

The ultimate shear stress or shear strength of given sample = …….. MPa W

Precautions

1. The load should be applied perpendicular to the axis of test specimen otherwise it will introduce tensile force in the specimen.
2. The measuring range of UTM should not be changed at any stage during the test.
3. The specimen should be in full cross-section i.e. its diameter should be constant throughout.
4. The specimen should be securely fitted in the test rig.
5. The diameter of the specimen should be measured accurately as an average of three measurements.

Informative Comments

The specimens in single shear test are non-symmetrical, which results in local bending of the specimen even under axial load; double-shear testing is generally used to obtain properties of material in shear. However, tensile load subjecting the test specimen to double-shear is preferred over compression loading.

If the specimen breaks in two pieces then it will be in single shear and if it breaks in three pieces then in double shear. The shear force required to shear the specimen in double shear is twice the shear force required in single shear since there are two shear planes (the total shear area is doubled). However, while the shear force is doubled, the shear stress at failure is the same in both cases. This is true because, like tensile and compressive strengths $\sigma_{ultimate}$, the shear strength $\tau_{ultimate}$ is a material property.

The sheared surface will be smooth in the case of mild steel.

Viva-Voce Questions

1. What is the equation to compute shear stress at any layer in the cross section of a beam?
2. Draw shear stress distributions for the rectangular and circular cross sections.
3. What is the significance of shear test?
4. What are the single and double shears?
5. What is the difference in single and double shear strength tests?
6. What is unit of shear strength?
7. How are the maximum and average shear stresses on a circular section related?

8. What is the shear modulus?
9. How are rigidity and young's moduli related?
10. Why is modulus of rigidity not determined from shear test?
11. If single shear test and double shear test are conducted on the same material, is there any variation in the shear strengths?
12. What are the limitations of double shear test?
13. Which IS code explains the testing method for determining shear strength of metals?

Notes and Comments

EXPERIMENT NO. 8: Flexural Bending Test

Objective

1. *To perform the three-point and four-point bending tests on metal specimen to investigate material response to bending.*
2. *To determine the bending strength, yield strength, stiffness and the modulus of elasticity in bending.*

Theory and Scope

Bending test is commonly used to measure the flexural strength and modulus of elasticity for all types of materials and products whose principal stressing mode is bending. For many materials, the tensile and compressive moduli are somewhat different; and the bending modulus being a combination of the tensile and compressive moduli, is often different from each of them.

The test procedure for determining the modulus of elasticity in bending, the bending strength and the offset yield strength in bending of metallic strips or sheets can be performed using: (i) a three-point loaded beam (that is, a beam resting on two supports and centrally loaded), and (ii) a four-point loaded beam (that is, a beam resting on two supports and loaded at two points equally spaced from each support) as illustrated in Fig. 14.21. Thus, the test procedure involves measurements of the applied moment and the corresponding deflection of a simply supported beam. The thickness range covered is 0.5 to 3.0 mm. This test method is not applicable for nonlinear elastic materials.

For general standard testing for the comparison of different materials, the test with a central load is sufficiently accurate. Where a more accurate determination of absolute properties of the material e.g. the modulus of elasticity, is required the four-point bending test has to be employed. Using this method, the beam is subjected to a uniform bending moment over a considerable proportion of its length and the modulus of elasticity can be calculated without the necessity of allowing for shear deflection which occurs along the whole length of a beam loaded at the centre.

To perform bending test the bending fixture is mounted on the test platform of the UTM for suitably supporting the specimen. The loading is applied through the middle cross-head. At a particular load, the deflection at the center of the beam is determined by using a dial gauge. The deflection for specimen of materials having a linear stress-strain relation at its center is given as follows:

1. For a simply supported beam of rectangular cross section $b \times t$ (thick) with a concentrated load W applied at its centre,
   Deflection δ under the load, $\delta = \dfrac{WL^3}{48EI}$ (14.2)
   where
   W = Applied load,
   L = Effective span of the beam,
   E = Modulus of elasticity and
   I = Moment of inertia.

   Therefore, modulus of elasticity, $E = \dfrac{WL^3}{48\delta I} = \left(\dfrac{W}{\delta}\right) \times \dfrac{L^3}{48I}$

   $$= \left(\frac{\Delta W}{\Delta \delta}\right) \times \frac{1}{4b} \times \left(\frac{L}{t}\right)^3 \quad (14.3)$$

The ratio $(\Delta W/\Delta\delta)$ which represents the stiffness of the beam/specimen is the slope of the straight-line portion of the load-deflection curve and can be expressed as

$$\frac{\Delta W}{\Delta\delta} = \frac{W_2 - W_1}{\delta_2 - \delta_1} \tag{14.4}$$

The maximum bending stress (σ) can be determined from linear elastic beam analysis as

$$\sigma = \frac{M_{\max}}{I} \times \frac{t}{2} = \frac{M_{\max}}{(bt^3/12)} \times \frac{t}{2} = \frac{6M_{\max}}{bt^2} \tag{14.5}$$

where M_{max} is the maximum bending moment in the specimen at its mid-span.
Under three-point bending at failure with the failure load W_f acting at the mid-span, the maximum bending moment, $M_{max}=(W_f L/4)$
Therefore, the modulus of rupture in bending or fracture stress,

$$\sigma_f = \frac{3W_f L}{2bt^2} \tag{14.6}$$

The fracture stress in bending is also called the *bending strength* or *flexure strength*. The bending strength is slightly different from the fracture stress obtained from the tensile test if failure takes place after yielding.
The yield strength (σ_y) is determined by replacing the failure load W_f by yield load W_y in Eq. (14.6). The yield load is determined at the definite yield point or at 2 per cent offset.
The yield strength obtained from the bending test is not different from the yield strength achieved from the tensile test. This is because the relationship between the load and the deflection remains linear up to yielding.

2. For a simply supported specimen of rectangular cross section $b \times t$ (thick) with two loads of magnitude (W/2) acting through two points at distance l from the supports

$$\delta = \frac{Wl}{48EI}\left(3L^2 - 4l^2\right) \Rightarrow E = \left(\frac{\Delta W}{\Delta\delta}\right)\left(\frac{l}{4bt^3}\right)\left(3L^2 - 4l^2\right) \tag{14.7}$$

In this expression, W is the load in Newton; b and t are the dimensions of the cross section in millimeters. L is the distance between supporting rollers or effective span in mm. l is the distance between points of application of the load and the supports.

The maximum bending moment, $M_{\max} = (Wl/2)$

Central deflection of the simple beam with concentrated loads, each equal to W/2, at third points (l=L/3) of span is

$$\delta = \frac{23WL^3}{1298EI} \tag{14.8}$$

Thus, the deflection is a measure of overall stiffness of a given beam specimen and can be seen to be a function of the stiffness of the material and dimensions of the specimen. Deflection measurements provide a method to calculate the modulus of elasticity for a material in flexure.

Apparatus

Universal Testing Machine (UTM) with Bending test fixture or Beam apparatus, Micrometer or Vernier calipers, Metallic tape, Permanent pen and Dial gauge.

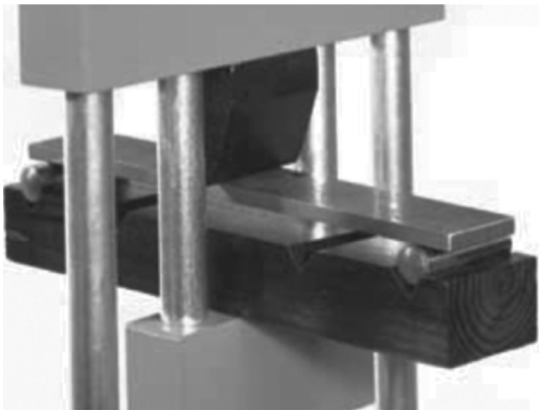


Fig. 14.21 *Typical bending test fixture or beam apparatus*

Procedure

Step 1: Insert the appropriate bending test fixture in the UTM. Adjust the supports for the required distance and clamp to the lower platform of the machine.
Step 2: Measure and record the width b and thickness t by vernier calipers; and distance L between the two supports or the span of specimen by metallic tape.
Step 3: Mark on the locations of supports and the points of application of load(s) on bending test specimen with permanent pen.
Step 4: Place the test specimen on the two supports provided on bending test fixture. The length of the supports shall be at least 10 mm more than the width of the test specimen.
Step 5: Mount the dial gauge on a stand and make its spindle knob bear on the test specimen.
Step 6: Apply the load gradually until failure takes place in suitable load increments such that about 8 to10 readings are available up to limit of proportionality.
Step 7: Measure and record the deflections at the centre of the length at each load increment. Record the reading of the load corresponding to each deflection reading given by dial gauge.
Step 8: Record the failure mode of the specimen according to its appearance and sequence of development and sketch the fractured surfaces.
Step 9: Plot a load-deflection curve with load as ordinate and deflection as abscissa from the recorded readings of deflection and the load.
Step 10: Determine the bending strength, yield strength and elastic modulus of the specimen.
Step 11: Discuss the experimental results and give conclusions.

Observations and Calculations

Type of product …….
Source……
Least count of vernier caliper or micrometer = ……
Width of specimen, b = …… mm
Thickness of specimen, t = …… mm
Span of specimen, L = …… mm
Distance of loads from the supports, l = …… mm

Load deflection Curve

Load W,	N									
Deflection δ,	mm									
Stiffness $\Delta W/\Delta\delta$ from curve	N/mm									
Modulus of elasticity,	MPa									
$E = \left(\frac{\Delta W}{\Delta \delta}\right) \times \frac{1}{4b} \times \left(\frac{L}{t}\right)^3$,	MPa									
$E = \left(\frac{\Delta W}{\Delta \delta}\right) \left(\frac{1}{4bt^3}\right)\left(3L^2 - 4l^2\right)$,	MPa									

Results

1. Bending strength of material, σ_{max} = ……..MPa
2. Yield strength of material in bending, σ_y = …….. MPa
3. Modulus of elasticity of the material in bending =…….. MPa
4. The stiffness of the specimen = …….. N/m
5. Fracture details = ……..……..……..

Precautions

1. The test specimen shall be placed in the machine correctly centered with the longitudinal axis of the specimen at right angles to the supports with the thickness oriented vertically.
2. The load applying blocks shall be brought in contact with the upper surface of the specimen at the predefined/marked points between the supports. If the full contact is not obtained between specimen and load applying blocks and supports due to the surface of the specimen being out of plane, the surface of the specimen where they are to be in contact with blocks or supports should be planed or packed to produce full contact.
3. The load shall be applied slowly without shock at the stipulated increments.
4. In case only the elastic properties of material are to be determined, it should be ensured that the elastic limit of the specimen does not exceed.
5. In the case of manual loading of thin specimens, further load should not be added until the deflection caused by the previously added load has stabilized; the equipment should not be jogged or tapped, as these actions affect the recorded data.
6. Address to the safety concerns.

Informative Comments

Apart from the test conditions, such as temperature, temperature variations, condition of the test equipment and adherence to the recommended test procedure, the precise determination of the modulus of elasticity in bending and bending strength is influenced by the specimen orientation with respect to the rolling direction, grain size, residual stresses, previous strain history, dimensions and specimen preparation, orientation of deformed grains relative to the direction of the normal stress.

The test is sometimes performed by subjecting a specimen of the material to a measured deformation to which it is likely to be subjected in service/ application. The test indicates the adequacy or otherwise of the material to undergo required deformation without fracturing or yielding.

The failures of loaded specimens are generally classified according to the manner in which they are initiated, as tension or compression; and according to the appearance of the fractured surface such as ductile or brittle.

The loading and unloading curves do not generally coincide due to *viscoelastic properties of material* under deformation. The viscoelasticity dissipates the energy in the material on loading. The area between the loading and unloading curves represents the elastic strain energy stored in the material. However the amount of energy is not high enough to cause problems.

The main advantage of a three-point over a four-point flexural tests is the ease of the specimen preparation and testing. However, this method has also some disadvantages: the results of the testing method are sensitive to specimen, loading geometry and strain rate.

The test procedure can also be used to investigate the relationship between load, span, width, height and deflection of a beam, placed on two supports subjected to a concentrated load at the center.

Viva-Voce Questions

1. What is deflection defined?
2. What is moment of inertia?
3. What deformation characteristics are observed during three-point bending testing?
4. What is the bending test for metallic strips?
5. What is the significance of bending test?
6. What are the factors which influence the result of bending test?
7. What is the drawback with these methods?
8. What is the equation governing simple bending?
9. What is the meaning of flexure equation: $M/I = f/y = E/R$?
10. What is the central deflection of a simply supported beam under concentrated load?
11. Sketch the variation of bending and shear stress over a beam cross section.
12. What are the types of loading used in laboratory flexure tests?
13. Why are tensile properties of most of the brittle materials determined by bending tests and not by tensile tests?

Notes and Comments

EXPERIMENT NO. 9: Torsion Test

Objective

To conduct a torsion test to draw the applied torque versus angle of twist curve and determine the following torsional properties of a material:

1. *The modulus of rigidity or modulus of elasticity in shear,*
2. *The shear stress at the limit of proportionality,*
3. *The yield shear strength,*
4. *The ultimate shear strength and*
5. *The modulus of rupture in shear.*

Theory and Scope

The objective of torsion test is similar to that of uniaxial tension tests; in torsion test also, the relationship between torque and degree of rotation is graphically presented and parameters such as ultimate torsional shearing strength (modulus of rupture), shear strength at proportional limit (τ_p), shear yield stress (τ_y) and shear elastic modulus or modulus of rigidity (G) are generally investigated. However, in contrast to uniaxial tension tests, the stresses are not distributed uniformly over the cross section.

Torsion test is applicable for testing brittle as well as ductile materials such as tool steels, cast aluminium, etc., and the test has also been used to determine the forgeability of the materials by means of torsion testing at elevated temperatures. Moreover, fracture surfaces of specimens tested under torsion can be used to determine the characteristics of the materials whether it would fail in a brittle or a ductile manner.

The shear properties of the material of the specimen are determined using elementary *solid mechanics theory*. Generally, the test specimens used are of a cylindrical rod type since the stress distribution across the section of the rod is of simplest geometry, facilitating the computation of the stresses. Within the elastic range of deformation, the relationship between applied torque, T and shear stress, τ is given by

$$\frac{T}{J} = \frac{G\phi}{L} = \frac{\tau}{r} \Rightarrow G = \frac{TL}{\phi J} = \left(\frac{\Delta T}{\Delta \phi}\right)\frac{L}{J} = \left(\frac{\Delta T}{\Delta \phi}\right)\left(\frac{32L}{\pi D^4}\right) \tag{14.9}$$

Thus, in the test a curve between applied torque and twisting angle is plotted to determine the shear modulus G by finding the slope of the curve ($\Delta T/\Delta\phi$). Within the elastic range of deformation, the maximum shear stress is given by

$$\tau = \frac{Tr}{J} = \frac{TD}{2J} = \frac{16T}{\pi D^3} \tag{14.10}$$

For a tube specimen, the maximum shear stress at the peripheral of the tube can be calculated as

$$\tau = \frac{16TD}{\pi\left(D^4 - d^4\right)} \tag{14.11}$$

where D and d are the outer and inner diameters of the tube, respectively.
Shear strain γ is calculated from

$$\gamma = \frac{\phi r}{L} = \frac{\phi D}{2L} \tag{14.12}$$

where
T = Applied torque in Nm,
$J = (\pi D^4/32)$= Polar moment of inertia or polar second moment of area in mm^4,
G = Shear modulus of rigidity in MPa/GPa,
ϕ = Angle of twist on application of torque (over length L) in radians,
L = Gauge length in mm and
$D = 2r$ = Diameter in mm.

Specimen made of various materials, with different diameters and lengths may be investigated. Test procedure involves mounting a shaft specimen onto a torsion testing machine, applying the twisting moment incrementally till failure. The applied torque and the corresponding angle of twist are measured and plotted as shown in Fig. 14.22. From the applied torque versus angle of twist curve, the shear properties of the material of specimen are determined. The tests are generally conducted until failure, i.e., buckling of the hollow specimen or fracture for the solid specimen. Thus, this experiment allows investigation in the different modes of failure for solid and hollow circular shafts made of ductile or brittle materials.

Therefore, from values of torque and the corresponding degree of rotation obtained from the experiment, the shear stress τ and the shear strain γ can be determined from Eqs. (14.10) and (14.12). A curve shear stress versus shear strain is plotted as illustrated in Fig. 14.22. This curve is somewhat similar to those typical stress-strain curves of specimens tested under tension, giving elastic and plastic ranges with respect to the torsional stress applied.

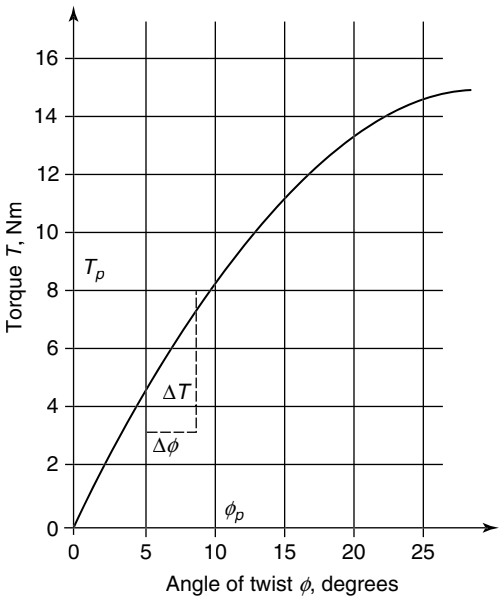


Fig. 14.22 *Relationship between torque and angle of twist*

Apparatus

Torsion testing Machine; Track base; Torsionmeter; Steel measuring tape and Micrometer; Caliper; Safety glasses.

Description of Apparatus

Typical torsion testing machine is shown in Fig. 14.23.

Fig. 14.23 *Typical torsion testing machine*

The main units of an automatic torsion testing machine typically are:
Loading device with scale and revolution counter for twisting angle measurement; Digital torque measurement unit; Calibration device; Specimen is mounted between the loading device and torque measurement unit into hexagon socket;

Torsion testing specimens The materials generally tested are round solid and hollow shafts of Structural steel; Cast iron; Cast aluminium alloys, Brass, etc. Figure 14.24 illustrates the profile of a typical torsion-test specimen.

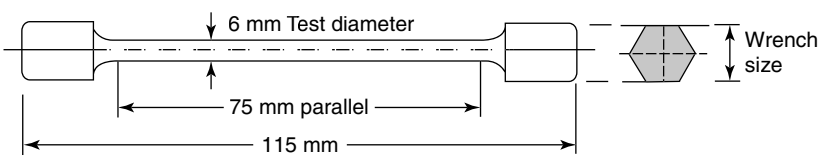


Fig. 14.24 *Typical torsion-test specimen*

Procedure

Step 1: Calibrate the torsion testing machine as outlined in manufacturer's manual.

Step 2: Measure and record the initial diameter, initial overall length and initial gauge length of the specimen. The diameter of the test specimen should be measured using the caliper as an average of five measurements.

Step 3: Draw a line using a pen along the length of the test specimen. This line will serves as a visual aid to monitor the degree of twist being put on the specimen during loading.

Step 4: Clean the clamps used to hold the specimen in place. Mount the specimen firmly in the torsion testing machine by inserting the specimen into the right clamps' chucks and tighten the clamp. Then slide the other clamp over the other end of the shaft and tighten down firmly.

Step 5: Set the torque meter indicator to read zero by aligning the red needle with the black one and measure the length between the torsion machine's clamps, L.

Step 6: Turn the crank manually forwards (counterclockwise) and observe the torque meter indicator. Increase the angle of twist by 1°/0.5° increments depending upon type of material until the specimen fractures.

Step 7: For each increment of strain record the following:

(a) Applied torque (T) displayed by the torque gauge.
(b) Angle of twist of the specimen over the gauge length in radians, as recorded by dial gauge indicator (ϕ) radians.
(c) When the elastic limit has been passed, continue the test to failure with increasing increments of strain.

Step 8: Record the angle of twist that was needed to fracture or buckle the specimen; also, record the final torque reading of the specimen at failure, T_f.

Step 9: Alter the specimen snaps at failure, investigate the mode of failure.

Step 10: Plot following curves for each specimen:

(a) Torque as ordinate versus angle of twist as abscissa
(b) Shear stress as ordinate versus shear strain as abscissa

Step 11: From the graphs plotted in Step 10, determine:

(a) Proportional shear stress (τ_p) for the hollow shaft: From the torque-twist (T–ϕ) curve determine the torque at the limit of proportionality, and calculate the corresponding shear stress.
(b) Yield shear stress based on a 0.2 per cent offset (τ_y) for the hollow shaft: At the point where the loading curve meets the 0.2 per cent offset line find τ_y.
(c) Shear modulus of elasticity (G): The shear elastic modulus, G, usually is not obtained as the shear stress, τ, divided by the corresponding shear strain, γ, but rather from the slope of the linear portion of the torque-twist (T–ϕ) curve as illustrated in Fig. 14.25.
(d) Fracture strain (γ_f) and corresponding fracture strength (τ_f) in torsion.

Step 12: Sketch the fracture surface of failed specimen and described its nature.

Step 13: Discuss the experimental obtained results.

Observations and Calculations

Dimension	Specimen # 1	Specimen # 2
Initial overall length of the specimen, mm		
Gauge length of the specimen, mm		

Initial diameter of specimen,	mm				
Final diameter of the specimen,	mm				
Final overall length of specimen,	mm				
Applied torque and corresponding angle of twist in degrees					
Sr. No.	**Applied torque *T*, Nm**	**Angle of twist ϕ, degrees / radians**	**S. No.**	**Applied torque *T*, Nm**	**Angle of twist ϕ, degrees / radians**
1.			09.		
2.			10.		
3.			11.		
4.			12.		
5.			13.		
6.			14.		
7.			15.		
8.			16.		

Results

Use the curve applied torque versus angles of twist to determine,

1. $\tau_p = T_p\, r\, /J$: valid only in the elastic range, for both solid and hollow shafts.
2. $\tau_{avg} = T/[2\pi(r_{avg})2t]$: valid only for the hollow shaft in the elastic and inelastic ranges.
3. $\gamma = \phi\, r/L$: valid in the elastic and inelastic ranges for both shafts.
   Maximum torque =…….…….…. (Nm)
   Maximum shear stress =……. (MPa)
   Shear stress at proportional limit =……. (MPa)
   Modulus of rigidity =…….. (GPa)
4. Fracture surface details

Precautions

1. It should be ensured that the whole length of the hexagon ends of the specimen are contained fully within the chuck jaws and are fully tightened.
2. When testing the more elastic materials the torsionmeter dial needs to be reset periodically to zero due to the limitation on the plunger travel.
3. The torsionmeter should be adjusted to the correct position from both ends, i.e., it should not touch any part of the testing machine.
4. Near failure torsionmeter should be totally loosened and let it hang loosely and twist the specimen to failure. The hollow aluminum shaft is considered to have failed when it buckles.

Informative Comments

For a circular cross section, in the absence of the other loads, pure shear stress state exists at each point. Torsional elastic shear stresses vary linearly from zero at the axis of twist to a maximum at the extreme fibres. Thus, in a solid circular bar specimen, when the surface fibres reach the yield shear stress they are, in a sense, supported by elastic interior fibres. Consequently, the elastic resistance of the remainder of the section masks

the effect of yielding of the surface fibres during their early stage of yielding. Usually, it is not until considerable yielding has taken place that any noticeable effect of nonlinearity is apparent using a simple mechanical torsionmeter to measure the angle of twist φ (calibrated in increments of 0.2 degrees). Therefore, it is practically impossible to determine when the extreme fibres of the solid specimen in torsion start to yield. This difficulty is overcome by the use of hollow (thin-walled) specimens, which give more sensitive measures of the elastic-plastic transition since all the fibres are at about the same stress. However, for thin-walled tubes with large ratios of diameter to thickness ($D/t > 10$) there is a tendency for premature local buckling failure to occur. Therefore, the actual dimensions of the specimen used must be carefully chosen.

The actual shear stress for the inelastic loading portion of the solid shaft plot can be determined, using the shear stress versus shear strain diagram for the hollow shaft by cross referencing the shear stress from the calculated shear strains attained from the solid shaft as illustrated in Fig. 14.25. This is possible because the stresses are nearly uniform throughout the wall thickness of the hollow shaft as compared to the solid one (both shafts are made of the same material). The cross-referenced shear stress can then be tabulated in the table as the 'actual' shear stresses at the surface of the solid shaft.

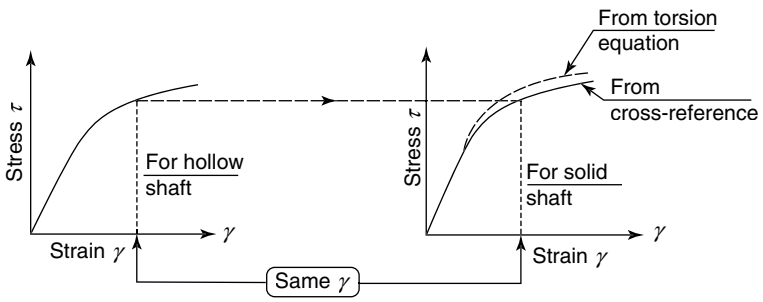


Fig. 14.25 *Cross-referencing actual shear stress for the inelastic loading portion of solid shaft plot*

A linear regression analysis, using excel program or a hand calculator, is an acceptable alternative to drawing a best fit curve through the data points for each specimen. The regression analysis will use a least squares fit to find the slope and *y*-intercept of a line through each set of data points. The slope is the shear modules *G*.

