PRINCIPLES OF FOUNDRY TECHNOLOGY

Fifth Edition

About the Author

Prakash Lall Jain received his BE degree in Mechanical Engineering from Birla College of Engineering, Pilani (later renamed as Birla Institute of Engineering and Science) [BITS] in 1955 and then his MTech degree in Production Engineering from the Indian Institute of Technology, Kharagpur, in 1962, and subsequently, specialized in metal-working and metallurgical processes, production systems and management, total quality management and computer applications. He has worked in industry, teaching, research and consultancy organisations for about 40 years, offering teaching and training programmes, technical know-how and consultancy services on total quality management to engineering, foundry and metallurgical industries.

He served as Professor and Head of Production Engineering Department for 24 years at the National Institute of Foundry and Forge Technology, Ranchi, where he also performed the duties of Chairman, Academic Affairs. The Institute offered postgraduate, undergraduate and advanced diploma programmes in different fields of production and metallurgical engineering, conducted short-term programmes for industrial personnel and carried out industry-sponsored research projects. He also provided consultancy services to industrial units in the fields of foundry technology, design and development of castings, production management, quality control and quality management. Prof. Jain has been an active member of several professional bodies like the Institution of Engineers, the Institute of Indian Foundrymen, Ranchi Management Association, Indian Society for Training and Development and also Member and Convenor of Standardisation Committees of the Bureau of Indian Standards, particularly, Foundry Sectional Committee and ISO: 9000 Committee on Quality Systems. He took up the assignment as a Director of Oswal Industries Ltd., Ahmedabad, a company engaged in manufacturing and exporting high-pressure steel valves for petrochemical, thermal and other industries, for a period of three years. During his tenure there, the company could enhance its production, productivity and profitability several times and attain the status of a leading manufacturing and exporting company for low carbon steel, stainless steel and alloy steel high-pressure valves.

Besides this book, he is also the author of three textbooks prescribed for graduate and postgraduate courses in Mechanical, Production and Metallurgical Engineering courses, including one published by Tata McGraw-Hill, namely, *Quality Control and Total Quality Management*. He has presented over 25 technical and research papers at technical and management conventions and conferences, and has published about 60 papers in technical journals of repute, both in India and abroad. He visited Japan and USA under a UNESCO Fellowship programme for a period of nine months (1962), revisited Japan on a marketing consultancy assignment (1996) and also visited Singapore and Malaysia on business missions.

Presently, he has been offering technical guidance and consultancy services for adoption of total quality control, and introducing ISO-related services in foundry, metal-working and engineering industries, having offices in the name of Virgo Services Pvt. Ltd. at Jodhpur and New Delhi. He can be contacted at pljain2006@gmail.com.

PRINCIPLES OF FOUNDRY TECHNOLOGY

Fifth Edition

P L Jain
Quality Management Adviser
Former Professor and Head
Department of Manufacturing Engineering
National Institute of Foundry and Forge Technology
Ranchi

Tata McGraw-Hill Education Private Limited
NEW DELHI

McGraw-Hill Offices
New Delhi New York St Louis San Francisco Auckland Bogotá Caracas
Kuala Lumpur Lisbon London Madrid Mexico City Milan Montreal
San Juan Santiago Singapore Sydney Tokyo Toronto

Tata McGraw-Hill

Published by Tata McGraw-Hill Education Private Limited,
7 West Patel Nagar, New Delhi 110 008

ISBN (13): 978-0-07-015129-1
ISBN (10): 0-07-015129-6

Managing Director: *Ajay Shukla*

General Manager: Publishing—SEM & Tech Ed: *Vibha Mahajan*

Dy Manager—Sponsoring: *Shukti Mukherjee*
Editorial Executive: *Surabhi Shukla*
Executive—Editorial Servicies: *Sohini Mukherjee*
Senior Production Assistant: *Stephen Manuvel*

General Manager: Marketing—Higher Education & School: *Michael J Cruz*
Sr. Product Manager: SEM & Tech Ed.: *Biju Ganesan*

Controller—Production: *Rajender P Ghansela*
Asst. General Manager—Production: *B L Dogra*

Typeset at Text-o-Graphics, B1/56 Arawali Apartment, Sector 34, Noida 201301 and printed at India Binding House, A-98, Sector-65, Noida, U.P.

Cover Printer: India Binding House

RCXCRRCFDXQAA

The McGraw·Hill Companies

To

My dear parents

to whom

I will be ever grateful

Contents

Preface

Foundry is the most basic input industry and stringent demands of quality and quantity are being placed on it with rapid industrialisation and growth in other fields of production, Up-to-date knowledge of materials and processes for casting is necessary in order to be able to produce sound castings economically.

This book has been prepared to meet the growing needs of undergraduate students of production, metallurgical and mechanical engineering, persons preparing for professional examinations like those of the Institute of Metals, Institution of Engineers (India), City & Guilds Examination, Institute of Indian Foundrymen, etc. in which foundry technology usually forms a complete paper. It is hoped that the book will also serve as a useful guide and reference book for the personnel already in the profession who may need to refresh their subject knowledge. It is further believed that the treatment in this book is in harmony with the current trends towards a more practical approach to engineering education.

It is heartening to observe that as in case of the previous editions, since the publication of its first edition in the year 1979, the response for the book from readers, consisting of teachers and students of production engineering, mechanical engineering and metallurgical engineering pursuing undergraduate and postgraduate courses as well as from engineers and technologists working in the foundry industry has been quite consistent and satisfactory. Students studying for diploma courses in the above-mentioned branches of engineering are also getting a lot of benefits from this book. This book has found markets not only in India but also in many overseas countries, including USA, England, South Africa, Indonesia and Bangladesh and others. The comments and feedback received from readers from time to time, since the publication of the second edition have been very useful and valuable; and the suggestions and advice from reputed teachers have been a source of inspiration in bringing out subsequent editions.

The global competition and consequently the developments in technology of casting production has created an urgent need to improve the quality of castings produced, particularly in keeping with the requirements of international standards. Adoption of simulation of casting processes through computers has helped a great deal in converting the art of foundry into an exact science. The revised editions of this book have therefore included the necessary information about computer applications. The new material added in this edition includes fresh information about mouldability test, sand reclamation, ceramic-shell investment casting, surface finish evaluation of castings, use of robots for material handling in foundries, automatic pouring system in melting shops and casting simulation. I am sure the readers would appreciate these additions in order to keep the matter in the book up to date. The review questions given at the end of each chapter have also been revised.

Chapter 1 introduces the student to the basics of foundry technology. Chapter 2, 3 and 4 discuss the technological processes of patternmaking, moulding, coremaking and metal-mould casting processes. Chapter 5 deals with gating, risering and design of castings.

Chapter 6 explains the technology of melting and casting in fair detail. Chapter 7 discusses the defects in castings and quality control including statistical quality control and statistical process control, while Chapter 8 deals with fettling and heat treatment of castings. Chapter 9 is on the modernisation, mechanisation and computerisation of foundries and finally, Chapter 10 is on the application of CAD/CAM in foundries covering product design and analysis, casting design and simulation and some typical software packages for use in the foundry.

The Online Learning Centre of the book can be accessed at

http://www.mhhe.com/jain/pft5e and contains the following materials:

- Powerpoint slides for *instructors*
- Web links for additional reading and case studies for *students*

As the subject is of a very extensive nature, and new development and innovations are taking place rapidly, there will always be scope for further improvement. Constructive suggestions in this regard are welcome from readers and will be given due attention when the next edition of the book is brought out.

P L JAIN

Acknowledgements

I am grateful to various persons and companies, who have shown their full cooperation in the revisions of this book. He wishes to express his thanks to Mr M R Shah, Editor, FOUNDRY journal for his constructive suggestions and cooperation in the preparation of material for revised edition and for giving permission to use the extracts from various articles printed in the said magazine from time to time and later for printing a detailed write-up about this book in his esteemed magazine.

I am grateful to Dr S S Khanna, the then Director, National Institute of Foundry and Forge Technology, for valuable guidance and constant encouragement and also to his colleagues and friends far their inspiration in producing this book. Grateful thanks are due to Dr V K Sinha, faculty member at NIFFT, for contributing the portion on "Heat Treatment of Castings" and for many constructive suggestions.

I am indebted to various organisations (acknowledged in the text) for kindly making available illustrations, diagrams and data. Thanks are due to the Indian Standards Institution for permission to include extracts from some of its standards. Thanks are also due to Mr B N Mahto of NIFFT for carefully preparing the script, and Mr S K Dasgupta and Mr R Horo, also of the NIFFT, for preparing various drawings, charts and diagrams.

I am also grateful to Mr P D Chaubal, Product Manager, M/S Inductotherm India Pvt. Ltd., for supplying photographs and text material about automatic pouring system, developed by them, for the first time in the country.

I also acknowledge with thanks the cooperation from Prof. B Ravi, Department of Mechanical Engineering, Indian Institute of Technology Bombay for making available information based on his research papers on Computer-aided-design in foundries and Autocast Software. I am thankful to American Foundrymen's Society for giving permission to include information about the casting software, AFSolid 2000, developed for them by Finite Solutions Inc. Thanks are due to Mr Niko Turunen of M/S CT-Castech Inc. for supplying information about their CastCAE software. Permission accorded by Mr Henrik Barth of M/S Nova Cast AB for using the information about their foundry software, 'Nova Flow and Solid' available on their home page on the Internet is solicited. Short references have also been taken from the home pages of M/S Flow Science Inc., UES Software Inc., Magma Foundry technologies Inc. and Solid Works Corporation.

Thanks are due to M/S Versatile Equipments Pvt. Ltd., Kolhapur, manufacturers of foundry sand testing equipment for supplying photographs of several sand testing items and giving permission to include them in the book. Few photographs have been adopted from the catalogue of M/S DISA, Denmark. Thanks are due to them.

Thanks are also due to the reviewers who took out time to go through the book. Their names are given below:

Sounak Kumar Choudhury	Department of Mechanical Engineering IIT Kanpur, Uttar Pradesh
Dinesh Khanduja	Department of Mechanical Engineering NIT Kurukshetra, Punjab
R K Gupta	Continental Institute of Engineering and Technology, PTU, Punjab
A K Bajpai	Department of Mechanical Engineering Madan Mohan Malviya Engineering College Gorakhpur, Uttar Pradesh
Munish Chhabra	Department of Mechanical Engineering Moradabad Institute of Technology, UPTU Moradabad, Uttar Pradesh
Gaurav Agarwal	Sri Ram Murty Smarak College of Engineering and Technology, Bareilly , Uttar Pradesh
G L Datta	Department of Mechanical Engineering IIT Kharagpur, West Bengal
H K Raval	Department of Mechanical Engineering SVNIT, Surat , Gujarat
Vijay Desai	Department of Mechanical Engineering NITK, Surathkal, Maharashtra

It is not possible for me to name each and every reader for their suggestions but I take this opportunity to thank them all for their cooperation. Further suggestions from readers would always be welcome. Finally, I wish to thank my publishers, Tata McGraw-Hill Education for their cooperation in bringing out this revised edition in a short time.

P L Jain

Visual Summary

Chapter 1

Introduction to Foundry Technology

Foundry engineering deals with the processes of making castings in moulds formed in either sand or some other material. The art of foundry is ancient, dating back to the dawn of civilisation. Even in prehistoric times, as far back as 5000 BC, metallic objects in the form of knives, coins, arrows, and household articles were in use, as observed from the excavations of Mohenjodaro and Harappa. One of man's first operations with metal was melting the ore and pouring it into suitable moulds. The casting process is said to have been practised in early historic times by the craftsmen of Greek and Roman civilisations. Since then, the role of metals has acquired unique significance. Copper and bronze were common in ancient times, but evidence indicates that iron had also been discovered and developed in the period around 2000 BC, though its use was greatly restricted.

The earliest use of the metals was mostly for making knives, arrow po

1. Introduction

Every chapter begins with an Introduction which is useful for beginners to familiarise themselves with the subject.

Chapter 2

Technology of Patternmaking

REQUIREMENT 2.1

A pattern is the principal tool during the casting process. The quality of the casting produced depends largely on the material of the pattern, its design and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of expensive patterns can therefore be justified where the quantity of castings required is relatively substantial. When only few castings are needed, a loose pattern made from a soft variety of wood serves the purpose. Where a large number of castings are required and are to be repeatedly produced, patterns should be made in metal or epoxy resin and mounted on pattern plates for use on moulding machines.

Technology of Pattern-making

Technology of Pattern-making is discussed in considerable detail, including both the design and practical aspects of patterns. New materials for patterns are also added.

Illustrations

Photographs, figures, and charts are provided plenty in each of the chapters so as to make the text more easily understandable.

14 Principles of Foundry Technology

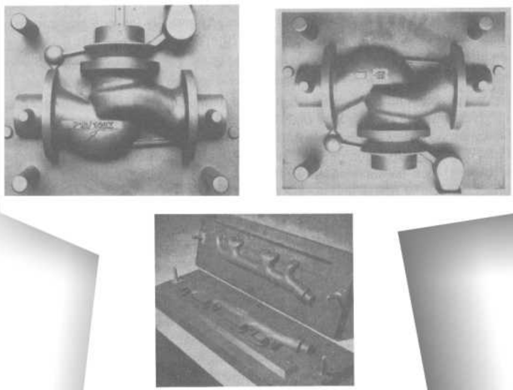


Fig. 2.3 *Typical epoxy resin pattern mounted on match-plates*

Plate 2

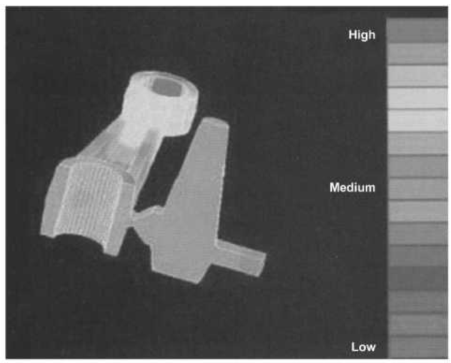


Fig. 10.1 *B.H.N. plot obtained from thermal micro-modelling analysis*

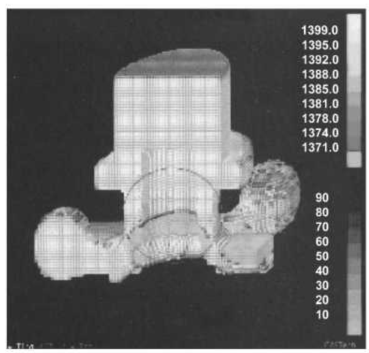


Fig. 10.3 *Old system of casting*

Plates

Several colour photographs on art paper are given in the form of plates to make the topic fully illustrative.

Chapter 7

Defects in Castings and Quality Control

DEFECTS IN CASTINGS 7.1

Several types of defects may occur during casting, considerably reducing the

New Topics

Quality control, SQC and SPC have been discussed in fair detail for the first time in a book on foundry technology, both from academic and practical points of view. Applications of computers, which have become essential in all technological fields, have been introduced for the first time.

394 *Principles of Foundry Technology*

APPLICATION OF COMPUTERS IN FOUNDRIES 9.3

Computers have now become an indispensable tool in every walk of life and for all sorts of applications, may it be administrative, operational, technological, trading, sports, communications or even domestic fields. From the industrial point of view, they have been in use in the administrative areas of finance, ac- ... personnel records, wage and salaries and inventory contr...

New Topics

Expert system for casting defect analysis and pollution control has been introduced in a foundry book for the first time.

EXPERT SYSTEM FOR CASTING DEFECT ANALYSIS 7.4

Expert systems are computer programs in which the knowledge and experience of one or more experts is captured and stored so as to make it widely available. These systems can be of great assistance in the decision-making process as the

POLLUTION CONTROL IN FOUNDRIES 9.4

9.4.1 Pollutants in a Foundry

Foundries are among the industrial plants causing environmental pollution, producing substantial quantities of air pollutants. The numerous processes available for moulding, melting and casting are accompanied by evolution of heat, noise, dust and gases. Dust, fines, fly ash, oxides, etc., which form particulate matter are generated in large quantities when preparing mould and core sands and moulds, melting metals, pouring moulds, knocking out poured moulds and loading and

Chapter 9

Modernisation, Mechanisation and Computerisation of Foundries

NEED FOR MODERNISATION AND MECHANISATION 9.1

An average person visualises a foundry as a dark, dirty place dotted with mounds of sand, coal, ashes and metal, an atmosphere filled with smoke; an enclosure where workers swear and breathe noxious fumes produced during the casting process. This picture is true to a fair extent of many foundries even today. There is thus a vital need for modernisation in this particular field of industry. Measures that lead to increased production, improved working conditions in the shop with an eye to ensuring a safe, healthy and happy life for the worker deserve enthusiastic

New Chapters

Modernisation of foundries and plant layout, the most current topics these days, have been introduced as a separate chapter.

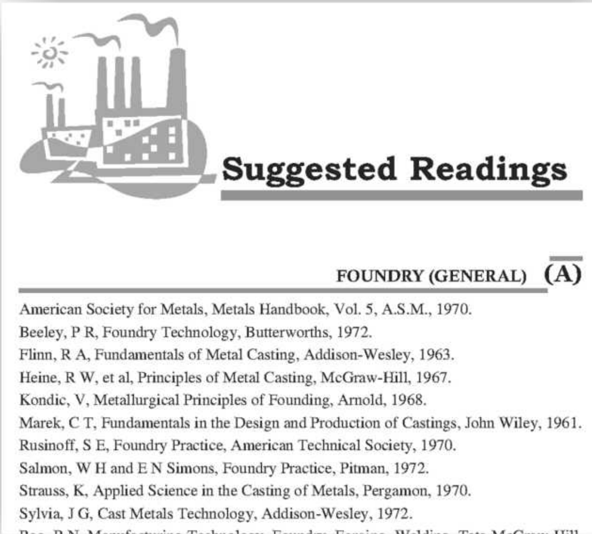
Case Studies

Case studies have been incorporated along with the text in different chapters.

For various reasons, production of castings is often subject to relatively high scrap levels. These reasons may include lack of process control, inadequate understanding of the casting process and poor producibility of castings due to defective designs. Foundries therefore often generate large amount of attributes data. Hence SPC can be easily introduced by making effective use of this data and plotting attribute control charts. These charts give an overall picture of the quality problems and can highlight instances in past production when scrap levels were significantly higher or lower than normal, i.e., out of control. This enables correct interpretation of process data. Heading to process improvements and improved productivity.

A Case study about Introduction of Statistical Process Control at a Gray Iron Foundry

The foundry unit is 100% export-oriented, supplying chilled cam shafts to automobile manufacturers in Europe. It is a QS 9000 company producing chilled cast-iron cam shafts and other automobile castings by the shell – moulding process. One of the important parameters to be controlled in these castings is *casting bend*. The specifications demand that castings having bend beyond 1.8 mm are to be rejected. To control the bend defect, the quality of shell mould needs to be controlled, which means the entire moulding process has to be controlled. One



Suggested Readings

FOUNDRY (GENERAL) (A)

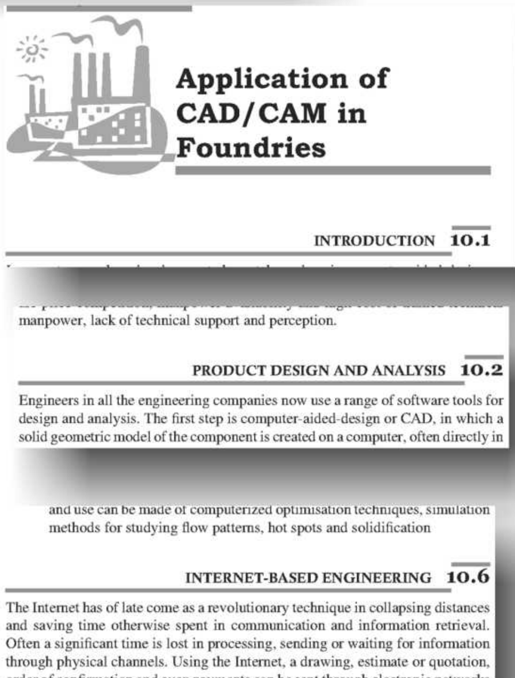
American Society for Metals, Metals Handbook, Vol. 5, A.S.M., 1970.
Beeley, P R, Foundry Technology, Butterworths, 1972.
Flinn, R A, Fundamentals of Metal Casting, Addison-Wesley, 1963.
Heine, R W, et al, Principles of Metal Casting, McGraw-Hill, 1967.
Kondic, V, Metallurgical Principles of Founding, Arnold, 1968.
Marek, C T, Fundamentals in the Design and Production of Castings, John Wiley, 1961.
Rusinoff, S E, Foundry Practice, American Technical Society, 1970.
Salmon, W H and E N Simons, Foundry Practice, Pitman, 1972.
Strauss, K, Applied Science in the Casting of Metals, Pergamon, 1970.
Sylvia, J G, Cast Metals Technology, Addison-Wesley, 1972.

References

A comprehensive list of reference on various topics has been given at the end of the book, chapter-wise for further reading.

Software Information

New standard software now available for use in foundries have been incorporated as a bonus to the readers for casting design, solidification, metal flow, getting systems, etc.



Application of CAD/CAM in Foundries

INTRODUCTION 10.1

manpower, lack of technical support and perception.

PRODUCT DESIGN AND ANALYSIS 10.2

Engineers in all the engineering companies now use a range of software tools for design and analysis. The first step is computer-aided-design or CAD, in which a solid geometric model of the component is created on a computer, often directly in

and use can be made of computerized optimisation techniques, simulation methods for studying flow patterns, hot spots and solidification

INTERNET-BASED ENGINEERING 10.6

The Internet has of late come as a revolutionary technique in collapsing distances and saving time otherwise spent in communication and information retrieval. Often a significant time is lost in processing, sending or waiting for information through physical channels. Using the Internet, a drawing, estimate or quotation,

6. Sand Slinger For medium- and large-sized cores, sometimes a sand slinger, similar to the one used for moulding work, is required. This is usually of the stationary type and smaller than the one used for making moulds.

'SPECIAL' SAND MOULDING PROCESSES 3.6

In recent years, special moulding processes have been developed to enable moulding with less effort and skill, effect a saving in time and expense, produce better quality moulds and cores, and effectively help in improving productivity. Generally, these processes eliminate the need for drying or baking of moulds and cores, and rapid hardening action takes place due to chemical reactions. Also, the castings can be produced to a higher degree of accuracy and finish than that possible by conventional green or dry sand moulding.

Special sand-moulding processes may be broadly classified under three heads:

(1) Processes based on sodium silicate or other inorganic binders;
(2) Processes based on organic binders; and
(3) Other special moulding processes.

3.6.1 Processes Based on Sodium Silicate Binder

The use of sodium silicate as a binder has considerably increased in recent years. It enables the preparation of mould and cores without any need for drying or baking and in certain cases even without ramming the sand.

Coverage

All new developments, which have taken place during recent years are covered so as to make the book fully up-to-date.

Review Questions

Review questions given at the end of each chapter help in revision, enabling students to prepare for exams.

7) Graphite Mould Casting

Graphite has been successfully used as a mould material for producing steel castings, particularly wheels for railway wagons and coaches. Graphite does not fuse with molten steel at high temperatures, has high resistance to burn-in allowing clean withdrawal of the casting from the mould, high resistance to thermal shock, low coefficient of expansion and ability to resist distortion. Thus, the mould once prepared from graphite blocks by machining can be used repetitively, though special measures, such as pressure pouring have to be adopted to prevent erosion of mould walls and to regulate the rate of entry of metal into the mould.

Review Questions

1. What are the principal ingredients of moulding sands? How are they specified?
2. What basic tests are prescribed for testing moulding sands? How are they performed?
3. What advanced tests are recommended for moulding and core sands? What is their significance?
4. What is permeability? How is it measured in case of dry and wet sands?
5. What is compatibility? What factors affect its evaluation?
6. Prepare a test-reporting programme for a medium-scale batch-production foundry producing grey-iron machine-tool castings.
7. What are the specifications of high-silica sands? For what conditions of working, is it most suitable?

Chapter 1

Introduction to Foundry Technology

Foundry engineering deals with the processes of making castings in moulds formed in either sand or some other material. The art of foundry is ancient, dating back to the dawn of civilisation. Even in prehistoric times, as far back as 5000 BC, metallic objects in the form of knives, coins, arrows, and household articles were in use, as observed from the excavations of Mohenjodaro and Harappa. One of man's first operations with metal was melting the ore and pouring it into suitable moulds. The casting process is said to have been practised in early historic times by the craftsmen of Greek and Roman civilisations. Since then, the role of metals has acquired unique significance. Copper and bronze were common in ancient times, but evidence indicates that iron had also been discovered and developed in the period around 2000 BC, though its use was greatly restricted.

The earliest use of the metals was mostly for making knives, arrow points, coins, and tools. The moulds were made in stone or sand. Around 500 BC, started the era of religious upheavals, and metals began to be used for making statues of gods and goddesses. Bronze was still the most popular metal. It was at this time that *lost-wax process* made its impact. Subsequently, a still greater application of metals figured in armoury, guns, and war material. Even in those days, the superior quality of metals and the absence of any impurities in them emphasise the ability and precise quality control of the refining process.

The greatest breakthrough in the application of metals for gunnery and other arms possibly took place at the time when Alexander was contemplating victory over the entire Eurasian continent. Since then, the whole art of metal casting has emerged as an exact science. Today, we have a variety of moulding processes and melting equipment and a host of metals and their alloys. And though the techniques and methods of production have changed considerably, the basic principles still remain almost the same.

Castings have several characteristics that clearly define their role in modern equipment used for transportation, communication, power, agriculture, construction, and in industry. Cast metals are required in various shapes and sizes and in large quantities for making machines and tools, which in turn work to provide all the necessities and comforts of life.

Other metal-shaping processes, such as hot working, forging, machining, welding, and stamping, are of course, necessary to fulfil a tremendous range of needs. However, certain advantages inherent in castings—design and metallurgical advantages—and in the casting process itself, endow them with superiority over other methods.

Design Advantages of Castings

The need of designers for objects having certain structural and functional shapes that can withstand stress and strain, fulfil other service conditions, possess a desirable appearance, and have an acceptable cost is remarkably satisfied by castings. The metal can be shaped to almost any configuration and may be produced with only slight limitations in size, accuracy, and complexity. The main design advantages are the following:

(i) Size Castings may weigh as much as 200 tonnes or be as small as a wire of 0.5-mm diameter. In fact, casting is the only method available for producing massive objects in one single piece.

(ii) Complexity The most simple or complex curved surfaces, inside or outside, and complicated shapes, which would otherwise be very difficult or impossible to machine, forge, or fabricate, can usually be cast.

(iii) Weight Saving As the metal can be placed exactly where it is required, large saving in weight is achieved. Such weight saving leads to increased efficiency in transportation and economy in transport charges.

(iv) Production of Prototypes The casting process is ideally suited to the production of models or prototypes required for creating new designs.

(v) Wide Range of Properties and Versatility Castings offer the most complete range of mechanical and physical properties available in metals and, as such, fulfil a large majority of service requirements. In fact, some alloys can only be cast to shape and cannot be worked mechanically. Almost any requirement such as mechanical strength, wear resistance, hardness, strength-to-weight ratio, heat and corrosion resistance, electrical and thermal conductivity, and electrical resistance, can be satisfied by cast alloys. In many cases, the appearance of the component plays a part in enhancing its value. The blending together of various sections through the use of angles, curves, and streamlining can produce a pleasing appearance in castings.

Advantages of Casting Process

(i) Low Cost Casting is usually found to be the cheapest method of metal shaping.

(ii) Dimensional Accuracy Castings can be made to fairly close dimensional tolerances by choosing the proper type of moulding and casting process. Tolerances as close as ± 0.1 mm can be achieved depending on the cast metal, the casting process, and the shape and size of the casting. The surface finish can also be controlled and may vary from 5 microns to 50 microns.

(iii) Versatility in Production Metal casting is adaptable to all types of production. It is as suitable for jobbing work as for mass production. For example, a large number of parts required for the automotive industry, agricultural implements, home appliances, construction, and transportation are all produced by the casting process.

Metallurgical Advantages

(i) Fibrous Structure Wrought metals have a fibrous structure, mainly due to a stringer-like arrangement of the inclusions of non-metallic impurities. In cast metals, the inclusions are more or less randomly distributed during the solidification process. When wrought metals are worked, the inclusions are strung out in the direction of working, and so the fibrous nature results in marked directional properties. Cast alloys do not usually exhibit any fibering or directionality of properties, except under unfavourable conditions of solidification.

(ii) Grain Size Although mechanical working of wrought metals causes breaking up of coarse grains and promotes fine grain size, many castings have grain sizes not very different from those of the former. Most non-ferrous alloys retain the grain size attained during freezing of the casting. Subsequent heat treatment of castings can also help in improving the grain size.

(iii) Density The density of cast alloys is usually identical to that of wrought alloys of the same chemical composition and heat treatment, when both are fully sound.

Today, it is becoming increasingly difficult to cope with the growing demand for various types of castings as required for automobiles, scooters, tractors, earth-moving machinery, and railways. Sophisticated castings needed for aeronautics, atomic energy, defence, and space research pose yet another challenge in terms of stringent requirements of quality. The problem is more or less similar in all developing countries. To achieve self-reliance, the foundry industry has to accept the challenge and quickly learn the new technology, methods and know-how already available and in use elsewhere. It is also possible, through a sharper awareness and greater appreciation of the need for improved materials and more efficient methods, to increase production with the existing level of inputs in terms of equipment and manpower. Adequate means of quality control at all levels of production, steps to keep the wastage of materials and unproductive efforts at the minimum through proper organisation and coordination, and the use of enlightened human relations can go a long way in enhancing production and productivity in foundries.

The casting process is basically one of introducing molten metal into a cavity in the mould, previously shaped as desired, and allowing it to solidify. The mould is usually prepared in sand; an object similar in shape and size to the casting required, which is called a *pattern*, embedded in the sand. The pattern is thus an exact facsimile of the articles to be cast.

The whole process of producing castings may be classified into five stages:

(i) Patternmaking In the patternmaking section, the patterns are designed and prepared as per the drawing of the casting received from the planning section and according to the moulding process to be employed. The material of the pattern may be selected from a wide range of alternatives available, the selection depending on factors such as the number of castings required, the possibility of repeat orders, and the surface finish desired in the casting. Core boxes needed for making cores and all other auxiliary tooling items are also manufactured in the patternmaking section.

(ii) Moulding and Coremaking After the patterns are prepared, they are sent to the moulding section. The moulds are prepared in either sand or a similar material with the help of the patterns so that a cavity of the desired shape is produced. For obtaining hollow portions, cores are prepared separately in core boxes. The moulds and cores are then baked to import strength and finally assembled for pouring. The moulding work may be carried out either by hand or with the help of machines, depending on the output required. Proper mould design and arrangement for flow of molten metal is very important for the production of sound castings. The last 25 years have witnessed far-reaching developments in the moulding materials and processes.

(iii) Melting and Casting The metal of correct composition is melted in a suitable furnace. When molten, it is taken into ladles and poured into the moulds. The moulds are then allowed to cool down so that the metal solidifies. The castings are finally extracted by breaking the moulds and are then sent to the cleaning section.

(iv) Fettling The castings as obtained from the moulds are not fit for immediate use or for work in the machine shop as they carry unwanted metal attached in the form of gates and risers. Sand particles also tend to adhere to the surface of the castings. The castings are therefore sent to the fettling section where the unnecessary projections are cut off, the adhering sand removed, and the entire surface made clean and uniform. The castings may also need heat treatment depending on the required specific properties.

(v) Testing and Inspection Finally, before the casting is despatched from the foundry, it is tested and inspected to ensure that it is flawless and conforms to the desired specifications. In case any defects or shortcomings are observed during inspection which may render the casting unfit, analysis is necessary to determine the causes of these defects, so as to prevent their recurrence. The production process then has to be corrected accordingly. Statistical quality control has been applied in foundries for design, process control, testing and inspection purposes in order to acieve consistent quality of castings at minimum cost.

All the five stages of casting are comprehensively covered in this book. Certain chapters deal with gating and risering of castings, and the modernisation and mechanisation of foundries. Foundry mechanisation and modernisation are of considerable importance today when foundry has evolved from an ancient art into a modern science. The various steps involved in producing a casting, as already mentioned; the economical considerations involved in such production; and measures that ensure quality and quantity are also discussed in this text. Computers have entered into all industrial applications, and more so in foundry technology. A separate chapter has therefore been added on computer applications in foundry, including the use of CAD/CAM for design optimisation and simulation, and process control at various stages of production.

Review Questions

1. What are the main design advantages of castings? Explain with examples.
2. Explain the metallurgical advantages of castings in comparison to other products.
3. Describe the various stages of casting production in brief.
4. Give a historic account of the developments in metal-casting technology. What breakthroughs have occurred during the last 2000 years?
5. What are the metallurgical drawbacks in the casting process? What alternative steps are taken to overcome the drawbacks?

Chapter 2

Technology of Patternmaking

REQUIREMENT 2.1

A pattern is the principal tool during the casting process. The quality of the casting produced depends largely on the material of the pattern, its design and construction. The costs of the pattern and the related equipment are reflected in the cost of the casting. The use of expensive patterns can therefore be justified where the quantity of castings required is relatively substantial. When only few castings are needed, a loose pattern made from a soft variety of wood serves the purpose. Where a large number of castings are required and are to be repeatedly produced, patterns should be made in metal or epoxy resin and mounted on pattern plates for use on moulding machines.

Much preparation is necessary before the patternmaker can actually start producing the pattern. The preparatory work includes decisions about (i) the type and form of material to be used, (ii) the type of pattern to suit the method of moulding to be adopted, (iii) the provision of core boxes, (iv) constructional details, including the provision of loose pieces, core prints, etc., (v) considerations as regards the value of allowances to be used, (vi) the method of gating and feeding to be followed, and (vii) the provision of various foundry aids. It is a good practice to prepare separate drawings for patterns and core boxes from the component drawing so that all details can be indicated thereon. The patternmaker then draws a layout in full scale which becomes the basis for the production, and subsequently also for the inspection, of the pattern.

The patternmaker has a very important role to play in casting production. It is he who is responsible for details of form and construction. He creates the first tangible evidence of the machine to be. He must be able to interpret the engineering drawings prepared by the designer, visualise the object in three dimensions, draw the layout of the item, and finally produce a pattern complete with gating, risers, and other auxiliary items of tooling. He has also to be conversant now with the use of computers for graphics, drawing and design.

PATTERN MATERIALS 2.2

The selection of pattern materials depends on factors such as

(i) service requirements, e.g., quantity, quality and intricacy of castings, minimum thickness desired, degree of accuracy and finish required;
(ii) possibility of design changes;
(iii) type of production of castings, and type of moulding method and equipment to be used; and
(iv) possibility of repeat orders.

To be suitable for use, the pattern material should be

(i) easily worked, shaped, and joined;
(ii) light in weight for facility in handling and working;
(iii) strong, hard, and durable (i.e., of high strength-to-weight ratio);
(iv) resistant to wear and abrasion, to corrosion, and to chemical action;
(v) dimensionally stable and unaffected by variations in temperature and humidity;
(vi) available at low cost;
(vii) such that it can be repaired or even re-used; and
(viii) able to take a good surface finish.

The wide variety of pattern materials in use may be classified as wood and wood products; metals and alloys; plasters; plastics and rubbers; and waxes.

2.2.1 Wood and Wood Products

Wood is the most commonly used material for patterns as it satisfies many of the aforementioned requirements. It can be easily shaped or worked and joined to form any complex shape, is light in weight, is easily available, and costs less than other materials. The common drawbacks, however, are its susceptibility to moisture, causing it to swell or shrink, its poor strength, and low resistance to wear.

Wood, like all living matter, is composed of cells resembling long thin tubes with tapered ends. The cell walls consist of cellular fibres, aligned parallel to the axis of the cells, and bonded together by a complex amorphous material called *lignin*.

Wood contains 50–60% cellulose and 20–35% lignin. Smaller amounts of other carbohydrates, such as pentosanes, resins, gums, and mineral matter, are also present. The cell walls are highly hygroscopic because the main constituent, cellulose, contains numerous hydroxyl groups which are strongly hydrophilic.

When exposed to moisture, the cell walls absorb large amounts of moisture and swell. This characteristic of wood reduces its rigidity and causes dimensional instability.

The moisture in green wood consists of water absorbed by the cell walls and water contained within the cell cavities (Fig. 2.1). As the wood dries, the water is first removed from the cell cavities until they are empty. At a point called *fibre saturation point*, the cell walls are fully saturated with water although the cell cavities are empty. This point occurs at about 25–35% moisture in wood. On further air drying, moisture decreases until an equilibrium moisture content (EMC) is reached. The value of EMC depends on relative humidity and temperature. For example, for 60% relative humidity and 20°C temperature, the EMC is about 11%. Variation in the moisture content of wood with atmospheric conditions results in swelling and shrinkage when the moisture content is below the fibre saturation point. The dimensional changes occur in a direction transverse to the long axis of wood, because the cell walls swell or shrink in the direction perpendicular to the fibre length.

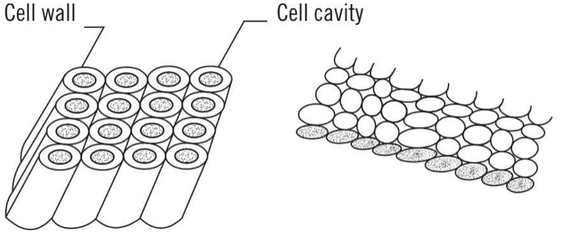


Fig. 2.1 *Cell structure of timber*

The tree trunk develops from a young sapling by a process of laying down successive concentric layers of cells outside the established wood and under the bark. The seasonal variations in temperate climate result in two stages of growth of the wood substance, one very rapid stage occurring in spring and the other, a slow rate stage occurring in summer. The cells formed in spring have very thin walls and the wood has an open texture. Those formed in summer have much thicker walls, making the wood texture close and relatively strong. This growth pattern results in marked differences in the wood structure, which appear in the form of characteristic annular rings representing the boundaries between spring and summer wood. The tree trunk becomes separated in two zones; the inner one, which is stronger, harder, and more durable, is *heart wood*, and the outer one is *sap wood* (Fig. 2.2). The outermost layer on the inside of the bark is cambium, followed by sap wood rings. The wood in this sap-wood region is fresh and, therefore, weak and prone to decay. The ray cells radially dispersed in the section

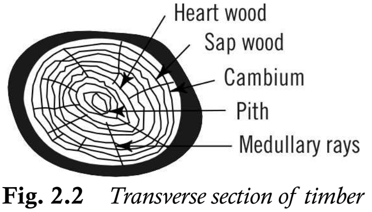


Fig. 2.2 *Transverse section of timber*

are called *medullary rays*. These rays are noted as fine white lines and serve as reinforcement against lateral spreading of vertical fibres under the axial load and also help in storing and distributing food material.

Seasoning of Timber To prevent excessive shrinkage or swelling, wood can be seasoned before it is finally put into service. Seasoning minimises the effect of subsequent moisture variations by adjusting the water content of wood as nearly as possible to what would be obtained at the equilibrium level under exposure to average atmospheric conditions. More precisely, wood is seasoned in order to make it (i) stable in dimensions; (ii) stronger and lighter; (iii) resistant to decay; and (iv) take preservatives, paint, or polish.

Seasoning can be done by natural or artificial methods. In *natural seasoning*, the wood is stacked suitably in open spaces and subjected to air drying for a period of time extending up to one full cycle of weather conditions. Another method of natural seasoning prescribes keeping the timber immersed in flowing water, so that a large part of the moisture is washed away and removed, and then air drying it for a shorter duration.

In *artificial seasoning*, the timber is stacked in drying kilns and subjected to fast air drying by allowing hot air to pass through the kiln chamber. The air is heated, usually by steam passing through pipes. The temperature and humidity have to be precisely controlled in the kiln to prevent the timber from developing defects, such as cracks and buckling. In the beginning, hot but moist air is introduced, so that heating may take place uniformly through the whole section of wooden pieces without appreciable drying to avoid any differential contraction. Then the moisture content in the air is gradually reduced to the desired value. The kiln is equipped with suitable arrangements for air circulation, heating, humidity control and ventilation. Ordinarily, one week is sufficient to carry out seasoning.

Another method of artificial seasoning is *electrical seasoning*. Fairly large sections of timber are exposed to a high frequency electric field such that the moisture content is brought down to the desired level within few minutes. *Chemical seasoning* has also been used where wood is kept immersed in suitable salt solutions and then exposed to air for drying. The following Indian standards can be referred to for detailed guidelines on wood seasoning and methods of preservation.

IS: 401–1967 gives the code of practice for the preservation of timber and deals with various methods of preservation.

IS: 1141–1973 gives the code of practice for seasoning of timber and lays down the procedure for kiln seasoning.

IS: 7315–1974 gives guidelines for design, installation and testing of timber-seasoning kilns.

Types of Timber for Pattern Work

The woods commonly used for pattern work are pine, mahogany, teak, walnut, and deodar. Pine wood, though weak, is often favoured for its extreme lightness, stability, ease of working, and ability to take good finish. It is suitable where a small number of castings, say up to 25 in number and under 500 mm in size, on any one side are required. Mahogany is a hard, strong, and very durable type of wood with negligible shrinkage or swelling after seasoning. It takes a very fine natural polish, stains well, and glues excellently. Amongst natural woods, therefore, mahogany is the best choice for pattern work. It is ideal where the number of castings required is large and involves permanent production work on moulding machines. Teak is also a hard and strong variety of wood, unaffected by fungus, and easily available in the country. Deodar is a soft variety, slightly harder than pine but easily machinable, and takes good polish.

The wood products gaining more popularity for pattern work in recent times include compressed wood laminates and laminated wood impregnates.

(i) Compressed Wood Laminates These laminates are available as plywoods and as laminated boards, plain or veneered. Thin wooden laminates are glued and pressed together such that the grains of alternate laminates occur in the opposite direction. These laminated forms of wood are stronger, denser, and dimensionally more stable than plain woods. These are available as sheets in different sizes in thicknesses varying from 12 mm to 50 mm. Metal-faced plywood is also available which has a facing of mild steel, stainless steel or brass. It is made by the hot pressing technique and has superior mechanical properties, resistance to wear and abrasion, and dimensional stability.

(ii) Laminated Wood Impregnates (Plastic Wood) These varieties are the result of attempts to overcome the drawbacks found in woods and to improve properties such as strength, density, hardness, resistance to wear, and dimensional stability, at the same time preserving the natural advantages of woods. The wood laminate may be simply impregnated with resins so as to fill up the cell cavities, or be impregnated and compressed to increase density and hardness. WPC, i.e., wood plastic combination, is one such compressed impregnate which possesses exceptional properties and has been used as a substitute for more expensive aluminium patterns for automotive casting work. Complete polymerisation of plastic resin is necessary and is achieved sometimes by using nuclear radiations in the form of intense gamma rays. Commercially, resins applied include phenol formaldehyde, methyl methacrylate, styrene, acrylonitrile, isocyanates and polyester. These varieties are also available as sheets of varying thicknesses.

Wooden Patterns with Metallic Coatings For short-production runs where metallic patterns cannot be economically employed and wooden patterns are not found satisfactory due to low strength and lack of high finish, metal-coated patterns are sometimes used. The wooden patterns are sprayed with a thin metallic coating of about 0.25-mm thickness, the metals generally used being bismuth, zinc or aluminium. The metal in the form of wires is fed into a spray gun, and is heated therein by an oxyacetylene flame. Then, under pneumatic pressure it is blown in an atomised form through a nozzle over the wooden surface. For details of this process, refer Section 8.1.2 (XV) on metal spraying.

2.2.2 Metals and Alloys

Metallic patterns are used where repetitive production of castings is required in large quantities. The metals commonly used are aluminium alloys, cast iron, steel and copper-base alloys such as brass or bronze. A comparative evaluation of these metals is given in Table 2.1.

Table 2.1 *Comparative evaluation of some metals used for pattern-making*

FACTORS	GREY CAST IRON	STEEL	ALUMINIUM	BRASS
Availability	Good	Good	Good	Good
Castability	Good	Difficult	Less difficult	Good
Machinability	Good	Good	Very Good	Very Good
Surface finish	Good	Good	Very Good	Very Good
Lending to modification	Good	Good	Good	Very Good
Weight	Very heavy	Very heavy	Very light	Heavy
Brittleness	High	Low	Low	Low
Tendency to oxidation	Yes	Yes	No	No
Requiring machining	Yes	Less	Not much	Not much
Cost	Low	Low	Medium	High

Grade 20 cast iron as per IS: 210–1962, which has BHN value 197–241, is the most suitable of all cast irons. High duty iron and SG iron are also now being increasingly used. Owing to its heavy weight, cast iron can be used only for small-sized patterns. The overwhelming advantages of aluminium make it the most popular choice for patterns. The alloys recommended are grade 4223, 4600 and 4420 as per IS: 617–1975.

A near equivalent of grade 4420 in British standards is LM 25 WP, widely used in the UK and elsewhere due to its easy castability, low shrinkage, good strength, and high wear resistance. The best properties are achieved after solution heat treatment and precipitation heat treatment. In case of simple shapes, the pattern can be prepared direct from standard rolled forms by machining. Duralumin is best suited after a stress-relieving treatment. Brass and bronze are excellent materials for pattern work because of their high physical strength besides their strong resistance to deformation and corrosion, ease of production and joining, and ability to take good finish. Their main limitation is the high price.

Low-melting-point alloys, such as white metal and cerro-alloys that contain tin and bismuth, are also used for dies, which are required for investment casting, and for moulds, which are used for making epoxy resin patterns or plaster patterns. These alloys have a low melting temperature, thus enabling easy and quick melting and immunity from the effect of chilling. Cerro-alloys containing tin and bismuth in the proportion of 60 : 40 or 43 : 57 have an extremely low coefficient of expansion (0.5 mm per metre). Besides, they are quite hard and malleable and the melting point is only about l38°C.

Metal electro-deposition or electro-forming has lately found application for pattern and die work. Like electroplating, this method uses an electrically conductive shaped mandrel (master pattern or mould) along with an electrolyte, which is made up of a solution of the metal to be deposited, such as nickel, chromium, and copper. On passing current at suitable voltage, the metal from the solution moves towards the mandrel and deposits a uniform layer on it. With proper equipment, high deposition rates are possible. The shape so formed is subsequently separated from the mandrel and used as either a mould or a pattern. The method can be used for producing intricate shapes with an extreme degree of accuracy. Fine details can be reproduced with utmost fidelity and the method is adaptable to large scale production.

Frozen mercury also has been used as pattern material in the *Mercast* process for producing highly intricate and accurate castings. Its use however is greatly limited due to its prohibitively high cost.

Metallic patterns being employed for mass production are generally required in a large number. They are therefore prepared by casting from a master pattern, which may be made in wood, plastic, plaster, or metal. Double allowances have to be made for contraction and machining on the master pattern. Metallic patterns are cast from the master pattern by sand casting. After machining and finishing wherever necessary, these patterns are mounted on pattern plates. Where patterns are of the split type, each half may be mounted on separate pattern plates or on either side of the same plate. Proper marking must be used when mounting patterns, which must be carefully executed. Templates and other tooling may be used to ensure that the cope and drag parts of the moulds prepared separately from the halves will match and produce a casting without any defect.

Pattern plates used for mounting patterns can be of wood or metal, though more often they are metallic. IS: 4604–1968 gives the specification for pattern plates for machine moulding boxes. Metallic pattern plates are usually made in grey cast iron (grade 20) or cast aluminium alloy (grade 4420).

2.2.3 Plasters

Gypsum plaster (Plaster of Paris) when mixed with the correct quantity of water sets in a given time and forms a hard mass having high compressive strength, e.g., up to 300 kg/cm^2. Plasters, ordinarily available expand on solidification. By choosing a plaster of proper expansion rate, it is possible to completely offset the shrinkage of the casting; then no contraction need be separately provided for on the pattern. Further, by careful design and the use of hardening and reinforcing materials, such as talc and Portland cement, the strength and hardness of plaster can be further enhanced.

Plaster can also be conveniently used for preparing follow-boards for moulding work. Proprietary varieties of gypsum plasters are also available. These have different setting times, expansion rates, and compressive strengths and are suited for varying requirements of pattern shops and foundries. The supplier's recommendations should be followed while selecting the plaster for a particular type of application.

Gypsum plaster patterns can be prepared either by directly pouring the slurry of plaster and water into the desired shape by the sweep-and-strickle method.

2.2.4 Plastics and Rubbers

Both thermosetting and thermoplastic materials are used for pattern work. The former are used for making long-lasting and durable patterns, and the latter for short runs or piece work. In the thermosetting variety, epoxy and polyester resins have found increasing use. In the thermoplastic type, polystyrene has become very popular. Silicone rubbers have been used for making dies in special cases.

Epoxy Resins

Epoxy-resin patterns have become very popular because of their (i) easily castable nature which renders machining superfluous, (ii) high strength-to-weight ratio (5.4 compared to 4.0 of aluminium alloys and 1.2 of cast iron), (iii) low cost of working, (iv) good resistance to wear and abrasion, and (v) complete immunity from the action of moisture and the effect of mild heating when in contact with sand. Epoxy resin patterns (Fig. 2.3) have thus tended to replace the more expensive metallic patterns for mass production. In spite of the high price of resin which is used as raw material, the cost of these patterns works out lower than that of aluminium patterns because there is no expense on casting and machining as is incurred in metal patterns.

Epoxy resin is used as a two-component material, namely a liquid binder resin and liquid hardener. When mixed together, the two liquids set and form a hard mass in a given length of time. Three types of resin combinations are commonly employed:

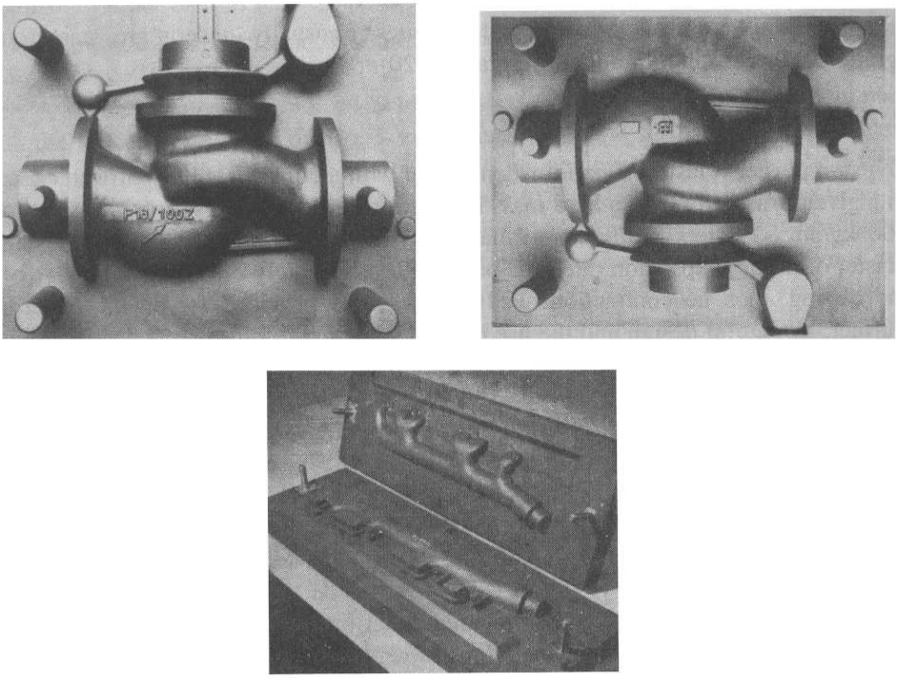


Fig. 2.3 *Typical epoxy resin pattern mounted on match-plates*

(i) Gel-Coat or Surface-Coat Resin This resin, mixed with the appropriate quantity of hardener (as prescribed by the resin manufacturers), is used to obtain the surface layer on the pattern, which is required to be harder and stronger than the inner layers. For forming the pattern, the mould (prepared earlier from a master pattern in metal, plaster, or epoxy resin itself) is first given a thin coat of release agent and then two or three layers of the gel-coat mix.

(ii) Laminating Resin This resin, mixed with its respective hardener, is used to apply a few layers of glass wool laminations on the back of the gel coat. Glass wool or glass fibre is soaked in the resin mixture and then applied all over the gel-coat layer. This treatment imparts additional strength, toughness, and flexibility to the pattern.

(iii) Casting Resin This resin, mixed with its respective hardener, is used to provide the necessary backing and to form the complete solid shape by filling up the void. To increase the strength, rigidity, and hardness of the pattern and at the same time reduce its cost, suitable fillers, such as talc, chalk powder, slate powder and fine sand, may be added to the casting resin. For large patterns, suitable reinforcements and solid inserts roughly shaped to the internal cavity may also be provided.

Depending on the service requirements of the pattern, all the three types of resin combinations may be used or lamination may be dispensed with and casting resin poured directly over the gel-coat. For quick jobs, which do not require a very hard surface layer, casting resin may also be directly poured over the master pattern. Complete setting of the resins takes place in about 24 hours after which the master pattern may be stripped off and the pattern so obtained used as either a loose pattern or a match-plate pattern (mounted on the pattern plate). Hot-setting resins which set within a much shorter time are also available, but they have greater shrinkage and are therefore unsuitable for pattern work. The manufacturers' instructions should be followed as regards resin selection, hardener proportions, etc. To economise on the resin requirement, coring and ribbing can be used on the patterns. Methods used for making epoxy patterns are shown in Fig. 2.4.

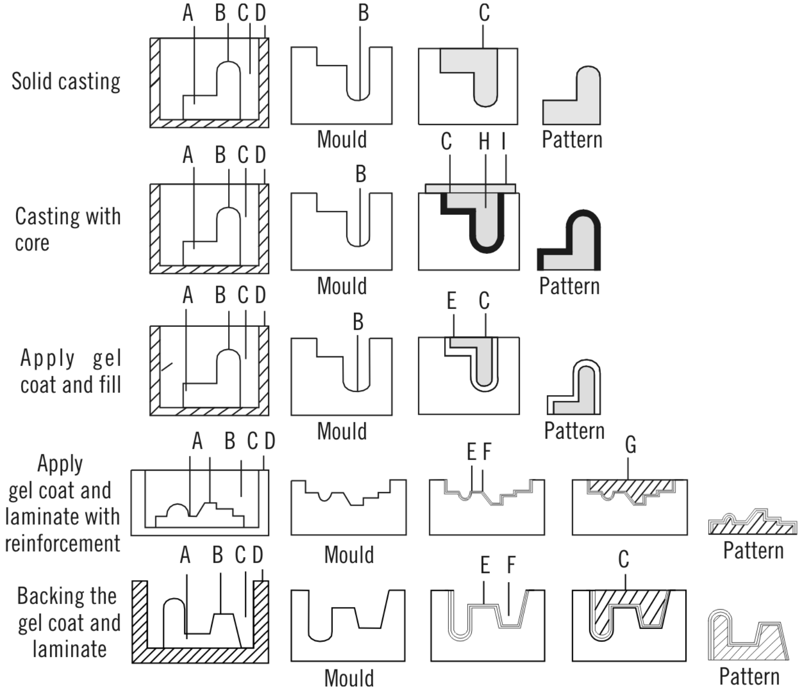


Fig. 2.4 *Method of constructing epoxy patterns:*

(A)	*Master pattern*	*(B)*	*Releasing agent*
(C)	*Casting compound*	*(D)*	*Mould box*
(E)	*Gel-coat*	*(F)*	*Glass fibre mat laminate*
(G)	*Wooden core*	*(H)*	*Insert*
(I)	*Backing plate*		

Polyester Resins

As a cheaper substitute for epoxy resins, fibre reinforced polyester resins (FRP) are also being increasingly used. The cost of polyester resins is less than half that of epoxy resins, and yet, the patterns produced are rigid, strong and durable. The setting time in case of FRP patterns is only about four hours and production rates can be much faster. Several brands and varieties of polyester resins are available. The one chosen for pattern work should possess

(i) ability to be cured at room temperature
(ii) low shrinkage characteristics
(iii) ability to produce hard, wear-resistant surfaces with high finish

Though polyester resins shrink more than epoxy resins, shrinkage can be taken care of by proper pattern design. The FRP patterns can easily be made hollow, i.e., the necessity for using a casting resin is not felt. One or two gel coat layers, followed by glass-fibre laminations in two or three layers can build sufficient rigidity, and no further backing is required. The stripping of the pattern is also easy. The polyester resin is used in three parts—a resin binder, an accelerator and a catalyst. For correct selection of resin variety and proportion of the three parts, the manufacturers' instructions should be followed.