Types of Torsion Tests

Torsion tests can be performed by applying only a rotational twist or by applying both axial (tension or compression) and torsional forces.

Torsion only Applying only torsional loads to the test specimen.

Axial torsion Applying both axial (tension or compression) and torsional forces to the test specimen.

Failure testing Twisting the product, component, or specimen until failure. Failure can be classified as either a physical break or a kink/defect in the specimen.

Proof testing Applying a torsional load and holding this torque load for a fixed amount of time.

In addition to experimental imperfections, the test suffers from the inherent limitations due to the assumptions made in the derivation of torsion equation.

Viva-Voce Questions

1. What is a torsion test?
2. Why is a torsion test performed?
3. What is the importance of the mechanical properties determined in torsion test to engineering design?
4. How is the gauge length determined?

5. What mechanical properties of the material represent its ductility?
6. What are the different failure modes of specimens?
7. Why does the ductile solid shaft in torsion test shears on a right section whereas the brittle (cast aluminum) solid shaft fractures on a helicoidal path?
8. Why does the hollow specimen experiences local-buckling (the twisting of shape at failure) under torsion?

Notes and Comments

EXPERIMENT NO. 10: Fatigue Test

Objective

To conduct constant amplitude Fatigue test on a given dog-bone specimen subjected to cyclic (fatigue) loadings to fracture.

Theory and Scope

As discussed under basics, the behaviour of material under the cyclic loading and unloading is known as *fatigue* which results in the failure of material prior to its ultimate strength. This limiting stress is termed as *fatigue strength* and failure due to such loading conditions is termed as *fatigue failure*. Fatigue failure is also termed as *Endurance Limit* which is about 0.3 to 0.5 times the static ultimate strength of the material. Fatigue testing is used to determine *fatigue life* of a material, i.e., how many load cycles a material can sustain or the failure load level for a given number of cycles. Fatigue has been estimated to be responsible for up to 90 per cent of the in-service part failures which occur in industry.

Fatigue testing is essential for process and quality control, product performance validation, failure analysis in metals subjected to cyclic loading. Results of a low-cycle fatigue (LCF) test program is generally used in the development of design criteria to protect against component failure by fatigue; in the formulation of empirical relationships between the cyclic variables of stress, total strain, plastic strain, and fatigue life. Examination of the cyclic stress-strain curve and its comparison with *monotonic stress-strain curves* gives useful information regarding the cyclic stability of a material, for example, whether the values of hardness, yield point, yield strength, and strain hardening exponent will increase or decrease i.e. whether a material will harden or soften due to cyclic plastic straining.

For engineering purposes, the fatigue behaviour of a material is generally expressed by a simple sinusoidal curve between stress and number of cycles to failure (time) as illustrated in Fig.14.26. The fatigue behaviour in terms of fatigue endurance limit or fatigue life and fatigue strength of the materials can be practically described in terms of following parameters; Maximum stress (σ_{max}); Minimum stress (σ_{min}); Stress range $\Delta\sigma = \sigma_{max} - \sigma_{min}$; Mean stress = $(\sigma_{max} + \sigma_{min})/2$; Stress amplitude = $(\sigma_{max} - \sigma_{min})/2$ and Stress ratio = $\sigma_{min}/\sigma_{max}$.

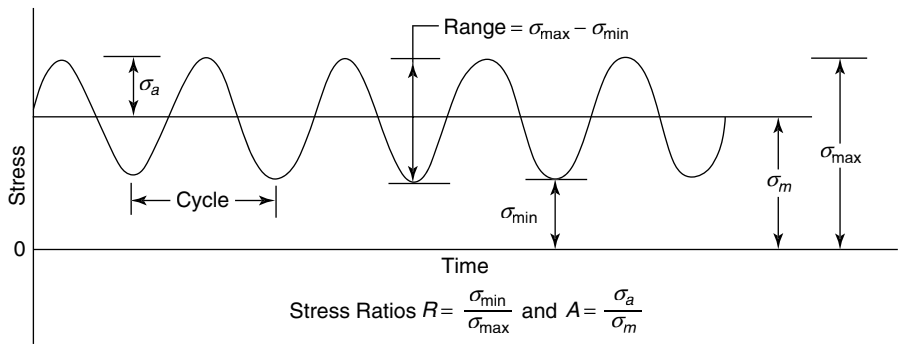


Fig. 14.26 *Simple sinusoidal curve stress vs. number of cycles (time) and fatigue test parameters*

These parameters significantly affect the fatigue behaviour of the materials. For example, increasing the maximum stress as well as mean stress and stress range leads to more severe fatigue conditions. If the

maximum and minimum stresses are tensile, they are considered to be more dangerous than compressive stresses as the tensile stresses open up the *fatigue crack*. Furthermore, if the maximum and minimum stresses are in similar amounts but having the opposite signs (tensile and compressive stresses), the stresses in this case are called completely reversed cyclic stresses in which the stress ratio equals –1.

The low-cycle fatigue testing consists of applying cyclic (uniaxial or bending) load of constant amplitude with alternating stress levels to the carefully polished test specimen of nominally homogeneous metallic materials to failure.

The fatigue life or endurance stress can be calculated as

1. **Goodman's straight line relation**

$$\sigma_a = \sigma_e \left(\frac{1}{FOS} - \frac{\sigma_m}{\sigma_u} \right)$$

2. **Soderberg's straight line relation**

$$\sigma_a = \sigma_e \left(\frac{1}{FOS} - \frac{\sigma_m}{\sigma_y} \right)$$

where

σ_a = Alternation stress,
σ_e = Endurance stress,
σ_u = Ultimate stress,
σ_y = Yield stress and
FOS = Factor of safety.

Here,

$\sigma_a = M_a / Z$ where M_a is the alternating bending moment and Z is the section modulus,
$\sigma_m = M_m / Z$ where M_m is the mean bending moment and Z is the section modulus,
$Z = \pi d^3 / 32$ and $M = W l /4$, where W is the load and l is the span of flexural specimen and
$M_a = (M_1 - M_2) / 2$ and $M_m = (M_1 + M_2) / 2$.

For M_1, use maximum load and for M_2, use minimum load.

These analysis methods consider fatigue to be sinusoidal based on constant amplitude sinusoidal loading; many situations in engineering fatigue problems cannot be considered as sinusoidal.

Apparatus

Fatigue testing machine; Micrometer or vernier caliper; Dead weights; Permanent pen, Safety goggles.

Description of Apparatus

Fatigue test specimens Test specimen must be carefully polished as surface flaws serve as stress concentrators; typical specimen is illustrated in Fig. 14.27.

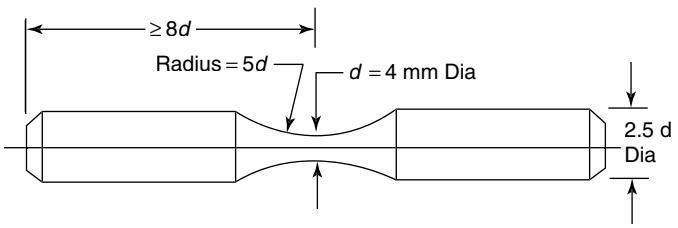


Fig. 14.27 *Typical fatigue test specimen*

Fatigue testing machine The fatigue testing can typically be conducted using the machine shown in Fig. 14.28. The fatigue test specimen of the type shown in Fig. 14.27 is clamped tightly on to a motor at one end to provide the rotational motion whereas the other end is attached to a bearing through which the specimen is subjected to a load. When the specimen is rotated about the longitudinal axis, the upper and the lower parts of the specimen gauge length are subjected to tensile and compressive stresses, respectively. This arrangement results in sinusoidal stress variation of the type shown in Fig. 14.26 at any point on the specimen surface. The test is continued to specimen failure; revolution counter records the number of cycles to failures corresponding to the applied stress.

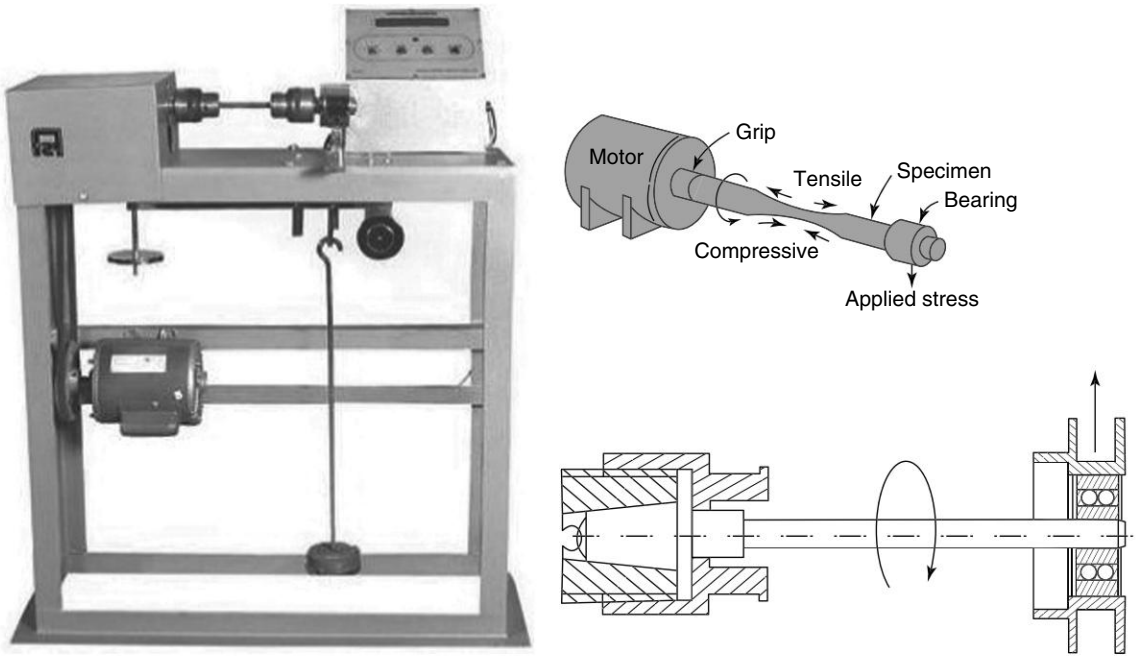


Fig. 14.28 *Rotary bending fatigue testing machine and its working principle machine*

In the recent years, the *servo-hydraulic fatigue testing machines* are increasingly being used to perform a fatigue test. This machine consists of a hydraulically operated actuator fitted into a high stiffness load frame to apply the load to the specimen. Provision of hydraulically operated test system enables achievement of both high loads and high cyclic frequencies. These machines are capable of both monitoring and controlling a desired cyclic pattern which may be in Load–Time; Strain–Time; and Displacement–Time format.

Procedure

Step 1: Measure and record the dimensions of the specimen.
Step 2: Document the testing parameters to be used namely, the waveform, maximum and minimum loads, frequency, etc.
Step 3: Clamp one end of the specimen to a motor of the testing machine and fit the other end to the bearing.
Step 4: Hang a predetermined weight at the bearing end for stressing the specimen to the required stress level.
Step 5: Measure the distance from the load end to the minimum diameter of the specimen l mm.
Step 6: Start the motor to rotate the specimen at a constant speed and continue till the specimen fails.

Step 7: Record the number of cycles at which the specimen failed from the revolution counter.
Step 8: Test the other specimen of the sample with changed weights as outlined in preceding steps.
Step 9: Construct the S–N curves for the material using fatigue data provided by the test specimens.
Step 10: Examine the fracture surfaces of broken fatigue specimen and sketch the result with details.
Step 11: Analyse and discuss the obtained results.

Observations and Calculations

Test Parameters		Specimen 1	Specimen 2	Specimen 3	Specimen 4
Minimum diameter of specimen d,	mm				
Load (weight) hung from bearing W,	N				
Distance of load from minimum section l,	mm				
Maximum bending stress, $\sigma = \frac{32Wl}{\pi d^3}$	MPa				
Frequency,	Hz				
No. of cycles to failure,	cycles				
Details of fractured surface					

Result

The endurance or fatigue strength for given sample is ……..

Precautions

1. The magnitude of load should not be changed during the fatigue test of a specimen.
2. Fatigue test specimen must be carefully prepared and polished as surface flaws can serve as stress concentrators.
3. Vibration of the machine should be avoided.
4. Safety concerns should be adequately addressed.

Informative Comments

If a bar of steel is repeatedly loaded and unloaded at say 85 per cent of its yield strength, it will ultimately fail in fatigue if it is loaded through enough cycles. Though steel ordinarily elongates approximately 30 per cent in a typical tensile test, but almost no elongation is evident in the appearance of fatigue fractures.

An increase in the load applied to the fatigue test specimen results in a reduction in number of cycles to failure.

The results of fatigue testing are material specific. For example, most steels and aluminum alloys behave very differently under fatigue. Steel typically has a *fatigue threshold*, which means that if it is tested at loads lower than the threshold, it will not fail. Most aluminum alloys do not have a *fatigue limit*, so it is more difficult to judge when they will fracture. Even at a small load, most aluminium alloys will fail after a sufficient number of cycles. The S–N curves of low carbon steel and aluminum alloys are compared in Fig. 14.29.

Plastics (Polymers) are very sensitive to strain rate, or the speed of testing. Testing plastics at a higher rate will lead to different results than testing them at a low speed. Similarly, plastics are temperature sensitive, i.e., their behaviour is quite different at high temperatures than at low temperatures.

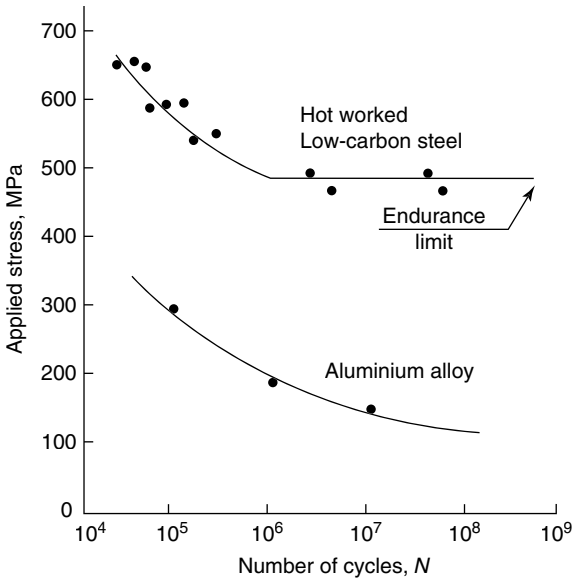


Fig. 14.29 *S-N curves of low carbon steel and aluminium alloys*

The practical difficulties with fatigue testing are twofold. First, any specimen must be subjected to a large number of loading cycles, and due to the statistical scatter in the data, a large number of samples must be tested. Low frequency loading may take considerable time to reach the desired cycles of interest (usually > 10^6 cycles). For example, at a frequency of 1 Hertz, achieving one million cycles of loading will take about 12 days.

Secondly, in most of the cases it is difficult to apply a non-zero mean load as these methods provide a completely reversed loading; typically with rotating-bending test that provides high frequency loading. However, in case of a push-pull fatigue test a non-zero mean load can be achieved.

The *fatigue strength* of engineering materials is in general lower than their *tensile strength*. A ratio of the fatigue strength to the tensile strength as described in the equation below is called the *fatigue ratio*.

$$\text{Fatigure ratio} = \frac{\text{Fatigue strength}}{\text{Tensile strength}}$$

It is normally observed that, in the case of steels, the fatigue strength increases in proportional to the tensile stress. Therefore, improving the tensile strength by hardening or other heat treatments normally increases the fatigue strength of the material. However for nonferrous metals such as aluminium alloys the fatigue ratio is found to be approximately 0.3 and the improvement of the tensile strength do not necessary increases the fatigue strength of the material.

Fatigue testing is common in the automotive and aerospace industries. This type of mechanical testing is performed using simple sinusoidal load cycles, or may include highly complex simulations of actual service life load profiles.

Viva-Voce Questions

1. How is fatigue failure defined?
2. What is meant by fatigue fracture?
3. Why is a fatigue test performed?

4. What are the methods used to prevent fatigue failure?
5. What are different types of fatigue tests?
6. What are the important parameters describing fatigue behaviour of a material?
7. What is the fatigue endurance limit?
8. How is fatigue strength obtained for non-ferrous alloys?
9. How can the fatigue life or endurance stress calculated?
10. What are the practical difficulties with fatigue testing?
11. How do the fatigue strength of an engineering material compare with its tensile strength?
12. What types of deformations are observed in fatigue failures?
13. What is a fatigue threshold?
14. What is S-N curve? What is the significance of S-N?
15. What is the difference in S-N curves of steel and non-ferrous alloys?

Notes and Comments

NATIONAL STANDARDS

1. IS: 2-1960 (revised): *Rules for Rounding off Numerical Values.*
2. IS 432 (Parts 1 and 2)–1982: *Specification for Mild Steel and Medium Tensile Steel Bars and Hard-Drawn Steel Wire for Concrete Reinforcement*, Part I: *Mild Steel and Medium Tensile Steel Bars*; Part 2: *Hard-Drawn Steel Wire*.
3. IS 961–1975: *Structural Steel* (*High Tensile*).
4. IS 1499:1977 (RA-2009) (1st revision): *Method for Charpy impact test* (U-*notch*) *for metals*
5. IS 1500:2005 (3rd revision)/ ISO 6506-1:1999; *Metallic materials—Brinell hardness test—Test method* .
6. IS 1501:2002 (3rd revision) / ISO 6507-1:1997: *Method for Vickers Hardness Test for Metallic Materials.*
7. IS 1586:2000 (3rd revision): *Method for Rockwell Hardness Test for Metallic Material.*
8. IS 1598:1977 (RA-2009) (1st revision): *Method for Izod Impact Test of Metals.*
9. IS 1599:1985 (RA-2011)/ ISO 7438:2005 (2nd revision): *Method for Bend Test for Steel Products Other.*
10. IS 1608-2005 (RA-2011)/ ISO 6892:1998 (3rd revision): *Metallic Materials—Tensile Testing at Ambient Temperature.*
11. IS 1716:1985 (RA-2001) (2nd revision): *Method for Reverse Bend Test for Metallic Wire.*
12. IS:1730-1989 (2nd revision): *Steel Plates Sheets, Strips and Flats for Structural and General Engineering Purposes.*
13. IS: 1732-1989 (1st revision): *Dimensions for Round and Square Steel Bbars for Structural and General Engineering Purposes.*
14. IS 1754:2002 (3rd revision) / ISO 6507-2:1997; *Method for verification of Vickers hardness testing machines*
15. IS 1757:1988 (RA-2009) (2nd revision): *Method for Charpy Impact Test* (V- *notch*) *for Metallic Material.*
16. IS 2281:2005 (RA-2011) (3rd revision)/ISO 6506-2:1999: *Method for Verification of Brinell Hardness Testing Machines.*
17. IS 2854:1990 (RA-2001) (1st revision): *Determination of Young's Modulus, Tangent Modulus and Chord Modulus—Test Method.*
18. IS 4258:1982(RA-2003) (1st revision): *Hardness Conversion Tables for Metallic Materials.*
19. IS 5069:1982 (RA-2003) (1st revision): *Glossary of Terms Relating to Methods of Mechanical Testing of Metals.*
20. IS 5074:1969 (RA-2001): *Method for Axial Load Fatigue Testing of Steel.*
21. IS 5075:1985 (RA-2001) (1st revision): *Method of Rotating Bar Bending Fatigue Testing of Metals.*
22. IS 5242:1979 (RA-2006) (1st revision): *Method of Test for Determining Shear Strength of Metals*.
23. IS 10588:1983 (RA-2001); *Tables of Brinell Hardness Values for Use in Test Made on Flat Surfaces.*
24. IS 12514:1988 (RA-2003): *Method for Torsional Stress Fatigue Testing.*
25. IS 13780:1993 /ISO 4506:1979: *Hard Metals—Compression Test.*
26. IS 13838:1993 (RA-2001): *Mechanical Testing of Metals—Determination of Poisson's Ratios.*
27. ISO 178*: Plastics—Determination of Flexural Properties.*

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2. ASTM E8 -Vol. 3.01: *Test Methods for Tension Testing of Metallic Materials.*
3. ASTM E606: *Standard Practice for Strain-Controlled Fatigue Testing.*
4. ASTM E855—08: *Standard Test Methods for Bend Testing of Metallic Flat Materials for Spring Applications Involving Static Loading.*
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CONSTRUCTION MATERIALS

Section 15
Structural Timber

This section describes the tests generally performed on structural timber. These include Moisture Content Determination; Tension Parallel to Grain, Tension Perpendicular to Grain; Compression Parallel to Grain, Compression Perpendicular to Grain; Static Bending; Hardness Test and Brittleness Test. The physical and mechanical characteristics of timber as determined using these tests are critical for ensuring quality structures that are safe, durable and economical.

15.1 INTRODUCTION

Wood is a complex organic construction material; sometimes defined as a natural polymeric material. It is a hard and fibrous material which forms a major part of the trunk and branches of a tree; the naturally occurring 'strength reducing characteristics' of wood such as knots, shakes, and splits play their part in determining its actual strength. It has been used successfully throughout the history of mankind for everything from structures to ships to planes to weaponry. Wood is considered as the most important raw material not only because it is used for literally hundreds of products, but also because it is a renewable natural resource. Through careful planning and use, forests may provide a perpetual supply of wood. It has broad range of physical and mechanical properties; wood from different species of trees can be selected to suit specific application requirements. Its wide application in building construction is, however, being rapidly replaced by composite wood materials in which natural wood is just a basic ingredient of a matrix or a laminate. For property enhancement for specific application, these wood products are generally treated chemically, thermally, acoustically, etc. Some examples are plywood, fiberboards, chipboards, compressed wood, impregnated wood, etc.

Wood is an anisotropic material, however, from structural point of view, it is considered an orthotropic material having unique and independent mechanical properties in three different directions namely longitudinal (main strength axis)—parallel to grain; radial and tangential (substantially lower strength axes) are "perpendicular" to the grain as illustrated in Fig. 15.1. The strength varies with moisture content.

Concept of wood as 'clear wood' is used to derive design parameters from clear wood specimens with adjustments for a range of 'strength reducing characteristics'.

Concept of timber as the useful engineering and construction material is used now for 'in-grade' testing to determine engineering properties for a specific grade of timber based on full-scale tests of timber, a mixture of clear wood and strength reducing characteristics.

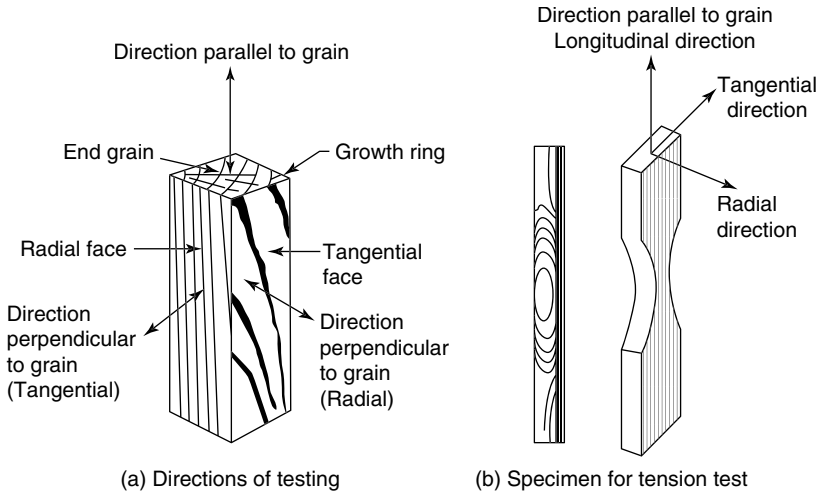


Fig. 15.1 *Orthotropic axes for determining the basic wood properties of timber*

Testing provides a quick and simple way for evaluation of basic properties of structural timber and timber products, such as strength and deformation, specific gravity or density, effect of various treatments on strength, etc., required for establishing the design parameters or functions for structural timbers. Bending and compression tests are particularly relevant because wood is frequently used in the form of beams and struts or columns where resistance to bending and compression, respectively, are important considerations. The strength of wood is influenced by factors, such as the types of loading, direction and duration of loading, specific gravity, moisture content and temperature. Timbers should be tested both in the green and the seasoned conditions.

It should be recognised that some of the tests specified are of an arbitrary nature and are intended to provide comparative data rather than to measure absolute properties of the material. They have been generally adopted and have produced useful results not only in the comparison of species of timber but also in the improvement of the design of timber structures.

This section covers the testing procedures to determine the physical and mechanical properties of the wood including flexure, tensile, compressive and shear strengths and related properties of wood by testing small clear specimens, i.e., the specimens that are free from defects, such as knots and shakes. This allows engineers to compare the properties of various species before choosing one which best suits the application requirements. However, testing small clear wood specimens is inaccurate and a more realistic way to derive them is to test structural size specimens containing defects.

15.2 MEASUREMENTS OF STRENGTHS

15.2.1 Types of Strength

In structural timber applications, following types of strength are measured:

1. **Tensile strength** One of the most important tests of structural timber is to evaluate its behaviour when subjected to tension. As wood is generally very strong in tension (of the order of steel) it is necessary to profile the sample (cut the wood into a specific shape) so that the region constituting test portion is uniform in the middle and weaker than the piece of wood in the grip as illustrated in Fig. 15.1.
2. **Compressive strength** It indicates the load a wood element can support parallel to the grain without buckling, while strength perpendicular to the grain is important in assessing its bearing resistance.