Polystyrene

Of the thermoplastic variety of plastics which tend to become soft and subsequently gasify on heating, the most common is polystyrene foam, often called EPS. This material is available in different densities in foamed (expanded) form. It can be easily shaped, machined, and fabricated by gluing to form the pattern. The pattern can be used in the conventional form of sand casting where it has to be removed from the mould by withdrawing it, if possible, or else by burning it with a gas torch or breaking it. Another way of using this pattern is as a full mould casting where the pattern is embedded in sand and, without removing it from the mould, the molten metal is poured. The heat of the molten metal causes gasification of the pattern. The ash content of the pattern material is extremely low and the gas developed during burning is easily able to permeate through the sand. Polystyrene patterns are also used in investment casting. The details of the moulding process known as *full-mould casting* are given in Section 3.6.3(2). IS : 10094–1981 gives the specification of expanded polystyrene for pattern making.

Polyurethane foam too has been used like polystyrene but to a much smaller extent. Urethane elastomers (referred to as flexanes) are applied on a limited scale for forming dies for investment casting in the same way as epoxy resins. This material has low thermal conductivity, high strength, and no shrinkage.

Certain types of rubbers, such as silicon rubber, are favoured for forming intricate types of dies for investment casting. This material, like epoxy resin, is available in two parts—binder and hardener. When the two parts, originally in liquid form, are mixed together, poured over a master pattern or into a die, and cured, a solid shape is produced.

2.2.5 Waxes

Wax patterns are excellent for the investment casting process. The materials generally used are blends of several types of waxes and other additives, which act as polymerising agents and stabilisers. The waxes commonly chosen are paraffin wax, carnauba wax, shellac wax, bees wax, cerasin wax, and microcrystalline wax. The properties desired in a good wax pattern include low ash content (up to 0.05%), resistance to the primary-coat material used for investment, high tensile strength and hardness, good wettability, resistance to oxidation, low shrinkage, and substantial weld strength. The blending or compounding of waxes and other additives is so done that most of the desired properties can be achieved. The actual ingredients and composition to be used have generally to be determined by trial and experimentation.

The normal practice of forming wax patterns is to inject liquid or semiliquid wax into a split die. Solid injection also is used to avoid shrinkage and for better strength, however, much higher injection pressures are required for solid injection. If wax is poured into the die in a liquid state under gravity, it will shrink much more and the size of the pattern will be affected. After injection, the die is cooled, opened and the wax pattern extracted. As the patterns are generally small in size, a number of patterns are welded (two ends to be joined by a hot spatula are heated and pressed lightly together) to a common runner or sprue through ingates. The whole assembly of patterns complete with runner, sprue, etc., which is often termed a *tree*, is then invested to prepare the investment mould. Details of the investment casting process are given in Section 3.6.3(1).

Casting waxes used for investment casting can be classified into the following categories:

1. Pattern wax
   - (a) Straight or unfilled wax
   - (b) Emulsified pattern wax
   - (c) Filled-pattern wax
2. Runner wax
3. Reclaimed or reconstituted wax
4. Water-soluble wax
5. Special waxes, such as dipping, patching and adhesive waxes

Straight wax is a complex compound made up of several waxes and resin components. Its surface finish is bright. It can be reclaimed after use from the investment mould for use on runner systems as also on patterns. *Emulsified waxes* are those varieties which are emulsified with water in the proportion of 7 to 12%. The water acts partially as a filler and hence very little cavitation takes place keeping the surface finish smooth. It is a versatile variety, giving good strength and flowability, and can be reclaimed and reused. *Filled-pattern waxes* are similar to straight waxes but they are blended with powdered and inert material which is insoluble in base wax in order to give the material greater stability, less cavitation, better hardness and strength and high pourability and flowability.

Runner wax is produced specifically for preparing runner systems by blending with various waxes and filler materials which can impart high strength which the runner systems demand. *Reclaimed waxes* are those which are obtained on heating the investment moulds. These are used again for preparing patterns and runner systems. *Water-soluble waxes* are used for producing internal shapes which are difficult or impossible to obtain by other means. These are soluble in water or in mild acidic solutions. *Special waxes* are unfilled wax compounds used for dipping, patching and adhesive applications.

Desirable Properties of Investment Wax

1. Low contraction rate and low cavitation or blow holes
2. Low ash content, preferably, less than 0.02%
3. Low viscosity and high flowability
4. Fast setting rate
5. Low congealing point or melting point
6. High strength and hardness in cold state
7. Good hardness
8. Good surface finish
9. Resistant to oxidation and high stability
10. Easy reclaimability

2.2.6 Old Castings

Old castings are sometimes used as patterns during an emergency when time is short. In order to increase the thickness and other dimensions to provide for contraction, machining, and other allowances, surfaces are lagged with thin strips of wood or leather. Metal coating by metal spraying may also be provided to build up the required size. The castings to be used as patterns have to be well cleaned and smoothened so that there are no undercuts and they can be easily withdrawn from the mould. Core prints, if necessary, may have to be provided on the casting.

2.3 MACHINES AND TOOLS FOR PATTERNMAKING

2.3.1 Machines for Wood Patternmaking

Most of the machines used for the patternmaking are the same as those for other jobs in woodworking. However, some of the operations otherwise done by a group of machines—for instance, boring, milling, slotting, shaping, grooving, and cutting special profiles such as gear teeth—are more efficiently performed on a special purpose machine called the *pattern miller*. The size and the capacity of the machines used depend on the size of the general run of work to be performed. The machines chosen for the pattern shop should not only be sturdily built and of sizeable proportions so that they can cope with a variety of jobs, but should also have dependable accuracy. The ones favoured for patternmaking are.

(1) woodworking lathe;
(2) circular saw;
(3) band saw;
(4) jig saw or scroll saw;
(5) jointer;
(6) planer;
(7) shaper;
(8) pattern-milling machine;
(9) disc and bobbin sander, and
(10) machines for tool grinding.

(1) Woodworking Lathe The woodworking lathe is one of the most important machines to the patternmaker since patterns and core boxes often involve some sort of cylindrical work. It is designed chiefly for turning jobs, both external and internal. However, by suitably manipulating the tool, tapers, and radii, other irregular shapes can also be easily turned. The woodworking lathe (Fig. 2.5) consists of four major parts—the head stock, which has a spur or live centre fitted in a hollow spindle; the tail stock, carrying a dead centre; a tool rest, which is stationary and adjustable; and a bed to which are fastened the other three parts.

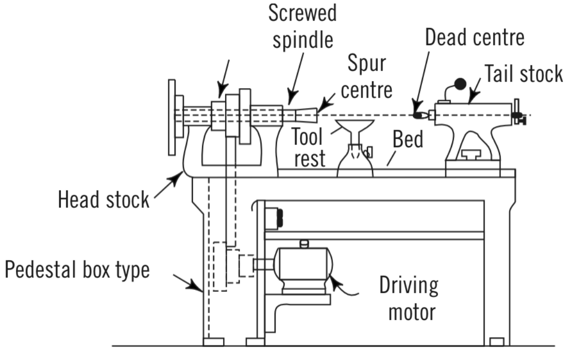


Fig. 2.5 *Woodworking lathe*

Pattern shops are equipped with a special type of woodworking lathe, known as the *patternmaker's lathe*. This lathe is a modified version of the woodworking lathe and in many respects resembles the centre lathe used for metal-working operations. The design of its various parts makes it more robust and sturdy and therefore more dependable than the woodworking lathe. First, the patternmaker's lathe has a backgearing arrangement by means of which the available number of spindle speeds is doubled. Secondly, it is equipped with a feed shaft and a sliding carriage in place of the fixed-type tool rest. On the carriage is fitted a cross slide, a compound slide, and a tool post. Thus, in this lathe, the tool traverse, both parallel to the work axis as well as across it, can be precisely regulated for better size control.

The size of woodworking lathes is usually specified in terms of the swing or height-of-centre of the lathe and the maximum distance between the centres. The height-of-centre is taken as the distance from the lathe centre to the upper surface of the bed, and the swing is double that of the height-of-centre.

Generally, the woodworking lathe is supplied together with a number of accessories, which considerably increase its usefulness and adaptability. Some of the typical accessories include different types of centres, such as drive centre, cup centre, and screw centre, a face plate, a 4-jaw independent chuck, a 3-jaw self-centring chuck, a tool holder, and a set of wood turning tools. The types of tools commonly used on these lathes are illustrated in Fig. 2.6. The material of these tools is high carbon steel containing about 0.8–1.0% carbon.

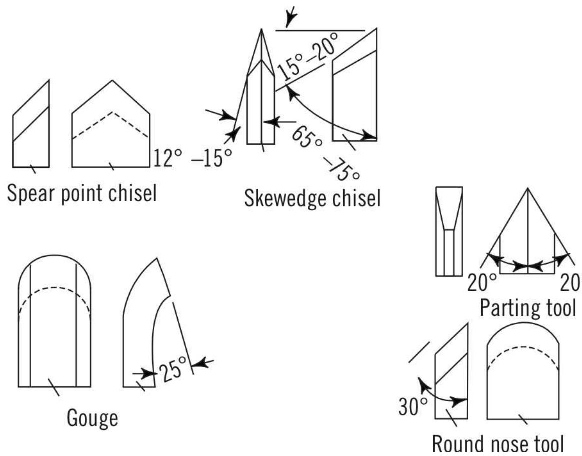


Fig. 2.6 *Woodworking lathe tools*

(2) Circular Saw The circular saw is also an essential machine in the pattern shop. It can be used for all cutting operations, such as ripping, cross-cutting, beveling, rabbeting, grooving, and mitering. The principal parts of the circular saw are a cast-iron table upon which the work is supported and from where it is fed into the saw; a circular saw blade supported in bearing on the under side of the table and rotating at high speed; a driving arrangement for the saw blade, consisting of an electric motor and a set of pulleys mounted on shafts; a cut-off guide, which is used during cross-cutting to steer the piece towards the saw blade; and a ripping fence, which acts as a guide while sawing along the grains of wood. The circular saw usually has provision for tilting the table, thus enabling cutting at an angle as required during mitering, beveling, etc. The tilting can be done up to an angle of 45°.

The size of the circular saw is specified by the diameter of the saw blade. A 300-mm saw is commonly used for small and medium-sized work. The cutting speeds for sawing vary from 1000 metres to 3000 metres per minute according to the hardness of the wood.

(3) Band Saw The band saw makes use of an endless metal saw band, which travels over the rim of two rotating pulleys. Although the number of operations that can be performed on a band saw is less than those on a circular saw, it is favoured for curved or irregular cuts in wood.

The main parts of a band saw are the following:

- (i) A set of cast-iron pulleys or wheels carrying the saw band on their periphery; of the two wheels, one is adjustable and the other is fixed so that the centre-to-centre distance can be slightly varied to maintain proper tension of the band
- (ii) A cast-iron table on which the workpiece is placed and from where it is fed into the saw band for cutting; the table, which can be tilted as in the case of the circular saw, carries a slot in the centre through which the band passes
- (iii) A roller guide, fixed to an adjustable arm, which helps in keeping the saw band in position while cutting
- (iv) A heavy cast-iron frame or body to which all the other parts are fitted
- (v) A driving arrangement, consisting of an electric motor and a set of pulleys, to transmit power to the driving wheel
- (vi) A ripping fence as in the circular saw

The band saw is available in two models—horizontal and vertical. In the former, the two wheels are arranged alongside each other and the table is underneath. In the latter model, the more popular of the two, the wheels are arranged one above the other and the band thus has to pass through the table, which is mounted in a central position between the two wheels.

The size of the band saw is specified as the distance from the saw band to the inner side of the frame. This distance is roughly equal to the diameter of the wheels. The width of the saw band varies from 6 mm to 50 mm and is dependent on the size of the machine. Narrow bands are usually employed on small machines where cutting is to be done along a small radius.

(4) Jig Saw or Scroll Saw The jig saw, which is also known as a scroll saw, is ideal for cutting small-size work to an intricate profile. It is actually a diminutive type of band saw and is specially adapted to irregular work. The table of the jig saw too can be tilted for angular work. The special characteristic of this saw is its ability to cut inside curves as well. This is done by first threading the blade through a previously bored hole and then working along the desired layout. This internal sawing facility is not available in any other traditional woodworking machine and is invaluable in patternmaking, such as for preparing strickle boards and core boxes. The width of the jig saw blades varies from 1.5 mm to 9 mm.

(5) Jointer The wood jointer is designed for planing the straight edges and surfaces of boards. Its use, therefore, eliminates the labour involved in hand planing. The jointer (Fig. 2.7) consists of a revolving cutter head to which three or more cutter knives are fitted; a table on which the board to be planed is kept pressed and fed by hand against the revolving cutter head; and an adjustable fence for guiding the board at a predetermined angle to the surface of the table. By means of the adjustment provided, the fence may be kept either at 90° to the table or inclined at any other angle for angular and bevel cuts. For regulating the depth of the cut, the cutter head can be raised or lowered by moving a handwheel.

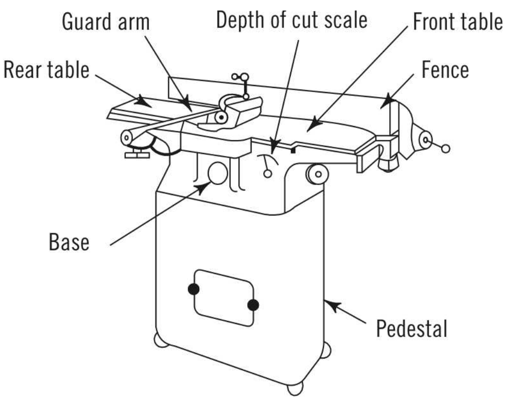


Fig. 2.7 *Wood jointer*

(6) Planer The purpose of a wood planer is similar to that of a jointer, but it is designed primarily for planing large and heavy stock at a comparatively faster rate and involving a lesser amount of manual labour (Fig. 2.8). The boards to be planed are fed into the machine by means of feed rolls along a table against a revolving cutter head, thus eliminating the labour of hand feeding. The cutter head is mounted on an overhead shaft which is adjustable for regulating the depth of the cut (Fig. 2.9). The table of the planer is generally much wider and longer than that of a jointer and more accommodating for large plants. The planer is also usually equipped to automatically surface the wood to desired thicknesses.

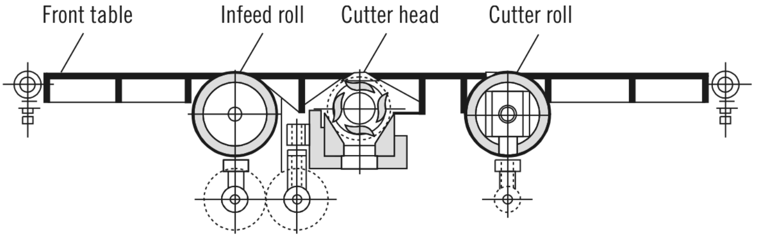


Fig. 2.8 *Principal parts of a wood planer*

(7) Shaper The machine consists of a cutter head, carrying a cutter and rotating about a vertical axis, and a horizontal table similar to that of a jointer. The wood is fed by hand along the table against the cutter and guided by an adjustable fence, Fig. 2.10(A). The shape of the cut on the surface of the wood is the same as that of the profile of the teeth on the cutter. By suitably designing the cutter, a variety of shapes can be produced. The types of cut that can be taken by a shaper are shown in Fig. 2.10(B).

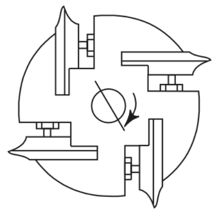


Fig. 2.9 *Cross-section of a cutter head of a planer*

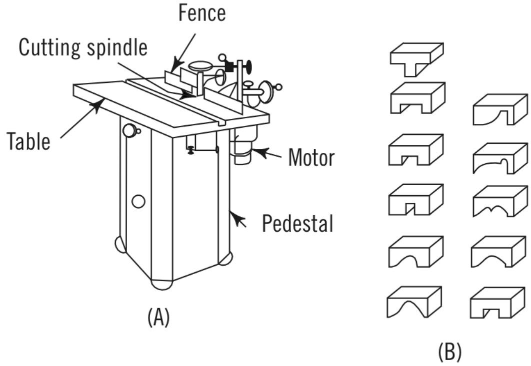


Fig. 2.10 *(A) Wood shaper; (B) Types of cut taken by a wood shaper*

(8) Pattern Milling Machine This machine has a large base on which a broad column is supported as shown in Figs 2.11(A) and (B). At the front of the base is a table support, which slides on rails and can be locked in the desired position. The workpiece is mounted on the table and it can be moved along both X–X and Y–Y axes, all the three movements being usually hand-operated. The column carries an overhanging arm which can be raised or lowered, both manually and by power operation. At the outer end of the arm is the spindle head, and cutter spindle. The spindle can be raised, lowered, and canted on both sides through 45° on the right and 30° on the left, working in vertical, horizontal, and any angular position. Six spindle speeds are provided varying from 850 to 4200 rpm. The machine is equipped with several tools and cutters, such as a pattern cutter, core box cutter, fillet cutter, and boring cutter, and gauging and recessing tools.

The pattern-milling machine, by virtue of its expansive table movements, the long vertical movement of its arm, the flexibility of its spindle, and its wide range of tools, cutters and accessories, is capable of numerous operations. These operations include boring, drilling, milling, facing, slotting, grooving, shaping, fillet-cutting, gear-cutting, worm-cutting and forming the radius, angular cuts and other shapes as required in the core box.

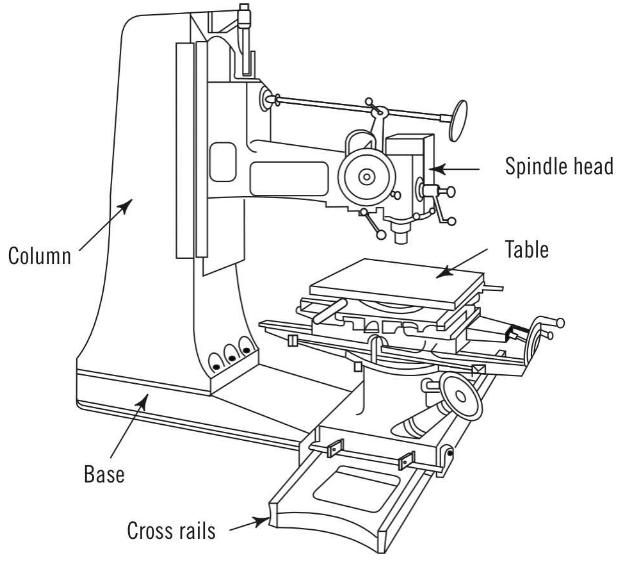


Fig. 2.11 (A) *Block diagram of parttern milling machine*

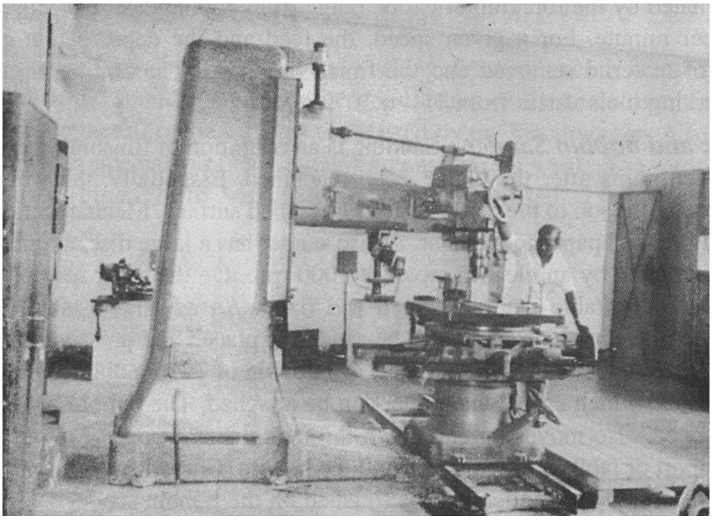


Fig. 2.11 (B) *Pattern milling machine*

The speeds and feeds needed for woodworking machines are as shown in Table 2.2. The workability of wood on the machines depends on its specific gravity, moisture content, and the directional arrangement of grains. For instance, low moisture content (about 6%) offers excellent conditions for machining. The type of operation has considerable influence on the quality of work. Surface cutting speeds, also regulated by the foregoing factors, range from 1200 metres per minute to 3000 metres per minute. For a given speed, the feed and the depth of cut control the amount of material removed and the finish produced. The cutting angle used on woodworking tools varies from 15° to 30°.

Table 2.2 *Speeds and feeds for woodworking machines*

Machine	Range of spindle speeds	Range of feeds
Jointer	4000–5000 rpm	Manual feed
Planer	4000–5000 rpm	5–20 m/min
Lathe	240–2880 rpm	Manual feed
Band saw	1500–1800 m/min	Manual feed
Circular saw	2000–3600 m/min	Manual or automatic, 12– 45 m/min
Borer	1200–3600 rpm	2–35 strokes/min
Pattern miller	850–4200 rpm	Manual

(9) Disc and Bobbin Sander

Sanding is an operation of finishing the surfaces of the wooden items after they have been machined. Essentially, the work involves sandpapering the job to present a uniformly sanded surface. Mechanical operation is provided for sandpaper movement. A disc sander has a large disc, about 450 mm in diameter, rotated by an electric motor at 3000 rpm. A sandpaper of suitable grade is glued and fixed on the outer face of the disc. An adjustable table is provided against the disc on which the job to be sanded is placed and pressed.

A bobbin sander consists of a cylindrical bobbin of 75-mm diameter and 200-mm length around which again sandpaper can be attached. The bobbin, while it rotates at high speed, also moves up and down through a short stroke of about 50 mm. A work support or table is provided around the bobbin. Curved surfaces, which cannot be sanded on the disc sander, can be finished on the bobbin sander.

Disc and bobbin mechanisms are often combined in a single unit called the disc-cum-bobbin sander in which one electric motor drives both the disc and the bobbin. Special sandpapers in different grades of finenesses are available for the machine.

Dust Exhaust System Woodworking machines, such as saws and sanders produce very fine dust which, if left uncollected, stays suspended in the atmosphere. Sawdust from the sander is also hot and can be dangerous. Dust exhaust systems should be installed on all such machines so that the dust is collected and disposed of in a convenient manner. A proper dust-collection system helps in maintaining a clean working environment and thus improves efficiency, besides preventing fire hazards and protecting the health of the workers. There should be an exhaust system, either one for each machine or a central exhaust system, which collects dust from various machines by means of a common suction fan.

The exhaust system consists of a hood or some other suitable arrangement to collect the dust and shavings, suction fan, a filtering arrangement for exuding clean air, a chamber for the collection of dust, and suitable pipelines. The filtering arrangement is usually of the 'bag-filter' type, which allows only clean air to pass through a series of bags and then escape lo the atmosphere, thus separating it from dust. There is also a vibratory system which periodically shakes the bags to rid them of the dust particles sticking to their linings. See Section 9.4.3(1). Modern woodworking machines are equipped with a built-in dust exhaust system, which is cleaner and more compact than the system installed as an appendage.

(10) Machines for Tool Grinding In order to efficiently use the woodworking machines, their tools and cutters have to be periodically sharpened and kept trim. It is not possible to grind or sharpen all the diverse types of tools by hand grinding. Equipment that is essential includes a circular saw and band saw blade sharpener (either in two separate machines or in the same machine); a band saw blade butt welder; a planer knife grinder; a tool and cutter grinder; and a double-ended tool grinder.

2.3.2 Hand Tools for Wood Patternmaking

Wood patternmaking is basically a woodworking process since a majority of the patterns used in the foundry are made in wood. Most of the tools required by the patternmaker are therefore the same as those used by the woodworker. A few of the tools are however specially suited to pattern construction work. The various tools commonly used (Figs 2.12 to 2.16) may be broadly classified as follows:

(1) Measuring and Marking Tools Rule; contraction rule; scriber; try square; bevel square; marking gauge; trammels; callipers; dividers; vernier callipers; and combination set

(2) Sawing Tools Hand saw; tenon saw; dovetail saw; compass saw; coping saw; and keyhole saw

(3) Planing Tools Jack plane; smoothening plane; foreplane: block plane; rabbet plane; router plane; spoke shave; circular plane; and core box plane

(4) Boring Tools Hand drill; breast drill; ratchet brace alongwith auger bits, twist drill, twist bits, centre bits, expansion bits, and countersink

(5) Clamping Tools Carpenter's vice; bar clamp; 'C' clamp; pinchdogs; and handscrew

(6) Miscellaneous Tools File; mallet; firmer, mortise and paring chisels; internal and external gouges and oilstone

The tools specially adopted for pattern work are the following:

(1) Patternmaker's Contraction Rule This rule has suitably oversized graduations marked on it so as to make allowance for the contraction of the casting. A

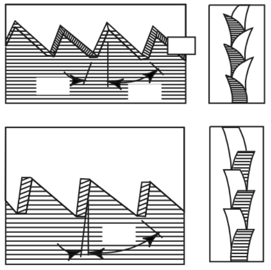


Fig. 2.12 (A) *Cross-cut saw teeth*
(B) *Rip saw teeth*

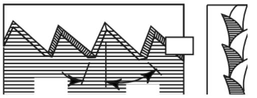


Fig. 2.13 *Tenon saw*

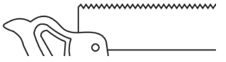


Fig. 2.14 *Compass saw*

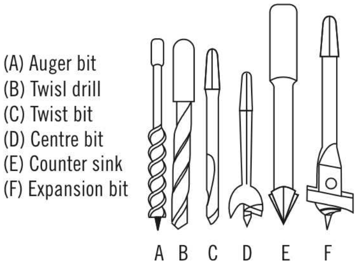


Fig. 2.15 *Various types of bits for boring*

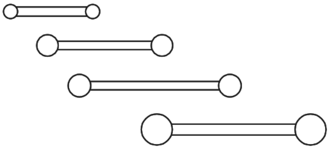


Fig. 2.16 *Fillet irons*

separate rule is available for four common cast metals, namely, iron, steel, brass, and aluminium. A single rule may also have all the four graduations, two on each side. Contraction rules are also available with marked contraction rates, such as 0.6 mm per metre, 1.0 mm per metre, 1.5 mm per metre, and 2.0 mm per metre. These rules are made of stainless steel.

(2) Corebox Plane This tool is specially designed for the planing of semicircular grooves and hollow portions, as required often in core boxes. The tool has two beds at right angles to each other, which guide a shaped cutter.

(3) Patternmaker's Saw This saw is designed particularly for the fine and accurate work required in patternmaking. It has a thin steel blade, 0.7 mm thick, 300 mm long, and 200 mm wide.

(4) Gouges Though gouges are used in all wood work, these have special application in patternmaking, particularly for making cavities, grooves, recesses, fillets, etc., in patterns and core boxes. They are made in different shapes and are both in convex and concave form.

(5) Pattern Fillet Irons Fillets, in wood, leather, wax, plastic, metal or fibre, are provided on the patterns to avoid sharp corners at the junction of two surfaces.

Wooden fillets have to be shaped separately and then attached by gluing. Leather fillets are favoured for costly patterns. These fillets are first pasted on the patterns and then pressed with a spherical tool, called the fillet iron, so that the exact radius as given on the tool is obtained on the fillet. The fillet iron is used similarly on wax fillets. Fillet irons are available in a range of sizes varying from 5 mm to 15 mm radius (Fig. 2.16).

2.3.3 Machines for Metal Patternmaking

The production of metallic patterns is an entirely different activity from that of wooden patterns. After the patterns are cast in a foundry, they have to be machined and finished in the metal pattern shop. This shop should have adequate facilities for machining and hand finishing. The machine tools desirable to produce good quality patterns are

(1) Universal milling machine, table size of 1200 mm × 400 mm;
(2) Vertical milling machine, copy milling machine or CNC milling machine;
(3) Shaping machine, 600 mm stroke;
(4) SS and SC lathe, 450 mm swing and 1500 mm bed;
(5) Vertical boring machine, 1000-mm table diameter;
(6) Column type drilling machine, 50-mm drilling capacity;
(7) Radial drilling machine, 50-mm capacity;
(8) Hydraulic hacksaw machine, 200 mm capacity;
(9) Metal band saw;
(10) Surface grinding machine, 450 mm × 200 mm table traverses;
(11) Tool-and-cutter grinder; and
(12) Coordinate marking and measuring machine for inspection of pattern equipment.

2.3.4 Tools and Instruments for Metal Patternmaking

The metal-pattern shop should be equipped with various types of hand tools for measuring, marking, fitting, finishing, and fabrication. These include the following:

(1) Measuring Tools and Instruments Standard rules, 300 mm and 600 mm; contraction rules, rigid and flexible; combination set; vernier bevel protractor; fixed and adjustable squares, straight edges of 300 mm and 600 mm; micrometers up to 150 mm; inside micrometer set, 25 mm to 300 mm; vernier height gauge, 300 mm and 600 mm; micrometer depth gauge, 300 mm; sine bar, 150 mm and 300 mm; dial gauge with stand and accessories: set of slip gauges with holders and accessories (87-piece set); radius gauge: feeler gauge; screw pitch gauge; wire gauge; surface roughness tester or profilometer.

(2) Marking Tools Marking table; surface plates; angle plates; vee blocks; rule clamp; callipers; dividers; trammels; marking gauge; scriber; punch; screw jacks (100 mm); engineer's level; sine table; rotary table; dividing head; steel stencils; and obverse and reverse punches for figures and letters

(3) Cutting and Finishing Tools Chisels, flat and diamond point; punches; electric hand drill; pneumatic drill; electric hand grinder; pneumatic grinder; drill bits; grinding wheels; files; reamers; rotary files; rotary burrs and rotary cutters for pneumatic operation; dies and taps; scrapers; hack-saw; countersinks and counterbores

(4) Fabrication Equipment Oxyacetylene gas-welding set; air compressor; electric arc welding set (dc type); metallising kit: soldering and brazing tools

2.3.5 Rapid Tool Manufacturing Techniques

(i) Rapid Prototyping (RP) *Rapid prototyping (RP)* or *free form fabrication techniques* were initially intended for creating prototypes of complex shaped products to verify their form, fit and to some extent, their function. Recently, these techniques have also been successfully used to create the tooling, and have been enthusiastically embraced by several foundries, tool rooms and service bureaus. This has enabled significant reductions in the lead time to manufacture cast products.

The RP technology is based on the philosophy of converting a 3-dimensional computer-aided design (CAD) model of the part into a series of 2D cross-sectional layers stacked on top of one another (Fig. 2.17). Each layer is created using one of the several techniques available, such as photocuring, cutting, fusing and deposition. The layers are created bottom-up and are joined to each other during the process itself. This approach enables complex shaped parts to be manufactured directly from a 3D CAD model without using part-specific tooling.

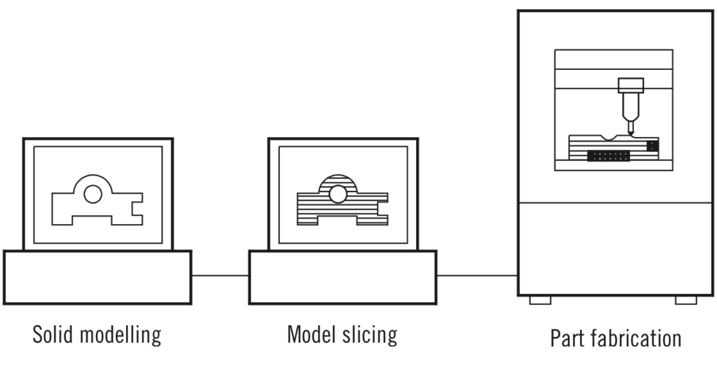


Fig. 2.17 *Main steps in rapid prototyping*

(ii) Modelling and Slicing The CAD model of the part can be created by any of the solid modelers available today, which includes Pro-Engineer, I-DEAS, Unigraphics, CATIA and AutoCAD Designer. These packages can differ from one another in terms of user interface, modeling facilities, hardware platform, operating system and other programmes available in the family.

After creating the solid model, it is converted to a faceted representation and stored in the STL format, which is supported by most RP systems. Some RP systems have a provision for converting the solid model created by one or more of the above packages to the STL format. Sometimes, errors can creep in during the conversion process, requiring interactive 'fixing' of these.

The next step involves 'slicing' the solid model into a number of 2D layers. This is automatically performed by the slicing software available with the RP system. For each layer, instructions for the movement of the machine elements are generated and transferred to the RP machine.

If there is an undercut in the part then the layer on top will have inadequate support during its creation, leading to sagging. This is prevented by creating support structures to fill up undercut regions during the layer formation. The support material is later removed by heating to melt it away, washing it in a solvent or simply breaking it off. The orientation of the model can influence the number and volume of support structures required.

(iii) Prototype Fabrication

A number of RP systems are available today, each incorporating a different technique for creating the part layers. This influences the size and complexity of the machine, range of part materials and quality characteristic.

Stereolithography Apparatus (SLA) uses an ultraviolet solid state laser beam moving in a criss-cross fashion to cure photocurable polymer resin contained in a vat. The polymer layer is lowered by a platform attached to it to enable generating the next layer on top.

The system is available in a wide range of sizes. The automatic resin-dispensing arrangement refills the vat between the builds. Vats are interchangeable for rapid and easy resin exchange. The resolution is about 0.05 mm.

Solid Ground Curing (SGC) is similar to stereolithography, the difference is that the entire layer of polymer within the specified boundary is cured by a flood of ultraviolet light passing through a glass mask containing a negative image of the cross section.

Fused Deposition Modeling (FDM) technique relies on melting and depositing a thin filament of thermoplastic polymer to form each layer. A separate head deposits the support material in each layer, which can be broken off later. It is used for the final design and prototyping phase of product development. It generates 3D prototypes from 3D CAD software data.

Selective Laser Sintering (SLS) process uses a high-power laser beam to melt thermoplastic powder spread on a layer. A roller spreads the next layer of powder on the previous layer. The unsintered powder serves the function of supports for undercuts.

Laminated Object Manufacturing (LOM) involves laser beam cutting of cross-section contours out of sheets of heat sensitive or polymer coated paper. The adjacent layers are joined by heating and compression by a roller.

(iv) Rapid Tooling The CAD model of the part can be converted into the corresponding model of the pattern, by splitting across the parting line, removing the holes, adding core prints, applying draft, fillets and various allowances. The master pattern can also be similarly generated. In addition, feeders and gates can be modelled and attached to the pattern model. The entire casting model can be analyzed on computer to ensure product quality before investing in tooling manufacture (Ravi, 1996).

The range of RP techniques and materials, coupled with different casting processes, provide several routes for producing metal castings. Some of these are useful for creating one-off parts or master patterns. Others are useful for creating patterns that can be used for short, medium or long runs.

Most RP systems can produce patterns out of investment casting wax or a similar polymer. This can be invested to create a single casting or a master metal pattern for large runs. The polymer parts created by most RP systems can be used as patterns for shell moulding. Some RP machines produce parts using ABS plastic, which are harder and may even be used in green sand casting for short runs. RP machines based on LOM technique can produce patterns which look and feel like wood. These can be used either as regular or as master patterns. The pattern life can be increased by coating with resins. Other routes to tooling include metal or ceramic spray techniques to create a shell around the polymer pattern, which can be used for shell moulding or creating master patterns.

(v) Criteria for Selection RP systems are useful to foundries, tool rooms and service bureaus in rapid tool manufacturing. Since each company may have a unique set of immediate and medium-term requirements, these should be carefully determined and then matched against the capabilities of the various systems available. One or more parts may be selected for benchmarking the systems for a detailed comparison. Finally, an economic analysis can help in pinpointing the right choice.

2.4 ALLOWANCES AND OTHER TECHNOLOGICAL CONSIDERATIONS

Pattern allowances are a vital feature in pattern design as it affects the dimensional characteristics of the casting. Thus, when the pattern is produced, certain allowances must be given on the sizes specified in the finished component drawing so that a casting with the particular specifications can be produced. The selection of correct allowances greatly helps to reduce machining costs and avoid rejections.

The allowances usually considered on patterns and core boxes are now detailed.

2.4.1 Contraction Allowance

All metals used for casting contract after solidification in the mould, and the pattern must therefore be made larger than the casting by an amount known as *patternmaker's* contraction. Generally, the patternmaker is equipped with the patternmaker's contraction rule, which is used to compensate for the shrinkage value.

To compensate for shrinkage, the graduations are oversized by a proportionate amount, e.g., on a 1-mm or 1% scale, each 100 cm is longer by 1 cm. The rates of contraction for important cast metals are listed in Table 2.3.

Table 2.3 *Rates of contraction for important cast metals*

Cast metal	Dimension (mm)	Contraction (mm/m)	Remarks
Cast iron	up to 600	10.5	
	600–1200	8.5	
	over 1200	7.0	
Cast steel	up to 600	21	
	600–1800	16	
	over 1800	13	
Aluminium	up to 1200	13	1.5 mm less for cored
	1200–1800	12	construction
	over 1800	10.5	
Magnesium	up to 1200	14.5	1.5 mm less for cored
	over 1200	13.0	construction
Brass	—	16	
Bronze	—	10.5–21	depends on composition
Malleable iron	—	11.8	6-mm section thickness
		10.5	9-mm section thickness
		9.2	12-mm section thickness
		7.9	15-mm section thickness
		6.6	18-mm section thickness
		4.0	22-mm section thickness
		2.6	25-mm section thickness
Spheroidal graphite iron	—	12–16	depends on structure

The value of contraction as obtained from Table 2.3 is only a guideline because the actual contraction taking place while the metal solidifies depends on several factors such as (i) composition of metal, and impurities and constituents present; (ii) method of moulding used, mould design, mould material, and resistance offered by the mould to shrinkage; (iii) pouring temperature; and (iv) design and intricacy of the casting, its bulk and size. In case of precision casting work, it is not enough to depend on the use of contraction rule, as the actual shrinkage occurring in the casting may be at variance with the one provided on the pattern through a contraction rule. The shrinkage may even vary within the same casting from one dimension to other. Therefore, in such cases it is necessary to calculate the actual dimensions of the pattern considering the shrinkage that is going to occur.

2.4.2 Machining Allowance

Machining or finish allowance is the extra material added to certain parts of the casting to enable their finishing or machining to the required size. The amount of machining allowance to be provided for is affected by (i) the method of moulding and casting used, viz., hand moulding or machine moulding, sand casting or metal-mould casting (Fig. 2.18); (ii) size and shape of the casting; (iii) the casting orientation: greater allowance is required on the surface at the top in the mould; (iv) the characteristics of the metal; and (v) the functional requirements of the casting and the degree of accuracy and finish required.

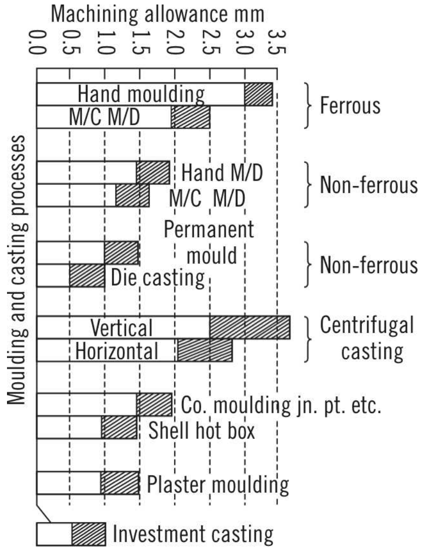


Fig. 2.18 *Machining allowances for dimensions up to 300 mm*

Providing too large a machining allowance would mean producing a heavier casting than required, involving an increase in the melting cost and removal of

Table 2.4 *Machining allowance for hand moulding using wooden patterns (mm)*

Maximum overall dimension (mm)	Ferrous castings								Non-ferrous castings							
	≤ 100	*101–200*	*201–300*	*391–500*	*501–800*	*801–1200*	*1201–1800*	*1801–2500*	*≤ 100*	*101–200*	*201–300*	*301–500*	*501–800*	*801–1200*	*1201–1800*	*1801–2500*
100	3.5								2							
101 to 200	4	5							2.5	2.5						
201 to 301	5	5	6	6					3	3	3					
301 to 500	5	6	6.5	7					3.5	3.5	3.5	4				
501 to 800	6	7	7	8	9				4	4.5	4.5	5	5			
801 to 1200	7	7	8	8	9	10			4.5	5	5.5	6	6.5	7		
1200 to 1800	7	8	8	9	10	10	11		5	5.5	6	6.5	7	7.5	8.0	
1800 to 2500	8	8	9	9	10	11	11	11	5.5	6	6	7	7.5	8	8.5	9

Notes 1. For machine moulding or dry sand moulding, using wooden patterns, machining allowance can be reduced by 20%.
2. For malleable iron, machining allowance can be increased by 40%.
3. On bores or covered surfaces, machining allowance can be increased by 20%.
4. Using metal patterns and machine moulding, machining allowances can be reduced by 30–40%.

greater quantity of metal during machining. This will lead to a rise in the cost of production. On the other hand, too small a machining allowance would lead to a difficulty in machining to achieve the desired dimensional accuracy, causing the casting to be rejected. Thus, good foundry practice demands selection of optimum values of machining allowances on different surfaces of the pattern. The machining allowance recommended for different cast metals is given in Table 2.4.

2.4.3 Draft or Taper Allowance

By draft we mean the taper provided by the patternmaker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the mould and without excessive rapping by the moulder. A draft is thus given to provide light clearance for .the pattern as it is lifted up.

Figure 2.19A shows a pattern having no draft allowance being removed from the mould. In this case, till the pattern is completely lifted out, its sides will remain in contact with the walls of the mould, thus tending to break it. Figure 2.19 is an illustration of a pattern having proper draft allowance. Here, the moment the pattern lifting commences, all its surfaces are free of the sand and the pattern can therefore be removed without damaging the mould.

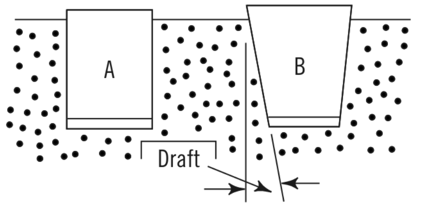


Fig. 2.19 *Draft allowance*

The amount of draft depends on

(i) the length of the vertical side of the pattern to be extracted;
(ii) the intricacy of the pattern;
(iii) the method of moulding; and
(iv) pattern material.

In case of hand moulding on exterior surfaces, the draft is about 10–20 mm per metre, and on interior surfaces, e.g., holes, etc., it should be 40–60 mm per metre. Table 2.5 gives the values of mould taper on external and internal surfaces using

Table 2.5 *Mould taper for pattern surfaces using hard wood patterns and machine moulding*

Height of wall (mm)	Taper (mm)	
	External surface	Internal surface
≤ 50	0.8	1.8
51–100	1.2	2.5
101–200	1.8	3.5
201–300	2.5	5
301–500	3.5	8
501–800	5	12

hard-wood patterns and machine moulding. In case of metal or resin patterns, mould taper can be reduced by 50%.

2.4.4 Rapping and Shake Allowance

When the pattern is rapped for easy withdrawal, the mould cavity gets slightly larger in size. This also causes the casting size to increase. To compensate for this growth, the pattern should initially be made slightly smaller than the required size. In small and medium-size castings, this allowance may be ignored, but for large-sized castings or where high precision is desired, this allowance should be considered. Its value is decided by experience or by trial as no guidelines can be made for this allowance.

2.4.5 Distortion Allowance

Sometimes castings get distorted during cooling due to their typical shape. For example, if the casting has the form of the letter U, it will tend to contract at the closed end causing the vertical legs to look slightly inclined and out of parallel. This can be prevented by making the legs of the U-pattern converge slightly (inwards) so that the casting after distortion will have its sides parallel (Fig. 2.20). This allowance is considered only for castings that tend to get distorted and have an irregular shape.

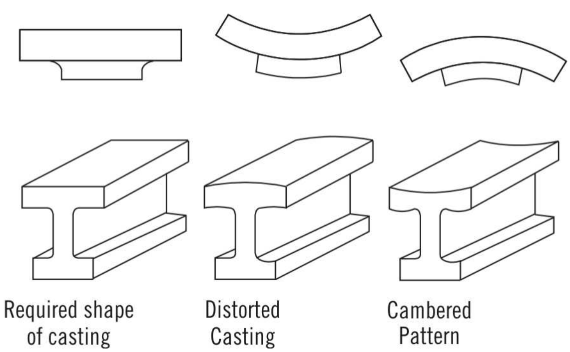


Fig. 2.20 *Distortion in casting*

The distortion in casting may occur due to internal stresses in casting, which in turn may be caused on account of unequal cooling rates of different sections of the casting, hindered contraction from cores, and unequal heat-transfer rates. Measures taken to prevent distortion include

(i) modification of casting design in consultation with the patternmaker and the foundryman so as to avoid abrupt changes in sections, areas of heat and stress concentration, intersecting ribs, etc.;

(ii) improving foundry practice and reducing casting strain by selecting metal that will be subject to minimum contraction, controlling pouring temperature, using proper moulding procedures, such as the use of chills for uniform cooling rates, and avoiding the use of rigid cores and restrictions;

(iii) providing sufficient machining allowance to cover the distortion effect;

(iv) straightening cambered (distorted) castings, which are of ductile nature, by pressing—cold pressing for small and medium-sized castings, and hot pressing by heating under load to 400–500°C for large castings—and

(v) providing suitable allowance on the pattern, called camber or distortion allowance (inverse deflection).

The amount of distortion that may occur is extremely difficult to work out because it depends on several parameters which differ in nature and have effects that cannot be easily correlated. The usual approach followed is one of trial and error, that is, after producing a trial casting, the distortion taking place is measured and then camber is provided on the pattern in the reverse direction. For machine tool castings in grey iron, camber graphs have been published; from these the amount of camber for a given length, wall thickness, and depth of casting can be computed. No camber data in published form is available for steel and aluminium castings. Table 2.6 gives the approximate values of distortion allowance in case of cast-iron castings.

Table 2.6 *Distortion allowance on CI castings*

Length (m)	*3*					*6*					*9*				
Wall thickness (mm)	12	25	37	50	67	12	25	37	50	67	12	25	37	60	67
Camber value 450 for depth or	12	8	5	3	1.5	27	20	14	9	4.5	50	37	25	15	7
width (mm): 600	7.5	5	3.5	2	0.8	18	12.5	8	5	2.5	35	25	17	10	4

2.4.6 Core Prints

Castings are often required to have holes, recesses, etc., of various sizes and shapes. These impressions can be obtained by using cores. Cores are separately made by pressing sand in boxes known as core boxes. For supporting the cores in the mould cavity, an impression in the form of a recess is made in the mould with the help of a projection suitably placed on the pattern. This projection is known as a core print. Thus, the core print is an added projection on the pattern and it forms a seat in the mould in which the sand core rests during the pouring of the mould. The core print must be of adequate size and shape so that it can support the weight of the core during the casting operation.

Core prints are of several types (Fig. 2.21):

(1) Horizontal Core Print This core print is provided in a horizontal axis, along the joint line on the pattern, so that the core is laid horizontally in the mould.

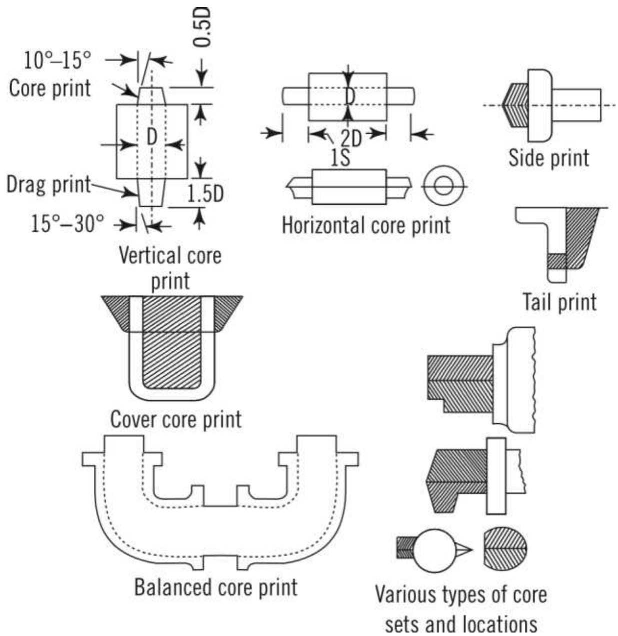


Fig. 2.21 *Different types of core prints*

(2) Vertical Core Print This core print, another common type, forms a seat for a core that will stand vertically in the mould. It is also called a *cope-and-drag* print. A generous taper should be given on the core print, especially on the cope side (about 10–15°) to facilitate the pattern withdrawal and the replacement of the cope on the drag. The taper on the drag print is only 1–3°.

(3) Balanced Core Print When the shape of the casting is such that it is not possible to support the core from both sides, a balanced print is required. The core and the core print are then so designed that the part of the core in the mould cavity balances the part that rests in the core seat. The shape of the print may not necessarily be the same as that of the core in the mould cavity. To aid in the support of the core in the cavity, however, chaplets may be used. Chaplets are small pieces of metal, having a height equal to the space between the core and the mould wall. The metal of chaplets and of the casting should be identical.

(4) Cover Core Print This type of core print, also called a hanging core print, is favoured when the entire pattern is rammed in the drag part and the core is to be suspended from the cope side.

(5) Wing Core Print A wing type of core print is used when a hole or recess is required to be cored above or below the parting line. Owing to the large size of core print required in this case, the draft provided on the vertical walls of the core is fairly high. Wing prints are also known as *drop*, *chair*, and *tail* core prints, depending on the position of the core in the mould and its shape.

Core Location Adequate location of cores is very important to avoid the tendency to shift their position or turn about. When the core must sit in only one particular position, the need for proper setting becomes essential. Various types of devices are used on core prints to ensure correct location as shown in Fig. 2.21.

Core Print Support The size of the core print should be correctly worked out or estimated so that adequate grip is obtained between the mould and the core, and the core has no tendency to shift or rise when molten metal, which has a buoyant effect, is poured. Buoyancy of the molten metal is due to the weight of the liquid metal being displaced by the core.

If the molten metal is iron, its weight in kg per cu m is equal to 7200 and the weight of the core per cu m is equal to (say) 1600. Then

buoyancy force (or core buoyancy) = 7200 – 1600

= 5600 kg/cu m, i.e., 5.6 g/cu cm

Then, the ratio of buoyancy force to weight of core (for cast iron)

= 5600 – 1600 kg/cu m = 3.5 g/cu cm.

Similarly, this ratio for steel, copper, brass, and aluminium is found to be 3.9, 4.5, 4.25, and 0.66, respectively.

The greater the ratio of buoyancy force to the weight of the core, the more the tendency for the core to float and the more secure the method of holding required. Core prints for heavy metals, such as iron, steel, and brass, are therefore larger than those of light metals, such as aluminium. Once the core buoyancy is known, the selected core print size can be verified for its effectiveness as follows:

Unsupported load (kg) = core buoyancy – core print holding force

where core print holding force = (core print surface area) × (compressive strength of moulding sand).

If sand strength is taken as 0.5 kg/cm^2,

core print holding force = 0.5 × (core print surface area)

The unsupported load so obtained should be zero or negative to ensure stability of the core in the mould, notwithstanding the buoyant effect of molten metal. If the result is a positive value, the proportions of the core print should be altered and the unsupported load again worked out to ascertain that its value is negative or zero. In order to give better support to cores and prevent their deflection, chaplets are often used (details about chaplets are given in Section 3.4.4).

Core print sizes can be calculated from basic principles. These values can also be adopted by referring to the following tables:

1. Core Supported on Both Sides

Table 2.7 *Length of core prints*

Core length (mm)	Types of mould	Length of core print (mm) for diameters				
		0–50	*51–100*	*101–160*	*161–250*	*251–400*
≤ 50	Green	20	25	30	35	—
51– 100	”	30	35	40	45	50
101– 200	”	35	40	45	60	90/75
201– 400	Green/dry	40	50	70/60	110/65	180/90
401– 700	”	—	80/60	125/75	190/90	—/110
701–1200	”	—	—	135/90	220/110	—/130
1201–2000	”	—	—	—	—/130	—/155

Cores can be supported on one end only if the length of the core is equal to or less than 1.2 times its diameter.

2. Cores Supported Vertically

H = height of core

d = diameter of core

l and b = length and breadth in cross section, in case of non-circular cores. Thus, value of d is equivalent to $(l + b)/2$.

(a) Only bottom core print is required if

$d <$ 250 mm and $H/d \leq 3$

$d =$ 250–400 mm and $H/d \leq 2.5$

$d =$ 401–650 mm and $H/d < 2$

(b) When both top and bottom prints are used, the bottom print can be half the top print in length. Heights of top prints can be taken from Table 2.8.

Table 2.8 *Height of core prints*

Height of core (mm)	Length of core print at the top for diameters of core d or $(l + b)/2$				
	≤ 50	*51–100*	*101–160*	*161–250*	*251–400*
≤ 50	30	30	30	30	30
51– 100	30	30	40	40	50
101– 200	40	50	50	60	60
201– 400	50	60	60	70	70
401– 700	60	70	70	80	80
701–1200	—	90	100	100	110
1201–2000	—	—	130	130	140

2.4.7 Core Boxes

Like patterns, core boxes also may be made of either wood or metal. Wood is the more popular material because it is easy to glue and join, is freely available, and cheap. Metal core boxes, however, are preferred where better quality is desired and cores are to be mass produced. The metals used for making core boxes are cast iron, steel, brass, bronze, and aluminium alloy.

The cavity in the core box must be of the exact shape and size of the core required, and it must conform to the type of core print used on the pattern, lest any difficulty is encountered while assembling the core in the mould. The accuracy maintained in the construction of the pattern should be applied also to the preparation of core boxes.

The shape of the core determines the type of core box to be used. Some of the familiar types of core boxes are illustrated in Fig. 2.22.

(1) Half Core Box When the shape of the core required is such that it can be prepared in identical halves, a half core box should be used (Fig. 2.22A). The halves are produced, one after the other, with the help of this core box and after they are dried, they are pasted together to form a complete core.

(2) Dump or Slab Core Box If the core produced by the core box does not require any pasting and is complete in itself, the box designed is referred to as a dump core box or a slab box. In appearance, this box can be similar to the half core box (Fig. 2.22B).

(3) Split Core Box When the core box is in two parts and a complete core results from a single ramming, the box is called a split core box. For alignment of the two parts, dowel pins are fixed in one part and corresponding holes are made in the other. Sometimes the parting surface of the halves is made along an irregular line to eliminate the use of dowels (Fig. 2.22C). For preparing the core, the two parts of the core box are held together by a clamp, and the core sand rammed from one side. The core is then taken out by separating the two parts.

(4) Strickle Type Core Box This is used when the core is required to have an irregular surface, which cannot be easily rammed by other methods. In this case, the desired irregular shape is achieved by striking off the core sand from the top of the core box with a piece of wood called a strickle board. The strickle is cut to correspond exactly to the contour of the required core (Fig. 2.22D). The strickle board is also ideal for large-sized work, such as for a pipe bend of, say 600 mm diameter or more, for which a regular core box, if prepared, would be too expensive. The core can be designed in halves, each half being prepared by ramming on a plate with the help of a strickle board. The use of a regular core box is thus eliminated.