3. **Bending or flexural strength** (also known as the modulus of rupture) It provides an estimate about the load the member can withstand perpendicular to the grain.
4. **Modulus of elasticity** The stiffness or modulus of elasticity indicates the magnitudes of deflection a member will undergo when a load is applied perpendicular to its grains, e.g., the sag of shelves.
5. **Hardness** The hardness reveals resistance the surface of the wood will offer to scratches, dents, abrasion and cuts or bends.

The compressive strength is generally measured by loading a block or prism of wood parallel to the grain until it breaks, and the bending strength by loading a prism perpendicular to the grain. Both are measured in MPa. Stiffness is determined by applying a load to a beam until it deflects a certain amount, and is measured in GPa. To find hardness, a metal ball is driven at specified depth into the surface of wood and the force used is recorded in Newton. In each case, the higher the number, the stronger the wood.

In a bend test to ensure that the primary failure of the specimen occurs from either tensile or compressive stress reaching its limit and not from the shear stress reaching the limit, many wood bend testing standards require a set up with a minimum span-to-depth ratio of 14. A typical bend test set up would be to use an electromechanical testing machine and three-point anvil set. In addition, a yoke deflectometer is available for measuring deflections as shown in Fig. 15.10. For the tension test, the grip for wood specimens is generally designed to meet the strict guidelines stipulated by the standard. The grip should essentially be self-aligning, the sample slotting into the two fingers measuring bending deflections with respect to the neutral axis, e.g., as specified by ASTM D143.

15.2.2 Factors Influencing the Strength of Timber

1. **Grain direction** To take full advantage of a wood's strength, the grain direction should be considered in the design of timber members. As mentioned in Section 15.1, the wood is a natural polymer consisting of parallel strands of cellulose fibres held together by a lignin binder. These long chains of fibres make the wood exceptionally strong in resisting the stress and spreading the load over the length of the member. Furthermore, cellulose is tougher than lignin. It's easier to split a board with the grain (separating the lignin) than it is to break it across the grain (separating the cellulose fibres).

   In wood construction, the grain should be so oriented that the fibres support the load. Whenever possible, the parts should be so cut that the grain is continuous, running the length of the member. This also applies to wood joinery. Straight-grained boards are stronger than those with uneven grain, knots, and other defects.
2. **Specific gravity** The specific gravity or density of the wood is an important parameter as it may serve as an index of strength properties of the wood; it may provide a rough estimate of strength. Generally, the higher the specific gravity, the denser and stronger will be the wood as can be seen from Table 15.1. However, the specific gravity of seasoned timber varies with moisture content.
3. **Moisture content** The wood is *hygroscopic* material. Almost all the mechanical properties particularly the strength and stiffness of seasoned timber vary with moisture content and it is therefore important that the moisture content of all test pieces be known at the time of test. When comparing results obtained with seasoned material, due allowance must be made for the effects of differences in moisture content determined immediately after the tests. In the process of seasoning, the loss of moisture in timber results in an increase in strength and stiffness, but development of shrinkage stresses reduces its resistance to horizontal shear. However, the reduction in moisture content should be beyond the *fibre-saturation point* to achieve significant increase in strength and stiffness.

   Immediately after each mechanical test has been made, a small sample for determination of moisture content shall be cut from each test piece. The sample shall consist of a transverse section from near the point of fracture, but for the 20 mm standard, the compression parallel-to-grain test piece as a whole shall be used as the sample.

The sample shall be weighed and then dried in an oven at a temperature of 103 ± 2°C until the weight is constant. The loss in weight expressed as a percentage of the final oven-dry weight shall be taken as the moisture content of the test piece. The value so obtained shall be recorded with the results of the particular test to which it refers. Following points need special attention:

(a) Precaution should be taken to prevent any change in moisture content between the cutting of the sample and the first weighing and between removal from the oven and the subsequent weighing.
(b) If it is required to determine the moisture content of a specimen of timber, apart from its mechanical properties, a transverse sample of the specimen should be taken as a cross section of the piece at a distance $b + d$ from one end, where b and d are the cross-sectional dimensions of the piece.

Control of moisture content Certain standards require that before the preparation of specimens for testing in the seasoned condition, the material should be brought practically at constant weight by storage under controlled temperature (20 ± 3°C) and 65 ± 2 per cent relative humidity conditions. Changes in moisture content during the preparation of test pieces should be avoided. The tests must be made under such conditions that large changes in moisture content do not occur.

One reason why the failure of a dry beam is different from one that is moist, is that drying increases the stiffness of the fibres so that they offer more resistance to crushing, while it has much less effect upon the tensile strength.

4. **Rate of application of load** As the mechanical properties vary with the rate of application of load, it is desirable that the specific rates should be adhered to wherever possible in order that comparable results may be obtained. The rate of strain of the testing machine used should not vary by more than ± 20 per cent from that specified for a given test. If the testing machine be of a type which does not permit the specified rate of loading, the actual rate employed should be recorded with the results obtained in order that these results may be corrected as and when the relationship between the observed mechanical property and the rate of application of the load has been definitely established.
5. **Temperature of wood specimen** The effects of temperature on mechanical properties of timber are dependent upon the moisture content; the dry wood expands slightly when heated, while wet wood shrinks owing to loss of moisture. At higher temperature, seasoned wood becomes weaker in most strength properties. Low freezing temperatures add to the strength properties of the wood.

   To avoid significant changes in strength properties, all test pieces shall be tested within the temperature range 20 ± 3°C. The temperature at the time of test shall be recorded.

15.2.3 Stress-Strain Behaviour

Unlike steel due to anisotropic or orthotropic nature of wood, in the absence of well-defined elastic limit, it does not have unique values of modulus of elasticity, shear modulus and Poisson's ratio. However, wood has three principal axes along longitudinal, radial and tangential directions as illustrated in Fig. 15.1. The stress-strain curves in these directions are fairly straight over a considerable range followed by gradual curving off. Thus in each direction, there is a proportional limit and mechanical properties are fairly constant. The wood has three values of modulus of elasticity in the range 150 to 1, three shear moduli in the range 20 to 1 and six Poisson's ratios varying from 40 to 1.

The wood is a ductile material; the relative positions of stress-strain curves for direct tension, direct compression and bending stress parallel to the grain are illustrated in Fig. 15.2. The figure shows that in the stress-strain curves of direct compression and bending, the proportional limits are of the order of 65 to 75 per cent of the ultimate strength. In the stress-strain curve for direct tension, there is no proportional limit for practical purposes.

The modulus of elasticity of timber along the grain is practically the same in direct tension, direct compression and bending in the absence of shear deformation; since the modulus of rigidity of wood is low (approximately 1/20 to 1/15 of the modulus of elasticity). However, the bending modulus of elasticity of

timber may reduce by 5 to 10 per cent of the true bending modulus of elasticity depending upon the type and rate of loading and span.

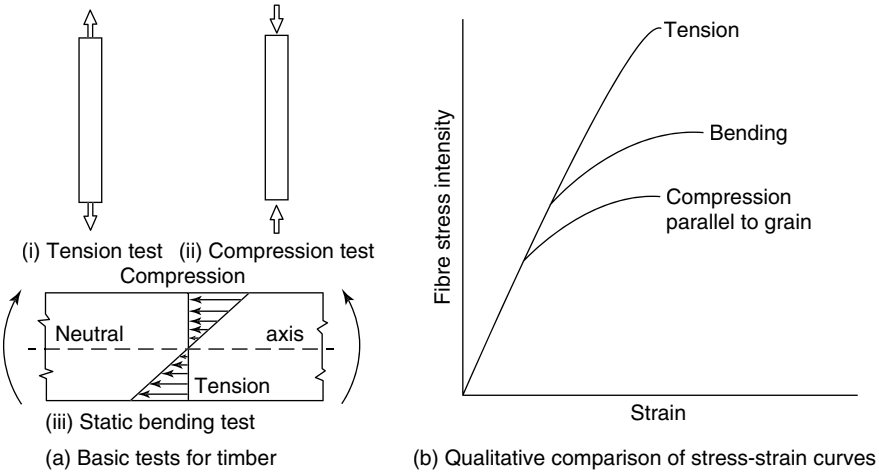


Fig. 15.2 *Typical stress-strain curves parallel to grains from different tests on structural timber*

The stress-strain curve for timber is generally obtained from tensile test on standard specimens as shown in Fig. 15.3. The details of the specimen and the method of testing are detailed in IS 1708 (Part 12)-1986. The important parameters in tensile test are the gauge length, L_o and the initial cross section area A_o. The loads are applied through the grips at the ends.

15.2.4 Properties of Timber Determined From Stress-Strain Curve

The ultimate or tensile strength of the timber is given by

$$f_u = \frac{\text{Ultimate tensile load}}{\text{Original area of cross section}} \tag{15.1}$$

Ideally, the ultimate strength would have been calculated based on reduced area of cross section, but it is not practical to determine reduced area of cross section at various stages of loading. Thus this stress is also called the *nominal* or the *engineering stress*. Similarly, the engineering strain is taken as the ratio of the change in length to original length. It is the largest value of stress that the material can support. This value is commonly used to determine the maximum or nominal strength of a member.

Table 15.1 *Unit weight and bending strength of some typical structural timbers*

Type of wood	Unit weight at 12% moisture content, kN/m^3	Bending stress, MPa location	
		Tension	*Compression*
1. Babul	8.35	18.2	15.4
2. Mango	6.55	12.4	10.2
3. Deodar	5.60	10 2	8 8
4. Fir	4.65	7.8	6.6

continued

Table 15.1 *contd.*

Type of wood	Unit weight at 12% moisture content, kN/m^3	Bending stress, MPa location	
		Tension	*Compression*
5. Chir	5.75	8.4	7.0
6. Jaman	8.50	15.2	12.6
7. Sal	8.00	16.8	14.0
8. Oak	8.65	14.8	12.4

Elastic constants

1. **Modulus of elasticity**, *E,* is a measure of a material's *axial stiffness*; it changes with the type of timber and direction of load. The modulus of elasticity is based on the slope of the line joining origin to proportionality limit on stress-strain curve.
2. **Shear modulus**, *G*, is a measure of the *shear stiffness* of the material; it changes with the type of timber and direction of load.
3. **Poisson's ratio** is not required in strength and serviceability computations. However, it is often used in structural analysis.
4. **Shearing strength** Wood has low shearing strength of 6.5–14.5 MPa along the fibres. Resistance of wood to cutting across the fibres is three to four times greater than that along the fibres, but pure shear generally does not take place since the fibres are also subjected to crushing and bending.

Toughness

The toughness is the ability of a material to resist fracture or to absorb large amounts of energy under impact loading; it involves both strength and ductility (flexibility). The toughness of structural timbers enables the timber members to be subjected to large deformations when they are sawed, sheared, cut and nails and screws are driven during fabrication and erection without fracture. This is an important consideration in timber construction where impact loads are significant and structures subjected to earthquake loading which is dynamic in nature. For low toughness cases, it is determined from the area under-stress curve. Generally, green wood is tougher than seasoned wood and hard woods excel in toughness. The toughness is estimated by the energy of the blow required to rupture a beam in transverse impact.

Hardness

In general, hardness implies the resistance to indentation, abrasion and scratching which are important properties for finishing the woodwork. Combined with wearing resistance, these properties form important consideration wooden floors and pavements. Depending upon the form of the indenter forced on to the surface and the manner in which the test is conducted the methods for determining the hardness of a wood sample are classified as: (i) Brinell hardness, (ii) Vickers hardness and (iii) Rockwell hardness. For details, readers may refer to Section 14(14.2.5.)

Shrinkage

The wood shrinks with changes in the moisture content; shrinkage is most pronounced in the radial and tangential directions, i.e., perpendicular to grain. It is determined on test pieces 25 × 25× 100 mm, the 100 mm being the direction for which the shrinkage is to be determined.

The test piece is weighed and measured before, drying and after subsequent drying, at both the air-dry and the oven-dry conditions.

The green test pieces shall be allowed to dry on wire racks in well-ventilated boxes until a uniform moisture content of approximately 12 per cent is reached. Subsequently they shall be placed in an oven and dried until the weight is constant at 100°C–105°C.

15.3 TEST PROCEDURES

The main purpose of testing of small clear specimens of timber has been to develop data for the comparison of the strength properties of different species. The test results are used also to determine the relation between strength and such properties as density, to determine the effect on strength of various treatments and conditions.

For structural design, it is necessary to supply the designer basic physical and mechanical properties of timber to be used in construction in advance. To this end, the producers need to specify the minimum requirements which their products meet. The tests are conducted to ensure that products conform to the material's specified properties and meet grading requirements.

15.3.1 Testing Equipment

Testing systems need to ensure accurate and consistent results. The test machine, its gripping and measurement systems must be unaffected by imperfections on the surface of timber specimens. Software used to control testing must incorporate sophisticated algorithms to determine test results from a wide variety of stress/ strain curves.

For mechanical tests on timber, it is preferable to have a single test platform universal test machine (UTM) with top-mounted hydraulic actuator (this will enable provision of loading area at ground level) of capacity of 500 kN which can accommodate commonly used timber specimens. This test machine can perform tension, compression and bend tests on the timber samples simply by adding compression adapters and bend fixture to the tension grips.

For tension test, hydraulic wedge grips are preferable because the initial clamping force will reduce the grip slippage on the uneven surface of the timber specimen. Currently machines with automatic extensometer to measure strain over adjustable gauge length are available. A typical universal testing machine is shown in Fig. 14.3.

15.3.2 Gauge Length for Test Specimen

For specimens that have the same cross-sectional area throughout such as rectangles, the gauge length is determined by simply measuring the distance between the grip faces. For the most commonly used dog bone specimens, illustrated in Fig. 15.3, the non-uniform shape often introduces errors in the gauge length measurement. However, in a dog-bone specimen, most of the stretching occurs within the narrow region of smaller area, A_o and not in the tabs because they have a larger cross-sectional area; the narrow length is taken as the gauge length L_o. For accurate strain measurement an extensometer can be used.

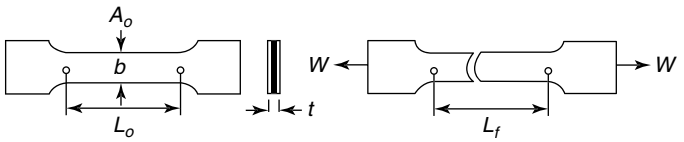


Fig 15.3 *Gauge length of tensile test specimen*

$$\text{Elongation, } \delta = \frac{\text{elongated length } (L_f) - \text{gauge length } (L_o)}{\text{gauge length } (L_o)} \times 100 \text{ per cent} \quad (15.2)$$

15.3.3 Preparation of Test Samples

15.3.4 Commonly Performed Tests on Timber

The tests described in this section are:

1. Determination of moisture content [IS 1708 (Part 1)-1986]
2. Determination of static bending strength [IS 1708 (Part 5)-1986]
3. Determination of static bending strength under two point loading [IS 1708 (Part 6)-1986]
4. Determination of compressive strength parallel to grain [IS 1708 (Part 8)-1986]
5. Determination of compressive strength perpendicular to grain [IS 1708 (Part 9)-1986]
6. Determination of tensile strength parallel to grain [IS 1708 (Part 12)-1986]
7. Determination of tensile strength perpendicular to grain [IS 1708 (Part 13)-1986]
8. Determination of hardness under static indentation [IS 1708 (Part 10)-1986]
9. Determination of brittleness by Charpy impact [IS 1708 (Part 17)-1986]

For all the tests described in this section, the method as specified in relevant ISO standard may also be followed as an alternate method. The final value, observed or calculated, expressing the result of a test or analysis, is rounded off in accordance with IS: 2-1960. The number of significant places retained in the rounded-off value should be the same as that of the specified value in the code.

EXPERIMENT NO. 1: Moisture Content

Objective

To determine the moisture content of wood samples by the oven-dry method.

Theory and Scope

The test procedure is used in determination of moisture content of wood samples. The moisture content of wood samples gives valuable information on its mechanical properties. The moisture content (MC) of a piece of wood is defined as the weight of water expressed as a percentage of the weight of the wood either the total (wet) sample weight (wet basis) or the dry wood weight (dry basis). All field calculations are carried out on a "wet basis" (MC_{wb}). On a dry basis moisture content can be expressed as

$$\text{Moisture content (MC)} = \frac{\text{Weight of water}}{\text{Weight of wood}} \times 100 \text{ per cent}$$

On dry basis, the weight of the wood does not include any water. It is the weight of the piece after it is oven dry and all water has been removed. The weight of the water is the difference in the weight of the piece before and after drying. Therefore,

$$MC_{db} = \frac{\text{Mass of specimen} - \text{Mass of oven dry specimen}}{\text{Mass of oven dry specimen}} \times 100 \text{ per cent}$$

The test is performed by cutting the sample to be tested, weighing it, drying it to a constant weight, reweighing, and doing the calculation. This simplified method is designed to provide an estimate of moisture content using the minimum of specialist equipment and should not be used for marketing purposes or as a substitute for a complete analysis conducted by an approved test centre.

Moisture determination is generally made on all specimens tested except those to be photographed or kept for exhibit. A 20–25 mm disk is cut from near the point of failure of bending and compression parallel specimens, from the portion under the plate in the case of the compression perpendicular specimens, and from the centre of the hardness test specimens.

Apparatus

For conducting the test following equipment is required:

A saw; Sample containers; Heat-proof containers: Balance of capacity of 5 kg; Well-ventilated thermostatically controlled oven to maintain a temperature of 100°C to 110°C; Oven thermometer; Heat proof mat and Oven gloves.

Description of Apparatus

Sample containers These are airtight sealable containers large enough to contain a complete sample. Plastic food containers are appropriate for the chip but for logs sealable airtight plastic bags may be used. All containers are weighed before use.

The heatproof container for oven drying (if used) should be corrosion resistant and non-combustible.

Oven Electrically heated thermometer mounted oven is suitable; it should be of appropriate size; a 300 × 300 × 600 mm external size oven can serve the purpose for small specimens. The oven needs to be able to attain and maintain a temperature of 105 ± 2°C. An adjustable hole or vent in the oven provides a way for moisture to get out and fresh air to get in. Some ovens have a second hole for mounting a thermometer to allow it to be read without opening the oven door.

Fan ovens may not be appropriate for testing chip as the air circulation may blow fine particles out of the sample container.

Balance or Scale The range or weighing capacity of the balance needs to be adequate to hold the sample. In general, the scale should read to 1 part in 1000 for the oven-dry weight of the sample to give accuracy to the nearest 0.1 per cent moisture content. Thus, for the oven-dry sample weighing more than 1000 g, a balance accurate to the nearest 1 gram is adequate. It must have a 're-zero' or 'tare' button to allow for the weight of containers, and be able to weigh several kg.

An electronic balance with adequate resolution is preferable for small samples.

Saw A radial arm saw can be used to cross cut the samples to an appropriate length for the oven drying and balance weighing. In the short-term, a hand-held circular saw can be used.

In-oven thermometers These should be accurate to nearest 2°C, adjustable and must have a waterproof sensor for calibration.

Heat proof mat These are used to provide insulation between hot samples and the balance.

Oven gloves The heat proof gloves are used while working with ovens.

Procedure

Step 1: Take representative samples from the lot of wood.

Step 2: Cut the test specimens (free from all defects) of a cross section, 15 to 20 mm and length in the direction of the grain from the sample. Immediately after each test specimen is cut, remove the loose splinters and saw dust by brushing or scraping.

Step 3: Weigh the specimen either immediately after cutting or store each specimen in a separate weighed airtight container or sealable plastic bag. After the initial weight is obtained, no particular precautions for storage need to be observed and the specimen can be oven-dried later at convenience.

Step 4: Weigh the specimen in the airtight container before opening it to provide an accurate weight of the specimen before any material or water is lost from the specimen.

Step 5: Record the initial weight on data sheet along with specimen numbers. If the initial weight is written directly on the specimen itself, it should be properly labelled for identification.

Step 6: Preheat the oven to an internal temperature of 103°C.

Step 7: Transfer each sample from the airtight container to a labelled heatproof container and place the weighed specimen in the oven to dry to a constant weight at the temperature of 103 ± 2 °C. While checking each sample weight every 4 hours if the difference in weight of a sample for two consecutive measurements is less than twice the sensitivity of the balance or scale, it can be considered to be oven dry. The total drying period is typically (12–18) hours. However, for a 25-50 mm sample cut from dimension lumber or boards the total drying period is typically taken as (24 ± ½) hours.

If the process of drying the samples to constant weight takes a time longer than that recommended for the oven operation by the manufacturers or if is required to leave the samples; then switch off the oven leaving the samples inside and allow it to cool down and start heating again later.

Step 8: Determine oven-dry mass of all the test specimens either directly after removing from the oven or after cooling them in desiccators to near room temperature.

Step 9: Calculate the moisture content of wood specimens. The average of moisture content of all the specimens from the lot tested is reported correct to the nearest whole number.

Observations and Calculations

Type of wood or product…….
Source……

		1	2	3	4	5
Initial mass of test specimen	W_i, g					
Oven-dry mass of test specimen	W_o, g					
Moisture content dry basis $MC_{db} = \frac{W_i - W_o}{W_o} \times 100$	per cent					
Average moisture content MC_{db},	per cent					
Moisture content wet basis $MC_{wb} = \frac{W_i - W_o}{W_i} \times 100$	per cent					
Average moisture content MC_{wb},	per cent					

Moisture content of wood samples on dry basis ….....… per cent.
Moisture content of wood samples on wet basis….....… per cent.

Precautions

1. The samples need to be representative from which they are taken. Thus, they should be collected from throughout a pile or shipment, not just the top or sides. After a board is chosen, the sample should be cut at least 600 mm from the end of the board because wood picks up and loses moisture very rapidly through the end grain.
2. Do not add wet samples to the oven when other samples are almost dry. Water will evaporate from the wet samples and be absorbed up by the drier ones causing an error when they are weighed due to a temporary increase in moisture content.
3. If the oven temperature is too low, the relative humidity in the oven will not be low enough. The ambient air contains moisture and raising its temperature simply lowers its relative humidity causing lower equilibrium moisture content.
4. If the oven temperature is too high, some of the wood components can be driven off. When these are counted as moisture, the indicated moisture content is too high.
5. Do not overload an oven. The heated, dry wood is liable to catch fire; good air circulation around the samples is needed to reduce the risk of fire.
6. While testing more than one sample, the containers should be labelled for identification. Put all of the samples in the oven at the same time.
7. Care should be taken to avoid overloading the balance, especially electronic scales when they are not plugged in.
8. While checking each sample weight every 4 hours it should be insured that a heat proof mat is placed between the samples and the balances.
9. Domestic ovens are not precision instruments and frequently have a wide margin of error in terms of temperature control, so some form of calibration is necessary.

Informative Comments

The method is simple and reliable, except for certain timber species containing volatile oils (like deodar). However, the method is time consuming and requires cutting of samples from the timber to be tested.

The critical factor in taking a sample is that it should be representative of the whole lot. It is desirable to have the same distribution of particle sizes in your sample as exist in the store, and the sample should have the same moisture content as the surrounding material. A sample should be taken from a minimum of five samples, taking material from the upper, middle and lower parts of the full stack. Ignore any material from the lowest 300 mm of the stack as this is likely to pick up additional moisture and other contamination from the ground.

The oven-dry test is suitable for obtaining the moisture content of a sample, but it can also be used to obtain information about the moisture distribution within a piece of wood. By cutting samples at predetermined distance along the length of a timber member to determine how moisture content changes or a piece of wood can be sliced to determine the moisture profile through the thickness. A shell/core moisture content test is a variation on the latter. Here, the outer shell of the sample is sawn away from the inner core and the two parts are weighed and dried separately. This might be useful for export wood when a customer specifies certain moisture content at the center of a piece.

In case of logs, the test specimens should be cut from the sample at least 600 mm from its end because wood picks up and loses moisture very rapidly through the end grain. In case, cutting of specimen from the selected samples is not possible, the moisture content in the whole sample may be determined by collecting borings to a depth of half the thickness of each sample (obtained by means of an auger) in pre-weighed weighing containers.

Other Methods for Moisture Content Determination

Hand held electrical moisture meter This non-destructive test is a direct, fast and convenient means of determining moisture content of timber and its products. These are of special value in field inspections and for checking of finished timber products. Resistance type meters are provided with electrode pins of suitable lengths for the thickness of timber under test, species correction and temperature correction.

To measure the moisture content of a wood log using a resistance type hand held moisture meter, it must be freshly split and then three measurements taken on the freshly split surface: 50 mm in from each end of the log and in the middle of the split surface with sufficient contact. A number of logs (at least 5 logs from each 2 m^3 batch) should be tested and the average (mean) moisture content over all of the readings be computed.

The resistance type of moisture meter can give only an approximate indication of the moisture content of logs. For an analysis of marketing, or assessment of compliance to standards or specifications a complete analysis conducted by an approved test centre is desirable.

Distillation method This method is suitable for species like deodar containing volatile extractives and for timber impregnated with chemicals that are likely to interfere with the correct determination of moisture content by oven-drying or electrical moisture meter methods.

About 50 g of each test sample is distilled till no more water collects in the water trap. Any water condensed elsewhere in the trap is washed down into the trap with the help of a solvent (xylene or toluene) spray. Sufficient time is allowed for a clear separation of water and solvent in the trap.