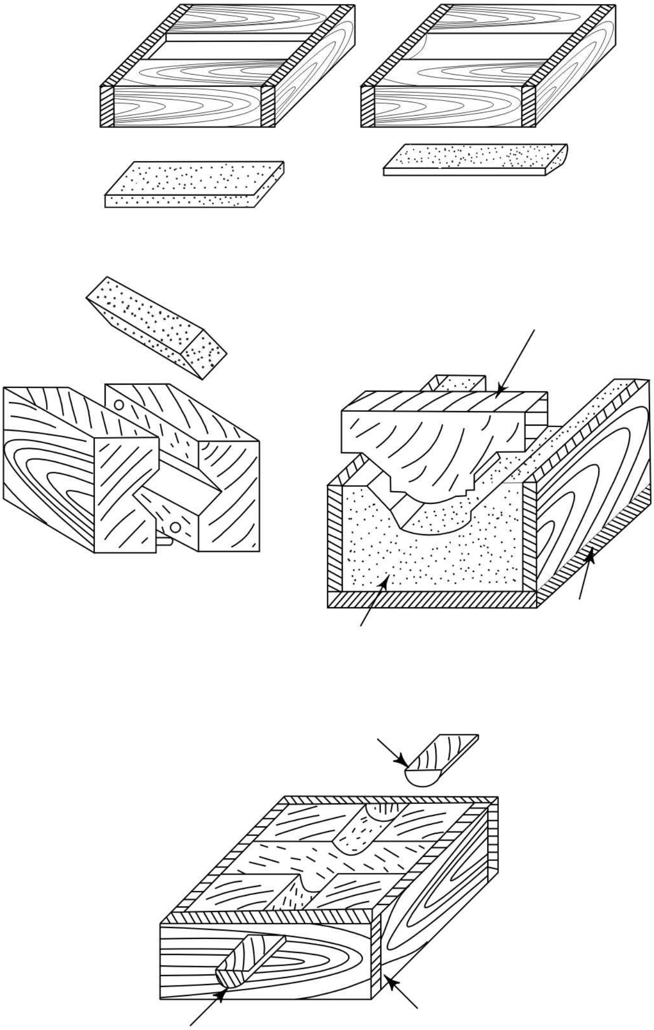


Fig. 2.22 *Types of core box*

(A) Half core box *(B) Dump core box*
(C) Split core box *(D) Strickle-type core box*
(E) Loose-piece core box

(5) Right- and Left-Handed Core Box When the core is required in two parts that are not identical, two different core boxes of the half-core type have to be provided for each part of the core. Such boxes are called right-handed and left-handed core boxes.

(6) Loose-Piece Core Box In case where two parts of the core are not identical, they can be prepared from a single core box with the help of loose pieces (Fig. 2.22E). The cavity in the box is made in the form of a cross, and in one of the two recesses, loose pieces (or a stop-off) are used. One part of the core is processed by placing the loose piece in the left-hand recess, and the other part by shifting the loose piece to the right-hand recess.

2.4.8 Other Technological Considerations in Patternmaking

Use of Loose Pieces Loose pieces are used on patterns to facilitate withdrawal of the latter from the mould where there are projections, bosses, or other configurations which will not otherwise allow 'drawing' of the pattern. The part liable to cause obstruction in withdrawal is prepared as a loose portion on the pattern so that it need not be withdrawn from the mould simultaneously with the pattern.

Two types of arrangements for fastening loose pieces on the pattern are in common use. In one case, the loose piece is temporarily held by a detachable pin. When the sand has been rammed up to a level such that the loose piece will not shift or move, the pin is withdrawn and the moulding completed. In the other case, a dovetail sliding arrangement is provided for the loose piece to fit on the pattern. Both the methods are shown in Fig. 2.23A. Loose pieces may be

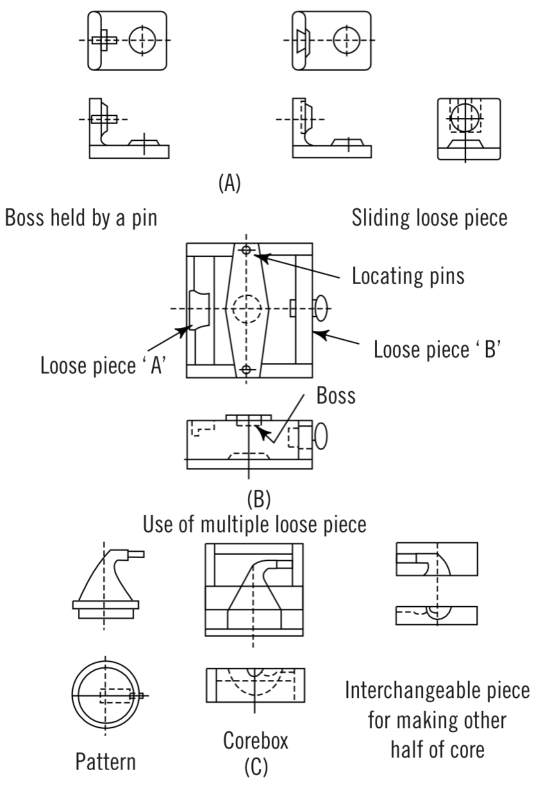


Fig. 2.23 *Types of loose pieces*

provided in core boxes in the same way as on the pattern so that the core can be easily withdrawn even though it has recesses or cavities (Fig. 2.23B). Loose pieces are also preferred where the use of half parts of core boxes or patterns is to be avoided (Fig. 2.23C).

Drawback Core This is a block of sand which is pulled away after the cope is removed to allow the pattern to be withdrawn. The drawback is then returned to the original position. This simple device may thus substitute for a regular core and a loose piece. If an old casting serves as a pattern, a loose piece cannot be provided and the use of a core requires core prints to be fitted on the pattern which may not be convenient. In such a case, the drawback is most suitable (Fig. 2.24).

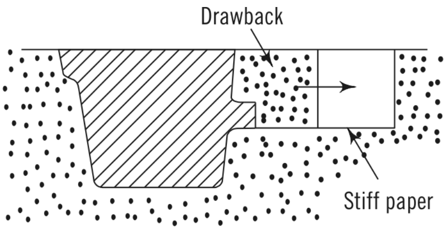


Fig. 2.24 *Use of drawback (green sand) core for large moulds*

Stop-Off This is an excellent aid in moulding work. If thin, plate-like, flimsy casting, without any ribs, is required, its pattern will normally tend to warp and get distorted and produce a deshaped casting. In such a case, stop-off pieces may be inserted on the pattern to prevent it from bending. After withdrawing the pattern, the cavities produced in the mould by the stop-offs are filled with sand (Fig. 2.25).

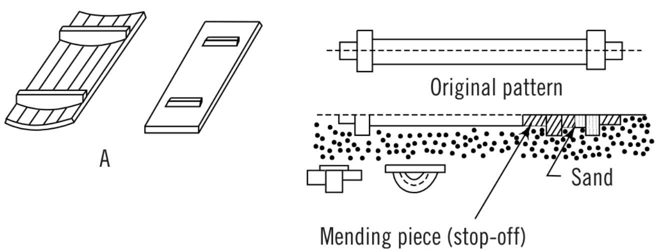


Fig. 2.25 *Use of stop-offs*

The stop-off is also used to enable production of a shorter length of casting when the pattern already available is longer than necessary. Instead of making a completely new pattern of shorter length, a mould is prepared with the long pattern and the extra length not required is filled in with sand by inserting a wooden mending piece called *stop-off*. This method is employed when the castings of varying lengths but the same cross section are required, for instance, pipes, machine-tool beds, etc. (Fig. 2.25)

Fillet This is a concave, connecting surface or the rounding of an internal corner caused by two intersecting surfaces. Wherever a sharp corner occurs, a smooth fillet should be provided to enable metal to flow easily into the mould, cooling to be uniform and without stress concentration, and allowing a more sound casting to be produced. Fillets also facilitate withdrawal of the pattern from the mould. They can be made of wood, leather, plastic, or a combination of sawdust and glue.

Finishing of Pattern After the patterns are prepared, they should be finished by sanding so that tool marks and other irregularities are erased. Then they should be applied with two or three coats of shellac. Shellac fills up the pores and imparts a smooth finish. The finish of casting depends on the finish of the pattern. If the pattern is to be preserved for a substantial period and if a colour scheme is to be used, a good quality enamel paint should be selected to spray or brush paint it. The colour scheme recommended by IS: 1513–1980 is given in Table 2.9.

Table 2.9 *Colour scheme for surfaces*

SURFACE	COLOUR/MARK
Surface to be left as cast (unmachined):	Blue (Steel)
	Red (Grey cast iron)
	Grey (Malleable cast iron)
	Orange (Heavy metal castings)
	Brown (Light metal castings)
Surfaces to be machined:	Yellow
Core prints for unmachined openings and end prints:	
Periphery	Black
Ends	Black
Core prints for machined openings:	
Periphery	Yellow stripes or black
Ends	Black
Pattern joints (split pattern):	
Cored section	Black
Metal section	Clear varnish
Touch core:	
Core shape	Black
Legend	'Touch"
Seats of and for loose core prints:	Green
Stop-offs:	Diagonal black stripes or clear varnish
Chilled surfaces:	
Outlined in legend	Black 'chill'
Fillets	Black broken line

Permissible Variations of Pattern and Core-Box Dimensions Exact dimensions cannot be produced and variations are bound to occur. The value of the tolerance to be provided depends on the nominal dimensions, materials and construction of patterns. Table 2.10 gives the values of permissible variations which can be used as a guideline. However, these values are not based on any standard specifications.

Table 2.10 *Permissible variations on pattern and core-box dimensions*

Nominal size (mm)	Hard-wood patterns	Soft-wood patterns	Metal or plastic patterns
≤ 50	0.5	0.8	0.25
51–150	0.7	1	0.3
151–300	0.8	1.2	0.4
301–500	1	1.5	0.55
501–800	1.2	2	0.7
801–1200	1.5	2.5	0.9
1201–1800	1.8	3	1.2
1801–2500	2.1	3.5	1.5

The values in the table indicate total tolerance, which may be positioned symmetrically about the basic size.

2.4.9 Types of Patterns

Patterns are of several types (Fig. 2.26), each satisfying certain casting requirements:

(1) loose patterns of one-piece type, split type, loose piece type, or with follow board;
(2) gated patterns;
(3) special patterns and devices such as sweep or skeleton type; and
(4) match-plate patterns or plate-mounted patterns

(1) Loose Pattern

Single Pattern The one piece or single pattern is the most inexpensive of all patterns (Fig. 2.26A). Generally made of wood, it is best suited for limited production or during the development stage of casting. Moulding with such a pattern requires manual operation. The pattern is similar to the casting required except that necessary allowance and core prints are provided.

The simplest type of single pattern is the one with a flat back, which acts as a parting plane. Patterns that do not have a flat back have either to be moulded, applying the odd side method, or they require the use of a shaped follow board

(Fig. 2.26B). The follow board can support the pattern during moulding and defines the parting plane. A gating system is made in the mould by cutting sand by hand tools.

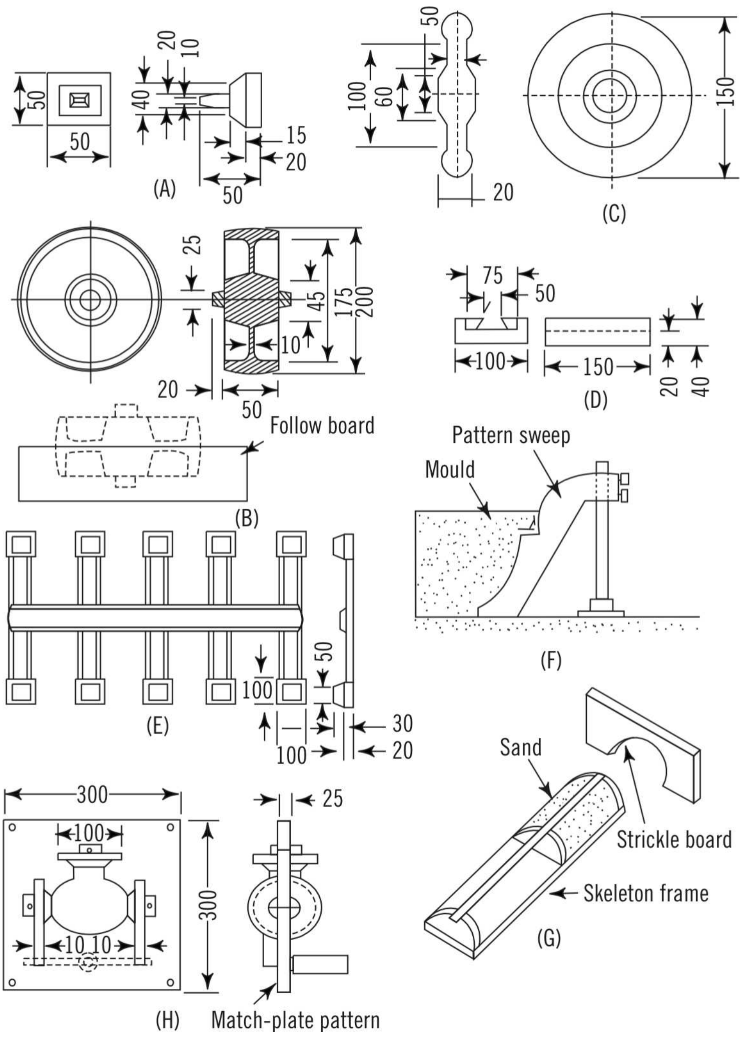


Fig. 2.26 *Different types of patterns*

(A) Solid pattern	*(B) Follow-board pattern*
(C) Split pattern	*(D) Loose piece pattern*
(E) Gated pattern	*(F) Sweep pattern*
(G) Skeleton pattern	*(H) Match-plate pattern*

Split Pattern This is used when the castings are of intricate design or are required in bulk. It is split along the parting surface, the position of which is determined by the shape of the casting (Fig. 2.26C). One half of the pattern is moulded in drag and the other half in cope. Gales are also hand-cut with split patterns.

Multiple Piece Pattern A pattern with loose pieces (Fig. 2.26D) or loose core prints, is required when a one-piece and a split pattern are unsuitable for withdrawal from the mould.

(2) Gated Pattern This is an improvement on the ungated pattern in which the gating system constitutes a part of the pattern. This type (Fig. 2.26E) eliminates hand-cutting of gates, runner, etc., and enables more rapid moulding. Generally, a set of patterns (e.g., 2, 4, 6, etc.) is arranged about a common runner and connected to it through in-gates.

(3) Special Patterns Devices, such as sweep (Fig. 2.26F) and skeleton (Fig. 2.26G), are ideal when preparation of a regular solid pattern would be too expensive and the shapes to be cast permit their use. Generally, large-sized castings of a symmetrical nature, such as wheels, rims, and bell shapes, can be prepared by sweeping. A skeleton pattern is made by using a wooden skeleton frame and filling spaces between the wooden pieces with moulding sand. The exact overall shape is obtained by firmly pressing the sand and strickling it. The method is suitable when just one or a few castings of large size are required. Skeleton patterns for round shapes, such as pipes and cylinders, are first prepared in halves which are then joined by dowels or by gluing.

(4) Match-plate Pattern This is convenient when small castings are to be produced in large quantities on moulding machines (Fig. 2.26H). Cope and drag parts of the pattern are mounted, along with the gating system, either on the two sides of the wooden or metal plate or on separate pattern plates. The pattern may be made of wood, metal, or epoxy resin. As high squeeze pressures and heavy jolting are to be withstood by such patterns, metal and epoxy resin are commonly used. Compressed wood patterns are also selected for match-plate work, owing to their superiority over wooden ones. In the case of wooden patterns, metal reinforcements and inserts ensure stability in high wear areas. When patterns are small in size, two or more can be mounted on the same plate with a common runner system. Separate pattern plates for cope and drag require accurate alignment of the two mould halves by means of guide and closing pins and bushings in flasks in order that the upper and lower parts of the mould assembly match properly. The Indian Standards specifications for pattern plates and moulding boxes are as follows:

(a)	Pattern plates for machine-moulding boxes	IS: 4604–1975;
(b)	Guide pins for foundry pattern plates	IS: 4981–1984;
(c)	Closing pins for foundry pattern plates	IS: 4982–1984;
(d)	Foundry moulding boxes of steel construction	IS: 1280–1967.

The conventional method of making match-plate pattern is to cast the loose patterns, machine and finish them, and then mount them on plates that are separately prepared. This method is complicated and requires extraordinary skill in mounting, which must be accurate. The shortcomings involved may be avoided by using the method of plaster moulding whereby a pattern (or patterns) is cast 'integrally' with the pattern plate in one piece. The integrally cast match-plate, which could be one-sided or both-sided, is made in aluminium alloy. The master pattern for one single loose pattern is wooden; and from the master pattern, the required composite mould is developed for the integral design. The required thickness and the outer profile of the pattern plate are obtained by keeping a suitable gap between the halves, which are enclosed within shaped spacer plates. As the moulding is done in plaster, excellent finish and accuracy of dimensions are achieved and no further machining is needed on the casting. As plaster lacks permeability, a pressure-feeding arrangement directs the molten metal into the mould cavity. Ceramic moulding has also lately been used for making integral cast match-plates.

The material for the pattern plate depends on the requirements of the foundry. It may be grey cast iron (Grade 20), cast aluminium alloy (Grade 4223), hard wood or compressed wood laminate. Wooden pattern plates may be lined with metal. The metal pattern plates are of ribbed construction and square or rectangular in shape. Top and bottom surfaces are to be machined true and parallel. The dimensions of pattern plate are given in IS: 4604–1975. Judicious selection of the type of pattern to be used is necessary to ensure that the castings are produced to the desired degree of accuracy and at the lowest cost. Loose patterns are suitable for small quantities of castings, not demanding close tolerances, and are used with hand moulding. Gated patterns, also loose, but being complete with gating system, ensure uniformity in the size of sprue, runner and in-gates and thus consistency in quality of castings. Match-plate patterns, used with machine moulding are feasible when the quantities required are large enough and dimensional tolerances are to be maintained within close limits.

2.4.10 Pattern and Core Box Construction

The types of construction generally employed for patterns and core boxes are shown in Fig. 2.27.

(1) Ring Construction (Segmental Construction) This type of construction is durable when hollow cylindrical shapes with diameter more than 200 mm are required. The whole length is built up in a number of layers or laminates, and each layer is made up of several segments of wood. Figure 2.27A shows the method of joining and the number of segments required. Such construction, which uses small wooden pieces, involves least wastage and produces strong, stable shapes.

(2) Tongue-and-Groove Construction Frequently, a job requires a circular pulley or flywheel type of pattern in which the hub and the rim are joined by arms. In such cases tongue-and-groove joints (Fig. 2.27B) in which a groove is cut to accommodate the tongue of the board, are necessary.

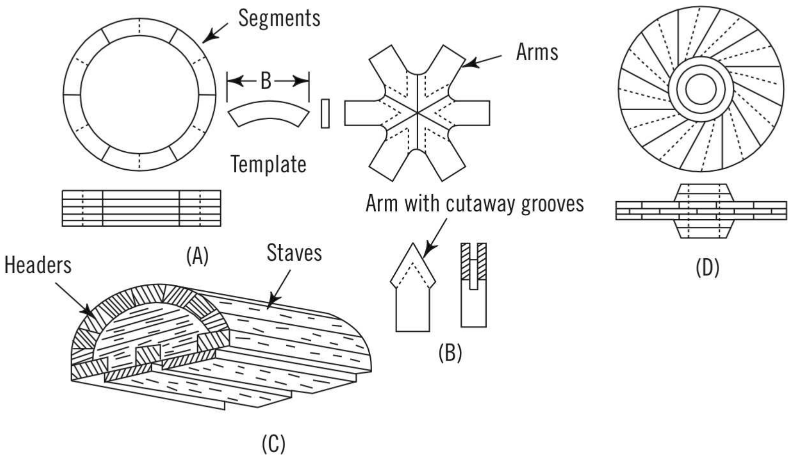


Fig. 2.27 *Types of construction used for pattern and core boxes*
(A) Ring pattern using segmental construction
(B) Tongue-and-groove construction
(C) Header and stave constuction
(D) Disc construction

(3) Header and Stave Construction For building up large shapes, it becomes too expensive and wasteful to make the whole pattern solid from the inside. In such cases, it is simpler and economical to close the ends by pieces called headers and fix on the headers the lengthwise sections, called staves, which are glued and shaped to the required dimensions (Fig. 2.27C).

(4) Disc Construction This method of construction also uses laminates to build up the desired thickness. Each laminate is formed by joining small pieces of wood which are laid down in a non-radial manner, as shown in Fig. 2.27D. The system achieves structural strength, the pieces remaining firm even during machining.

(5) Box Construction When the inside of a pattern is hollow and the pattern itself is of sizeable proportions, box construction is effective as it saves the quantity of wood and reduces weight.

(6) Composite Construction of Wood and Metal Metal plates or strips are used to strengthen such surfaces where extensive wear is expected during moulding. Projecting pieces such as webs, ribs, and vanes, which are very fragile if made in wood, can be prepared in metal and attached to the main body of the pattern and core box (Fig. 2.28).

Joints Used in Wooden Construction

The joints used to hold together required shapes are of many types, each adapted to special construction needs. The joint selected should be one that lends sufficient

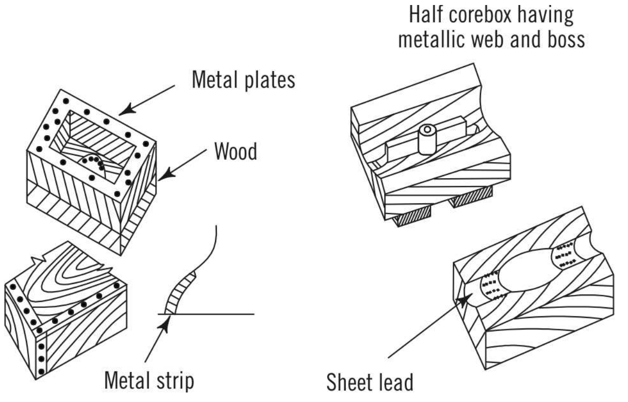


Fig. 2.28 *Use of metal on wooden pattern*

strength and at the same time is easy and cheap to make. Where pieces are to be fastened at right angles, lap, dowel, mitre and butt joints are usually employed. Mortise-and-tenon joints and dovetail joints are less common in pattern work. For securing pieces parallel to each other, glued butt joints are most suitable. Where wide-sized stock is required, it is common practice to glue narrow boards together to form the desired width, care being taken to ensure that the boards are placed with grains alternating in opposite directions. For obtaining large thicknesses too, narrow layers of wood are glued together such that the grains in alternate boards are in the same direction. This is done to keep the swelling effect due to climatic changes at the minimum.

2.4.11 Preparation of Pattern Layout

Before the pattern is taken up for manufacture, the layout must be prepared. Layout is a full scale drawing in either orthogonal or isometric projection or both, with complete details of the pattern, including allowances, core prints, parting planes, loose pieces, etc. This drawing is prepared in the same manner for both pattern and core box, by using the appropriate contraction rule. The type of construction to be followed, joints used, proportions of wooden pieces and all other relevant details, including the size, shape, and location of gates, risers, etc., are depicted on this layout, which can be drawn on a sheet of plywood or perspex. Lines are drawn with a scriber so that they are permanent, and dimensions may be accurately transferred on to the pattern by using dividers or trammels.

Once the layout is prepared and checked by the inspector, it becomes easy for the patternmaker to make the pattern; the chances of his erring in construction are much reduced. Layout is also useful in subsequent checking of the pattern.

The preparation of a pattern and core box is illustrated in Fig. 2.29.

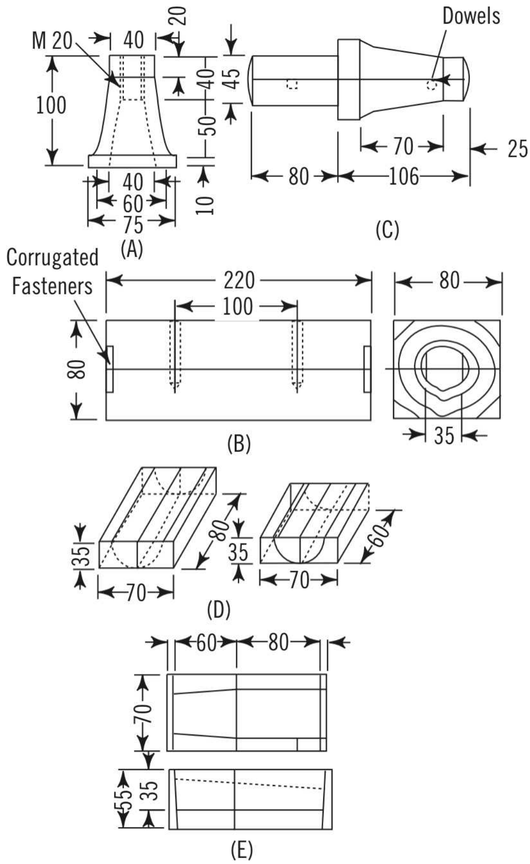


Fig. 2.29 *Preparation of pattern and core box*
(A) Final dimension of casting
(B) Preparation of stock for pattern (ready for turning on lathe)
(C) Layout of stock for core box
(D) Core box

2.5 METAL PATTERNS

With the increasing trend of mechanization and modernization, the design and manufacture of pattern equipment is becoming an organised engineering activity. A pattern shop, to cater to the needs of a modem foundry, has to be a well-planned set-up. Metal-pattern manufacture is an intricate job involving many other spheres of work, and is thus a complex activity. A modern pattern shop has to have different sections to achieve this type of highly skilled job. This section deals with the infrastructure and different techniques applied to the manufacture of metal-pattern equipment.

Pattern Drawings Pattern drawings are made by a technical cell, considering different allowances such as machining allowance, core-print sizes and shapes, contraction allowance, draft angles, holes to be cast solid, and machining pads and fillets. Specially core prints are drawn showing dimensions, setting allowance and other features. When the pattern drawings are drawn to the standard scale, the manufacture of the pattern equipment is made easy, as standard marking and measuring instruments can be used while manufacturing and at the time of inspection. Such specific drawings then become standard documents and can be used whenever a duplicate is required immediately. Each and every information regarding the manufacturing process is contained in the drawing itself which helps in replacement or repair of a part of the pattern or a core box in case of damage or wear off under continuous use. These standard drawings save time when distributed at different activity centres to manufacture the components.

2.5.1 Manufacture of Gauges and Templates

Actual constructive activity starts from the manufacture of gauges and templates. Templates are the aids directly cut after marking on a Bakelite sheet, 0.4- to 0.5-mm thick, with a hard-tip scriber or compass, and do not require any filling and finishing after cutting, except slight deburring with fine sandpaper. Bakelite being a hard and tough material, does not deform or lose its shape and size and is used while the component is under manufacture or at the time of its final inspection.

Gauges are made generally for use in foundry and are constructed out of MS plates or aluminium sheets. If required, these gauges are provided with stiffener plates riveted or screwed to the main gauge to avoid springing or flexibility and also to provide adequate strength. After marking the correct shapes, the extra material is cut and removed either with a jig saw or on a milling machine, keeping some allowance for filing and finishing with hand tools.

1. The use of this type of gauges is to check the accuracy of the cores individually or after joining two cores together and are named as *Go* and *No Go* gauges.
2. Another type of gauges are prepared in sets to provide guidelines for the setting of cores in the mould in proper position, maintaining accuracy up to the last core setting.
3. Gauges are also prepared for checking the complete mould after core setting to ensure the correctness of centre distances, wall thicknesses and other important locations of lugs, ribs and bosses, etc., in relation to the reference points. The profiles in templates and gauges are inspected thoroughly before initial use and periodically thereafter.

2.5.2 Layout

Pattern drawings, supplied for manufacture of pattern and core boxes in metal are drawn in full scale, taking into consideration all aspects of 'layout'. In other words, these are layout drawings. In case of metal core boxes, each and every detail which is required for manufacture is made available; but in pattern drawings more importance is given to overall critical dimensions, core print sizes, their shapes, setting angles and tolerances. Details of fixing core prints and mounting of the pattern on the plates are made clear.

The patternmaker must make his own full-scale layout, even though he is supplied with the method drawing or a proper pattern-equipment drawing. This gives him the correct picture of the size of the pattern. While drawing the layout, he has to study each and every line from the drawing and also read all the dimensions. This helps him in understanding the drawing, fixing the dimensions which are to be calculated, and he can also comprehend and visualize the templates which he will have to make for manufacturing the pattern equipment. He can as well think of the construction method and machining sequence required for his pattern. Accordingly, he can plan and start the actual work. Thus, chances of errors are minimized.

2.5.3 Manufacturing Processes for Metal Patterns

There are various methods of manufacturing metal patterns. The selection of process mostly depends upon the quality standard of product to be manufactured in the foundry as well as the infrastructure available and the process of core and mould making in a particular foundry. The basic consideration with small units having inadequate facilities is the cost factor. Generally, they prefer to go in for the equipment which is cheaper and can serve their purpose. For example, for a small foundry producing manhole covers in green sand, adopting the pit-moulding process, will not require a high standard machined and mounted pattern and will prefer a solid self-cored cast pattern finished by hand. At the same time, a foundry equipped with moulding machines and other core-making facilities will definitely like a standard and accurate equipment. So the process of manufacture of metal pattern depends upon individual foundry requirements.

1. By Fabrication Patterns with very simple shapes which are possible to fabricate in metal are generally made by this technique. No master pattern or casting is required. Blanks according to the required shape of the pattern are fabricated by lamination of metallic pieces, preferably of aluminium. In case of ring-type construction, the segmental lamination of pieces cut from a suitable size of plate overlapping at the joints is formed; and in other types, the horizontal and vertical members are joined together by means of riveting, screwing or welding at the corners. These blanks are kept oversized to take out the required dimensions, keeping in view the machining and contraction allowances. After formation of the blanks, these are marked properly according to the required shape and are processed with hand tools, such as chisels and gauges for roughing, and files and refillers for finishing. Finally, these patterns are finished with emery paper and put to use.

2. By Casting Method This method requires a *master pattern* for making of the casting to manufacture metal pattern. The conventional consideration of double contraction allowance is taken into account while making the master pattern, and proper ribbing is provided inside to give adequate strength and to reduce weight and cross section. If the pattern is to be hand finished, the allowance for finishing are kept as minimum as possible for labour saving, but it is ensured that complete shape of the pattern is achieved with contraction and machining allowances required to make the casting. Maximum care is taken in producing casting for making a metal pattern by ensuring a proper gating system to avoid pin holes, shrinkage and other casting defects.

After making the castings, these are marked and finished with hand tools with the help of templates. The same procedure is adopted for making core boxes keeping in mind to provide proper ribbing at the back of the sides to reduce the weight and cross section of the casting.

3. Manufacture of Metal Pattern for Machine Moulding To make any metallic pattern a 'master pattern' is required, which can be built up out of suitable wood keeping in view the shrinkage effect in timber, or out of particle board which is much easy to process on wood-working machines and no joinery is required. This saves time. A wooden master pattern does not require framework and joinery. The formation of the block to take out the shape is quite sufficient.

2.5.4 Manufacture of Master Pattern

The patternmaker should consider the following points before making a master pattern for the manufacture of a metal pattern.

1. The design of the master pattern is made depending upon the material in which the pattern is to be made. Patternmakers should draw the complete layout of the pattern and core boxes to cross check and to construct these items correctly.
2. If required, at the parting line, a collar-type metal strip is provided in the master pattern which will help in mounting the pattern on match-plates.
3. Enough wall sections are necessary behind the loose pieces for accommodating sliding and dovetail portions of loose pieces (Fig. 2.30).
4. Sufficient ribbing with proper metal thickness should be given inside the hollow portion of the pattern for obtaining strength and rigidity. Solid bosses may be kept in full depth for mounting on the plate with bolts.
5. Enough ribbing with proper metal section should be provided on the outer side of the core-box walls.
6. The patternmaker should decide the machining process of his pattern while making the master pattern. The levelling pads or supports, if required on the master pattern itself, will facilitate in machining and marking of the pattern. After obtaining the castings, it is very essential to check it for any

deformity, generally cupping, bowing or twisting. These types of defects can be checked by simple visual observation with the help of a straight edge.

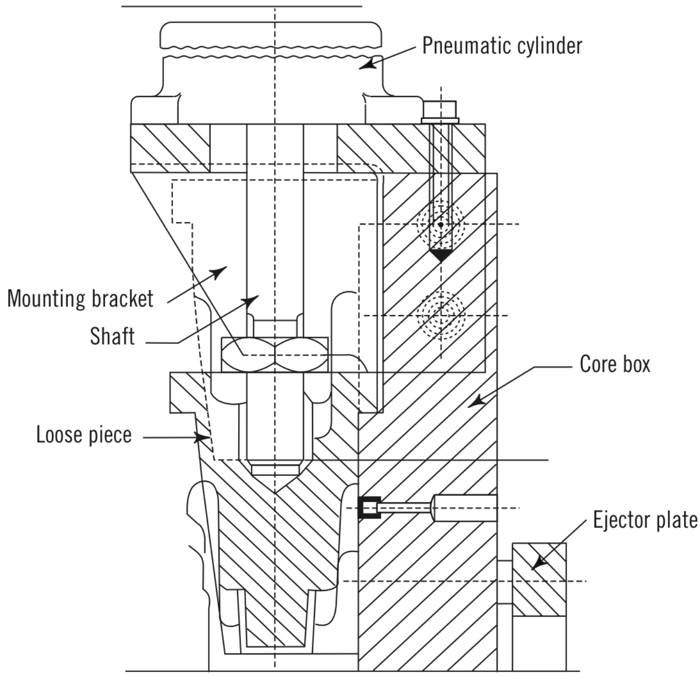


Fig. 2.30 *Mounting of loose piece in a shell core box*

2.5.5 Marking of the Pattern

Generally, three conventional operation methods are adopted for marking of the pattern for further machining on different machines.

1. First Operation Marking the thickness of the pattern and the positions of all details falling in the thickness of the pattern

2. Second Operation Width of the pattern and all details in the width

3. Third Operation Length of the pattern and the details in the length

First Operation Both halves of the pattern, the cope and the drag, are loaded on screw jacks and levelled perfectly with a height gauge on the top surface. Now, leaving about 3 to 4-mm machining allowance on the top, a machining line is scribed. This becomes the reference line for the marking of thickness of the pattern at the parting line in both the cases. The line marked at the bottom leaves extra material to machine. Now, the pattern is loaded on a milling machine and levelled with a height gauge for parting-line machining. The same operation is conducted in both the halves and both the surfaces are checked on the surface plate and matched together. All shapes and sizes coming in thickness of cope and drag are marked properly and machined, leaving 0.1 to 0.2 mm oversize for hand finishing.

After matching outer shapes of the pattern, cope and drag are clamped together firmly and set on a drilling machine table exactly in level to the table face to maintain the perpendicularity of a drilled hole of 10 mm diameter through both halves at three different positions to check longitudinal and cross movement. After drilling, bright bar pins are driven in the holes which should be tightly fitted and are cut to the level of the pattern from both sides. These three holes help in mounting of pattern on the match-plates at a later stage.

Second Operation After dowelling, the pattern is ready for marking the second operation, widthwise. The pattern is mounted on the surface plate, keeping the parting line exactly perpendicular to the surface plate. This is achieved by providing suitable packings and screw jacks. First of all, a centre line is marked all around the pattern. Now, taking this as a reference line, all dimensions coming widthwise according to the drawing are marked on the pattern.

Third Operation Clamping with an angle plate, the pattern is set on the surface plate maintaining perpendicularity of the centre line to the surface plate. After marking the bottom and machining line, which becomes the reference line, all shapes and sizes coming in the length of the pattern according to the drawing are marked. For shapes which cannot be marked in these three marking operations, templates are prepared and used in coordination with the centre line of the pattern and the other reference points.

2.5.6 Machining of Metal Pattern and Core Boxes

Manufacture of metal patterns and core boxes require the combined skill of metal patternmakers and die sinkers which require working with precision-measuring instruments and first-class machine tools. Great emphasis is placed on shop finish standards.

As a common practice, sign *f* indicates some kind of finish. Another symbol is inverted triangles '∇' marked on the surface which shows the type of finish required. The desired finish is indicated approximately by the number of these symbols arbitrarily selected to represent different degrees of finish or smoothness of the surface, such as

(i) lapped surface
(ii) ground finish
(iii) fine machining
(iv) standard machine finish
(v) rough finish

1. The sequence of machining operations to be conducted on different machines is always preplanned, keeping in view the maximum number of operations to be achieved in a single setting.
2. Proper speed, feeds, depth of cut and coolants are the main considerations while machining a component.
3. Proper tooling is arranged according to the materials to be cut and the finish required.
4. If any portion of the pattern or a core box is not possible to be machined in any setting, or the approach of the tool is not feasible, that portion is manufactured separately and fixed in position with suitable type of fasteners.
5. Angular cutting can be achieved by
   (i) tilting head of the machine
   (ii) taper cutter of required degree
   (iii) draft angle plate for vertical and horizontal mounting
   (iv) sine table
6. Circular cutting can be done by mounting on a rotary table. If the machine is not provided with this feature, the job can be accommodated on the rotary table.
7. Any complicated shape, difficult to form with the conventional machining process, is copied from the master model, preferably made of epoxy resin for fine finish and smooth movement of styli. If a particular portion is beyond the copying range of the machine, it is copied separately and is fixed in position with suitable fasteners.
8. While copying, it is very essential to select a suitable type of cutter to form the shape with the relevant stylus.
9. Maximum care is taken while machining core prints. Set-in tolerances are maintained to the exact given dimension.
10. Suitable clamping is prearranged for loading of the job on the machine.
11. While manufacturing the pattern in the copying mode, the work piece and master model are screwed up from the bottom on cast iron machined plates and these plates are clamped on the table, keeping the centre-line alignment true. Direct clamping is avoided.
12. According to the finish being achieved under machining or copying operations, the component is kept oversized, which ranges between 0.1 to 0.3 mm maximum for hand finishing.

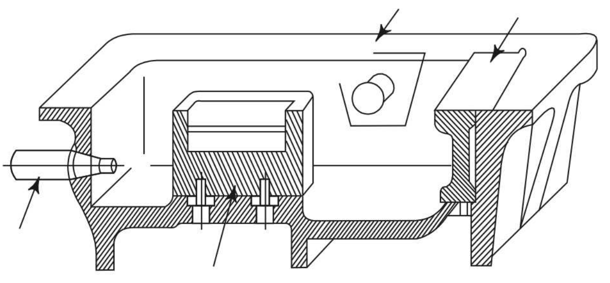
As metal patterns are used for large scale production of castings, they are rarely required as loose patterns. They are employed in mounted form on one-sided or two-sided pattern plates. When patterns are small, several patterns can be mounted on the same plate. As the patterns are cast, there is no need lo make joints or segments. However, the method of manufacture is intricate and requires extraordinary skill. The patterns and core boxes when made in metal have to be as light as possible in order to reduce both weight and cost. The section thickness should therefore be kept as thin as practicable. Ribs, webs, etc., on the outside of core box surface impart strength. Core boxes, if used on core blowers or core shooters, may have an entirely different design in which adequate arrangement for venting, blowing, etc., has to be provided.

Loose pieces are used in metal patterns in the same way as in wood patterns. The equipment required for machining metal patterns is far more expensive than that for wood patterns. The patternmaker must be practised in metal cutting, finishing, and fabrication methods and in precision testing and inspection techniques in addition to normal patternmaking and foundry work.

The system of mounting patterns on pattern plates depends on the type and shape of pattern and the moulding requirements. The plates in customary use may be one of the following types:

(1) one-sided pattern plate;
(2) reversible pattern plate;
(3) stripper-type pattern plate;
(4) inserted-pattern-type pattern plate;
(5) two-sided pattern plate; and
(6) integrally cast match-plate.

Two types of metal core boxes, one using loose pieces and the other of the two-part type, are illustrated in Fig. 2.31.



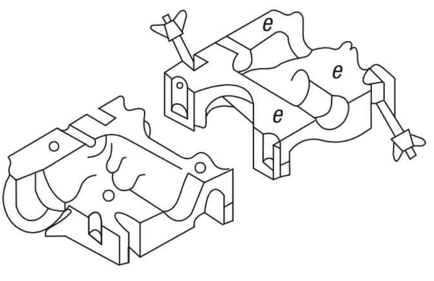


Fig. 2.31 *Types of metal core boxes*

LIFE EXPECTANCY OF PATTERNS 2.6

The life of patterns and core boxes can be expressed in terms of the number of moulds or cores that can be produced. The material of the pattern, type of construction, method of moulding and core-making, care with which patterns are handled, and type of storage affect the life expectancy. Table 2.11 gives the expected life of patterns for guidance purposes.

Table 2.11 *Life expectancy of patterns*

Sl. No.	Method of using pattern	Pattern material	Type of construction	Expected life in number of moulds
1.	Loose	Soft wood	Skeleton	10
2.	Loose		Segmental, disc, box, etc.	50
3.	Loose	Hard wood	Ring, tongue and groove, header and stave, disc, box and composite	200
4.	Mounted	As above		1000
5.	Mounted	Epoxy resin	Cast in plaster or plastic moulds	2000
6.	Mounted	Epoxy resin with filler	Gel coat, lamination with glass fibre	5000
7.	Mounted	Aluminium pressure cast	As cast and cleaned	3000–5000
8.	Mounted	Aluminium, sand cast	Machined all over and polished	30,000
9.	Mounted	Brass, SG iron, grey iron, steel	Machined all over	50,000

PATTERN STORAGE AND REPAIR 2.7

In order to be able to use the patterns for a long time, it is essential to give due consideration to storage and repair requirements. It is advisable that the patterns, after use in the foundry, are carefully inspected for any breakage or loss, adequately repaired, and sent for safe storage. Similarly, when a pattern is requisitioned by the foundry, it should be obtained from storage, inspected, repairs, if any, carried out, and then issued to the foundry. It is also desirable to maintain a complete history of each pattern by recording, date-wise on a card, the issue and return of patterns to and from the foundry, number of moulds produced, inspection carried out, and nature of repairs done.

The principal factors governing space requirements for pattern storage are (i) quantity and volume of patterns, (ii) rate of acquisition of new patterns to be added to storage, (iii) types of patterns, and (iv) general rate of obsolescence due to changes in casting design, or design of product.

Pattern-storage areas should be so designed that they are weather-proof and fireproof, with adequate arrangements for extinguishing fires. For expensive patterns, it is also desirable to have temperature and humidity controls. Separate areas or floors should be earmarked for light, medium and heavy patterns. Small patterns are kept in racks, and large ones are placed on the floor with proper identification marks.

Repair of patterns is often required for various reasons. It is relatively easier to manufacture new patterns than repair old ones. It needs skill, hard work and experience to correctly repair the pattern equipment. Pattern repair may be required due to normal wear and tear during use, breakage during transportation and handling, careless moulding work, falling of slag or molten metal, seasonal effects, improper placement when not in use, use of sub-standard material, wrong designs and weak construction.

In case of foundries with a large turnover of patterns, it is preferable to have a repair section attached to the storage area and separate from the main pattern shop. A properly organised pattern-repair facility can help improve the technological discipline amongst patternmakers, keep a constant check on undesirable and careless practices during manufacture, and even guide in improving moulding and core-making practices.

Review Questions

1. What is the role of a patternmaker in casting production?
2. What preparation is necessary before a pattern is actually produced?
3. What are the commonly used pattern materials? Give their relative evaluation.
4. Why is wood so commonly used for patternmaking? How can stability of timber be improved?
5. What tests are prescribed for the inspection of timber? What various types of timber are suitable for pattern work?
6. What metals and alloys are suitable for foundry patterns? What are the advantages of aluminium patterns?
7. Explain the steps involved in the preparation of epoxy patterns and polyester patterns. In what way are they superior to wooden patterns?
8. In what form is polystyrene used for patternmaking? How are expanded polystyrene patterns prepared?
9. Explain the working of a pattern-milling machine. What tools and accessories are used on this machine and what types of operations can be performed?

10. What allowances are usually provided on patterns? Explain.
11. How can distortion be avoided or controlled on castings? How can pattern design help in this respect?
12. Write short notes on
    (i) Loose pieces
    (ii) Stop-offs
    (iii) Rapping and lifting operations
    (iv) Colour coding of patterns
    (v) Gated patterns
13. What are match-plate patterns? How are they designed? Show the design of a match plate for producing 50-mm size body of a gate valve.
14. What are the various types of pattern waxes? How are they used for investment casting? Give their salient properties and uses.
15. Describe the principle of 'rapid tool-manufacturing techniques' and show how they are used in pattern, tool and die shop.
16. Show with an example the procedure of manufacturing metal patterns. What accessories are required in the process?
17. Explain the typical characteristics of cellular structure of timber.
18. What is the effect of seasoning on the properties of timber? Why is it carried out?
19. Write short notes on:
    (a) Electro-deposited patterns
    (b) Plaster patterns
    (c) Low-melting-point alloy patterns
    (d) Rubber patterns
20. What are the advantages of using pattern-milling machine over conventional machine tools? Explain with examples.
21. What are the gains from dust-exhaust system? On which machines is this system commonly installed?
22. Show diagrammatically the types of construction used for making wooden core boxes.
23. What are the important considerations to be kept in mind during storage and repair of pattern equipment?

Chapter 3

Technology of Moulding and Coremaking

3.1 MOULDING SANDS

Sand is the principal moulding material in the foundry shop where it is used for all types of castings, irrespective of whether the cast metal is ferrous or non-ferrous, iron or steel. This is because it possesses the properties vital for foundry purposes. The most important characteristic of sand is its refractory nature due to which it can easily withstand the high temperature of molten metal and does not get fused. Moulding sand has chemical resistivity. It does not chemically react or combine with molten metal and can therefore be used time and again. Sand has a high degree of permeability; it allows gases and air to escape from the mould when molten metal is poured without interfering with the rigidity and strength of the mould. The degree of strength, hardness, and permeability can also be adjusted, as desired, by varying the composition or the ingredients of the sand. Such flexibility is extremely difficult to achieve with any other moulding material. But the properties vary from one sand to another, and it should be noted that only those sands, characterised by the foregoing features, are considered suitable for moulding work.

3.1.1 Principal Ingredients of Moulding Sands

The principal ingredients of moulding sands are (l) silica sand grains, (2) clay (bond), and (3) moisture.

(1) Silica Sand Grains

Silica sand grains are of paramount importance in moulding sand because they impart refractoriness, chemical resistivity, and permeability to the sand. They are specified according to their average size and shape. The finer the grains, the more intimate will be the contact and lower the permeability. However, fine grains tend to fortify the mould and lessen its tendency to get distorted. The shapes of the grains may vary from round to angular (Fig. 3.1). The grains are classified according to their shape.

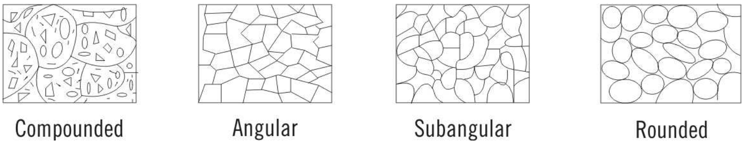


Fig. 3.1 *Types of sand grains*

(i) Rounded Grains These grains have the least contact with one another in a rammed structure, thereby making the sand highly permeable to gases. Sand having rounded grains, however, lacks strength and does not pack up to the optimum extent. The binder requirements are minimum.

(ii) Subangular Grains These grains have comparatively lower permeability and greater strength than the rounded ones.

(iii) Angular Grains These grains have defined edges, and the surfaces are nearly flat. They produce higher strength and lower permeability in the mould than subangular grains. The binder consumption is likely to be high.

(iv) Compounded Grains In some cases, the grains are cemented together such that they fail to separate when screened. They may consist of rounded, subangular, or angular grains or a combination of the three. Such grains are called compounded grains and are least desirable due to their tendency lo break down at high temperature.

In practice, sand grains contain mixed grain shapes, depending on origin. A subangular-to-rounded grain mixture would be the best combination.

(2) Clay Clay imparts the necessary bonding strength to the moulding sand so that after ramming, the mould does not lose its shape. However, as the quantity of the clay is increased, the permeability of the mould is reduced.

Clay is defined by the American Foundrymen's Society (AFS), as those particles of sand (under 20 microns in diameter) that fail to settle at a rate of 25 mm per minute, when suspended in water. Clay consists of two ingredients: fine silt and true clay. Fine silt is a sort of foreign matter of mineral deposit and has no bonding power. True clay supplies the necessary bond. Under high magnification, true clay is found to be made up of extremely minute aggregates of crystalline particles, called clay minerals. These clay minerals are further composed of flake-shaped particles, about 2 microns in diameter, which are seen to lie flat on one another.

(3) Moisture Clay acquires its bonding action only in the presence of the requisite amount of moisture. When water is added to clay, it penetrates the mixture and forms a microfilm which coats the surface of each flake. The molecules of water forming this film are not in the original fluid state but in a fixed and definite position. As more water is added, the thickness of the film increases up to a certain limit after which the excess water remains in the fluid state. The thickness of this water film varies with the clay mineral. The bonding quality of clay depends on the maximum thickness of water film it can maintain.

When sand is rammed in a mould, the sand grains are forced together. The clay coating on each grain acts in such a way that it not only locks the grains in position but also makes them retain that position. If the water added is the exact quantity required to form the film, the bonding action is best. If the water is in excess, strength is reduced and the mould gets weakened. Thus, moisture content is one of the most important parameters affecting mould and core characteristics and consequently, the quality of the sand produced.

3.1.2 Specification and Testing of Moulding Sands

Moulding sand is specified in terms of the size and shape of the silica grains it contains, the clay content, and the moisture content. These are determined as follows:

(1) Grain Size The grain size of sand is expressed by a number called *grain fineness number*. A given grain fineness number corresponds to a standard sieve of 280 mm diameter which has the identical number of meshes in it. To determine this number for a given sand sample, it is customary to use a standard sieve set (Fig. 3.2) which contains several sieves one above the other, having a varying but known number of meshes. The coarsest sieve is placed at the top and the finest at the bottom. After separating the clay and the moisture from the sand under test, the sample is placed in the top sieve and the whole set is shaken in a sieve-shaking machine for a definite length of time. The amount of sand remaining in each sieve is then collected, weighed, and expressed as a percentage of the original sample weight. The comparative sieve designations of IS, BS and ASTM sieves are given in Table 3.1.

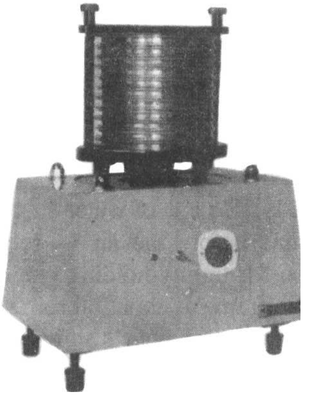


Fig. 3.2 *Sieve shaker*

The percentage collected in each sieve is multiplied by its own multiplying number—a given constant, one for each sieve—and all the products are added to arrive at the total product. Thus

$$\text{Grain fineness number} = \frac{\text{Total product}}{\text{Total sum of percentages collected in each sieve}}$$

Table 3.1 *Comparative sieve designations of IS, BS and ASTM test sieves*

IS SIEVE (MICRONS)	BS SIEVE	ASTM SIEVE
850	18	20
600	25	30
425	36	40
300	52	50
212	72	70
150	100	100
106	150	140
75	200	200
53	300	270

The grain fineness number is a concept that can be used for comparing finenesses of different sands. The distribution of different grain sizes present in a sand is a more significant test. For good compaction of sand, the amounts retained on 3 or 4 consecutive sieves should be in the range of 75–80%. In addition, the sieve distribution (percentage of sand retained on various sieves) should not show a double peak when the relationship between sieve size and percentage of sand retained are plotted. The distribution should show a normal curve with a single peak. Table 3.9 gives suggested values of grain fineness numbers of new sands suitable for casting various metals and alloys.

(2) Grain Shape The grains may be round, subangular, angular, or compound. The shape can be determined by observing the grains under a magnifying glass or microscope.

(3) Clay Content The total clay content in sand can be calculated by means of an apparatus called the *clay-content tester*. The sample under test is first dried and cooled and then a particular amount of it, say 50 g, is taken into a receptacle or jar. Finally, 475 cc of water and 25 cc of standard solution of NaOH are added to the sample before the jar is securely covered and sealed. The apparatus has a provision for tightly holding one or two or more such jars in a frame and rotating the whole frame at about 60 rpm so that the solution gets shaken vigorously.

After about an hour's rotation, the jar is removed and unsealed, and the sand adhering to the cover and sides is washed into the container. The jar is then filled with water to a predetermined mark, usually 150 mm above the bottom, the contents allowed to settle for 10 minutes, and water siphoned off to a depth of 125 mm. Water is again added up to the original mark and is once again siphoned off after allowing the sand to settle for ten minutes. The process is then repeated a few more times, allowing only a five-minute period for settling through 125 mm. The material that fails to settle down to 125 mm in 5 minutes, i.e., 25 mm per minute, is separated and removed from the container. This material is nothing but clay. The remaining sand in the jar is filtered carefully, dried for half an hour, and weighed. The difference between this weight and the original weight gives the weight of the clay.

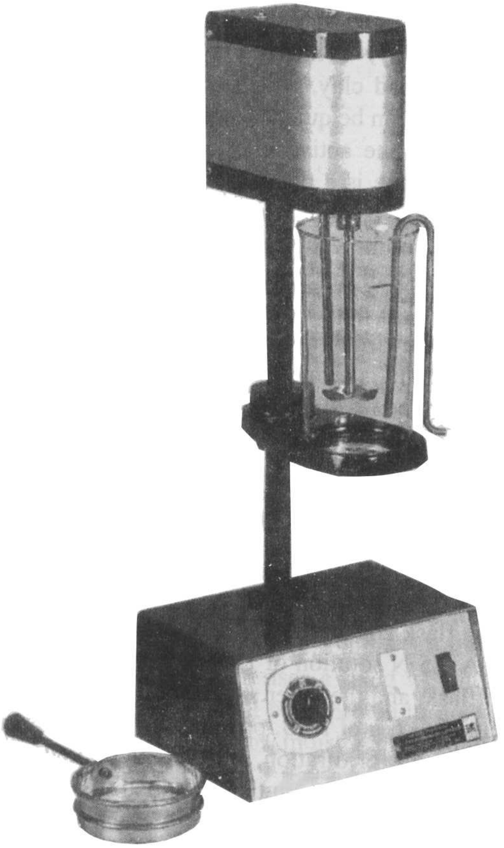


Fig. 3.3 *Clay content tester*

As seen above, total clay, expressed as AFS clay (so designated after the method of measurement prescribed by the American Foundrymen's Society), includes all particles finer than 20 microns in size, whether they be clay particles, silt or organic matter. Thus, AFS clay includes matter which does not function as effectively as clay, and its value may be misleading from a practical viewpoint. Besides total clay percentage, there are several other terms in use, which should be clear for proper understanding of sand characteristics.

True clay is expressed as AFS clay minus the weight of organic matter and water of hydration present. True clay thus includes fine particles of silt or dead clay, which do not function as effective clay or new clay and do not contribute to bonding properties.

Effective clay is defined as the clay equivalent to new clay in its bonding ability of developing desired properties in a system sand mix or used sand. It is, thus, the clay present in total clay which contributes effectively to developing bonding strength. It is necessary to maintain a close control on the effective clay present in a sand mix during moulding and particularly in case of closed-cycle machine-moulding operations.

When the sand is used and reused for moulding work, the clay particles, being subjected to high temperatures, lose their combined water and become incapable of bonding. They may also fuse and get burnt due to severe heating. A part of the effective clay is thus continuously converted into dead or burnt clay, which cannot contribute any more to bonding properties. New clay, therefore, has to be continuously added during each moulding cycle to make up for the loss.

For evaluation of the effective clay in a system sand or used sand mix, graphical representation is used. By taking new sand and clay mixtures and using varying amounts of moisture, the graphical relationship between green shear strength and green compressive strength is prepared for different sand–clay proportions. Once this graph is available, it can be used to evaluate an unknown system sand sample for effective clay percentage. The green shear and green compression values for the sample under test are measured and plotted on this graph. From the intersection of the two values, by interpolation, the effective clay percentage can be obtained. In place of shear strength, splitting strength and compactability values have also been used, leading to greater accuracy in results.