Viva-Voce Questions

1. What is the significance of oven-dry test?
2. How is a representative sample collected from a pile or shipment?
3. What are the different methods for expressing the moisture content of a sample?
4. What are the different methods used for evaluation of moisture content?

5. Why is the oven-dry test most widely used for obtaining the moisture content of a sample?
6. What are the disadvantages of oven-dry test method?
7. What are the special features of the oven used for oven-dry test?
8. Why is it necessary to calibrate the domestic oven before using it for moisture content determination by oven-dry test?
9. What are the effects of oven temperature being too high or too low?
10. Why should the wet samples not added to the oven when other samples are almost dry?

Notes and Comments

EXPERIMENT NO. 2: Tensile Test

Objective

1. *To examine the constitutive behaviour of the timber tested to failure in tension.*
2. *To determine the tensile strength, modulus of elasticity, modulus of resilience and modulus of toughness.*

Theory and Scope

The tensile testing of a standard timber specimen to failure provides the important basic properties, viz., the proportional or elastic limit of the material, the ultimate stress, the elongation (strain) at fracture and the material stiffness, i.e., Young's modulus of elasticity. This data enables in setting the required performance level, checking the suitability of the product for a particular application and to control the quality of production. The load-elongation curve of a timber specimen subjected to axial tension can be used to determine the

tensile stress at proportional limit $= W_p/A$

tensile stress at maximum or failure load $= W_f/A$

modulus of elasticity in tension parallel to grain,

$$E = \frac{W/A}{\delta/L} = \left(\frac{W}{\delta}\right)\left(\frac{L}{A}\right) = \left(\frac{\Delta W}{\Delta\delta}\right)\left(\frac{L}{A}\right)$$

The ratio $(\Delta W / \Delta\delta)$ is obtained from load-elongation curve

where

W_p = load at the limit of proportionality,

W_f = maximum load to cause the failure of the specimen,

A = cross-sectional area,

L = gauge length and

δ = elongation.

The tension test specimens used for determining the tensile strength of timber parallel to grain are of two types with cross section of the central portion of the specimen 7 × 7 mm or 5 × 5 mm as illustrated in Figs. 15.4(a) and (b), respectively.

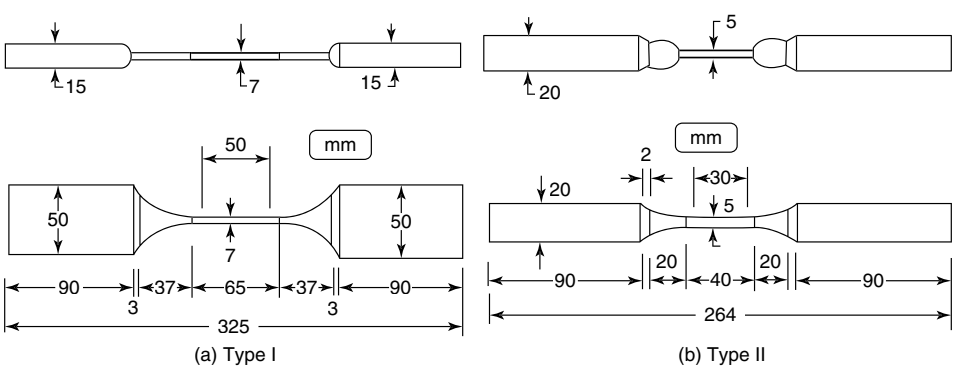


Fig. 15.4 *Timber specimens for tension test parallel to the grain*

There are two types of tension test specimens used for determining the tensile strength perpendicular or across the grain as shown in Figs. 15.5(a) and (b); the notches are provided to confine the failure on to 50 × 20 mm or 20 × 10 mm cross sections in the radial or tangential surface as illustrated in Figs. 15.5(a) and (b), respectively.

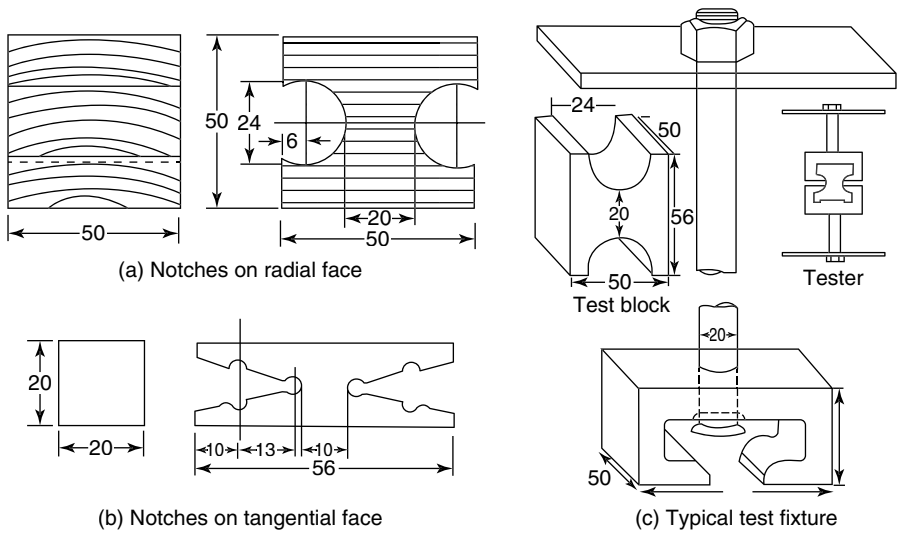


Fig. 15.5 *Test specimens and typical text fixture for tension test perpendicular to grains*

Apparatus

Universal Testing Machine (UTM) with applicable tensile grips; Mechanical extensometer; Calipers; Mechanical dividers; Machinist scale; Gauge length marker.

Description of Apparatus The special testing device for tension test at right angles to the grain consists essentially of two clamps, one of which is suspended from the centre of the top of the cage, the other extended above the movable head. At each end a 25 mm hole is bored with its centre equidistant from the two sides and 6 mm from the ends.

The free ends of the clamps are fitted into the notches in the ends of the specimen as illustrated in Fig. 15.5(c). The movable head of the machine descends at the specified rate, pulling the specimen in two at right angles to the grain. The maximum load only is taken and the result expressed in MPa. A piece 25 mm thick is split off parallel to the failure and used for moisture determination.

Procedure

Part 1: Tensile Strength Parallel to Grains

Step 1: Prepare standard specimens as per IS 1708 (Part 12)-1986 specifications.

Step 2: Take and record physical measurements including the mean cross-sectional dimensions of the specimen in the central portion of the specimen.

A small preload was applied to ensure that all jaws moved an equal amount and maintained axial alignment of specimen and grips.

Step 3: Mark a 200 mm gauge length near the middle of the specimen. *The gauge mark will provide reference points for determination of the per cent elongation. Gauge marks shall be light, sharp, and accurately spaced (200 © 1.5 mm).*

Step 4: Insert the specimen in the UTM. Hold the specimen firmly in the grips and securely clamp with special care to have the longitudinal axis of the specimen and the grip coincide so that the tensile forces are axial and generally uniformly distributed throughout the cross sections without flexure along its length. Ensure that the grips to the section remain outside the gauge length.

Step 5: Attach suitable elongation measuring device i.e. extensometer to the gauge length carefully.

Step 6: Select a load range for the UTM that will accommodate the maximum anticipated load during the test.

Step 7: Apply the load continuously at a constant rate of 1 mm/minute for both types of specimens. Record simultaneously the readings of load from the UTM and elongation from the extensometer at suitable load intervals such that 8–10 reading are available up to limit of proportionality.

Step 8: Remove the extensometer when load nears its range and continue monitoring the elongation of the specimen well beyond the proportional limit using the mechanical dividers and machinist scale in 1.5 mm increment until fracture occurs. Record the load at fracture of specimen.

Part 2: Tensile Strength Perpendicular to Grains

The test is conducted on a testing machine provided with suitable grips to hold the specimen as described in Part 1 above. However, the load is applied continuously at a constant rate of 2.5 mm/minute until the maximum load is reached for both sizes.

Step 1: Determine the moisture content as follows:

(a) Immediately after test has been completed, cut a small sample from each test piece for determination of moisture content. The sample shall consist of a transverse section from near the point of fracture.

(b) Weigh the sample and then dry it in an oven at a temperature of 103 ± 2 °C until the weight is constant.

(c) Express the moisture content of the test piece as the loss in mass as a percentage of the final oven-dry mass. Record the value so obtained with the results of the particular test.

Step 2: Draw a complete load-elongation curve for the entire test to fracture.

Step 3: Clearly mark and record the following values on load-elongation curve plotted in Step 2:

(a) Proportional limit load,
(b) The maximum or failure tensile load,
(c) Modulus of elasticity,
(d) Modulus of resilience, and
(e) Modulus of toughness.

Step 4: Compare the experimental values to the known theoretical values for the given type of timber.

Observations and Calculations

Type of wood or product …….
Source……
Test temperature……
Moisture content……

Load W,	N										
Elongation δ,	mm										
Ratio $\Delta W / \Delta\delta$ from curve											

Cross-sectional area of the test section A,	mm^2	
Gauge length L,	mm	
Load at the limit of proportionality W_p,	N	
Maximum load to cause the failure of the specimen, W_f	N	

Results

Tensile stress at proportional limit, W_p/A = ...MPa
Tensile stress at maximum or failure load, W_f/A = ...MPa
Modulus of elasticity, $E = \left(\frac{\Delta W}{\Delta \delta}\right)\left(\frac{L}{A}\right)$ = ...MPa
Modulus of resilience = ...
Modulus of toughness = ...

Precautions

1. The function of the gripping or holding device of the machine is to transmit the load from the heads of the machine to the specimen under test. Thus, it is essential that the load shall be transmitted axially. This implies that the centers of the action of the grips shall be in alignment, insofar as practical, with the axis of the specimen at the beginning and during the test, and that bending or twisting be held to a minimum.
2. For proper working, the extensometer should be attached carefully as per manufacturer's directions.
3. Great care should be exercised to prevent any change in moisture content between the cutting of the sample and the first weighing and between removal from the oven and the subsequent weighing.

Informative Comments

Resilience is the amount of energy (or work) that can be absorbed during the linear behaviour of the specimen. This is the area under the linear portion of the stress strain curve up to the point of proportionality. Modulus of resilience is the amount of energy stored per unit volume at the elastic limit.

Toughness is the amount of energy the specimen can absorb until failure. This is represented by the area under the load-extension curve up to the failure point and can be easily obtained by counting the squares under the curve on graph paper. Modulus of toughness is the amount of energy stored per unit volume at fracture of the material; this is a measure of the ductility of the material.

The tensile strength of wood parallel to the grain is very high; it is of the order 80.0 to 190.0 MPa. Therefore, wood tension members are rarely used as it is difficult to design end connections that allow the tensile strength of a member to be fully developed. The timber tension members restrained at their ends are liable to suffer from shearing stresses and crushing which wood resists poorly. Moreover, as the tensile strength of timber parallel to the grain is two to four times the compressive strength, the latter governs the strength of beams.

The tensile strength parallel to the grain is basically influenced by the straightness of the grain and the thickness of the walls of the longitudinal elements. When failure occurs, these elements are ruptured transversely. The defects in timber like knots, shakes, etc., significantly reduce the tensile strength parallel to the grain. The tensile strength is less affected by moisture than are other mechanical properties.

The tensile strength of timber perpendicular or across the grain is low; the failure across the grain occurs through separation of the cells and fibres in longitudinal planes. The defects like knots, shakes, etc. reduce the tensile strength of wood across the grain. This property is closely related to cleavability, and it often determines the strength of a beam which has cross-grain or spiral-grain in its tension fibres.

Viva-Voce Questions

1. What is a tension test? What is the significance of this test?
2. What is the importance of the mechanical properties determined in tensile test to engineering design?
3. How is the gauge length determined?
4. What mechanical properties of the material represent its ductility?
5. Why is alignment important in tensile testing?
6. When testing some specimens, why do the strain values appear to go backwards?
7. What is the effect extensometer slippage?

Notes and Comments

EXPERIMENT NO. 2: Compressive Strength Test

Objective

1. *To examine the constitutive behaviour of the timber tested to failure in compression.*
2. *Determine the compressive strength, modulus of elasticity, modulus of resilience and modulus of toughness.*

Theory and Scope

The compression test on a standard timber specimen loaded to failure is used to determine the important basic properties i.e. the proportional or elastic limit of the material, the ultimate stress, the compressive strain at crushing and the material stiffness, i.e., Young's modulus of elasticity. This data enables in setting the required performance level, checking the suitability of the product for a particular application and to control the quality of production.

From the load deformation curve for a timber specimen subjected to axial compression following properties can be computed

Compressive stress at proportional limit = W_p/A

Compressive stress at maximum or failure load = W_f/A

Modulus of elasticity in compression parallel to grain

$$E = \frac{W/A}{\delta/L} = \left(\frac{W}{\delta}\right)\left(\frac{L}{A}\right) = \left(\frac{\Delta W}{\Delta \delta}\right)\left(\frac{L}{A}\right)$$

The ratio $(\Delta W / \Delta \delta)$ is obtained from load-deformation curve

where

W_p = load at the limit of proportionality,

W_f = maximum load to cause the failure of the specimen,

A = cross-sectional area,

L = gauge length and

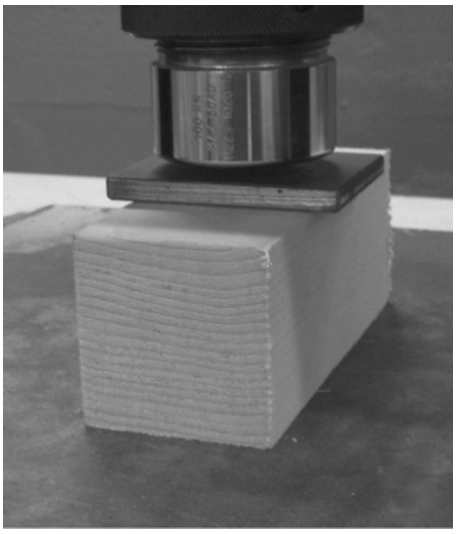
δ = shortening or compression.

There are two sizes of standard test specimens used in determination of compressive strength of timber parallel to grain; the sizes are $50 \times 50 \times 200$ mm or $20 \times 20 \times 80$ mm.

The test specimens used in determining the compressive strength perpendicular or across the grain are of two sizes $50 \times 50 \times 150$ mm or $20 \times 20 \times 100$ mm and should be free from defects and faces should approach closely to the true radial and tangential directions.

A typical arrangement for compression test parallel to grain is shown in Fig. 15.6. The gauge length is approximately 75 per cent of the length of specimen.

(a) Compression paralled to grain



(b) Compression perpendicular to grain

Fig. 15.6 *Timber test specimens under compression along and perpendicular to grain.*

Apparatus

Universal Testing Machine (UTM); Mechanical compressometer; Gauge length marker; Dial calipers and Dial gauge.

Procedure

Part 1: Compressive Strength Parallel to Grains

Step 1: Prepare standard specimens as per IS 1708 (Part 8)-1986 requirements.

Step 2: Take and record physical measurements of the specimen.

Step 3: Mark a 150 mm gauge length at the middle of the specimen. *The guage marks will provide reference points for determination of the per cent compression.*

Step 4: Place the specimen in the UTM centrally. For 200 mm specimen apply a preload of 2.5 kN to set the specimen. Attach suitable deformation measuring device to the gauge length.

Step 5: Select a load range for the UTM that will accommodate the maximum anticipated load during the test.

Step 6: Apply the load continuously at a constant rate of 0.6 mm/minute for both sizes. Record simultaneously the readings of load from the UTM and deformation under compression at suitable load intervals such that 8 –10 reading are available up to limit of proportionality.

Step 7: Remove the deformation meter when it nears its test range and continue monitoring the deformation of the specimen well beyond the proportional limit using the mechanical dividers until fracture occurs. Record the load at fracture. For 80 mm specimen, final reading of the crushing maximum load only is recorded.

Step 8: Record the compression failures according to the appearance of the fractured surface as illustrated in Fig. 15.7. In case two or more kinds of failures develop, they are described in the order of their occurrence (for example, shearing followed by shearing crushing).

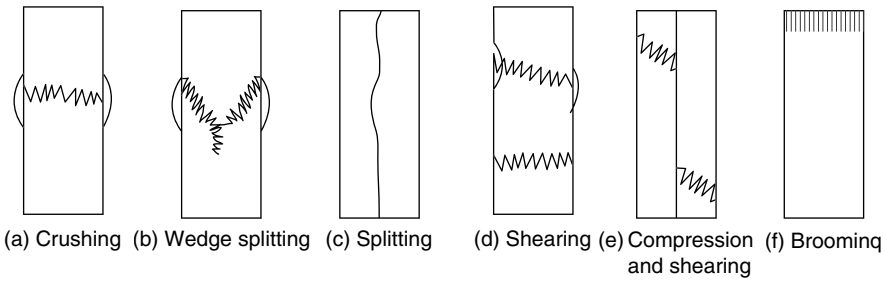


Fig. 15.7 *Failure of timber specimen under compression parallel to grain*

Part 2: Compressive Strength Perpendicular to Grains

Conduct the test on the testing machine with specimen placed under preload not more than 500 N on 150 mm and 100 N on 100 mm specimen as described in Part 1 above.

Apply the load continuously at a constant rate of 0.6 mm/minute and the deformation is measured to obtain to 8-10 readings up to limit of proportionality and is continued up to a deformation of 2.5 mm. Record the load at 2.5 mm deformation. If maximum load is reached at some lesser value of compressive load, record the same along with corresponding deformation.

Step 1: Determine the moisture content as follows:

(a) Immediately after test has been completed, cut a small sample from each test piece for determination of moisture content. The sample shall consist of a transverse section from near the point of fracture, but for the 200 mm standard compression parallel to grain test piece as a whole shall be used as the sample.
(b) Weigh the sample and then dry it in an oven at a temperature of 103 ± 2°C until the weight is constant.
(c) Express the moisture content of the test piece as the loss in mass as a percentage of the final oven-dry mass. Record the value so obtained with the results of the particular test.

Step 2: Draw a complete load-deformation curve for the entire test to fracture.

Step 3: Clearly mark the salient points and compute the various characteristics from the load-deformation curve plotted in Step 2:

(a) Proportional limit load,
(b) Compressive load at 2.5 mm compression
(c) Maximum or failure load,
(d) Modulus of elasticity,
(e) Ultimate or failure tensile stress,
(f) Modulus of resilience, and
(g) Modulus of toughness.

Step 4: Compare the experimental values to known theoretical values for the given type of timber.

Observations and Calculations

Type of wood or product …….
Source……
Test temperature……
Moisture content……

1. Data for the compression test parallel to grain

Load W,	N										
Deformation δ,	mm										
Ratio $\Delta W / \Delta\delta$ from curve											

Cross-sectional area, A	mm^2		
Gauge length L,	mm		
Load at the limit of proportionality W_p	N		
Maximum load to cause the failure of the specimen W_f	N		

Results

Compressive stress at proportional limit, W_p/A = ...MPa
Compressive stress at maximum or failure load, W_f/A = ...MPa
Modulus of elasticity, $E = \left(\frac{\Delta W}{\Delta\delta}\right)\left(\frac{L}{A}\right)$ = ...MPa
Modulus of resilience = ...
Modulus of toughness = ...

2. Data for the compression test perpendicular to grain

Load W,	N										
Deformation δ,	mm										
Ratio $\Delta W / \Delta\delta$ from curve											

Cross-sectional area, A	mm^2		
Gauge length L,	mm		
Load at the limit of proportionality W_p	N		
Load at 2.5 mm compression $W_{2.5}$	N		
Maximum load to cause the failure of the specimen W_f	N		

Results

Compressive stress at proportional limit, W_p/A = ...MPa
Compressive stress at compression of 2.5 mm, $W_{2.5}/A$ = ...MPa
Compressive stress at maximum or failure load, W_f/A = ...MPa
Modulus of elasticity, $E = \left(\frac{\Delta W}{\Delta\delta}\right)\left(\frac{L}{A}\right)$ = ...MPa
Modulus of resilience = ...
Modulus of toughness = ...

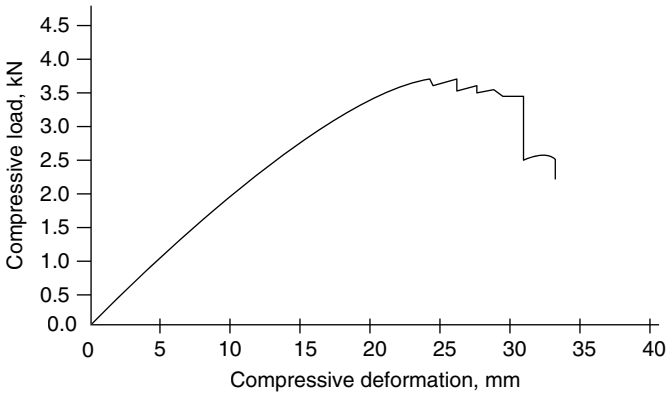


Fig. 15.8 *Typical compressive load-deformation curve parallel to grain for a timber specimen*

Precautions

1. The specimen under test should be centrally placed on the machine so that the load is transmitted axially.
2. For proper working, the compressometer should be attached carefully as per manufacturer's directions.

Informative Comments

Compression stress shortens or compresses the material. In wood construction, the primary types of compression encountered are parallel to the grain and perpendicular to the grain. Compression parallel to the grain shortens the fibers in the wood lengthwise. Wood is very strong in compression parallel to the grain and is considerably weaker in compression perpendicular to the grain. If at a contact point the applied pressure exceeds the fibre stress at proportional limit for the wood, permanent indentations will result on the surface.

Resilience is the amount of energy (or work) that can be absorbed during the linear behaviour of the specimen. This is the area under the linear portion of the load-deformation curve up to the point of proportionality. Modulus of resilience is the amount of energy stored per unit volume at the elastic limit.

Toughness is the amount of energy the specimen can absorb until failure. This is represented by the area under the load-deformation curve up to the failure point and can be easily obtained by counting the squares under the curve on graph paper. Modulus of toughness is the amount of energy stored per unit volume at fracture of the material; this is a measure of the ductility of the material.

The compressive strength parallel to the grain is basically influenced by the straightness of the grain and the thickness of the walls of the longitudinal elements. When failure occurs, these elements are ruptured transversely. The defects in timber like knots, shakes, etc. significantly reduce the tensile strength parallel to the grain. The compressive strength is less affected by moisture than are other mechanical properties.

Viva-Voce Questions

1. What is a compression test?
2. What is the significance of this test?
3. What is the importance of the mechanical properties determined in compression test to engineering design?
4. What is the gauge length for specimen tested in compression?
5. What mechanical properties of the material represent its ductility?

6. Why is alignment important in compression testing?
7. When testing some specimens, why do the load values appear to go backwards? What is the effect compressometer slippage?

Notes and Comments

EXPERIMENT NO. 4: Static Bending Test

Objective

1. *To perform the three-point static bend test.*
2. *To determine the bending strength or the modulus of rupture of timber.*
3. *To determine the modulus of elasticity of timber.*

Significance

Bending test is commonly used to measure the flexural strength and modulus of all types of materials and products; it is performed by subjecting a specimen of the material to a measured deformation to which it is likely to be subjected in service/ application. The test indicates the adequacy or otherwise of the material to undergo required deformation without fracturing or yielding.

Theory and Scope

Bending tests are carried out in accordance with IS 1708 (Part 5)-1986 to ensure that a timber has sufficient bending strength to withstand bending without fracturing. In the test procedure, a standard specimen at room temperature is subjected to a load acting through one or two points. Depending upon load application the bending tests are called *one-point loading test* and *two-point loading test* as shown in Fig. 15.9. These tests are also called *three-point bending* and *four-point bending tests*. For general standard testing of timber for the comparison of different species, the test with a central load is sufficiently accurate. Where a more accurate determination of absolute properties of the material e.g. the modulus of elasticity, is required the four-point bending test has to be employed. Using this method, the beam is subjected to a uniform bending moment over a considerable proportion of its length and the modulus of elasticity can be calculated without the necessity of allowing for shear deflection which occurs along the whole length of a beam loaded at the centre.

The direction of grain flow is noted whether the bending is parallel or across the grain.

1. For a simply supported beam with a concentrated load applied at its centre,

   Deflection δ under the load, $\delta = \dfrac{WL^3}{48EI}$

   where

   W = Applied load,

   L = Effective span of the beam,

   E = Modulus of elasticity of wood, and

   I = Moment of inertia.

   Therefore, modulus of elasticity, $E = \dfrac{WL^3}{48\,\delta\, I} = \left(\dfrac{W}{\delta}\right) \times \dfrac{L^3}{48\ I}$

   $$= \left(\frac{\Delta W}{\Delta \delta}\right) \times \frac{1}{4\ b} \times \left(\frac{L}{d}\right)^3$$

   The ratio $\dfrac{\Delta W}{\Delta \delta}$ is obtained from the load-deflection curve.