M.B. Clay (Methylene Blue Clay) The true clay present in a sand mix, excluding unwanted matter like silt or dead clay, which can effectively contribute towards developing bonding properties, can be quickly measured by the 'methylene blue dye absorption test'. The value of the active clay content so obtained, therefore, is called MB clay. Methylene blue is a convenient dye for the test. It exploits the base-exchange capacity of active clay and the inert nature of dead clay.

It can be seen that if the mulling efficiency is low, the coating of clay on sand grains would be inadequate and all the active clay present as MB clay would not be utilised to produce the bond. A part of the active clay may remain unutilised due to poor mulling operation or low mulling time. Such active clay which is not used effectively for producing a bond is termed 'latent clay'. Thus, due to poor mulling efficiency, effective clay may be less than the total MB clay, the difference being shown as 'latent clay'. Thus, in a sand-control programme, if the total MB clay is high but the effective clay is dropping, the proper response is not to add more clay but to develop the latent clay by improving the mixing efficiency.

To determine the total MB clay in a given sand mix, it is first necessary to breakdown the fines, clusters, clay balls and heavy coatings. This is usually accomplished by ultrasonic scrubbing for five minutes. Then, 5 g of the dry-sand mixture is taken in a 250-ml conical flask and 50 ml distilled water is added to it.

The slurry is shaken for 15 minutes. A 0.5 N solution of H_2SO_4 is then prepared, 2 ml added to the sand solution in the flask, and the latter shaken well.

Methylene blue solution (3.6 g of MB powder in one litre of distilled water) is prepared and filled in a burette for titration. It is added gradually to the mixture in the conical flask. Each time the MB solution is added, the flask is shaken and a drop from it placed, by means of a glass rod, on a filter paper. Initially, a faint blue spot is observed surrounded by a clear water ring. As titration proceeds and more MB is added, the colour of the spot changes from faint blue to dark blue with a clear water boundary. At a certain stage of titration, the clear water ring would change into a light blue-green halo, radiating outwards. The titration is stopped here and the volume of methylene blue added is noted from the burette reading.

A calibration curve is prepared in advance showing a straight-line relationship between the percentage of active clay (new clay) and volume of methylene blue, by taking varying amounts of clay-in-sand mix. From the calibration curve, the methylene blue value can be easily converted into the percentage of active clay in a given test mix.

The method can be readily used for measuring the active-clay content in sand. Instead of sulphuric acid, tetra sodium pyrophosphate is also being used for greater accuracy of results. Incoming clay consignments can also be tested for purity by the same method.

(4) Moisture Content This can be determined by taking a weighed sand sample, heating it in an oven so that all the moisture evaporates, and by reweighing it. The difference in weights will give the weight of the evaporated water. From this difference, the percentage of moisture can be calculated. Figure 3.4a shows a sand moisture-drying device.

As the conventional method is time-consuming and cumbersome, direct reading instruments are often used to quickly assess the moisture content. In one such instrument, called the moisture teller (Figs 3.4b and 3.5), the working depends

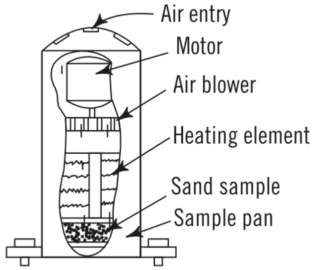


Fig. 3.4a *Sand moisture drying device*

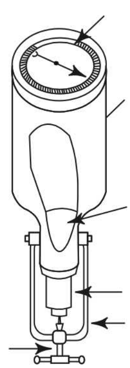


Fig. 3.4b *Moisture teller using calcium carbide*

Fig. 3.5 *Moisture teller*

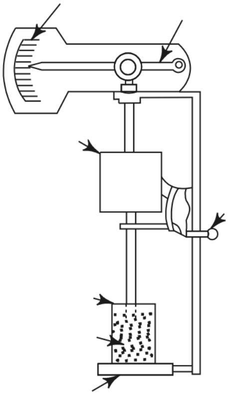


Fig. 3.6 *Direct-reading moisture indicator*

on the pressure of acetylene gas generated by the chemical reaction of carbide with the moisture present in the sand. Weighed amounts of sand sample and calcium carbide are placed in two compartments and then allowed to mix by shaking the container. The resulting pressure of the gas so generated is indicated on a scale, which is calibrated directly in the percentage of moisture. Figure 3.6 illustrates another type of direct-reading moisture indicator which uses a fixed weight for ramming the sand sample. A direct-reading apparatus cannot be expected to give very high accuracy of results. Specifications of equipment for moisture determination are covered by IS: 10034–1981.

(5) Bulk Density and Specific Surface Area The bulk density gives an indication of the packing properties of sand and can be used to check incoming sand supplies for consistency. Different sand samples can also be compared. The specific surface area is a measure of the roundness and fineness of sand grains and can be measured by apparatus available for the purpose.

(6) Acid Demand Value (ADV) This is a measure of alkaline matter in the sand. When using binder systems which are acidic in nature, or where the catalysts are weak or strong acids, the setting properties are considerably influenced by the presence of alkaline impurities. It can be used as a routine test on incoming sand supplies to confirm the source and maintain sand quality.

The test procedure is as follows:

(i) Take 50 g of a sand sample in a 600 ml-beaker and add 100 ml of 1N H_2SO_4. Heat at 50°C for 2 hours and cool.

(ii) Filter off through cotton and wash with hot water till the filtrate is acid-free.

(iii) Back-titrate the filtrate with 1N NaOH using methyl red as indicator.

(iv) Acid Demand Value = ml of 1N H_2SO_4 required to neutralise the alkalinity present in 100 g of sand.

For example, if the original amount of 1N H_2SO_4 is 100 ml, and 1N NaOH used in back titration is 90 ml

Material reacted = 10 ml

$\therefore$ ADV = 10

(7) Fines Content It is desirable to estimate the fines content in sand. 'Fines' is that portion of sand which passes through a 150-mesh sieve. The binder requirement of sand is significantly influenced by the fines content, so it should be kept below 3%.

(8) Loss on Ignition Organic combustible matter present as impurity leads to gas evolution and reduces the refractoriness of the sand. The amount of combustible matter is estimated by heating a weighed sand sample at 875°C for one hour, cooling, and finding the percentage loss in weight. This value is called loss on ignition.

(9) Sintering Temperature or Fusion Point The refractoriness of sand is determined by measuring the sintering temperature. The Pyrometric Cone Equivalent (PCE) value is also used as a measure of refractoriness. The test is carried out in accordance with IS: 1528 (Part 1)–1974 (See Fig. 3.17).

Besides determining the size and the shape of the grains, and the content of the clay and moisture, the evaluation of other features, as now outlined is also generally required for controlling sand mix properties.

(1) Mould Hardness The hardness of the mould is affected by the proportion of ingredients in the sand and the degree of ramming. It is tested by an instrument resembling a dial gauge (Fig. 3.7) and having a plunger protruding from a flat base. When the tester is placed base down on the mould surface, the plunger gets pressed and forced into the sand. The distance through which it moves depends on the mould hardness. The movement of the plunger actuates a spring and is indicated on a dial which is graduated from zero to hundred.

(2) Permeability Permeability and strength are two of the most essential properties of sand, and their values should therefore be as high as possible. Although the permeability and strength of sand depend primarily on the size and shape of the sand grains and the clay content, the required values would not be realised unless the correct quantity of water were mixed with the sand and the sand itself were rammed to a particular degree of hardness. If the sand hardness number does not exceed 85, it is observed that the product of the hardness number and the permeability remains a constant. Therefore, the permeability of any sand may be found by comparing the sample with a standard sand specimen whose hardness number and permeability number are known.

Fig. 3.7 *Mould hardness tester*

For absolute determination, permeability is tested with an apparatus known as the *permeability meter*. This has an arrangement for allowing a controlled amount of air to pass through a sand sample. The time taken for all the air to pass through the sample is measured. The principle of working and design of a permeability meter are delineated in Figs 3.8 and 3.9 respectively.

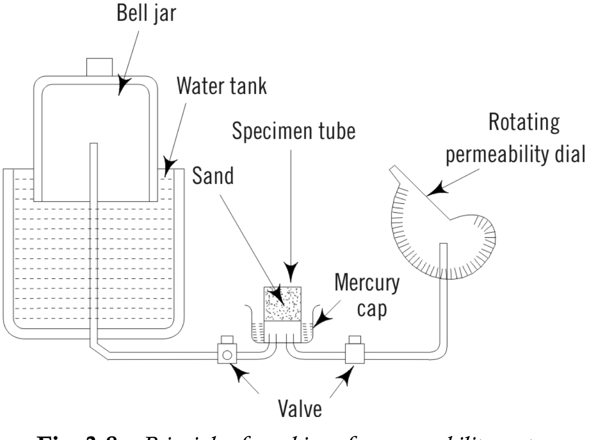


Fig. 3.8 *Principle of working of a permeability meter*

Permeability is expressed in terms of the permeability number, which is defined as the volume of air in cc that will pass per minute through a sand sample of 1 sq cm in cross section and 1 cm high, at a pressure of 1 gm per cm^2. Thus,

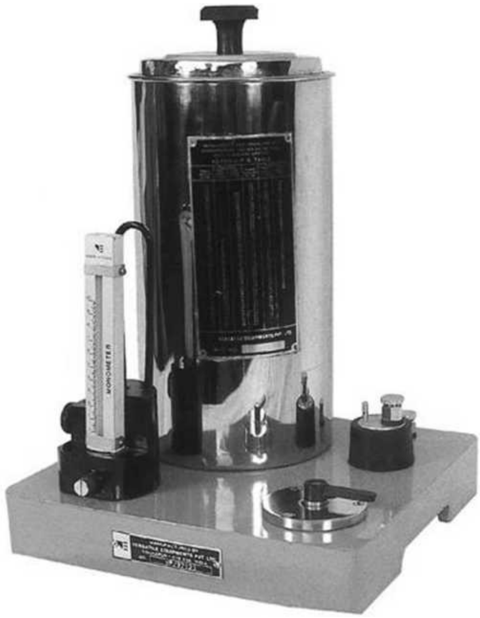


Fig. 3.9 *Permeability meter*

$$\text{Permeability number} = \frac{vh}{pat}$$

where v is the volume of air in cc;
h, the height of the sample in cm;
p, the pressure of air in g/cm^2;
a, the cross-sectional area of the sample in cm^2; and
t, the time in minutes.
IS: 10498–1983 covers the specifications of permeability meter.

(3) Strength Strength testers are used to estimate the compressive, tensile, and shear strengths of sand. The sand sample, as prepared by a standard sand rammer (Fig. 3.10), is placed in a holder and squeezed mechanically until it breaks. The force applied in squeezing it is shown on an indicator. The force registered at the breaking point is the compressive strength of the sand (Fig. 3.11). By changing the holder, the same tester may be used for testing shear and tensile strengths. Figure 3.12 shows a hydraulic-type sand strength testing machine, which can measure green and dry compressive strength of a sand sample. Figure 3.13 shows a lever-type universal sand-strength-testing machine, for testing compressive, tensile or sheer strengths. The specifications of a universal sand-strength testing machine are given in IS: 11099–1984.

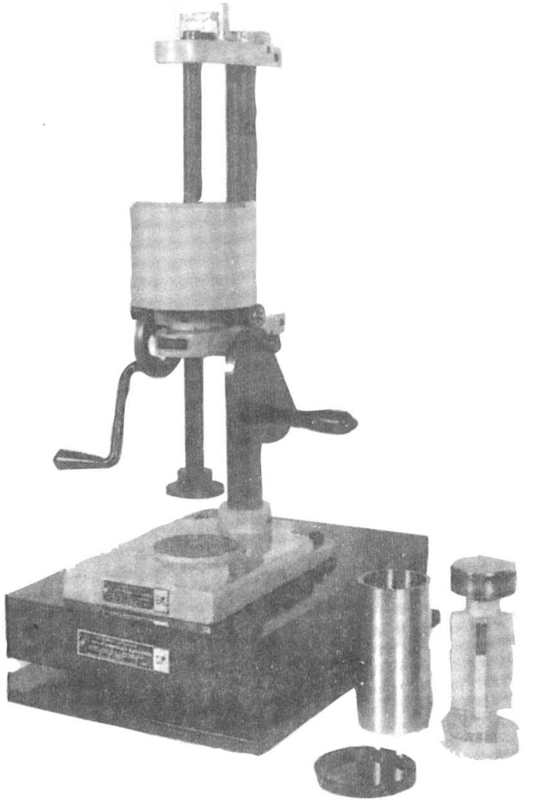


Fig. 3.10 *Sand rammer*

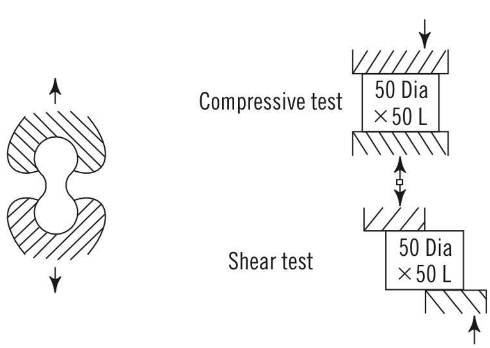


Fig. 3.11 *Principles of tensile, compressive and shear-strength test*

(4) Deformation and Toughness Deformation, also called plasticity of sand, is indicated by the decrease in length of the sand specimen during its green compressive strength test. The decrease in length occurring due to compressive load

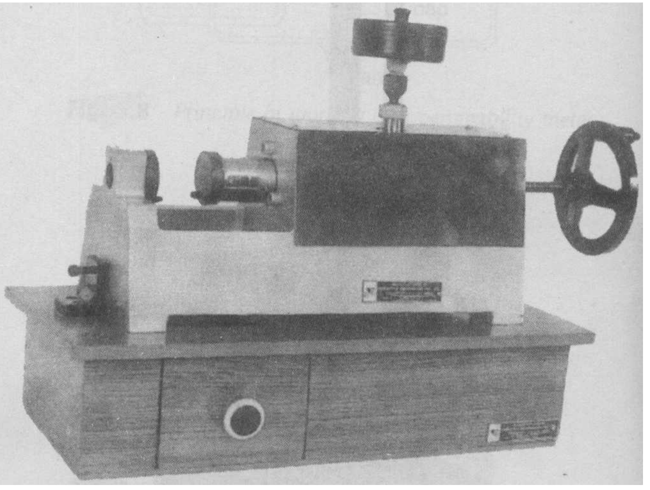


Fig. 3.12 *Sand strength tester (hydraulic type) with dry strength attachment*

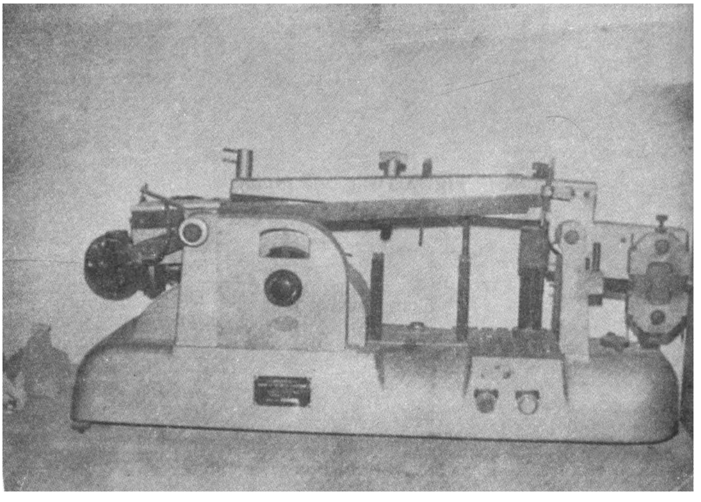


Fig. 3.13 *Universal sand strength testing machine*

just before the specimen fails is measured. High deformation value of the sand relates to better capacity of the moulds to withstand hydrostatic pressure as also to volumetric contraction of the casting.

Toughness is a term that relates deformation with green compressive strength and gives an idea about the quality of sand mix. Thus,

Sand toughness number = deformation (mm) × green compressive strength (kg/mm^2).

(5) Shatter Test This is also a measure of sand toughness, particularly the capacity of sand to withstand rough handling and strain during pattern withdrawal. It is specified by a shatter index number.

The apparatus for the shatter index test has provision for a standard specimen to fall through a given height onto a steel anvil. The broken pieces are put on a 12-mm mesh sieve. The ratio of the weight retained on the sieve to the total weight, percentagewise, gives the shatter index. Both extra low and extra high values of shatter index are deleterious to the mould (Fig. 3.14).

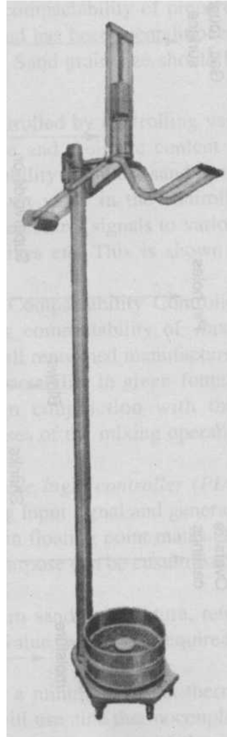


Fig. 3.14 *Shatter index tester*

(6) Compactability This test measures the percentage decrease in height from the original constant level of loose sand, under the influence of fixed compacting force. The test directly simulates the behaviour of system sands used on moulding machines. A specimen tube filled with loose riddled sand is rammed with three drops of the sand rammer, or squeezed at a chosen pressure, e.g., 10 kg/cm^2. The percentage decrease in height is read from a scale as *percentage compactability*. A compactability test accessory is available with the standard sand rammer.

Compactability is a direct measure of the degree of temper water of the sand. As the composition of the system sand changes, the moisture must chance to maintain the desired moulding characteristics, indicated by the compactability level. In practice, the compactability level (%) is selected on the basis of moulding performance and casting quality. Its value is maintained through appropriate adjustments in moisture additions. High compactability would indicate voids on the vertical faces of the mould. Low compactability would render the sand friable and subject to cuts and washes.

Figure 3.15 shows the effect of compactability on mould and casting quality.

Factors Influencing Compactability

(a) Sand cooling The bonding capacity of sand-bentonite – Water mix starts reducing above 50°C and becomes non-existent above 70°C. Therefore, cooling of the return sand is important. The higher the difference of ambient air temperature with discharged sand from muller, the higher will be the loss of moisture by evaporation. This evaporation loss lowers the compactability.

(b) Maintenance Mullers and mixers require regular maintenance to ensure proper mixing and dispersion of sand bond, carbon, new sand and organic additives.

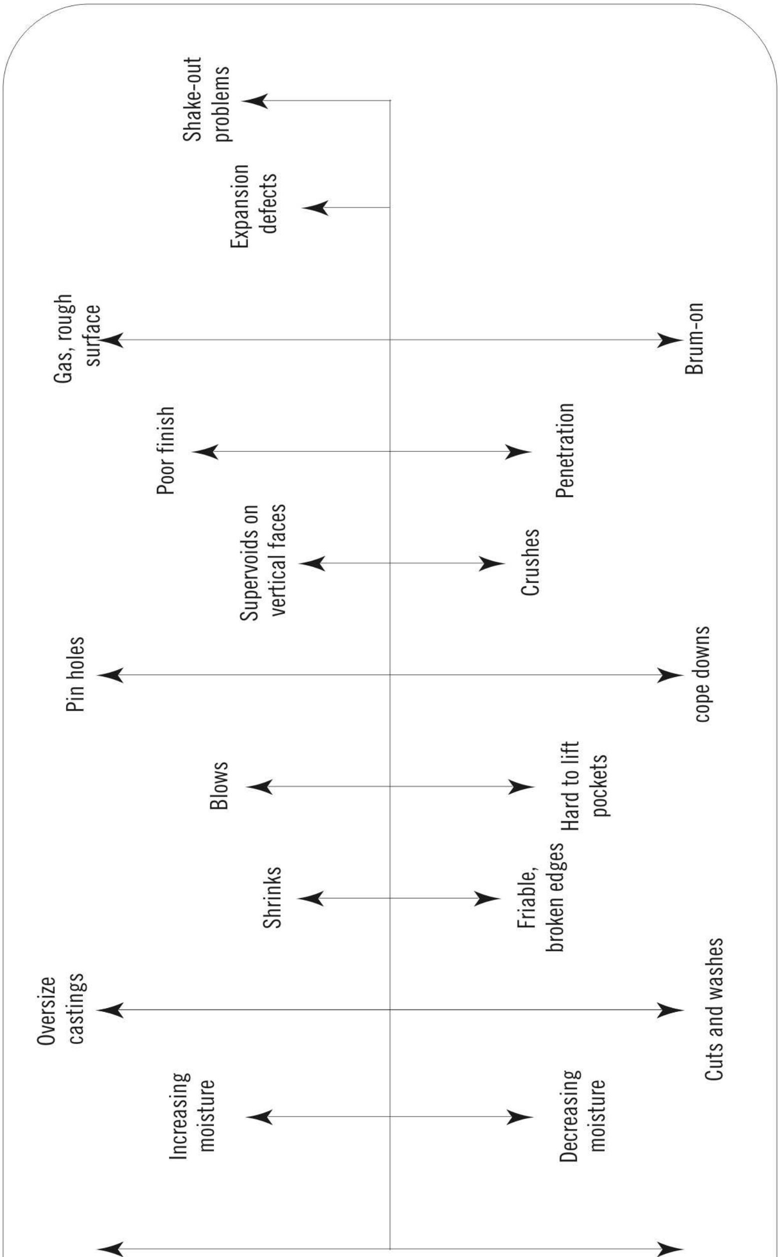


Fig. 3.15 Compactibility and its effect on mould and casting-quality

(c) Moulding sand preparation Reconditioning of system sands is one of the most difficult steps in moulding sand technology. The compactability of prepared sand is very much dependent on how well the return sand has been reconditioned. Dead clay, core lumps, metal pieces should be removed. Sand grain size should be within a narrow AFS band.

Compactability measurement Compactability is controlled by controlling various input parameters, taking cognizance of temperature and moisture content of new/conditioned return sand. After measuring the compactability of mixed sand in the compactability tester, the same is compared with the set value in the controller which is the *heart of the system*. The controller sends the control signals to various control points for controlling addition of water, additives etc. This is shown in Fig. 3.16.

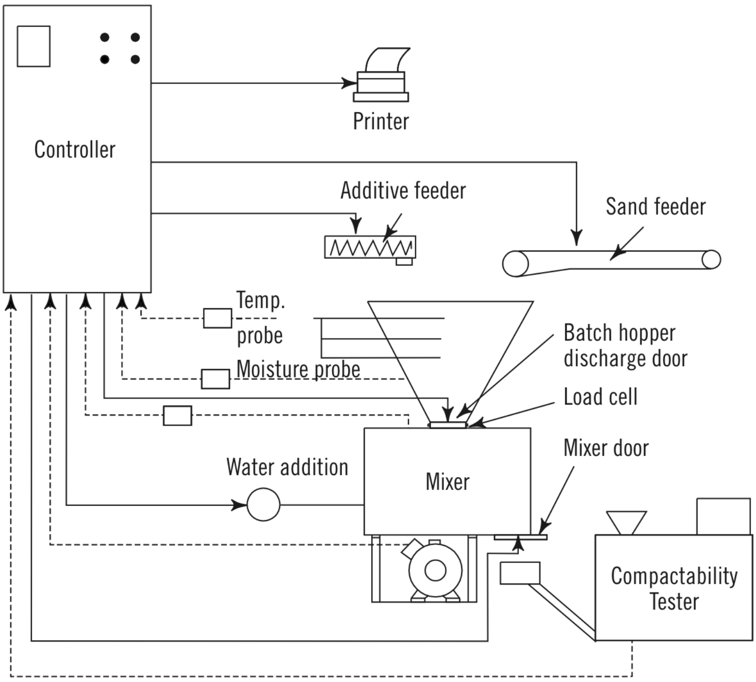


Fig. 3.16 *Schematic of compactability controlling system*

This unit is designed to control the compactability in green foundry sand prepared in a batch-and-continuous mixer in conjunction with their compactability tester. In addition, it controls all phases of the mixing operation from charging through discharging.

The heart of the control unit (PC) is a *programmable logic controller (PLC)*. The processor receives the analog input signal and generates an analog output signal with the help of PLC program in floating point math. The PLC software program, especially developed for this purpose, can be customised to fit the customer's specific mixer.

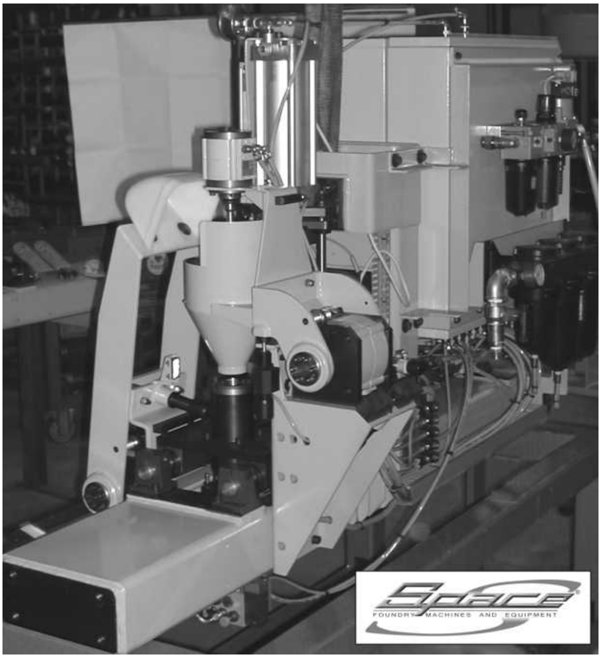


Fig. 3.17 *Automatic compactability Controller*

The program utilises the measured value of return sand temperature, return sand moisture, batch weight, and compactability set-point value, which are required to achieve accurate compactability.

The return-sand temperature is monitored by using a minimum of six thermocouples mounted in the batch hopper. (Larger mixers use nine thermocouples.) These are hot-tip, type-J thermocouples. They are mounted in groups of three on opposite sides of the batch hopper. Each group has three thermocouples of differing lengths to monitor the temperature at various depths, thus producing an accurate average temperature of the sand volume. The thermocouple leads are terminated in a junction box that houses two or three transmitters. These transmitters convert the temperatures to a 4–20 mA signal which is sent to the analog input module via a shielded cable.

The **return-sand moisture** is read as a conductivity signal through moisture probe. The PC control sends current between two copper electrodes immersed in the sand in the batch hopper. The current value flowing through the sand between these electrodes is proportional to the moisture present within the sand.

The next input is *batch size*. This is determined by weight, where the batch hopper is equipped with load cells, to produce the 4–20 mA signal necessary for the PLC input. The hopper sits on two pivot blocks and a load cell located in an equilateral triangle. The PC program is set to shut off the feed at a predetermined weight. It will take a second reading of the actual weight after the bin gates have closed or feed-belt stopped. The processor will calculate the percentage of overweight or underweight and make the corrections for the water requirements.

Once the temperature, moisture and volume are determined, the processor will calculate the water requirement. The water is added through a pulse flow meter and an air-driven diaphragm valve. All the water is added at the beginning of the cycle as flush water to achieve optimum blending. The water is normally started prior to feeding of the sand to help flush out the mixer. The PC control will signal the valve to open and remain open until the required number of pulses are counted through the flow meter, regardless of water pressure.

The above three items constitute most of the control which is done prior to the sand entering the mixer. The loop is closed by the compactability value obtained from the compactability tester. The compactability tester is installed at the discharge of the mixer. If the measured compactability does not match the desired compactability entered into the program, the set point value will be adjusted up or down slightly and alter the autotune algorithm in the controller to calculate the water requirement accordingly.

A current sensor to monitor the mixer motor is also included in the system for the protection of the motor. The outer door of the controller contains the touchscreen that indicates the status of the various functions of the mixing operation and the inputs that allow the system to be run in automatic or manual mode.