From the basic bending equation, $\frac{M}{I} = \frac{F}{y} = \frac{E}{R}$, the breaking or rupture stress, F_{max}, can be computed as

$$\frac{M_{max}}{I} = \frac{F_{max}}{y_{max}} \quad \Rightarrow \quad F_{max} = \frac{M_{max}}{(I / y_{max})} = \frac{M_{max}}{Z}$$

For a simply supported timber specimen of rectangular section $b \times d$ (deep):

$$F_{max} = \frac{M_{max}}{Z} = \frac{(WL/4)}{(bd^2/6)} = \frac{3WL}{2bd^2}$$

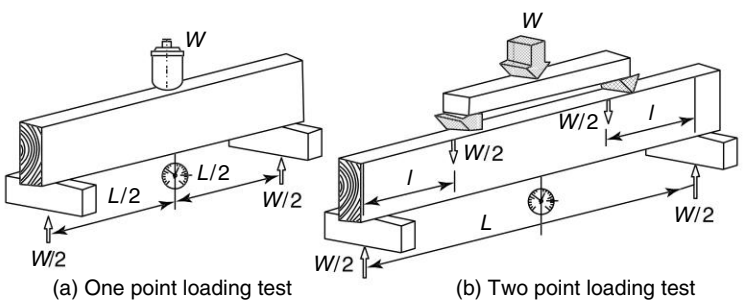
2. For a simply supported timber specimen of rectangular section $b \times d$ (deep) with two loads of magnitude (W/2) acting through two points at distance l from the supports

$$\delta = \frac{Wl}{48EI}(3L^2 - 4l^2) \quad \Rightarrow \quad E = \left(\frac{\Delta W}{\Delta \delta}\right)\left(\frac{l}{4bd^3}\right)(3L^2 - 4l^2)$$

$$F_{max} = \frac{M_{max}}{Z} = \frac{(Wl/2)}{(bd^2/6)} = \frac{3Wl}{bd^2}$$

In this expression, W is the breaking or failure load in N; b and d are the lateral dimensions of the cross section in mm. L is the distance between supporting rollers or effective span in mm. l is the distance between points of application of the load and the supports.

All strengths are in MPa.



(a) One point loading test (b) Two point loading test

Fig. 15.9 *Concept of one load point and two load point static bending of a simply beam*

Apparatus

Universal Testing Machine(UTM); 20kN Wood bend test fixture base beam; Yoke for measuring the deflection.

Procedure

Step 1: Estimate the maximum or failure load the beam can support:
Specified working bending stress for the type of wood, σ_b = ... MPa
Factor of safety, FS = ... (e.g. 5)
Probable bending stress at failure, $f_{max} = \sigma_b \times FS$ = ... MPa
Probable fracture or failure load,

(a) One point loading test: $W = f_{max} \times (2/3) \times (bd^2/L)$ = ... N
(b) Two point loading test: $W = f_{max} \times (1/3) \times (bd^2/l)$ = ... N

Step 2: Insert the appropriate bend test fixture in the UTM. Adjust the supports for the required distance and clamp to the lower platform of the machine.

Step 3: Measure and record the physical dimension, i.e., width b, depth d and distance L between the two supports or the span of timber specimen.

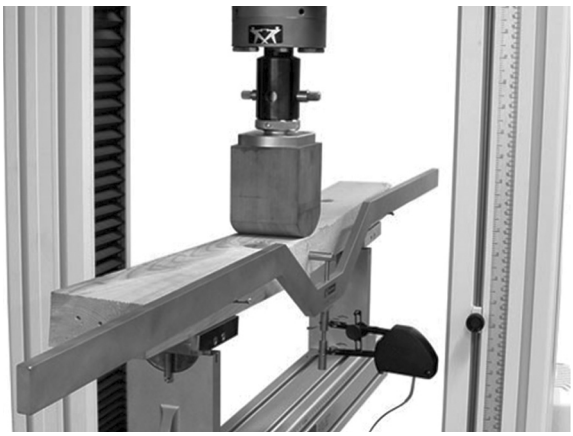


Fig. 15.10 *Typical bend testing fixture with a test specimen loaded and ready to be tested*

(a) One-point loading test The size of specimen may be 50 × 50 × 750 mm or 20 × 20 × 300 mm. The test specimen is supported on the adaptor or fixture as shown in Fig. 15.10.

(b) Two-point loading test The specimen is of 50 × 50 × 1000 mm or 20 × 20 × 400 mm size. The distance l between points of application of the load and the supports shown in Fig. 15.9(b) is 150 mm for 50 × 50 mm and 60 mm for 20 × 20 mm cross-section beams.

Step 4: Place the specimen on the two supports provided on bend test fixture with the depth oriented vertically in the apparatus. The length of the supports shall be at least 10 mm more than the width of the test specimen.

Step 5: Apply the load continuously at the following rates:

(a) In the case of one point loading test, apply the load at a constant rate of 2.5 mm per minute in case of 50 × 50 × 750 mm and 1.0 mm/minute in case of 20 × 20 × 300 mm.

(b) In the case of two point loading test apply the load at a constant rate of 3.0 mm/minute and 1.5 mm/minute in the case of 50 × 50 × 1000 mm and 20 × 20 × 400 mm, respectively.

Step 6: Measure and record the deflections of the neutral plane at the centre of the length with respect to the points in the neutral plane above the supports at suitable load intervals such that about 8 to10 readings are available up to limit of proportionality. Record the reading of the load corresponding to each deflection reading.

Step 7: Continue loading beyond the limit of proportionality up to maximum load or beyond maximum load until a deflection of 150 mm for 750 mm and 60 mm for 300 mm specimens is reached or the specimen fails to support 1.0 kN for 50 × 50 × 750 mm or 0.2 kN for 20 × 20 × 300 mm specimens, whichever is earlier.

Step 8: Record the failure mode of the specimen according to its appearance and sequence of development.

Step 9: Determine the moisture content as follows:

(a) Immediately after test has been completed, cut a small sample from each test piece for determination of moisture content. The sample shall consist of a transverse section from near the point of fracture.

(b) Weigh the sample and then dry it in an oven at a temperature of 103 ± 2 °C until the weight is constant.

(c) Express the moisture content of the test piece as the loss in mass as a percentage of the final oven-dry mass. Record the value so obtained with the results of the particular test.

Step 10: Plot a load-deflection curve with load as ordinate and deflection as abscissa from the recorded readings of deflection and the load.

Step 11: Determine various strength characteristics of timber specimen.

Step 12: Calculate the percentage of elastic strain energy that is stored in a loading-unloading cycle for a wood sample.

Step 13: As an exercise compute the stiffness of this wood sample using loading and unloading curves.

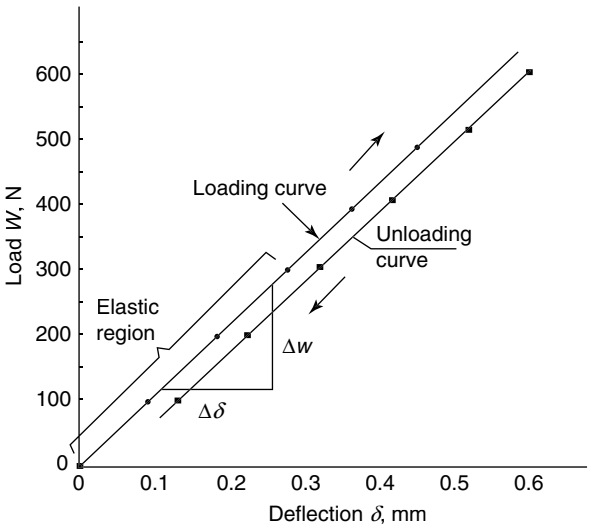


Fig. 15.11 *Typical load- deflection curve for a timber test specimen under static bending*

Observations and Calculations

Type of wood or product …….
Source……
Test temperature……
Moisture content……

1. Load deflection curve

Load W,	N									
Deflection δ,	mm									
Ratio $\Delta W / \Delta\delta$ from curve										
$E = \left(\frac{\Delta W}{\Delta\delta}\right) \times \frac{1}{4\,b} \times \left(\frac{L}{d}\right)^3$, MPa										
$E = \left(\frac{\Delta W}{\Delta\delta}\right)\left(\frac{l}{4bd^3}\right)(3L^2 - 4l^2)$										

2. Flexural properties of timber specimen

Specimen no.	Size of specimen $b \times d \times L$ and l, mm				Maximum applied load at failure, W N	Flexural strength, MPa (i) $F_{max} = 3(WL / bd^2)$ (ii) $F_{max} = (WL / 2bd^2)$
	b	d	L	l		
1.						
2.						
3.						
Average flexural strength nearest to 0.5 MPa						
Specified flexural strength, MPa						

Results

1. Modulus of elasticity of the wooden beam is ..... MPa.
2. Modulus of rapture is ..... MPa.

Precautions

1. The test specimen shall be placed in the machine correctly centred with the longitudinal axis of the specimen at right angles to the supports with the depth oriented vertically.
2. The load applying blocks shall be brought in contact with the upper surface at the predefined points between the supports. If the full contact is not obtained between specimen and load applying blocks and supports due to the surface of the specimen being out of plane, the surface of the specimen where they are to be in contact with blocks or supports should be planed or packed to produce full contact.
3. The load shall be applied slowly without shock at the stipulated rate.
4. As the elastic properties of timber are being determined it is important to ensure that the sample does not become permanently deformed.
5. In the case of manual loading of thin specimens, further load should not be added until the deflection caused by the previously added load has stabilized; the equipment should not be jogged or tapped, as these actions affect the recorded data.

Informative Comments

The failure of long wooden beams of uniform width initiates in the form of wrinkling of the overstressed compression fibres like those in compression prisms; finally such beams generally fail in tension. At the maximum load the specimen snaps due to rupturing of individual fibres. Very dry specimens sometimes fail suddenly in tension before any wrinkling of the compression fibres is observed. However, green test specimens fail silently in compression without breaking of the tensile fibres. On the other hand, short deep beams fail suddenly by horizontal shear; this type of failure is common in well-seasoned timber of structural sizes than in green timbers or in small beams. Shear failures generally result from the defects in the timber.

Failure mechanism in timber beams The failures of loaded beams are generally classified according to the manner in which they are initiated, as tension, compression, and horizontal shear; and according to the appearance of the fractured surface, as brash, and fibrous.

Since the tensile strength of wood is on the average about three times the compressive strength, a beam is generally expected to fail by the formation ripples or folds (buckling of fibres) on the compression face due to the crushing action, followed by failure on the tension side. This is usually the case in green or moist wood. In dry material the first visible failure is frequently on the tension side.

Within the elastic limit, the elongations and shortenings are equal, and the neutral plane lies in the middle of the beam. On increasing the load, the fibres on the compression side progressively fail; however this failure may not be visible. The reduction in effective area on the compression side results in the gradual movement of neutral plane toward the tension side, i.e., the tension area becomes smaller than the compression area. Under increasing load when the stresses in the outer fibres on the tension side become sufficiently high, the fibres are pulled resulting in a rupture. The rupture is often irregular as in the case of direct tension tests. Sometimes failure may occur partially in individual bundles of fibres before the final failure takes place.

Classification of failure

1. **Tension failures** Depending upon the toughness of the wood, the arrangement of the grain, defects, etc. the tension failures may be classified as follows:
   - *(a) Simple tension failure* In this type of failure, there is a direct pulling in two of the wood fibres on the underside (tension face) of the beam due to a tensile stress parallel to the grain as illustrated in Fig. 15.12(a). This type of failure commonly occurs in straight-grained seasoned wood beams.
   - *(b) Cross-grained tension failure* In this type of failure, the fracture is caused by a tensile force acting oblique to the grain as illustrated in Fig. 15.12(b). This type of failure generally occurs in the beam having diagonal, spiral or other form of cross grain on its tension side. Since the tensile strength of wood across the grain is only a small fraction of that along the grain resulting a cross-grained tension failure.
   - *(c) Splintering tension failure* This type of failure consists of a considerable number of minor tension failures, producing a ragged or splintery break on the tension surface of the beam as illustrated in Fig. 15.12(c). In this case, the surface of fracture has fibrous appearance. This failure is common in tough woods.
   - *(d) Brittle tension failure* In this type of failure, the beam fails suddenly without warning by a clean break extending throughout its depth as illustrated in Fig. 15.12(d); the surface of fracture is described as brash. This type of failure occurs in brittle woods.
2. **Compression failure** The compressive stress parallel to the fibres causes fibres to buckle or bend on the top (compression) face shortly after the elastic limit is reached. It appears at various distances from the neutral plane of the beam as illustrated in Fig.15.12(e). This buckling of fibres extends downward, sometimes almost reaching the neutral plane before complete failure occurs. Frequently two or more failures develop at about the same time. This type of failure is very common in green timbers.

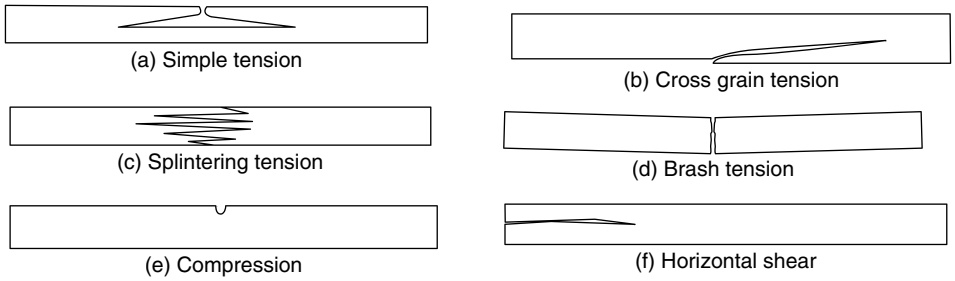


Fig. 15.12 *Characteristic failures of simple beams under static bending*

3. **Horizontal shear failure** In this type of failure, the upper and lower portions of the beam slide along each other for a portion of their length either at one or at both ends as shown Fig. 15.12(f). This type of failure is fairly common in air-dry timber and green timber when the ratio of the depth of the beam to the span is relatively large. It is not common in small clear specimens. It is often due to shake or season checks, common in large timbers, which reduce the actual area resisting the shearing action considerably. The effect of a failure in horizontal shear is to divide the beam into two or more parts (beams) the combined strength of which is much less than that of the original beam. These parts may behave independently and compression failure may occur in a part above the original location of the neutral plane.

   One reason why the failure of a dry beam is different from one that is moist, is that drying increases the stiffness of the fibres so that they offer more resistance to crushing, while it has much less effect upon the tensile strength

   It should be noted that the difference in requirements for different codes makes achieving the compatibility to multiple standards a challenge. For example, ASTM D143, states that the supporting anvils of the three-point static bend fixture should be provided with bearing plates and the load should be applied to the centre of the specimen by a rigid upper block. However, ISO 3133 states that the support and load applying anvils should be rollers of a specified diameter.

   The commonly used definition of softwood and hardwood does not relate to the wood's mechanical properties. For example the softwood pine is much stiffer than the hardwood, balsa. This is mainly due to the ultra-low density of balsa; the stiffness and hence the strength of wood correlates with density.

   The loading and unloading curves do not exactly coincide; this demonstrates *viscoelastic properties of wood under deformation*. Viscoelasticity which is due to the lignin matrix present in the wood is advantageous as it dampens vibrations. A stiff material could also limit deflections, but at the expense of high stresses. Overall, it is preferable to be flexible (able to bend). The viscoelasticity dissipates the energy in the wood on loading. The area between the loading and unloading curves represents the elastic strain energy that is being stored in the wood. However the amount of energy is not high enough to cause problems.

Viva-Voce Questions

1. What is the basic difference between hardwoods and softwoods?
2. How does the mechanical properties of wood change with moisture content?
3. What deformation characteristics are observed on three-point bend testing?
4. What is the failure mechanism of wood on loading during three-point bend testing?
5. What is the bending test for timber beams?
6. What is the significance of bending test?
7. What are the factors which influence the result of bending test?
8. What is the drawback with these methods?
9. What is the equation governing simple bending?
10. What is the meaning of flexure equation: $M/I = f/y = E/R$?
11. What is meant by modulus of rupture?
12. How is the fibre bending stress calculated in a loaded beam?
13. What is the central deflection of a simply supported beam under concentrated load?
14. How simple bending is ensured in the loading arrangement?
15. Sketch the variation of bending and shear stress over a beam cross section.
16. Why a beam is generally provided with depth larger than the width?
17. What are the types of loading used in laboratory flexure tests?

18. What is the rate of loading in flexure test?
19. How are flexure test results expressed?
20. What is the permissible variation in strength of a specimen while taking the average?
21. Why the beams are generally tested along or parallel to the fibres?

Notes and Comments

EXPERIMENT NO. 5: Hardness Under Static Indentation Test

Objective

To determine the Brinell hardness for the given specimens of timber and its products.

Theory and Scope

Hardness is the resistance of a material to localized deformation. The term can apply to deformation from indentation, abrasion, scratching, cutting or bending. The deformation considered is plastic or permanent deformation of the surface and is subject to different interpretations. Hardness measurements are widely used for the quality control of materials because they are quick and considered to be nondestructive tests when the marks or indentations produced by the test are in low stress areas.

In Brinell hardness testing, steel bar with hemispherical end or a ball of diameter 11.28 mm to a depth of 5.64 mm that is the projected area of greatest circle is 100 mm^2 are used as indentor. The specimens are same as that used in compressive strength test perpendicular to grain.

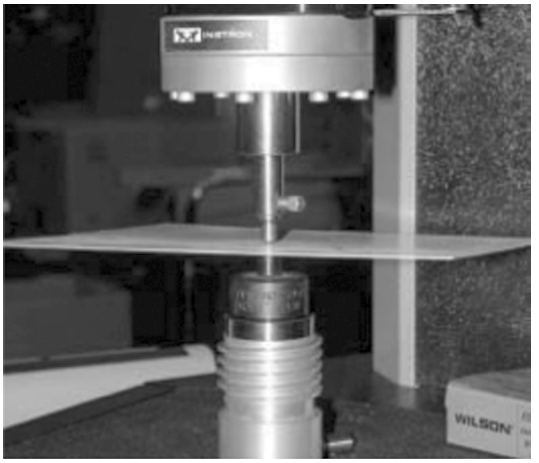


Fig. 15.13 *Brinell hardness testing machine*

Apparatus

Brinell Testing Machine, Timber specimen and Brinell microscope.

Procedure

Step 1: Prepare timber specimen of 50 × 50 × 150 mm and 20 × 20 × 100 mm sizes.

Step 2: Clean the indenter and anvil and insert the indenter in the indent holder of the machine.

Step 3: Clean the specimen surface by removing dust, dirt, and grease, etc., and place it on the anvil of the machine such that two penetrations are made on the radial face, two on the tangential face and one on each end in case of 50 × 50 × 150 mm size and for 20 × 20 × 100 mm size one penetration is made on tangential and one on radial face.

Step 4: Adjust the jack by hand operated wheel so that the specimen surface just touches the indenter

Step 5: Press the loading button and apply the load continuously at a constant rate of 6 mm/minute till the standard steel ball or hemispherical end of the steel bar indent or penetrates to the specified depth of 5.64 mm for tangential surface. Perform two penetrations on one surface or one penetration on both opposite sides. Record the average value.

Step 6: Repeat the procedure of Step 4 for radial surfaces; take the average of radial and tangential hardnesses as side hardness.

Step 7: Remove the specimen from the anvil and locate the indentation so made.

Step 8: View the indentation through microscope and measure the diameter d by micrometer fitted on microscope.

Step 9: Repeat the test three times.

Step 10: Determine the Brinell hardness number (BHN) by dividing the applied testing load with the surface area of the spherical cup. This results in the formula:

$$BHN = (0.102)\frac{2F}{\pi D(D - \sqrt{D^2 - d^2})} = (0.102)\frac{F}{\pi D h}$$

where F is the test load in N , D is the diameter of the ball penetrator in mm and d is the diameter of the indentation in mm, h is the depth of impression in mm. The units of BHN are MPa.

Observations and Calculations

Reporting Brinell test results The test conditions should be reported along with the Brinell hardness number. In Brinell test report, the abbreviation BHN (Brinell hardness) follows the Brinell hardness number and is followed by the ball diameter in mm, the test load as per specification and the testing time in seconds, if it differs from the standard time (10–15 seconds). For example, a value reported as 60 BHN 10/14710/30 means that a Brinell hardness of 60 was obtained using a 10 mm diameter ball with a 14710 N load applied for 30 seconds.

Test piece material = ----------

Sr. No.	Ball diameter, D mm	Load applied, F N	Diameter of indentation, d mm	F/D^2	BHN
1					
2					
3					

Average hardness of the material: …..BHN…...../.....…../…...…

Precautions

1. The indenter and anvil should be clean and well seated.
2. The surface of specimen to be tested must be well prepared, clean and dry.
3. The surface should be flat and perpendicular to the indenter.
4. The thickness of the specimen should be such that a mark or bulge is not produced on the reverse side of the piece. It is generally recommended that the thickness be at least 10 times the depth of the indentation. The spacing between indentations should be three to five times the diameter of the indentation.

Informative Comments

The method uses very high test loads generated by relatively simple and robust devices. Furthermore, the indentation can be measured with the help of a simple microscope or even with a measuring magnifier. The Brinell value can be multiplied with a certain coefficient, which is specific for every material, to determine the material's tensile strength.

The main drawback with the Brinell hardness test is that the Brinell hardness number is not independent of the applied load; as the ball is pressed into the surface under increasing load the geometry of the indentation changes.

Although high test loads are used, the surface must be well prepared in order to achieve the high accuracy needed for the measurement of the indentation.

For further details reader should refer to Section 14.5.

Viva-Voce Questions

1. Define the hardness.
2. Why is the hardness not a basic property of the material?
3. What are the different forms of hardness?
4. What are the units of Brinell hardness?
5. What are the limitations of Brinell hardness test and why?
6. Can the tensile strength of a material predicted if its hardness in known?
7. Which ball size is generally recommended for Brinell test?

Notes and Comments

EXPERIMENT NO. 6: Brittleness Evaluation by Impact Tests

Objective

To evaluate the toughness or impact strength of structural timber by Charpy V-notch and Izod Impact tests.

Significance

The Charpy impact test or Charpy V-notch test is a standardised high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of toughness of material of specimen. It is widely used in industry, since it is easy to prepare and conduct and results can be obtained fast and economically. But a major disadvantage is that all results are only qualitative or comparative rather than a definitive and as such is often used in quality control applications.

Theory and Scope

The test is performed with a pendulum-type single-blow impact apparatus wherein a standard size machined, notched specimen of material is broken by a falling pendulum hammer (swinging through a fixed distance) one blow. In Charpy test, a specimen with a V-notch at the centre is supported at both ends as a simple beam, while in Izod test a specimen with a saw-notch near the end is supported as a cantilever.

The energy absorbed, as determined by the difference in the height of the hammer before and after fracture of specimen, is a measure of impact strength or notch toughness. The impact test results are expressed in kilo joules as an assessment of toughness or energy absorption. A typical test set up for the test and standard specimens are shown in Fig. 15.14.

In case of brittle fracture, the material breaks on a flat plane and in ductile fracture the material breaks with jagged edges or shear lips. Usually a material does not break in either way; thus comparing the jagged to flat surface areas of the fracture will give an estimate of the percentage of ductile and brittle fracture.

Apparatus

Pendulum-type single blow impact testing machine as schematically illustrated in Fig. 15.14(a); Vernier caliper; Specimen setting fixtures.

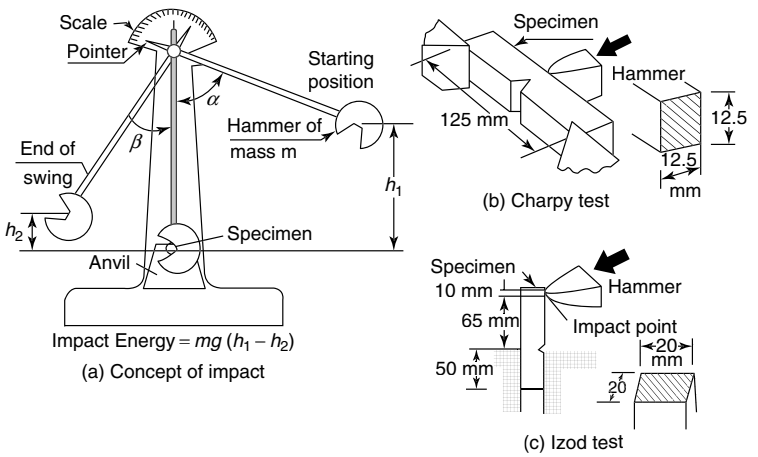


Fig. 15.14 *(a) Schematic of impact machine, (b) Charpy V-Notch test and (c) Izod Test specimens*

The machine should have a calibrated dial so as to give direct reading of energy absorbed in breaking specimen on a single blow.

The specimen geometry for the Charpy and Izod impact tests are shown in Fig. 15.14(b) and (c), respectively.

Charpy impact test The specimen of 12.5 × 12.5 mm cross section and 125 mm length is provided with a V type notch 2.5 mm in depth and 5 mm in width at the centre on the radial face so as to obtain maximum concentration of impact stress in a cross section of 12.5 × 10 mm.

Izod impact test The specimen of 20 × 20 × 125 mm (length) in size is provided with a saw notch 2 mm in width and 7 mm in depth on the radial face at a distance of 50 mm from one end so as to produce maximum concentration of impact stress on the cross section of 20 × 13 mm.

Procedure

Step 1: Measure the dimensions of the timber specimen; and record the mass m of striker/hammer marked on its surface and length of the pendulum *l*.

Step 2: Set the latching mechanism in the upper position.

Step 3: Lift the pendulum to its upper position and secure it with the safety latching mechanism.

Step 4: Release the pendulum with no specimen on anvil; record the reading which gives friction at the bearings, and air resistance offered to striker and pendulum.

Step 5: Using positioning gauge place the Charpy V-notch test specimen horizontally across supports on the anvil in the path of a pendulum with the notch facing away from the hammer. Make sure the specimen is centered within the anvil jaws and tightened firmly in the position.

Step 6: Slide the indicator pointer to the left until it indicates the maximum energy range on the upper Charpy tension scale.

Step 7: Raise the pendulum arm to the right until it is firmly supported by the latching mechanism. Caution: Make sure the safety latch is in the clear when raising the pendulum arm into this test position.

Step 8: The test conductor or laboratory instructor shall then release the pendulum by pushing up on the release knob. The hammer will drop and attain a striking velocity of 16.8 ft/s, striking the specimen, with a swing through dependent on the amount of energy absorbed by the test specimen. The indicator will move and stop when peak swing through is registered, providing a direct reading of the energy absorbed by the specimen.

Step 9: Read the indicated value from the Charpy scale and record.

Step 10: Apply the hand brake when the pendulum has returned to its stable hanging vertical position.

Step 11: Remove the specimen from the testing area and examine the failure surface.

Step 12: Leave pendulum in the down hanging vertical position until another test is to be performed.

Step 13: Determine the moisture content as follows:

(a) Immediately after test has been completed, weigh the sample.
(b) Dry the weighed sample in an oven at a temperature of 103 ± 2 °C until the weight is constant.
(c) Express the moisture content of the test piece as the loss in mass as a percentage of the final oven-dry mass. Record the value so obtained with the results of the particular test.

Step 14: For Izod test, clamp the specimen tightly in vertical position as a cantilever in anvil of the machine in the path of the pendulum with the notch facing hammer. Ensure that the pendulum strikes the radial face of specimen horizontally at a distance of 10 mm from the upper end. 50 mm length of the specimen is under the clamp.

Step 15: Compute modulus of rupture and notch impact strength as follows:
Modulus of rupture = Rupture / effective volume of specimen
Notch impact strength = Energy absorbed/ effective cross-section area

Observations and Calculations

Type of material……
Source……
Date of sampling……..
Moisture content……per cent
Mass of striking hammer, m = ……. kg
Swing diameter of hammer, $2r$ = …….. mm
Breath of cross section, b =…….. mm
Depth of cross section, d =…….. mm

Test condition	Angle of fall α^o	Angle of rise β^o	Computed absorbed energy, mgr ($\cos\beta - \cos\alpha$)	Recorded absorbed energy (Scale reading)
1. Test without specimen 2. Actual test with specimen				
Energy absorbed, $E = (2) - (1)$ joules				
Impact velocity $= \sqrt{2gr(1-\cos\alpha)}$ m/sec				
Notch impact strength $= \frac{\text{Energy absorbed}}{\text{effective sectional area}}$ joule/mm^2				

Note: (i) Angle of fall α^o gives initial energy and (ii) Angle of rise β^o gives residual energy

The impact strength of given specimen = ……..joule/mm^2.

Precautions

Since the impact tester is hazardous with the potential for injury, safety considerations listed in the section 14.5 should be observed.

Informative Comments

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of standard dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain which is the basis of energy computation.

When the striker is at its highest point, h_1, before its release, the energy is only potential (mgh_1). The striker transforms its potential energy to kinetic energy when it swings through and fractures the specimen. In the process striker loses a part of its energy, and consequently swing up (rises) to a lesser height after the impact, h_2 with potential energy (mgh_2). Thus, the energy used to fracture the specimen is therefore, $E = mg(h_1 - h_2) = mgh$ as illustrated in Fig. 15.14; where, m is the mass of the hammer at the end of the pendulum, g

is the acceleration due to gravity and h is the vertical distance between the highest and the lowest positions of the pendulum. In terms of angle of pendulum before and after striking, α and β respectively, the energy used to fracture the specimen can be expressed as, $E = mgr$ (cos β – cos α); where r is the length of pendulum. A tougher material absorbs more energy; consequently the striker attains smaller height after the impact; whilst brittle materials tend to absorb very little energy on fracture.

The notch serves as a stress concentration region and some materials are more sensitive towards notches than others. The notch geometry is therefore very important factors.

For Further details reader should refer to Section 14.4.

Viva-Voce Questions

1. What is Notch-toughness or Charpy V-Notch Impact Test?
2. What is the significance of this test?
3. What is impact energy?
4. What are factors affecting Charpy impact energy?
5. Why is it necessary to make a notch in impact test specimen?
6. How does V-notch test differ from Izod test?
7. How does the sharpness of V-notch affect the test result?

Notes and Comments

NATIONAL STANDARDS

1. IS 287-2008 (3rd revision) (RA-2005): *Permissible Moisture Content for Timber used for Different Purposes – Recommendations.*
2. IS 707-2005 (2nd revision) (RA-2005): *Glossary of Terms Applicable to Timber Technology and Utilization*.
3. IS 1708 (Part 1-18)-1986 (2nd revision) (RA-2005): *Methods of Testing of Small Specimens of Timber:* **Part 1***: Determination of Moisture Content;* **Part 2:** *Determination of Specific Gravity;* **Part 3:** *Determination of Volumetric Shrinkage;* **Part 4:** *Determination of Radial and Tangential Shrinkage and Fibre Saturation Point;* **Part 5:** *Determination of Static Bending Strength;* **Part 6:** *Determination of Static Bending Strength Under Two-Point Loading;* **Part 7:** *Determination of Impact Bending Strength;* **Part 8:** *Determination of Compressive Strength Parallel to Grain;* **Part 9:** *Determination of Compressive Strength Perpendicular to Grain;* **Part 10***: Determination of Hardness Under Static Indentation;* **Part 11:** *Determination of Shear Strength Parallel to Grain;* **Part 12***: Determination of Tensile Strength Parallel to Grain;* **Part 13:** *Determination of Tensile Strength Perpendicular to Grain;* **Part 14:** *Determination of Cleavage Strength Parallel to Grain;* **Part 15:** *Determination of Nail and Screw Holding Power;* **Part 16:** *Determination of Brittleness by Izod Impact;* **Part 17:** *Determination of Brittleness by Charpy Impact;* **Part 18:** *Determination of Torsional Strength.*
4. IS 1900-2008 (1st revision) (RA-2008): *Methods of Tests for Wood Poles.*
5. IS 2408-1963(RA-2005): *Methods of Static Tests of Timber in Structural Sizes*.
6. IS 4907-2004 (1st revision): *Method of Testing Timber Connector Joints*.
7. IS 6874-2008 (1st revision): *Method of Test for Bamboos.*
8. IS 8242-1976 (RA-2004): *Methods of Tests for Split Bamboos*.
9. IS 10420-1982 (RA-2004): *Method of Determination of Sound Absorption Coefficient of Timber by Standing Wave Method*.
10. IS 10754-1983(RA-2004): *Method of Determination of Thermal Conductivity of Timber*.
11. IS 11215-1991(1st revision) (RA-2005): *Moisture Content of Timber and Timber Products - Methods for Determination*.
12. IS 13621-1993(RA-2008): *Determination of Dielectric Constant of Wood Under Microwave Frequencies - Method of Test*.
13. SP 33(S&T)-1986: *Handbook on Timber Engineering*.

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2. ASTM D198: *Test Methods of Static Tests of Lumber in Structural Sizes*.
3. ASTM D2395: *Test Methods for Specific Gravity of Wood and Wood-based Materials*.
4. ASTM D3043: *Test Methods for Structural Panels in Flexure*.
5. ASTM D3500: *Test Methods for Structural Panels in Tension*.
6. ASTM D4442: *Test Methods for Direct Moisture Content Measurement of Wood and Wood-based Materials*.
7. ASTM D4761: *Test Methods for Mec*hanical *Properties of Lumber and Wood-based Structural Material*.

8. ASTM E8 Vol. 3.01: *Test Methods for Tension Testing of Metallic Materials*.
9. BS EN 789-2004: *Timber Structures. Test Methods. Determination of Mechanical Properties of Wood-based Panels*.
10. BS EN 14774(2)-2009: *Solid Biofuels—Determination of Moisture Content–Oven Dry Method. Total Moisture: Simplified Method*.
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INVESTIGATIVE TESTS

Section 16

This section describes investigative tests which are planned to illustrate the effect critical parameters on the properties of concrete; failure modes of reinforced concrete beams under gradually applied loads, and analysis of fresh and hardened concretes. This is aimed to initiate students in the research activities leading to application domain. The physical characteristics of plastic and hardened concrete associated with these projects are critical for ensuring quality structures that are safe, durable and economical.

16.1 INTRODUCTION

The *admixtures* are the materials other than water, aggregates and cement, added to the concrete mix immediately before or during mixing to modify one or more of the specific properties of concrete in fresh or hardened state. The use of admixture should offer an improvement not economically attainable by adjusting the proportions of cement and aggregates, and should not affect adversely any properties of the concrete. Admixtures are no substitute for good concreting practices. An admixture should be employed only after appropriate evaluation of its effects on the particular concrete under the conditions in which the concrete is intended to be used. It is often necessary to conduct tests on the representatives of materials for the particular job under simulated job conditions in order to obtain information on the properties of concrete containing admixtures.

The admixtures ranging from addition of chemicals to waste materials have been used to modify certain properties of concrete. The properties commonly modified are the rate of *hydration* or *setting time, workability, dispersion* and *air-entrainment.* The admixture is generally added in a relatively small *quantity.* A *degree of control* must be exercised to ensure proper quantity of the admixture as an excess quantity may be detrimental to the properties of concrete. In using any admixture, careful attention should be given to the instructions provided by the manufacturer of the product.

16.2 PURPOSE OF ADMIXTURE

Some of the important purposes for which the *admixtures* could be used are:

1. Acceleration of the rate of strength development at early ages,
2. Retardation of the initial setting of the concrete,
3. Increase in strength,
4. Improvement in the workability,
5. Reduction in heat evolution,
6. Increase in the durability or in the resistance to special conditions of exposure,
7. Control of alkali-aggregate expansion,
8. Reduction in the capillary flow of water and increase in impermeability to liquids,
9. Improvement of pumpability and reduction in segregation in grout mixtures,
10. Production of coloured concrete or mortar.

16.3 CLASSIFICATION OF ADMIXTURES

According to the characteristic effects produced by them, the admixtures may be broadly classified as follows.

16.3.1 Accelerating Admixtures

The *accelerating admixtures* are added to concrete either (a) to increase the *rate of hydration of cement,* hence to increase the rate of *development of strength* or (b) to shorten the *setting time.* An increase in the rate of early strength development may help in (i) earlier removal of forms, (ii) reduction of required period of curing, (iii) earlier placement of structure in service. Accelerating admixtures are also used when the concrete is to be placed at *low temperatures.*

The most widely used accelerator is *calcium chloride* ($CaCl_2$). IS: 7861 (Part II)-1981 recommends a maximum of 1.5 per cent of $CaCl_2$ for plain and reinforced concrete works in cold weather conditions. Large doses of $CaCl_2$ result in *flash set* of concrete and also in increased shrinkage.

16.3.2 Retarding and Water-Reducing Admixtures

The *retarding admixtures* delay the setting of concrete. They are used primarily to offset the accelerating and damaging effect of high temperature and to keep concrete workable during the entire placing period which should be sufficiently long so that the succeeding lifts can be placed without development of cold joints or discontinuities in the structural unit. Some of the retarding admixtures also reduce the water requirement of the mixture.

The *water-reducing admixture* are mainly used to improve the quality of concrete, to obtain specified strength at lower cement content, or to increase the slump of a given concrete mix without increasing the water content.

16.3.3 Grouting Admixtures

Some retarders are especially useful in cement grout slurries, particularly where the grouting is prolonged, or in cases where the grout must be pumped for considerable distance, or where hot water is encountered underground.

16.3.4 Air-entraining Admixtures

These admixtures help to incorporate a controlled amount of air in the form of minute bubbles in the concrete during mixing, without significantly altering the setting or the rate of hardening characteristics of concrete. The capillaries are interrupted by relatively large air voids in *air-entrained concrete.* Entrainment of small amount of air results in the concrete of insufficient durability whereas with large amounts of entrained-air an excessive reduction in strength may occur. Thus air-entrainment alters properties of both the freshly mixed and hardened concrete. Air-entrained concrete is considerably more plastic and workable than non-air-entrained concrete. The durability of hardened concrete is improved by increased uniformity, decreased absorption and permeability, and by elimination of planes of weaknesses at the top of lifts.

16.3.5 Pozzolana Admixtures

A *pozzolana* is a siliceous material which as such does not possess cementitious property in itself, but reacts in the presence of water with the lime at the normal temperatures to form compounds of low solubility having cementitious properties.

The pozzolanas can be used in combination with or for partial replacement of Portland cement. Some of the advantages obtained through their use are: (i) Improved workability with lesser amount of water, (ii) Reduction in heat of hydration, (iii) Increased resistance to the attack from salts and sulphates, and (iv) Prevention of calcium hydroxide leaching.

The *fly ash* or *pulverized fuel ash* (PFA) is the most commonly used pozzolana. It is the residue from combustion of pulverized coal collected by the mechanical or electrostatic separators from the fuel gases of thermal power plants. Its composition varies with the type of fuel burnt, load on boiler and type of separator, etc. The fly ash obtained from electrostatic precipitators may have *specific surface* of about 3500 to 5000 cm^2/g, i.e., it is finer than the Portland cement. The fly ash obtained from cyclone separators is comparatively

coarser and may contain large amounts of unburnt fuel. The carbon content in fly ash should be as low as possible, whereas the silica content should be as high as possible.

The fly ash may be used in concrete either as an *admixture* or in part replacement of cement. As an admixture, the fly ash reduces the *segregation* and *bleeding;* whereas, when used as a replacement of cement, the silica content combines with the free lime liberated during the *hydration of cement.* The optimum amount of pozzolana as a replacement may normally range between 10 to 30 per cent. A fine grinding of silica and *high temperature curing* increases the reactivity of pozzolana.

16.3.6 Colouring Admixtures or Pigments

Pigments are the admixtures added to produce coloured cements. The *pigments* used must be permanent and should not react with free lime in concrete.

EXPERIMENT NO. 1: Effect of Admixtures on the Concrete Strength

Objective

To determine the effect of mixing following admixtures on the strength of concrete at different time intervals.

1. *Calcium chloride and sodium chloride*
2. *Gypsum or Plaster of Paris*
3. *Surkhi or fly ash*

Theory and Scope

The objective is to study the effect of admixtures on the development of strength with time under conditions expected, to ensure that the improvement in the desired property is not accompanied by detrimental effect on another property.

Apparatus

Platform balance; Weighing balance (with 0.2 g sensitivity); Measuring cylinder; Tamping rod; Trowels.

Procedure

Step 1: Take the proportions of cement, sand and coarse aggregate as 1: 3: 6 and water–cement ratio as 0.70 for preparing the concrete mix, take about 30 kg of coarse aggregate.

Step 2: First mix the ingredients dry and then with water to obtain a homogeneous mass with uniform colour.

Step 3: Prepare six 150 mm cubes of the ordinary concrete.

Step 4: Test three cubes in compression after 3 days and the other three after 28 days of curing.

(a) Effect of calcium chloride and sodium chloride

Step i. Take 30 kg of coarse aggregate, 15 kg of sand and 5 kg of cement and mix them dry to uniform colour.

Step ii. Take calcium chloride equal to 2 per cent by mass of cement (i.e., 100 g) and dissolve it in the mixing water.

Step iii. Add $CaCl_2$ water to the dry mixture and mix until a homogeneous mass is obtained.

Step iv. Prepare six 150 mm cubes with this concrete having calcium chloride water.

Step v. Test three of them after 3 days and the remaining three after 28 days of curing.

Step vi. Similarly, prepare six 150 mm cubes to be tested after 3 days and 28 days of curing, with sodium chloride mixing water containing 5 per cent NaCl by mass of cement (i.e., 250 g of NaCl for same amount of ingredients).

(b) Effect of gypsum

Step i. Take 2 per cent gypsum by mass of cement as retarder passing through 150 μm IS Sieve and mix it with cement.

Step ii. Take the same amount of ingredients as above and prepare six 150 mm cubes.

Step iii. Test three of them after 3 days and other three after 28 days of curing.

(c) Effect of surkhi

Step i. Replace 20 per cent cement by mass with surkhi passing through 150 μm IS sieve. Take 15 kg of coarse aggregate, 7.5 kg of fine aggregate, 2.0 kg of cement and 500 g of surkhi and mix them dry to obtain uniform colour.
Step ii. Add 1.75 litre of water and mix to obtain a homogeneous mass.
Step iii. Prepare three 150 mm cubes.
Step iv. Test them after 28 days.

Observations and Calculations

Sr. No.	Type of concrete		Crushing load, kN		Average compressive stress, MPa			
							Per cent strength of ordinary concrete	
			3 days	28 days	3 days	28 days	3 days	28 days
1.	Ordinary concrete 1: 3:6 with 0.7 w/c ratio	1 2 3					100	100
2.	2% $CaCl_2$ (Calcium Chloride)	1 2 3						
3.	5% NaCl (Sodium Chloride)	1 2 3						
4.	2% Gypsum	1 2 3						
5.	20% Surkhi or Flyash	1 2 3						

Results

(a) Addition of $CaCl_2$ (2 per cent) increases the strength of concrete by……per cent in 3 days and…… per cent in 28 days.
(b) Addition of NaCl decreases the strength of concrete by……per cent in 3 days and……. per cent in 28 days.
(c) Addition of gypsum ($CaSO_4$) increases the strength by……per cent in 3 days and……..per cent in 28 days.
(d) Addition of surkhi decreases the strength of concrete by……per cent in 28 days.

Precautions

1. The concrete should be mixed until homogeneous mass is obtained.
2. Compact the concrete in moulds by distributing strokes uniformly over the whole surface.
3. In case of $CaCl_2$, the concrete should be placed and finished with the minimum delay because of rapid setting.
4. $CaCl_2$ must always be dissolved in water before mixing.
5. The moulds should be properly oiled before placing the concrete in them.
6. The test cubes shall be properly labelled indicating the date of test, proportion of aggregates, water-cement ratio and percentage of admixture.

Discussion

$CaCl_2$ is normally used in concentrations ranging from 1 to 2 per cent of the mass of cement. It may also be sometimes used up to 4 per cent but special care is required because of the resulting decrease in setting time. Even with 2 per cent of $CaCl_2$ it is necessary to place and finish concrete with minimum delay because of rapid setting. Very dilute solutions may have a retarding effect hence it is dissolved in mixing water in appropriate amount. Use of $CaCl_2$ has the effect of reducing the setting time and hence the time for which the form work must be left in position, and the curing time. The increase in crushing strength is lesser at greater period; the increase being 10 to 15 per cent at 28 days age and half as much at one year age. The crushing strength obtained under different conditions varies considerably.

Retarders are used to delay the setting of cement but they also decrease the rate of development of strength and may reduce the ultimate strength by as much as 50 per cent. Retarder may be used in very hot weather when initial set of normal cement takes place rapidly or when a particular batch of cement has an unduly short setting time. But they should never be used where a concrete of high strength is required. It may be used in positions where placing of concrete is difficult and mortar must remain plastic for considerable time, as for example in grouting of tunnel lining.

Pozzolanic material (Surkhi) increases workability and reduces *segregation* and *bleeding.* They reduce evolution of *heat of hydration.* Because of low strength of pozzolanic material compared with cement there is always a reduction in strength of concrete which is not serious in mass concrete works. Generally, 10 to 20 per cent of cement is replaced in the given mix.

Flyash in the form of extremely small particles is obtained as the residue from the modem thermal electricity generating stations. Flyash being comparatively cheaper than cement has been used in concrete mixes as cement replacement material. Replacement of Portland cement by flyash on an absolute volume basis up to 30 per cent results in the lowering of strength up to about 28 days, but in greater strength at 2 months and beyond. It is possible to proportion flyash mixes for equal 28 days strength to mixes by using flyash quantities in excess of the amount of the cement removed.

Due to variability of flyash, when mixed with cement its use in concrete should be based on tests of particular flyash with the other ingredients of concrete. IS: 3812 (Part II)-1981 covers fly ash for use as admixture for concrete.

Table 16.1 *Physical requirements of flyash*

1.	Fineness: Specific surface (minimum), cm^2/g	2800
2.	Lime reactivity: Average compressive strength (7 days minimum) of one part of hydrated lime and two parts of flyash by mass, MPa	4.0

(continued)

Table 16.1 *Contd.*

3.	Drying shrinkage at 28 days of four parts of ordinary Portland cement and one part of flyash by mass	0.1
4.	Soundness by autoclave test: Expansion of specimen of a mix as in 3, per cent maximum	0.1

Viva-Voce Questions

1. What is an admixture?
2. What are the principal purposes for which admixture most commonly used?
3. What are the effects of calcium chloride when it is used as an admixture in concrete?
4. What chemical compound is used as an admixture to hasten the development of strength? What is the rate at which it is used?
5. What are the retarders and their significance?
6. What are the bad effects of the retarder?
7. What are the workability admixtures?
8. What side effects do they have on the concrete properties other than workability?
9. What is the purpose of the air entrainment when it is known that appreciable air content tends to lower the strength?
10. What materials are used for air entrainment?
11. What is pozzolanic action?
12. What materials are included in pozzolanic materials category?
13. In what way do some of the accelerators also serve as antifreeze agents?
14. What is flyash?
15. Why is flyash used as cement replacement material?
16. What are its effects on strength properties? What are impediments in its use?

Notes and Comments

EXPERIMENT NO. 2: Effect of Percentage of Sand on Yield and Strength of Concrete

Objective

To determine the effect of sand on the yield and compressive strength of concrete, keeping water–cement ratio and slump constant in each case.

Theory and Scope

This experiment illustrates relationship between

1. Aggregate-cement ratio and percentage of sand
2. Cement content of concrete against percentage of sand
3. Yield of concrete and sand
4. Percentage sand and compressive strength

The yield value is the number of cubic metre of concrete produced by one bag of cement. In order to keep the slump constant aggregate-cement ratio must be varied.

Apparatus

Compression testing machine; Weighing balance; Cylindrical measure; Tamping rod; Shovel; Trowels; Buckets for weighing water; Slump cone apparatus; Pans for mixing concrete; Cube moulds and Humidity chamber for storing test specimens.

Procedure

Step 1: Determine the quantities of material required per batch, for four different cases.

(a) Take percentage of sand by mass of coarse aggregate as 30, 40, 50 and 60.
(b) Select water-cement ratio to be used in all batches (say 0.7).
(c) Select slump value (say 40 mm).

For making three cubes of 150 mm size, take 18 kg coarse aggregate for each batch.
Sand required for first batch (30 per cent of coarse aggregate) is 5.40 kg.

Step 2: Weigh all the material for a batch and mix them into a uniform colour.

Step 3: Make cement slurry with 0.7 water–cement ratio.

Step 4: Find out by trial the slurry required (gradually increasing) in each case to get a desired slump of 40 mm.

Step 5: Prepare three cube specimens for each sample.

Step 6: Find the density of concrete by weighing the residue concrete after making the three cubes in each case. Adopt the following procedure:

Fill the standard container in layers of about 50 mm height and tamp each layer at least 60 times by a tamping bar distributing the strokes uniformly all over the cross section. Tap exterior surface of the cylinder until no bubble appears on the surface. Strike off level the concrete. Clean the excess concrete from exterior and weigh the filled container.

Calculate the mass of concrete by difference. Find the volume of container by weighing the container filled with water and empty, respectively. Calculate yield of cement.

Step 7: Test the cubes in compression after 28 days of wet curing.

Step 8: Plot the following curves:

(a) Yield of concrete and percentage of sand.
(b) Strength of concrete and percentage of sand.
(c) Cement content of concrete and percentage of sand.

Observations and Calculations

Type and grade of cement		
Water-cement ratio,	x	
Slump,	mm	
Volume of standard container,	m^3	
Date of cube casting		
Test date		

Precautions

1. The curves should be plotted with the independent variables along abscissa and dependent variables on the ordinates.
2. Slump test and compression test should be performed as per the specifications.
3. The slurry should be stirred well to form homogeneous and uniform mixture.
4. The tamping rod strokes should be uniformly distributed.

Discussion

Keeping in view the parameters that were varied and the ones that were held constant, following conclusions about the relationships between various parameters can be observed:

1. The minimum yield and maximum cube strength reach simultaneously for a fixed percentage of sand.
2. Adding more fine aggregate, the concrete produced is less for the same quantity of cement.
3. The strength of all mixtures is nearly the same which confirms the Abrams's law, i.e., strength is same since water–cement ratio is same.
4. Generally strength increases up to an optimum percentage of sand and then falls slightly with the addition of more sand.

Sample No.	Cube specimen	Sand, per cent	Mass of slurry used, W_s kg	Batch mass, kg				Total mass of concrete W kg	Mass of concrete in container W_1 kg	Density $d = \frac{W_1}{V}$ kg/m^3	Yield $\frac{W}{d} \times 50$ m^3/bag	Cube strength	
				Cement $\frac{W_s}{1+x} = W_c$	*Sand*	*Coarse aggregate*	*Water*					*Load,* kN	*Average Strength,* MPa
1	1												
	2												
	3												
2	1												
	2												
	3												
3	1												
	2												
	3												
4	1												
	2												
	3												

Viva-Voce Questions

1. What is meant by the yield of a concrete mix?
2. What are the major variables?
3. What parameters are held constant?
4. What parameters then are to be varied in order to hold the slump constant?
5. How well the slump is held constant?
6. What is the range of actual slump values?
7. How will the aggregate–cement ratio vary with the percentage of the sand?
8. According to water–cement law, the strength of all hatches should be the same since the water-cement ratio is same for all batches; are they the same?
9. What is the maximum variation of a batch from the average?
10. In averaging concrete strength, what is the permissible variation usually permitted?
11. How does the cement content of concrete vary with the percentage of the sand?
12. How does the density of the concrete vary with the percentage of sand?
13. Since the concrete strength do not vary appreciably with change in percentage of sand, should it be concluded that any percentage of sand is permissible?
14. What other factor is being varied which has a bearing on the percentage of sand to be used?
15. Does the maximum unit mass of concrete occur at the same percentage of sand as does the maximum unit mass of the combined aggregate?
16. In selecting the best of several mixes of given water-cement ratio and given slump value, why is it logical to select the one giving the greatest yield?

Notes and Comments

EXPERIMENT NO. 3: Effect of Water-Cement Ratio on Strength of Concrete

Objective

To determine the effect of water-cement ratio on the strength of concrete with a given proportion of fine and coarse aggregates (say 1: 2.5 by mass) and having a constant slump of 40 mm.

Theory and Scope

The concrete is a *variable material* and its quality is usually assessed from the results of crushing tests on concrete cubes/cylinders. One of the various causes of variation in concrete strength is water–cement ratio. The individual contribution of water–cement ratio can be studied by this test.

The concrete of uniform quality can be produced by controlling the workability (as given by slump) by varying the water–cement ratio. If the grading of the aggregates remains constant, the variation in water content to give constant workability will effectively control the water-cement ratio. Hence, this test is based on the principle that concrete having more cement paste (after tilling the voids in aggregate) in relation to total surface area is more workable. Moreover, as the proportions of sand and coarse aggregate are same, and the slump is to be the same to enable all the samples of concrete to be compacted to the same extent; the quantity of cement will determined by trial to get the desired slump of 40 mm.

Sample No.	Cement	Sand	Gravel	Water-cement ratio
1	*To be found by trial*	1	2.5	0.4
2		1	2.5	0.5
3		1	2.5	0.6
4		1	2.5	0.7

Three 150 mm cubes will be cast for each of the above samples.

Apparatus

Universal testing machine; Slump cone apparatus; two Buckets; two trowels; Graduated cylinder; Platform balance; Foot rule; Tamping rod (15 mm diameter; 600 mm long); Cube moulds of 150 mm size and Non-porous plate.

Procedure

Step 1: Weigh the sand and gravel in a ratio of 1: 2.5. The materials required are 20 kg of gravel and 8 kg of sand for making three 150 mm cubes.

Step 2: Mix the ingredients dry until a uniform distribution is attained.

Step 3: Prepare cement slurry with given water-cement ratio, (e.g., 0.4) in the bucket and note the mass of the bucket.
Step 4: Add certain amount of slurry in the aggregate and mix it to the uniform colour.
Step 5: Test the mix for slump (as described in slump test) and increase the amount of slurry until required slump of 40 mm is obtained.
Step 6: Weigh the bucket and find (by difference) the quantity of cement slurry used.
Step 7: Prepare 150 mm cubes three in numbers as described in compressive strength test.
Step 8: Test the cubes in compression after 28 days of wet curing.
Step 9: Repeat the above procedure with cement slurry of different water–cement ratios (i.e., 0.5, 0.6 and 0.7).
Step 10: Calculate the average compressive strength for each sample.

Observations and Calculations

Sr. No.	Water-cement ratio	Specimen number	Average load, kN	Compressive strength, MPa
1.	0.4	1 2 3		
2.	0.5	1 2 3		
3.	0.6	1 2 3		
4.	0.7	1 2 3		

Precautions

See under slump test and compressive strength test.

Discussion

The water in excess of that required for hydration and absorption, is necessary to endow the concrete with sufficient workability to enable it to be fully compacted. This excess free water renders the concrete permeable and it is this water which causes trouble when concrete is exposed to freezing. In order to keep this free water to a minimum, water–cement ratio must be as low as possible consistent with full compaction. For same water-cement ratio, a richer mix containing more water gives more porous concrete.

The strength of concrete decreases with increase in the water-cement ratio as shown in Fig. 16.1.

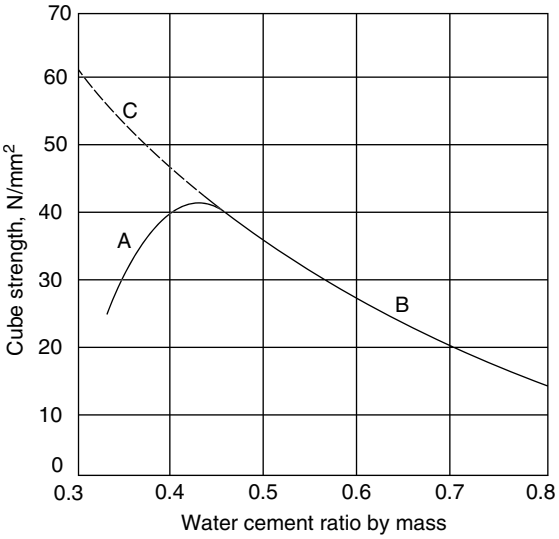

Fig. 16.1 *Relation between the strength of concrete and water-cement ratio*

The test verifies the Abram's rule that with given materials and condition of test, the water–cement ratio alone determines the strength of concrete so long as the mix is of workable plasticity. This is known as *water–cement ratio law*. This is true when specimens under test have same material, workability, compaction and temperature conditions.

The quantity of cement required will be the maximum with smaller water–cement ratio; because a larger amount of thicker cement paste is needed than the thinner one to cause the same slump.

Viva-Voce Questions

1. What is the major variable determining concrete strength?
2. What parameters are held constant?
3. Which parameter then has to be varied in order to hold the slump constant?
4. How well is the slump held constant?
5. What was the range of actual slump values?
6. How did strength vary with water-cement ratio?
7. What is water–cement ratio law? Does it apply to all mixes?
8. What other factors affect the strength of concrete?
9. How is a concrete of uniform quality produced?
10. What is the underlying principle for this test?
11. What considerations besides strength affect the selection of a water–cement ratio?
12. Why is it that a rich mix may be weaker than a leaner mix, both mixes being of the same lots of cement and aggregate?
13. For a given water–cement ratio which is more economical a stiff mix or a lean mix?
14. Why is a more economical mix not always used on the job?
15. What are the disadvantages of excess water than that required for hydration, absorption and to endow the concrete with sufficient workability?

Notes and Comments

EXPERIMENT NO. 4: Bond Strength

Objective

To determine the bond strength between ordinary mild steel bars and concrete:

1. *By testing a reinforced concrete beam with overlapping reinforcement.*
2. *By pull-out test.*

Theory and Scope

The bond between concrete and steel, i.e., resistance to withdrawal of steel embedded in concrete may be divided into two parts:

1. Grip caused by shrinkage of concrete.
2. Frictional resistance caused by unevenness of the surface of the bar.

Both parts of bond act together until the bar begins to slip. At this stage, the grip is destroyed and frictional resistance alone resists the pull.

1. **Reinforced concrete beam test** The bond stresses are caused by the change in flexural stresses from point to point, i.e., increment in stresses in longitudinal bars. This increase in stresses in steel bars as computed is proportional to the amount of increase in bending moment and, therefore, is equal to the vertical shear. The effect is smaller near the point of maximum tensile stress (where concrete might have cracked) and larger near the support where concrete may carry more stress even at maximum loads. The bond stresses are not proportional to the shear as the increment of stress in steel is not proportional to shear. In this test, a beam with spliced reinforcement is loaded until it fails in bond stress.
2. **Pull-out test** The pull-out test specimen consists of a bar imbedded in a concrete block. The load is applied at free end of the bar which is resisted by the resistance to withdrawal of the steel embedded in the block.

   In practise, similar conditions occur in the end anchors for fixed or cantilever beams where concrete at the support corresponds to the block in pull-out test.

   The maximum stress in steel at the edge of the support, which is transferred to the support by the bond, corresponds to the applied force.

Apparatus

Beam mould 1850 mm long; 100 ×150 mm in cross section; Cylinder mould; Aligning stand; 50 kN Transverse testing machine; 100 kN Universal testing machine with pull-out test attachment; Dial gauge; Tamping bar and Trowels.

Procedure

Step 1: Prepare concrete mix of given proportions, say 1: 2: 4 with 0.6 water-cement ratio. Take 32 kg of coarse aggregate, 16 kg of sand and 8 kg of cement with 480 ml of water.

Step 2: First mix the ingredients dry to uniform colour and then with water to homogeneous mass in a mixer.

Step 3: Cast the concrete beam using two bars of given diameter (say10 mm diameter) having an overlap of 200 mm at the centre. Use four pieces of bars each having a hook at one end only.

Cast three cylinder specimens of 150 mm diameter and 200 mm in height with 10 mm diameter bar embedded axially in the full 200 mm length of the cylinder at the centre. Use aligning stand for keeping the bar vertical and in the centre of the cylinder.

Step 4: Test the beam after 28 days of wet curing by applying gradually two point loads 200 mm apart on 50 kN transverse testing machine.

Step 5: Record the loads at first crack in the beam to give tensile strength of concrete and at ultimate bond failure.

Step 6: Test the pull-out specimens after 28 days of wet curing on 100 kN universal testing machine, using pull-out test attachment. Attach a dial gauge for finding out the slip between steel and concrete.

Step 7: Plot the curve between load and the slip.

Step 8: Record the load at 0.125 mm slip and at the bond failure.

Observations and Calculations

1. For beam test

		I	II	III
Load at first crack,	kN			
Ultimate load at bond failure,	kN			
Max. B.M. at first crack,	kNmm			
Max. B.M. at failure,	kNmm			
Actual effective depth, D	mm			
Tension in concrete at first crack,	kN			
Ultimate bond stress, $\sigma_b = \dfrac{P}{2\pi\, d\, l}$	MPa			

In the expression for bond stress, P is total tensile force in steel, d is diameter of the bar (10 mm) and l is the length of overlap (200 mm).

2. For pull-out test

Type and size of bar	**Age, days**	**Proportion of concrete**	**Slip, mm**	**Stress at the surface of bar**		
				Load, kN	***Surface area, $\pi\, d\, l$***	***Bond stress, MPa***
10 mm diameter plain bar		1: 2: 4				

Plot a graph between load and slip, and from the graph:

		I	II	III
Load at 0.125 mm slip, P_1	kN			
Load at bond failure, P_2	kN			
Average bond strength at 0.125 mm slip, $\frac{P_1}{\pi d l}$	MPa			
Average bond strength at failure, $\frac{P_2}{\pi d l}$	MPa			

where d is diameter of the bar and l is the embedded length.

Precautions

1. For comparing bond resistance in two tests, the concrete used in both tests should be of the same proportion, age and cured under similar conditions.
2. In case of pull-out test, the test specimen should be mounted in testing machine in such a manner that the bar is pulled axially from the block.
3. The bars used in the two tests should be of same cross section.
4. Plywood packing should be placed between top face of the block and surface of the test ring bearing on it.
5. A dial gauge of desired accuracy should be attached to the unloaded end of the bar with spindle in contact with concrete in such a manner that the gauge records the relative slip.

Discussion

Figure 16.2 shows the relationship between bond stress and slip; for plain bars the progress of loading indicates that the initial slip occurs at about 60 per cent of the maximum bond resistance. After the maximum bond resistance which corresponds to a certain slip was reached the resistance to withdrawal decreases. After a slip equal to five times the slip at maximum resistance has taken place, only a fixed percentage of the maximum load is required to produce further slipping.

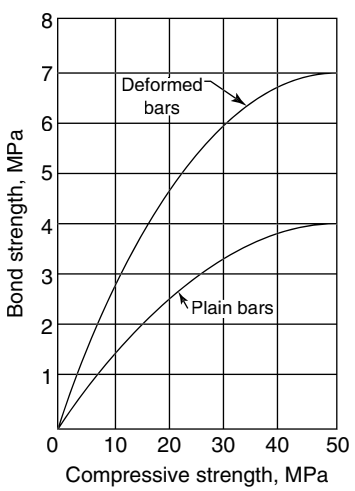

Fig. 16.2 *Relationship between bond strength and compressive strength*

The computed bond stress at ultimate load is smaller than maximum bond strength in pull-out test.

In computation the bond stresses are considered as uniformly distributed over whole surface of contact between steel and concrete. Generally, the bond stress varies from a maximum at the edge of the support to a minimum well inside the support. Ordinarily, the portion of the bar near the point of support offer frictional resistance only, while the farther end of the bar offers both grip and frictional resistance. The variation in magnitude of bond stresses along the length of embedded bar depends upon the length of embedment. Hence, allowable bond stresses are decided by taking into account the ratio of embedded length and the diameter of the bar.

The safe bond resistance is equal to the unit stress at which the bar begins to slip, divided by a factor of safety (F.O.S.).

The bond strength of the concrete at specified slip in pull-out test will be found to increase with the compressive strength of the concrete as is shown in Fig. 16.2.

Viva-Voce Questions

1. What is meant by bond strength?
2. What are the main factors responsible for bond strength?
3. In reinforced concrete beams, how the bond strength comes in to picture?
4. What is pull-out test? Where do you encounter similar condition in practise?
5. What are the requirements concerning size of the specimen, curing and testing?
6. What precautions are taken during pull-out test?
7. What is the principal factor affecting bond strength at initial slip?
8. How does bond strength correlate with compressive strength?
9. At what bond resistance level, the initial slip occurs?
10. What is the simplifying assumption made in computation of bond stresses?
11. What is safe bond resistance?

Notes and Comments

EXPERIMENT NO. 5: Ultimate Strength of Beams

Objective

To determine the ultimate strength of the following beams in bending:

1. *An under-reinforced beam of size 100 × 150 × 1850 mm.*
2. *An over-reinforced beam of the same size as above and to compare the results with those obtained by Whitney's ultimate load theory.*

Theory and Scope

The test is aimed to visually illustrate the progressive failure of under-reinforced and over-reinforced beams subjected to the gradually applied transverse load.

Since the concrete cease to be elastic after certain stage of loading, inelastic behaviour of concrete starts right from very low stresses and that of steel after elastic limit is reached. To be able to calculate the collapse load, it is necessary to take into account the inelastic or plastic strains that occur in the material before it fails. The method of calculations taking into account these plastic strains near failure is called *ultimate load theory*. The ratio of collapse load to the working load on the structure is called *load factor*.

By Whitney's ultimate load theory, the ultimate moment of resistance of an under-reinforced section is given by

$$M_r = pbd^2 f_y \left(1 - \frac{p f_y}{1.1\sigma_{cu}}\right)$$

Similarly, ultimate moment of resistance of an over-reinforced section is given by

$$M_r = 0.185\sigma_{cu} bd^2$$

In the above expressions,

M_r = ultimate moment of resistance,

b = width of the section,

d = effective depth of the section,

A_{t1} = area of steel in the section = pbd,

σ_{cu} = cube strength of concrete in compression, and

f_y = yield stress in steel.

Apparatus

Platform balance; Graduated cylinder; Concrete mixer; Trowels; Tamping bars; 50 kN Transverse testing machine; Table vibrator; Form work for casting of beam with 100 × 150 × 1850 mm as internal dimensions.

Procedure

Step 1: Prepare concrete mix of given proportions, say 1: 2: 4 with 0.6 water-cement ratio; taking 100 kg of coarse aggregate; 50 kg of sand and 25 kg of cement.

Step 2: Mix the above ingredients first in dry condition and then add 15 litres of water in a mixer to obtain a homogeneous mass.

Step 3: Cast the following specimens on a table vibrator:

(a) One 100 × 150 × 1850 mm beam reinforced with two 6 mm diameter bars at the bottom at an effective cover of 12.5 mm.

(b) One 100 × 150 × 1850 mm reinforced beam with four 10 mm diameter bars at the bottom in two layers of two bars each.

(c) Three 150 mm cubes.

The bars to be used will have hooks at both the ends in case of mild steel.

Step 4: Test under-reinforced and over-reinforced beams in wet condition after 28 days of curing on the 50 kN transverse testing machine under gradually increasing two concentrated loads spaced at 200 mm apart in the middle. Effective span of the beam may be kept equal to 1700 mm. Test the cubes on the compression testing machine and determine the cube strength of concrete.

Step 5: Record the load and sketch the pattern of cracks during the failure of beams.

Step 6: After failure at a certain section; measure the effective depth of reinforcement.

Observations and Calculations

1. For the cube strength of concrete

Age	Specimen No.	Crushing load; kN	Cube strength, MPa
28 Days	1		
	2		
	3		
Average cube strength, MPa			

2. For the strength of beams

Specimen No.	Proportions of concrete	Type of beam	Age	Load at failure; kN	Percentage of steel	Actual effective depth, mm	Whitney's ultimate moment of resistance, M_r	Calculated failure load, kN
1	1: 2: 4	Under-reinforced	28-days					
2	1: 2: 4	Over-reinforced						

Precautions

1. Add the ingredients in proper order in the mixer. The interior surface of mixer should be buttered before use; and the time of mixing should be constant.
2. The test specimens should be cast from three separate batches of concrete.
3. The mould should be filled in equal layers each compacted by uniformly distributed hand ramming.
4. The completion of compaction can be judged by the fact; that when compaction is complete the air bubble cease to rise to the surface.
5. The cubes and beams stored in water should be tested immediately after they are removed from water and any surface water, grit and projections should be removed. The cube should be tested on the sides and not on faces; and cubes should be accurately placed with in the locating marks on the bottom platen so that it is truly concentric with the special seat of upper platen.
6. No packing should be placed between cube and platens.

Discussion

The beams in which steel is strained beyond the *yield stress* at their failure are called under-reinforced beams and those in which the steel is still in *elastic stage* at their failure are called *over-reinforced beams.*

When a reinforced concrete beam is subjected to a loading test its behaviour can be described in three stages:

1. **Before the appearance of first crack** The reinforced concrete beam behaves like a homogeneous beam, i.e., compression is resisted by concrete; and tension is resisted by concrete and steel in proportion to their *modulii of elasticity*; and *neutral axis* (N.A.) coincides with C.G. of the section. It lasts till strain in *concrete* is equal to ultimate strain of plain concrete and *first crack* appears in beam.
2. **After-first crack is developed but before either of the materials passes its elastic limit** In this stage, the cracks increase. They widen and move up towards centre of the beam section. The larger the amount of reinforcement; the larger will be the number of cracks and smaller their width. In this stage tension is resisted by steel and by the portion of concrete above the crack but below N.A.

   The ratio of tensile stresses carried by concrete to the total tension decreases with the increase in the load. Furthermore the tensile strength of concrete may be totally destroyed by *shrinkage* or *temperature contraction cracks.* Hence the assumption made in the design of structures that concrete does not take any tension is justified.

   The difference between actual stresses in steel resulting from the deformation and theoretical stresses gives the tension carried by concrete.
3. **After elastic limit of materials has passed** In this case, two situations arise:

   (a) Tension failure for under-reinforced beams At this stage of loading, one or two cracks which have been small up to this point; begin to widen and extend towards the top. The deflection increases appreciably as the cracks widen and extends towards to top (N.A. rising); *compression area* becomes smaller and finally the beam fails by the total destruction of compression area. Thus; exceeding of elastic limit of steel marks the failure of the beam. *Ultimate strength of steel is never reached.*

   (b) Compression failure for over-reinforced beams In this case the beams fail by crushing of concrete. The stage is marked by cracks in top of the beam which appear after elastic limit of concrete in compression has been reached. At increased load wedge shaped pieces of concrete spall off and the beam fails.

The computed compressive stresses in extreme fibre in concrete at load causing failure are much larger than the strength of concrete in compression obtained by cubes of same material; cured in the same way; tested at same time as the beams. This difference is largely due to inexactness of formulae for computing fibre stresses. The formulae are based on modulus of elasticity of concrete; which vary with composition and intensity of stress.

Viva-Voce Questions

1. What is meant by reinforcement?
2. What is the main purpose of steel reinforcement in concrete?
3. Why is steel alone used in R.C. members; why not aluminium?
4. What are the assumptions made in bending theory of reinforced concrete?
5. Explain how far these assumptions are valid?
6. Why is it necessary to take into account the inelastic or plastic strains for calculating the collapse load?
7. What is ultimate load theory and how does it differs from limit state theory?
8. What is load factor?
9. What are under-reinforced and over-reinforced sections?
10. What is the relation between cylinder strength and cube strength of the concrete?
11. What are the requirements concerning size and reinforcement of the specimens?
12. What is the nature of cracks and what do they indicate?
13. What are the requirements for curing and testing of the specimens?
14. What is the effect of shrinkage and temperature on the tensile strength of the concrete?
15. What is meant by tension and compression failures for under-reinforced and over-reinforced beams, respectively?
16. As in both types of beam failure occurs by crushing of concrete; what is the difference in behaviour at failure?
17. What are the different types of reinforcing steel?

Notes and Comments

EXPERIMENT NO. 6: Ultimate Strength in Diagonal Tension and Bond

Objective

To determine the ultimate diagonal tension or shear and bond strengths of reinforced concrete beam 100 × 150 × 1220 mm in size.

Theory and Scope

The test illustrate the behaviour of beams having reinforcement with and without hooks at the ends of the bars.

The knowledge of bond strength is essential, as the bond is the agency which causes cooperation between concrete and steel; and that the resistance of steel to tension can be utilised only through the bond between concrete and steel. When the bond between steel and concrete is not sufficient the bar will slip instead of resisting tensile stress and the beam will fail even if it is provided with a sufficient amount of tension reinforcement; because there is no medium which will bind the two materials. The diagonal tension stresses require special attention in reinforced concrete.

Apparatus

Platform balance; Moulds; Graduated cylinder; Concrete mixer; Trowels; Tamping bars; 50 kN Transverse testing machine and Reinforcement bars.

Procedure

Step 1: Prepare concrete mix of given proportions, say 1: 2: 4 with 0.6 water–cement ratio; taking 140 kg of coarse aggregate, 70 kg of fine aggregate and 35 kg of cement.

Step 2: First mix the ingredients dry to uniform colour and then with water to a homogeneous mass.

Step 3: Cast the following specimens:

(a) Two beams 100×150×1220 mm in size; reinforced with four bars of 10 mm diameter, with hooks at the ends, at the bottom in two layers of two bars each at an effective cover of 25 mm to be tested in shear.

(b) Two other beams of the same size but reinforced with only two bars of 10 mm diameter without any hook at the ends with an effective cover of 25 mm, and

(c) Three 150 mm cubes.

Step 4: Test the specimens after 28 days of wet curing. For testing the beams in shear and bond, place the beams on supports with an effective span of 1050 mm on the 50 kN transverse testing machine and apply a gradually increasing concentrated load at 230 mm from one support.

Step 5: Record the loads when the first crack appears and at failure in each case.

Step 6: Sketch the crack pattern at failure of beams. Ascertain the actual effective depth of reinforcement.

Step 7: Test the cubes in compression.

Observations and Calculations

1. For cube strength of concrete

Sr. No.	Failure load, kN	Cube strength, MPa	Average, MPa
1.			
2.			
3.			

Average cube Strength of concrete σ_{cu} is……..MPa.

2. For shear strength of concrete

1. Load at first crack,	kN		
2. Ultimate load,	kN		
3. Actual effective depth,	mm		
4. Shear stress when first crack appears, $\sigma_{sh} = \frac{V}{b\ jd}$	MPa		
5. Ultimate shear stress,	MPa		
6. Theoretical shear stress, $0.1\sigma_{cu}$	MPa		

3. Bond strength of concrete

1. Load at first crack,	kN		
2. Ultimate load,	kN		
3. Actual effective depth,	mm		
4. Bond stress when first crack appears, $\sigma_b = \frac{V}{jd\sum O}$,	MPa		
5. Ultimate bond stress,	MPa		

In above expressions *jd* is internal lever arm.

Precautions

1. The test cubes should be compacted with the strokes uniformly distributed over the whole surface.
2. All standard precautions casting, curing and testing should be observed.

Discussion

Until the diagonal cracks appear; a reinforced concrete beam acts like a homogeneous beam and final failure closely follows the appearance of first cracks. A beam properly reinforced with stirrups or bent bars sustain three to four times as much load as same beam without above reinforcement

Beam with longitudinal reinforcement having hooks show larger load carrying capacity than similar beam with ends of the bars straight.

The difference between the intensity of load at first diagonal crack and at ultimate failure depends upon the strength of the concrete. Lean concrete beams fail with little or no warning so that load at first diagonal crack coincides with breaking load; whereas in richer and stronger concrete beams; diagonal cracks are visible before final failure occurs.

Viva-Voce Questions

1. What is the significance of bond and diagonal tension?
2. How does the insufficiency of bond between steel and concrete affect the strength of the beam?
3. What are the requirements for the size; reinforcement and curing of test specimens?
4. What precautions should be taken while fixing the reinforcement?
5. What is the difference in the behaviour of beams having lean and rich concretes, respectively?
6. Why do you provide hooks at the ends of the bars?
7. If a length of steel rod is embedded in hardened concrete and is pulled outward; on what factors does this pulling force required to withdraw the rod depends?
8. Why is generally the length of embedment kept equal to 45 times the diameter of the bar?

Notes and Comments

EXPERIMENT NO. 7: Analysis of Fresh Concrete

Objective

To determine the mix proportions of freshly mixed concrete.

Theory and Scope

This method of analysis is used to determine the proportions of the ingredients of freshly mixed concrete. This test plays an important role in the periodical spot checks on the quality of concrete going into a particular job.

Essentially, it consists of weighing the sample of concrete in air and in water; and then thoroughly washing it through two sieves to separate coarse and fine aggregates and to remove the cement. The recovered clean aggregates are then weighed in water. The mix proportions by mass are calculated with the help of specific gravities of aggregates and cement.

Apparatus

Semi-automatic balance; Eight bucket shaped containers; Water tank; Two nesting sieves; Funnel; A hose with fine nozzle; Spider for supporting meshes; A metal stirring rod 16 mm in diameter; Ventilated oven able to maintain temperature at 100°C to 110°C.

Description of Apparatus

A **semi-automatic balance** capable of weighing up to 5 kg to an accuracy of 0.5 g with counter poises for balancing.

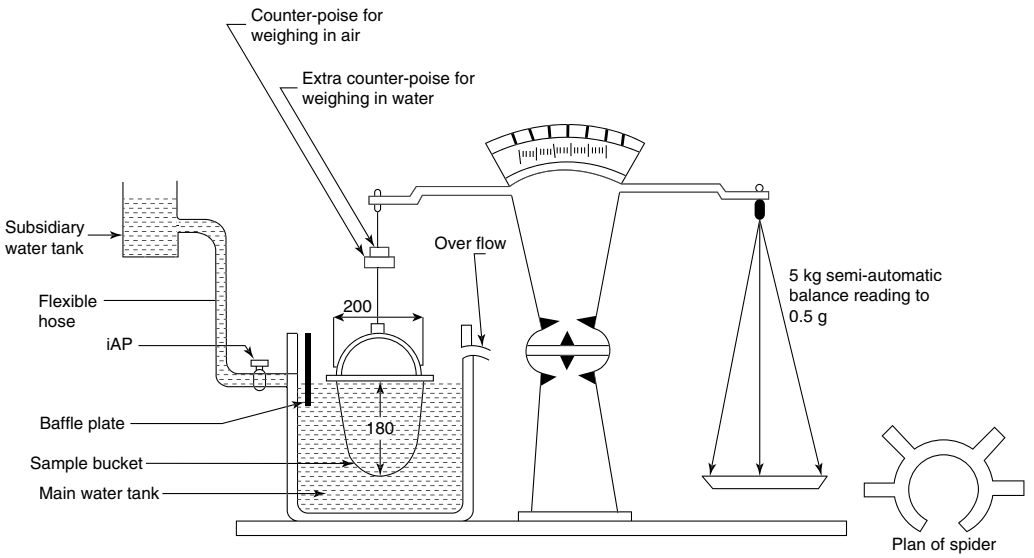

Fig. 16.3 *Apparatus for the analysis of fresh concrete*

Eight bucket shaped non-ferrous containers of identical mass each 200 mm in diameter at top and 180 mm deep and having sloping sides and rounded bottom to prevent trapping of air during immersion of the container as shown in Fig. 16.3.

A tank large enough to receive the bucket easily with an overflow spout in such a position that the rim of the bucket hung from balance is completely immersed when tank is full. The tank is connected by a flexible hose to a subsidiary water tank so that the water level can be raised or lowered by altering the level of the subsidiary tank. The main tank is provided with a baffle plate extending from top of the tank to a position 50 mm below the connection to minimise disturbances due to water current.

Two nesting sieves; the top one is 460 mm in diameter and 100 mm deep with IS: 480 mesh and the lower one is 460 mm in diameter and 300 mm deep with IS: 15 mesh.

A 250 mm deep funnel having approximately 500 and 150 mm diameters at the top and bottom, respectively; to facilitate the transfer by washing of the materials from sieves to the container without loss.

A hose fitted with fine nozzle to give a strong spray for washing the constituents of the concrete.

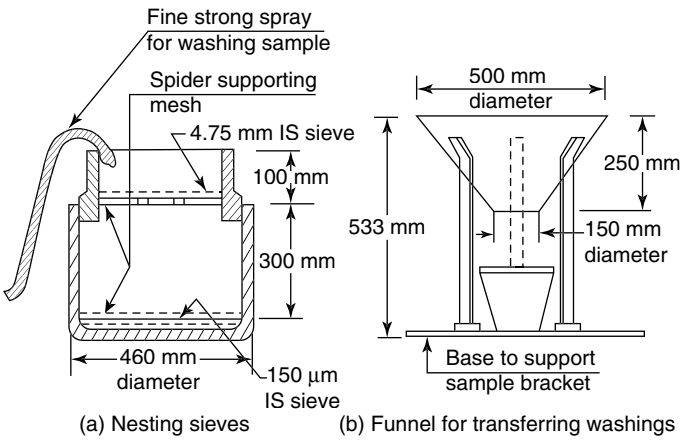

Fig. 16.4 *Nesting sieves and funnel*

Procedure

Before actual analysis is carried out, it is essential to know the specific gravities of coarse and fine aggregates, and cement; and percentage passing the selected sieves. Since the aggregate absorbs moisture when immersed; and the amount of the fine sand passing 150 μm IS sieve depends upon the pressure of the jet; the determination must be made under conditions identical with those to be applied to the analysis of concrete.

The test may be divided into three parts as follows:

Part 1: Determination of Specific Gravity of Aggregates

Step 1: Sampling of aggregates.
Take four samples of each coarse and fine aggregate obtained by quartering as specified in IS: 383-1970; and reduce the main samples to the required size (the mass of these samples should be in same ratio as nominal proportions of the concrete and total weight should be about 3.5 kg).

Step 2: Dry each sample of coarse and fine aggregates in ventilated oven at 100°C to 110°C for 24 hours; cool and weigh. Let the masses for coarse and fine aggregates be A_a and A_s; respectively.

Step 3: Place each sample in a clean bucket and fill it with water to within 25 mm of its tip.

Step 4: Stir the sample to remove entrapped air and hung the bucket from the balance.

Step 5: Fill the bucket with water and raise the level of subsidiary tank until bucket is immersed and water runs from the overflow.

Step 6: Weigh the sample in water. Care should be taken to limit the movement of bucket to 6.5 mm.

Step 7: Repeat the weighing every 20 minutes; sample should be stirred before each weighing to remove air released by the aggregate until difference between successive weighing is less than 0.5 g. But in any case the period of immersion should not exceed 8 hours. Let these masses be B_a and B_s; for coarse and fine aggregates; respectively.

Step 8: Determine the specific gravity of coarse and fine aggregates. The specific gravity of Ordinary Portland cement can normally be assumed as 3.15.

Part 2: Determination of Correction Factor by Sieve Analysis

(Determination of proportions of coarse aggregate which passes the 4.75 mm IS mesh and fine aggregate which passes the 150 μm IS mesh under the experimental conditions).

Step 1: Place a sample of coarse aggregate on 4.75 mm IS sieve held over the 150 μm IS sieve and wash with the jet of water and stir for 2 minutes.

Step 2: Wash into a clean bucket by means of funnel the material retained on 150 μm IS sieve. Weigh under water as described above. Let its mass be D_a.

Step 3: Add a sample of fine aggregate to the material retained on 150 um IS sieve and wash with jet spray for a minute; continuing until water is clear.

Step 4: Wash the residue into a clean bucket and weigh in water as described above.

Step 5: Repeat the above procedure with each of the three samples of coarse and fine aggregates.

Step 6: Determine the average correction factor for each type of aggregate.

Part 3: Analysis of Concrete

Step 1: Sampling

Obtain a truly representative composite sample of the batch of concrete mix made in the field by collecting samples from several distributed positions. Mix the composite sample on a non-absorbent base with a shovel to uniform composition. Reduce the main sample to the required size by the method of quartering. The sample should be about 4 kg if nominal size of aggregate does not exceed 20 mm.

Step 2: Place the sample of concrete in a clean bucket and weigh in the air. Let the mass be W.

Step 3: Fill the bucket with water to about 25 mm of the tip of the bucket and stir the concrete for 1 minute to remove any air.

Step 4: Leave the sample immersed for a period not less than that required for absorption of water by aggregate as determined during tests on the aggregates; but in any case the period of immersion should not be more than 8 hours.

Step 5: Stir vigorously for 1 minute to remove all the air expelled from the aggregate.

Step 6: Hang the bucket from the balance in water tank with water level in tank below the tip of the bucket. Fill the bucket carefully up to the tip and leave the sample to settle for 5 minutes.

Step 7: Raise the water level in the main tank until it overflows. Turn off the tap and weigh the sample in water. Care should be taken as before to limit the movement of the bucket to 6.5 mm. Let this mass be m'.

Step 8: Transfer the concrete sample to the 4.75 mm IS sieve placed over 150 μm IS sieve and wash under jet of water until aggregate is clean. Stir the material with brass rod to facilitate washing.

Step 9: Wash the clean coarse aggregate retained on 4.75 mm IS sieve into a clean bucket with a jet of water by means of the funnel. The jet should remove all small particles from the mesh. The colour of the water is a check on the cleanliness of the sample.

Step 10: Cover the coarse aggregate in the bucket with water and stir thoroughly for 1 minute to remove any entrapped air. Immerse the bucket in the main tank and weigh the aggregate as before. Let this mass be w_a.

Step 11: Wash the aggregate retained on 150 μm IS sieve with jet of water until all fines have been removed. The mechanical agitation of sample is not necessary since jet is sufficiently powerful to move the sand over the surface of the sieve.

Step 12: Wash the sand into bucket; stir and immerse. And weigh in water in the same way as coarse aggregate. Let this mass be w_s.

Observations and Calculations

1. Specific gravity

(a) Coarse aggregate

	1	2	3	4	Average specific gravity
1. Mass of oven dry coarse aggregate A_a; g					
2. Mass of material and bucket in water; g					
3. Mass of bucket immersed in water; g					
4. Mass of aggregate immersed in water (2) – (3) = B_a g					
5. Specific gravity; $S_a = \frac{A_a}{A_a - B_a}$					

(b) Fine aggregate

	1	2	3	4	Average specific gravity
1. Mass of oven dry fine aggregate; A_s g					
2. Mass of material and bucket in water; g					
3. Mass of bucket immersed in water; g					
4. Mass of aggregate immersed in water (2) – (3) = B_s; g					
5. Specific gravity; $S_s = \frac{A_s}{A_s - B_s}$					

2. Correction factors

	1	2	3	4	Average correction factor
1. Mass of coarse aggregate retained on 4.75 mm IS sieve immersed in water; D_a g					
2. Mass of fine aggregate retained on 150 μm IS sieve immersed in water; D_s g					
3. Correction factor for C. A; $C_a = \frac{B_a}{D_a}$					
4. Correction factor for F. A.; $C_s = \frac{B_s}{D_s}$					

3. Proportions of mix

1. Multiplying factor for coarse aggregate;	$F_a = \frac{S_a}{S_a - 1}$		
2. Multiplying factor for fine aggregate;	$F_s = \frac{S_s}{S_s - 1}$		
3. Multiplying factor for cement;	$F_c = \frac{S_c}{S_c - 1}$		

4. Analysis of Concrete

1. Concrete sample mass in air, W;	g	
2. Mass of material and bucket in water,	g	
3. Mass of bucket immersed in water, m′	g	
4. Mass of cement immersed in water (2) – (3)		
5. Mass of coarse aggregate retained on 4.75 mm sieve, W_a;	g	
6. Mass of aggregate retained on 150 μm IS sieve, W_s;	g	

Note: Specific gravity

$$S = \frac{\text{mass in air}}{\text{mass of displaced water}}$$

$$= \frac{\text{mass in air}}{(\text{mass in air}) - (\text{mass in water})}$$

$$\text{Mass in air} = \frac{S}{S-1} \times (\text{mass in water})$$

$$= \text{F} \times (\text{mass in water})$$

1. Thus, mass of coarse aggregate in concrete sample; $W_a = w_a C_a F_a$;	g	
2. Mass of the fine aggregate in the sample; $W_s = w_s C_s F_s$;	g	
3. Mass of cement in the sample; $W_c = [W - (w_a C_a + w_s C_s)] F_c$;	g	
4. Mass of water in the sample; $W_w = W - (W_a + W_s + W_c)$;	g	

In above expressions W *is* mass of concrete in air; w is mass in water; C is the correction factor; w_a is mass of coarse aggregate in water and w_s is mass of fine aggregate in water.

Proportions of concrete mix are.....

Water-cement ratio; $\frac{W_w}{W_c} = ...$

Precautions

1. Before weighing the material in water; the sample should be stirred to remove any entrapped air.
2. During weighing; care must be taken to avoid shaking of the sample and vertical movement of the bucket should be limited to 6.5 mm to avoid inaccuracy due to variations in its displacement or agitation of the contents.

3. Care should be taken in performing these tests so that no material is lost in transferring the sample to the sieve and back to the bucket.
4. The maximum time required for washing any of the samples should be adopted as the time required for washing the concrete on 150 μm IS sieve.
5. Water in main tank should be raised steadily so that even little of water containing fine particles of cement may not spill out of the bucket.
6. If the water in main tank; at any instant; becomes turbid it should be changed between weighing to avoid any change in specific gravity.

Discussion

The method of analysis of freshly mixed concrete as described above is too elaborate for normal field use; but this gives an important check on the efficiency of concrete mixer and is also used for periodical spot checks on the quality of concrete going into a particular job.

The sample of concrete mix should be taken and analysis commenced within 5 minutes of the time of discharge of concrete mix from the mixer. If this is not possible the sample should be placed in an air-tight container within 5 minutes of discharge and stored until the commencement of the analysis which should be within a period of 2 hours from the addition of water to the solid ingredients. Samples of coarse and fine aggregates from the consignment used for making the concrete should be taken and tested for specific gravity and for proportions passing the appropriate sieves.

The value of water-cement ratio obtained will include any water which has been absorbed by aggregate before mixing.

Viva-Voce Questions

1. What is the significance of this test?
2. What are the basic underlying principles for the determination of the ingredients of freshly mixed concrete?
3. Why is the determination of specific gravities of ingredients made under conditions identical with those to be applied to the analysis of concrete?
4. How is the specific gravity of the aggregate determined?
5. What precautions are taken in the determination of specific gravity?
6. What is the correction factor and how is it determined?
7. How is a representative composite sample of the batch of concrete determined?
8. Why is so little use made of this test in the field?
9. What is the other important use of this test?
10. What is the time limit within which testing be commenced? If it is not possible to commence the test within 5 minutes of the time of discharge of concrete mix from mixer; what arrangement is recommended for later testing?
11. What is multiplying factor and how is it expressed in terms of specific gravity?

Notes and Comments

EXPERIMENT NO. 8: Chemical Analysis of Hardened Concrete

Objective

To determine cement content of hardened Portland cement concrete, i.e., to perform chemical analysis for cement.

Theory and Scope

With this analysis, the cement content of hardened Portland cement concrete or cement mortar can be estimated to check whether the mix conforms to the specifications laid for a particular job. Hence, this analysis plays an important role in controlling the quality of cement concrete work. However, the test suffers from the drawback that it is based on the following assumptions to qualify it.

1. There are no supplementary cementing materials.
2. Soluble calcium oxide and silica contents of cement are assumed as fixed values unless given from another source.
3. Concrete does not contain aggregates or admixtures which liberate soluble silica under the conditions of the analysis; such as slag; sodium silicate etc.

If any of these assumptions are not correct the results of the analysis are likely to be inaccurate.

The basic procedure is to take a representative sample of the mortar or concrete, crush it to a fine powder, dissolve it in acid and then use standard chemical analytical techniques to measure the relative proportions of calcium, silica, alumina, magnesia.

Apparatus

A balance sensitive to within 1 per cent of masses of sample to be weighed; three 250 ml Beakers; Glass rod; Gooch crucible; Vacuum filtering arrangement; Ash-less filter papers; Wash bottle; Burners; a set of Sieves and Crushing machine.

Reagents

1. Hydrochloric acid HCl (3.3 N). This is obtained by adding 20 ml of HCl (specific gravity 1.19) to 600 ml of distilled water.
2. Hydrofluoric acid (40 per cent).
3. Sodium hydroxide NaOH (1.0 N). This is obtained by dissolving 40 g of NaOH in 500 ml of distilled water and then diluted to a volume of 1000 ml (one litre).
4. Sulphuric acid H_2SO_4 (specific gravity 1.84).

Procedure

Step 1: Sampling

Select a truly representative sample of the material under consideration by taking several samples each weighing 2 kg from different points. Break up these samples and crush in a suitable machine to about 10 mm size. Grind these samples in a ball mill disc pulveriser to a fineness of approximately

100 μm IS sieve to 80 μm IS sieve. Mix these portions thoroughly and reduce the main sample to about 100 g by method of quartering. Remove the particles of metallic iron abraded from pulveriser ball mill from the sample by means of a strong magnet.

Step 2: Dry the clean sample at 105°C for about 2 hours.

Step 3: Take three 250 ml beakers and weigh into each of them about 3 g of prepared sample.

Step 4: Moisten with a steam of hot water while stirring to prevent adhesion to the beaker or the formation of lumps.

Step 5: Slowly add 100 ml of HCl (hydrochloric acid) and stir thoroughly. The lumps should be reduced with a glass rod.

Step 6: After the reaction is complete, i.e., the evolution of CO_2 (carbon dioxide) has ceased; heat it for a few minutes and allow the contents to settle.

Step 7: Decant through an ignited Gooch crucible. Regulate the suction so as to maintain a rapid rate of dropping during greater part of filtration without allowing the mat and accumulated residue to dry out until filtration is complete.

Step 8: Retain as much residue in beaker as possible and wash by decantation twice with hot water from a wash bottle.

Step 9: Add about 75 ml of NaOH to the residue while stirring and heat it to about 75°C.

Step 10: Again, wash by decantation twice with hot water. Transfer the residue from beaker to the crucible and wash with about 60 ml of hot water.

Step 11: Add about 10 ml of HCl (specific gravity 1.19) to the filtrate which contains silica in the form of silicic acid.

> **Note:** This HCl should only be added when aggregate in original sample is largely calcareous or dolomitic.

Step 12: Transfer the filtrate to a clean beaker with several rinsing of the filter flask.

Step 13: Evaporate to dryness and bake at a temperature not over 120°C for 1 hour.

Step 14: Moisten with HCl (specific gravity 1.19); evaporate and bake again.

Step 15: Dissolve in 75 ml of HCl of 2N to 3N and heat to boiling.

Step 16: Filter through ash less filter paper and wash the residue with 50 ml of hot 1 N HCl and then with water until the washings are free from chloride ions (Cl^-).

Step 17: Repeat the evaporation and filtering process to recover the small amount of silica dissolved and add these to first residue.

Step 18: Determine the silica present in sample by titrating it with hydrofluoric acid and sulphuric acid.

Step 19: Calculate the percentage of the cement in the sample by dividing the percentage of silica by a factor 0.214 (i.e., silica content of the cement).

Observations and Calculations

1. Mass of original dry sample;	g		
2. Mass of silica in sample;	g		
3. Percentage of silica in sample			
4. Percentage of cement in sample			

The ratio is.....

Precautions

1. For washing purposes, distilled water should be used.
2. Never heat or put any hot solution in the standard volumetric apparatus.

Discussion

The method is tedious and time consuming and gives accurate results only when silica is fully recovered from the sample in the form of silicic acid. There are many complexities involved in the analysis, typical ones are as follows:

(a) Hydrated Portland cement continues to gain strength, though at a decreasing rate, when in the presence of water. This complicates chemical analysis because the system is continually changing from the time of first mixing to the time of test.

(b) It is not sufficient to just measure the chemical composition of the hardened material to estimate cement content because all the constituents of hardened concrete may contain the same chemical elements.

(c) Meaningful analysis of the sample requires answers to the questions such as: What is the type of cement used? Does the sample contain mineral admixtures, and if so, approximately how much? What is the aggregate type and is it possibly soluble in acid? What is the water–cement ratio? What is the extent of hydration? In addition, information is required about the condition of the sample, contaminants, possibility of removed constituents by leaching.

Not all of this information can always be made available, and often the answers are given as ranges of values, all of which have to be built into the final interpretation.

Though the raw materials in hardened concrete and mortar can be theoretically measured, this data do not necessarily give enough information to state the cement content without some assumptions and qualifications that, in some cases, are not valid.

The method can also be used to determine the percentage of silica in cement sample as follows:

Weigh accurately about 0.5 g of cement sample into a 250 ml porcelain disc. Add about 15 ml distilled water while stirring the sample and then add 7 ml of concentrated HCl. Break up the lumps; if any; with a glass rod. When effervescence has ceased; evaporate the solution on the water bath with stirring till the residue is just dry. Moisten the mass with 5 ml of concentrated HC1; warm and allow it to stand for 5 minutes. Add 20 ml of water and heat over water bath for 20 minutes break the lumps; if any. When all the soluble matter present has been dissolved filter it through Whatman filter paper No. 31. Wash the residue on the filter paper with hot water till the wash liquid is free from the chlorine (Cl^-) ions. Dry; ignite; cool to room temperature and weigh the residue as SiO_2.

The filtrate can be used to determine the percentage of the oxides of iron and aluminium in the cement sample as follows:

Concentrate the filtrate as obtained above to about 200 ml (obtained after removing silica). Add 2 ml of concentrated nitric acid (HNO_3) and boil to oxidise the ferrous to ferric state. Then add about 5 g of solid ammonium chloride (NH_4C1). Add slowly strong ammonium hydroxide (NH_4OH) with stirring until smell of ammonia comes. Boil and stir for about 5 minutes and filter the hot solution through a No. 42 Whatman filter paper. Wash the precipitate thoroughly with hot water preferably containing 2 per cent ammonium nitrate till the wash water is free of Cl^- ions. Dry; ignite; cool and weigh the residue as R_2O_3 (where R represents aluminium and iron).

The filtrate can be used to determine the percentage of lime in the cement sample as given below:

Add two drops of methyl red indicator and acidify the filtrate as obtained above with dilute HCl. Add ammonia drop by drop till the solution is just alkaline. Add glacial acetic acid till the solution is distinctly acidic. Heat to boiling and add an excess of saturated ammonium oxalate solution (about 10 per cent) with stirring till complete precipitation. Boil and stir for about 10 minutes and allow the contents to cool for about an hour. Test for complete precipitation by adding a drop of ammonium oxalate solution to the clear supematent liquid from the side of the beaker and note if any fresh precipitate has formed on the clear liquid surface. Filter through Whatman filter paper No. 42 and wash with cold water until free from Cl^- and oxalate ions (tested using $KMnO_4$). Dissolve the precipitate in hot dilute sulphuric acid H_2SO_4 and add water to make volume

to about 150 ml. Heat to boil to get clear solution. Cool the solution to the room temperature and make up the volume to 250 ml in a standard volumetric flask with distilled water. Titrate 25 ml of the solution with standard potassium permanganate ($KMnO_4$) solution (N/50 approximately). Standardize the $KMnO_4$ solution standard oxalic acid solution.

1 ml of (N) $KMnO_4$ = 0.02004 g of calcium (Ca)
= 0.02804 g of calcium oxide (CaO)

Viva-Voce Questions

1. What is the significance of this analysis?
2. What are the limitations of the method described?
3. What reagents are required for this analysis?
4. How is representative sample selected?
5. What is the process of quartering?
6. How can it be ensured that the reaction with HCl is complete?
7. What is decantation?
8. What is meant by filtrate and residue?
9. In which form the silica is obtained in the filtrate?
10. How is silica present in the sample determined?
11. How is the percentage of cement obtained from the percentage of silica?
12. What is the condition for obtaining the accurate results?
13. How can the percentage of silica, oxides of iron and aluminium, and percentage of lime obtained?
14. What does N/50 indicate?

Notes and Comments

NATIONAL STANDARDS

1. IS 383-1970 (2nd revision, reaffirmed 2011): *Specification for Coarse and Fine Aggregates from Natural Sources for Concrete*.
2. IS 456-2000 (4th revision, reaffirmed 2011): *Code of Practice for Plain and Reinforced Concrete*.
3. IS 516:1959 (reaffirmed 2008): *Method of Test for Strength of Concrete*.
4. IS 1199-1959 (reaffirmed 2008): *Methods of Sampling and Analysis of Concrete*.
5. IS 2386 (Part 3) -1963 (reaffirmed 2011): *Methods of Test for Aggregates for Concrete*: Part 3: *Specific Gravity, Density, Voids, Absorption and Bulking*.
6. IS 2770 (Part 1)-1967 (reaffirmed 2007): *Methods of Testing Bond in Reinforced Concrete;* Part 1: *Pull-Out Test.*
7. IS 3812 (Part 1)-2003 (2nd revision, reaffirmed 2007): *Specification for Pulverised Fuel Ash:* Part 1: *For Use as Pozzolana in Cement, Cement Mortar and Concrete.*
8. IS 4032-1985 (1st revision, reaffirmed 2009): *Method of Chemical Analysis of Hydraulic Cement*.
9. IS 6461 (Part 10) -1973 (reaffirmed 2011): *Glossary of Terms Relating to Cement Concrete;* Part 10: *Tests and Testing Apparatus.*
10. IS 8112-1989 (1st revision, reaffirmed 2009): *Specification for* 43 *Grade Ordinary Portland Cement*.
11. IS 9103-1999 (1st revision, reaffirmed 2008): *Specification for Admixtures for Concrete*.

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3. Gambhir, M. L. and Neha Jamwal, *Building Materials: Products, Properties and Systems*; McGraw-Hill Education (India), 2011.
4. Gambhir, M. L., *Fundamentals of Reinforced Concrete Design*; Prentice-Hall of India, 2006.