There are many display functions such as temperature at thermocouples, conductance of return sand, water required, measured and set compactability, etc. In addition, the user can access and change all set points which control the mixing cycle. Some examples are desired compactability, bond feed, and mulling time. The touchscreen will display system-failure messages, generate a hardcopy printout of the system performance as well as diagnostic help screens.

Performance Capability The suggested system is capable of controlling prepared green sand to within ± 4 points compactability from the desired 99.99% of the time on a properly designed system (as described below) where good sand-handling practices are followed. Most systems typically operate at ± 3 points 90% of the time, with actual results varying from system to system, depending on the system design and sand-handling practice. Tests that are deemed *out of control* due to special causes will be ignored when measuring performance.

Description of a properly designed system and good sand-handling practices

1. Adequate sand should be maintained so that the system only turns over a maximum of 4 times per shift. Bins and smoppers should be designed to prevent *funnelling*.
2. Spilled sand and unpoured mould sand should be returned back with the used return sand on a continuous basis.
3. The mixer-muller should be operated in automatic mode continuously at the manufacturer's specifications. Maximum batch-system delays between

batches of 3 minutes or less should be maintained. Maximum continuous system shutdown of 3 per hour or less should be maintained.

4. Batch systems should be designed to furnish an accurate weight of each batch. Continuous systems should be designed to furnish a slow, even and constant charge of sand to the mixer-muller.
5. All water additions to the sand system should be as per specifications and controlled automatically by the control system.
6. All other additives to the sand should be controlled resulting in consistent sand properties with a methylene blue range not to exceed 1.0%.
7. Return-sand moisture should be above 0.7%, but should not exceed the level required to meet the customer's desired compactability.

(7) Mouldability Mouldability and compactability are similar terms, the former denoting the condition of the sand before compaction and the latter the condition after compaction. The mouldability tester (Fig. 3.18) consists of a rotating sieve with a timer arrangement and a powerful electric lamp over the sieve. A standard 50-mm specimen is placed in the cylindrical sieve and the latter is rotated at a fixed speed for a given time. The weight of sand lumps retained on the sieve indicates mouldability.

Fig. 3.18 *Mouldability tester*

(8) High-Temperature Characteristics Apart from the vital properties just covered, it is also useful to evaluate the high-temperature characteristics of sand. These tests attempt a realistic evaluation by simulating in the laboratory the conditions under which a mould is used in the foundry.

Specimens subjected to high-temperature tests are evaluated for their (i) hot compressive strength; (ii) hot deformation; (iii) expansion; and (iv) refractoriness. Hot compression and hot deformation tests are carried out in a special furnace, called a *thermolab dilatometer* (Fig. 3.19), in which the specimen is heated to testing temperature, soaked at that temperature for a fixed period, and then subjected to the compressive test. Hot tensile strength is also measured in the same apparatus. By using a suitable attachment, hot deformation and collapsibility can also be estimated. A special apparatus is available for measuring expansion characteristics.

Refractoriness of sand is evaluated by measuring the sintering point of sand and a sintermeter (Fig. 3.20) is used for the purpose.

Several core and mould binders produce a large amount of gas while burning. In case of self-hardening and no-bake processes, the gas evolved during casting, as the binders burn is enough to produce defects, like gas holes, blow holes, cavities and porosity in castings. It is, therefore, desirable to measure the quantity of gas produced. Figure 3.21 shows a gas determinator used for measuring the volume of gas produced from a given sand sample.

Fig. 3.19 *Sand testing thermo-lab dilatometer*

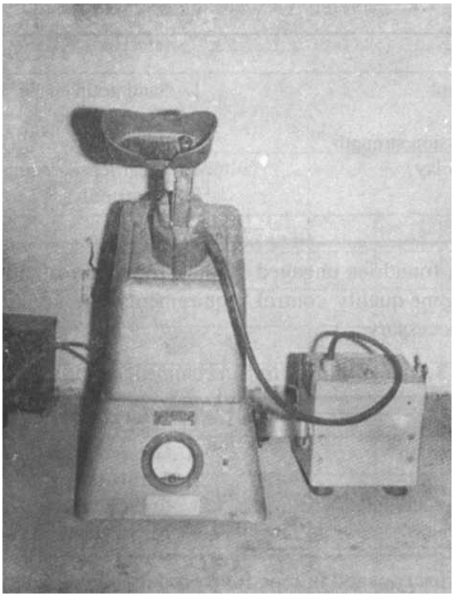


Fig. 3.20 *Sinter meter*

Fig. 3.21 *Core gas determinator*

3.1.3 Routine Sand Testing Programme

Each foundry should draw out a minimum test programme which should be strictly followed for control of the sand system. The type of tests to be performed on a routine basis and their frequency will depend on the nature of production, type of sand system used, sources of raw material, and complexity grade of castings produced. In general, however, the tests given in Table 3.2 could be accepted for a minimum sand control for jobbing-type foundries:

Table 3.2 *Minimum tests recommended for sand control*

For moulds	For cores
1. Moisture content	1. Sand grain shape, size and distribution
2. Permeability	2. Clay content
3. Green compression strength	3. Permeability
4. Total (AFS) clay	4. Shear/tensile/compressive strength
5. Sieve analysis	5. Sinter point
6. Combustibles	

In case of large foundries engaged in the production of multifarious types of castings with stringent quality control requirements, the additional tests given in Table 3.3 may be necessary:

Table 3.3 *Additional tests recommended for sand control*

For moulds	For cores
1. Green shear strength	1. Gas evolution
2. Shatter index	2. Curing tune
3. Dry compressive strength	3. Collapsibility
4. Acid demand value	4. Any special tests

In case of foundries engaged in repetitive production using unit sand system with high-speed machine moulding on semi-continuous or continuous cycle basis, the following tests are also recommended:

1. Compactability
2. Splitting strength
3. Specimen weight
4. MB total clay
5. Effective clay
6. Total combustibles
7. Volatile matter
8. Mouldability
9. Deformation

Standard Silica Sand for Raw Material Testing Many raw materials used in foundries as sand binders, for example, shell resins, hot and cold box resins, bentonite, dextrin, core oils, etc., are tested by preparing a standard sand mix and testing its physical properties. These properties, apart from depending on the quality of the raw materials under test, are affected by the quality of sand used for testing. Keeping this in view, specifications for standard silica sand have been prepared and published as IS: 3018–1977. This standard sand can be easily prepared in the laboratory from raw silica sand. The sand specified for the purpose is required to conform to Grade A of IS: 1987–1974, having rounded grains, moisture up to 0.1%, clay content up to 0.2%, sintering temperature 1685°C minimum, acid-demand value up to 8 mg/100 mg of sand, and grain fineness number between 40 and 52. The percentage sand retained on 425, 300, 212 and 150 micron IS sieves shall be 9 to 14%, 20 to 30%, 30 to 40% and 15 to 25%, respectively.

In foundries using sand moulding and core-making, it is essential to maintain sand-testing data in the form of sand test reports as shown in the formats given on pages 85 and 86.

3.1.4 Classification of Moulding Sands

Moulding sands may be classified into four different types:

(1) natural moulding sands;
(2) high silica sands;
(3) special sands; and
(4) bonding clays.

(1) Natural Moulding Sands These sands occur as deposits in various parts of the country, such as Kanpur, Jabalpur, Rajkot, Bhavnagar, Secunderabad, Guntur, Damodar (West Bengal), Barakar (Bihar), Burdwan, and Jamalpur. They possess an appreciable amount of clay which acts as a bond between the sand grains. The quantity and type of clay minerals present affect the strength, toughness, and refractoriness of the sand. The clay may belong to different mineralogical groups, such as kaolinite, montmorillonite, halloysite, dickile, and nacrite. The other minerals present as contaminants, namely, feldspar, Fe_2O_3, CaO, MgO, K_2O, and Na_2O, lower the refractoriness.

Natural moulding sands are obtained by crushing and milling soft yellow sandstone, carboniferous rocks, etc. During the milling operation, clay aggregates break down and clay particles get uniformly distributed over the sand grains. These sands usually have clay bond in excess of the minimum needed for developing the necessary strength in the sand mixture. To get the desired properties, crude silica sands such as those obtained from river banks and dunes, which are relatively free of clay, are mixed with natural sands.

Sand Test Report (Page 1)

For the week from (Date) ———— to (Date) ————

Name of the Foundry:

1. Sieve Analysis Data

US Sieve No.	Retained on Sieve		Multiplier	Product				
	GRAM	%						
20 mesh			10					
30 mesh			20					
40 mesh			30					
50 mesh			40					
70 mesh			50					
100 mesh			70					
140 mesh			100					
200 mesh			140					
270 mesh			200					
PAN			300					
Total								

AFS Grain Fineness No.

Notes:
1. During sieve analysis, up to 140 mesh is considered as sand fraction.
2. Below 140 mesh can be taken as *clay fraction*.
3. (Total AFS clay) minus (LOI of clay fraction) = (AFS clay excluding combustibles) (*on clay washed sand*).
4. From AFS clay, excluding combustibles, subtract MB active clay. This gives inert fines in the sand system.
5. Sieve analysis of new sand can also be conducted during the week (at least 2 readings can be recorded).

2. Other Test Results

Total AFS Clay	(%)	:
Permeability (from the mean value record)	(No.)	:
LOI Before Clay Wash	(%)	:
LOI After Clay Wash	(%)	:
Methylene Blue Active Clay	(%)	:

3. Additions in the Muller

Batch size : ———— kg

New sand : ———— kg

Bentonite : ———— kg

Coal Dust (or its Substitute) : ———— kg

4. Remarks, if any

Laboratory Incharge

Sand Test Report (Page 2)

For the week from (Date) ———— to (Date) ————

Name of the Foundry:

Properties		Dates					
Moisture (%)	Max.						
	Mean						
	Min.						
Compactability (%)	Max.						
	Mean						
	Min.						
Gr. Compr. Str. (psi) or (g/cm^2)	Max.						
	Mean						
	Min.						
Gr. Splitting Str. (psi) or (g/cm^2)	Max.						
	Mean						
	Min.						
Gr. Tensile Str. (psi) or (g/cm^2)	Max.						
	Mean						
	Min.						
Permeability (No.)	Max.						
	Mean						
	Min.						
Specimen Weight 2″ × 2″ (or 50 × 50 mm), g							
Total AFS Clay (%)							
Methylene Blue Active Clay (%)							
Loss on Ignition (%)							
Volatile Matter (%)							
Batches prepared in the Sand Muller (Nos.)							
Batches tested in the Sand Lab. (Nos.)							
Items produced (Nos.)							
Moulds Broken (Nos.)							
Remarks: (Surface Finish, Main Sand Defect, Abnormal findings, etc.)							

Sand Technologist

By virtue of their ease of availability and low cost, natural moulding sands are used for most of the casting of both ferrous and non-ferrous metals. The requirements of these sands are satisfied by IS: 3343–1965, which has classified them into three grades A, B, and C, according to their clay content and sintering temperature:

	Grade A	Grade B	Grade C
Clay percentage	5–10	10–15	15–20
Sintering temperature	1350–1450	1200–1350	1100–1200

The grain shape of these sands is required to be subangular to round. According to the distribution of sand grains, the sands of grades A, B, and C may belong to any one of the eleven sub-grades listed in Table 3.4.

Table 3.4 *Sub-grades of sand*

Sub-grade	Fraction retained on IS sieve designation (micron)	Percentage (minimum)
850/450	850, 600, 425	60
600/300	600, 425, 300	60
425/212	425, 300, 212	60
300/150	300, 212, 150	60
212/106	212, 150, 106	60
150/75	150, 106, 75	60
850/300	850, 600, 425, 300	60
600/212	600, 425, 300, 212	60
425/150	425, 300, 212, 150	60
300/106	300, 212, 150, 106	60
212/75	212, 150, 106, 75	60

Natural moulding sands possess high flexibility of operation. Unlike the synthetic sands (see 3.1.5), here accurate adjustment of moisture is not required and the range of permissible moisture is high. These sands are therefore suitable for hand moulding, particularly for light castings that use dry sand for moulding. The quantity of sand required in such cases is large.

(2) High Silica Sand These sands contain less than 2% of clay, alkalies, and minerals. They occur as loose or poorly consolidated deposits of sedimentary origin, dunes blown inland from the coast, or accumulated deposits in estuaries and rivers along the coast. They are also produced by first crushing quartzite sandstones of open texture, and then washing and grading these to yield a sand grade of requisite shape and grain distribution.

IS: 1987–1974 covers the requirements of high silica sand for use in foundries and classifies it (Table 3.5) into three grades according to the silica content.

Table 3.5 *Classification of silica sands*

Grade	Silica	Alumina (max)	Iron oxide (max)	Ca and Mg oxides (max)	Alkalies (max)
A	98	1.0	1.0	1.0	0.5
B	95–98	1.5	1.0	1.0	0.5
C	90–95	2.0	1.5	2.0	1.5

The clay content of high silica sands should not be more than 2%. The grain distribution should fall under one of the specified grades, viz., 850/425, 600/300, 425/212, 300/150, 212/106 and 150/75. The sintering temperature for grade A should be in the range 1685–1710°C.

Choice of Base Silica Sands for Ferrous Foundries The quality of the base sand has a significant influence on the quality of the casting produced.

The properties given in Table 3.6 should be considered in the selection of base sand: (i) silica content, (ii) clay content, (iii) sieve grading and grain fineness number, (iv) grain shape, (v) bulk density and specific surface area, (vi) fines content, (vii) loss on ignition, (viii) acid demand value, (ix) sintering temperature, and (x) moisture.

Table 3.6 *Suggested sand sources, (regionwise) and suitability*

Region	Source	IS grade	Suitability for cast metals
Northern	(a) Rajasthan (Jaipur) (b) Allahabad Shankargarh	A, B, C	Small, medium and heavy iron castings and steel castings
Southern	(a) Gudur (b) Chirala (c) Tungabhadra, Harihar	C C C	Iron castings up to 1 tonne
	(d) Cochin (e) Mangalore	A, B, C	Small, medium and heavy iron castings and steel castings
	(f) Hyderabad	A, B	Quartz, suitable for heavy iron castings and steel castings
Eastern	(a) Barakar	C	Small iron castings up to 1 tonne
	(b) Rajmahal	A, B	Heavy iron castings and steel castings
Western	(a) Goa	C	Small and medium iron castings up to 1 tonne
	(b) Ratnagiri (c) Vengurla	A, B, C	All types of iron castings and steel castings
	(d) Saurashtra (Rajkot)	C	Small iron castings
	(e) Phondaghat	B	Heavy iron castings

(3) Special Sands These sands are ideal for achieving special characteristics, which are not otherwise possible in ordinary silica sands. Zircon, olivine, chamotte, chromite, and chrome-magnesite are often used as special sands.

Zircon sand Chemically, zircon is zirconium silicate ($ZrSiO_4$). This sand has certain outstanding characteristics which distinguish it from other sands. These are given below:

(i) Low thermal expansion—being only l/6th that of silica sand—which strengthens the mould against thermal and mechanical stresses and helps in producing accurate castings, free from scabbing defects;

(ii) Chemical inertness to the action of molten metals which enhances the finish of castings while protecting them from sand burns; this property is particularly useful for high alloy steel, such as high chrome steels and manganese steels;

(iii) High heat conductivity, about double that of silica sand, which promotes quick formation of a solidified metal layer and helps in producing castings with a fine-grained structure;

(iv) Greater density than that of silica sand, which prevents metal penetration; and

(v) High sintering temperature and refractoriness, which hinders sand burns and enables the casting of high melting point metals to be produced.

Zircon sand is required in greater volume than silica sand due to its high density. Mixing times are longer and good venting is necessary. The unit cost of this sand is very high and, for this reason, it finds use only as facing sand for iron, steel, and alloy steel castings. The sand mix is prepared from zircon sand with 2–3% bentonite and 2–3% temper water. It is suitable for cores of brass and bronze castings. In India, zircon sand is found in Kerala. There are extensive deposits of high-quality zircon sand in Australia. Good-quality zircon sand should have minimum of 65% ZrO_2, maximum of 0.6% TiO_2. and maximum of 0.15% Fe_2O_3. Its clay content should be nil and moisture 0.1% maximum.

Olivine sand This is orthosilicate of iron and magnesium (MgFe) $O.SiO_2$ and it occurs as forsterite and fayalite. Its density, conductivity, and refractoriness are higher than those of silica sand. Its fusion point is high about 1800°C and as such, it is favoured for heavy sections of alloy steel castings. Its resistance to slag reaction makes it suitable for the casting of high manganese steels. Some foundries also use olivine sand for non-ferrous castings of an intricate nature. The largest deposits of olivine sand are found in Norway. It is covered by IS: 7297–1974.

Chamotte This is produced by calcining high-grade fire clay at about 1100°C and crushing it to the required grain size. The chemical composition on a dry weight basis is.

Al_2O_3	$Si.O_2$	Fe_2O_3	CaO and MgO	Loss on ignition
40% min.	30% min.	4% max.	2% max.	0.5% max.

Its refractoriness (fusion point) is 1780°C, and maximum of 7% water-absorption capacity. The thermal expansion is low and it has negligible affinity to liquid steel.

Chamotte is much cheaper than zircon or olivine. Yet its characteristics make it valuable for heavy steel castings. A mixture of chamotte sand for steel casting may consist of 70–72% chamotte, 18–20% fire clay, 1% graphite, and 8–10% water. The mix may have a green compression strength of 700–800 g/cm^2, dry compression of 10–12 kg/cm^2, and dry shear strength 2.5–3.5 kg/cm^2. Chamotte is covered by IS: 7295–1974.

After preparing chamotte moulds, a mould wash, again made of chamotte, may be applied. The wash is water-based and contains about 7% fire clay, 4% sulphite lye, 1% graphite, and 33% water, the rest being chamotte.

Chromite and Chrome-magnesite sands These sands have a high degree of refractoriness, high density, and high chilling power. Binder and temper water requirements of chromite sands are very low. Further, they are not easily wetted by molten metal. These sands are useful particularly where the chilling tendency is to be increased to control solidification. They are also suitable as facing materials in moulds for steel castings.

Chromite sands are covered by IS: 6788–1973. A chromite sand mix may contain 2–3% bentonite and about 2% temper water. A cereal binder may be added, if required. Table 3.7 shows the properties of various types of sands used for moulding.

Table 3.7 *Properties of various types of sounds*

DATA	SILICA SAND	CHAMOTTE	ZIRCON	CHRO-MITE	MAGNE-SITE	CHROME-MAGNESITE
Availability	Very abundant	Abundant	Limited	Good	Good	Good
Refractoriness °C (approx)	1700	1780	2500	1850	1850	1850
Thermal expansion (× 1000 mm/m)	.019	.0052	.0032	.007	.014	.012
Thermal conductivity	9.5–12.5	6–9.5	12–15	9–15	20–30	13–20
Wettability with molten metal	Easily wetted	No problem	Not easily wetted	No problem	No problem	No problem
Approx. cost (Rs per tonne)	150	200	750	1800	820	1200

(4) Bonding Clays

Bentonite, the most common type of bonding clay, is used with high silica sands as a green sand additive to increase the bonding action and impart plasticity. It belongs to the montmorillonite group of minerals and possesses typical characteristic properties. It enhances strength without requiring drying. Unlike other bonding materials, bentonite can be re-circulated in closed systems and the bond is generated simply by the addition of water. No swabbing or dusting is required; patterns are easily stripped and moulds quickly produced. Moreover, bentonite resists erosion of moulds and its volumetric contraction helps in compensating the expansion of silica grains.

Bentonites are of two types, viz., sodium bentonite and calcium bentonite, depending on the kind of substitution metal present. The chemical composition is

$$\begin{array}{c} Na.33 \\ \uparrow \\ \text{Sodium bentonite: } (Al_{1.67}\ Mg_{0.33})\ Si_4O_{10}(OH)_2 \end{array}$$

$$\begin{array}{c} Ca_{0.33} \\ \uparrow \\ \text{Calcium bentonite: } (Al_{1.67}\ Mg_{0.38})\ Si_4O_{10}(OH)_2 \end{array}$$

Sodium bentonite produces high swelling properties, high dry strength, very high hot strength, high liquid limit, low plasticity, and low green strength.

Calcium bentonite produces low swelling properties, low dry and hot strength, low liquid limit, high plasticity, and high green strength. Bentonites of both types are found in abundance in the country. Both Na and Ca varieties have been traced in Bhavnagar and Kutch (Gujarat). Na-Bentonite is found also in Jodhpur (Rajasthan) and Ca-Bentonite at Tinpahar, near the Rajmahal hills in Bihar, and also in Chennai and Kashmir.

The requirements of sodium- and calcium-base bentonites are given in Table 3.8 for guidance.

Tests used in the Evaluation of Bonding Clays The following tests are desirable for the evaluation of bentonite or other bonding clays for the purpose of deciding suitability for various casting requirements:

(i) Moisture content
(ii) pH value
(iii) Liquid limit
(iv) Gelling index
(v) Swelling capacity
(vi) Cone fusion temperature
(vii) Bonding properties, e.g., green and dry compressive strength and shatter index of a sand mix prepared under standard conditions.

Table 3.8 *Requirements of Na- and Ca-base bentonites*

Characteristics	Moisture content %	pH value at 2% susp.	Gel index (min)	CaO replaceable Ca++ (ions) %	Fineness Dry: To pass through 100 mesh BS (150 μm) IS	Fineness Wet: To pass through 150 mesh BS (75 μm) IS	Fineness Wet: To pass through 300 mesh BS (45 μm) IS	Liquid Limit
Sodium base	5–12	9–11	60	0.7	97	90	95	500
Calcium base	5–12	8–9	10	3.0	97	90	95	250

The procedure for carrying out these tests and the values required for sodium and calcium base bentonites are given in IS: 12446–1988.

3.1.5 Use of Synthetic Sands

Synthetic sands are basically high silica sands containing little or no clay binder in natural form. The desired strength and bonding properties of these sands (unlike in the case of natural moulding sands) are developed by separate additions of clay in the form of bentonite. This allows greater flexibility in the control of properties such as green and dry strength, permeability, and others that can be precisely varied at will. These sands therefore have much more powerful bonding properties than natural sands and give a better uniformity of product. After re-use, only fresh clay need be added to make up the loss due to dead clay, and a small quantity of new sand suffices to prevent the high build-up of dead clay. Thus, the total requirements of both sand and bentonite clay are small and the process is much more economical for close-cycle operation on moulding machines. Use of synthetic sand does away with the practice of the two-sand system, facing and backing sands making it more convenient for machine moulding. As only one sand mix is used, this system is also called *unit sand* or *system sand* system. In natural sands, on the other hand, fresh sand containing clay has to be constantly added in large quantities. Figure 3.22 shows the effect of moisture, specimen weight, permeability and green compressive strength on process parameters and resulting casting defects.

In order to develop optimum properties in synthetic sands, precise control of moisture is necessary and the range of moisture permissible is small. Figures 3.23, 3.24 and 3.25 show typical characteristics of synthetic sands, which can be considered while selecting process parameters. It is not much suited to hand-moulding work where patching and repair are habitual. Synthetic sands are also more expensive than natural sands. In jobbing foundries, synthetic sands prove

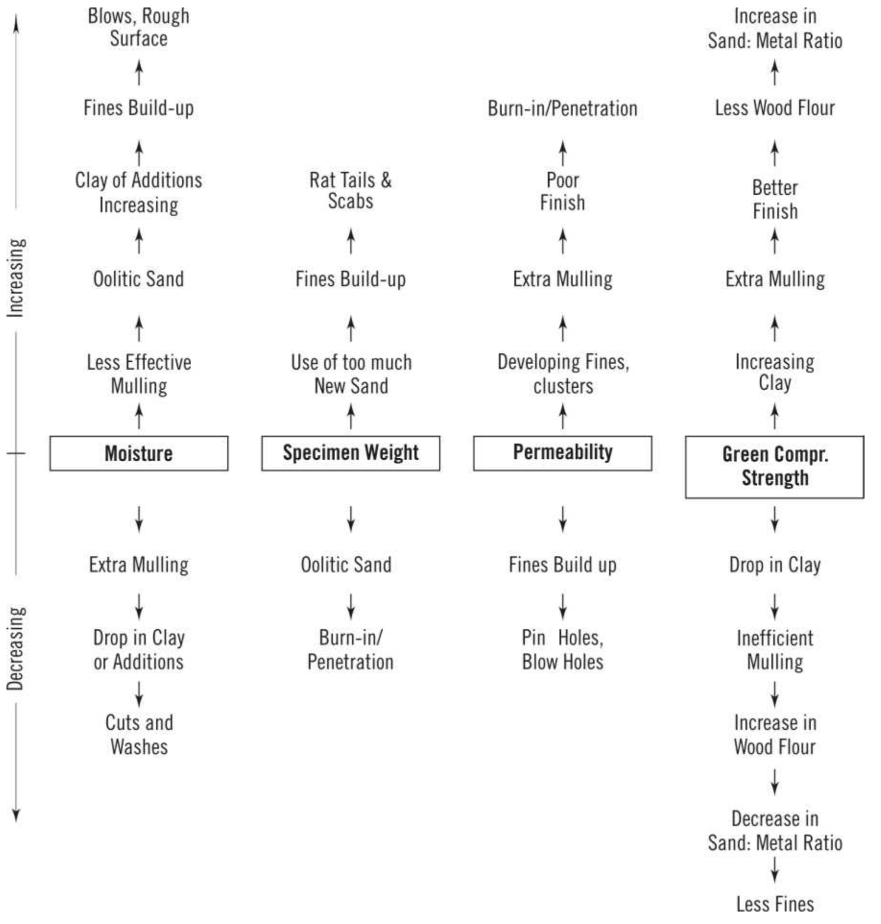


Fig. 3.22 *Effect of moisture, specimen weight, permeability and green compressive strength on process parameters in unit sand (Courtesy: HW Dietert & AL Grahm)*

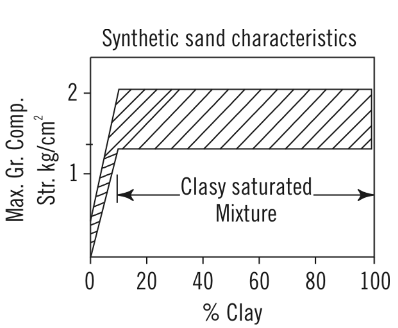


Fig. 3.23 *Effect of clay content on green compressive strength of synthetic sand*

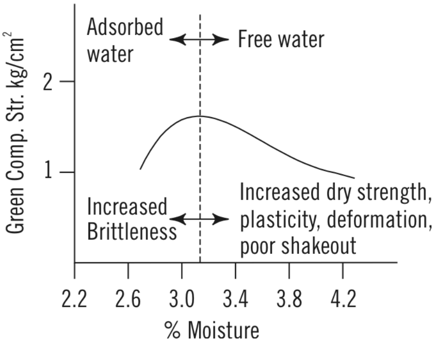


Fig. 3.24 *Effect of moisture content on green compressive strength of synthetic sand*

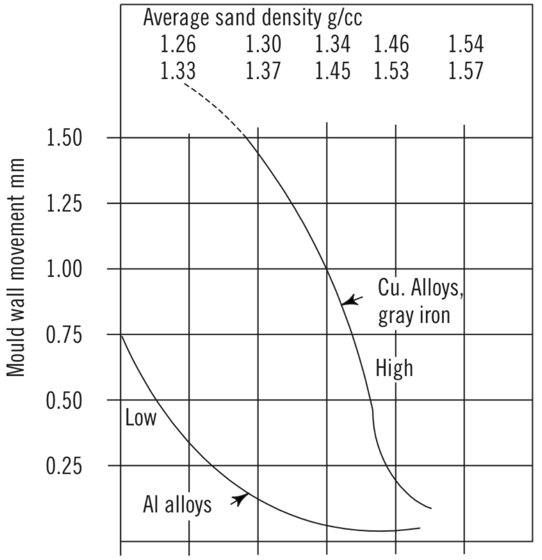


Fig. 3.25 *Effect of mould hardness on mould wall movement in case of synthetic sand*

suitable if patterns are of good quality and a reasonable rate of delivery of sand that has controlled moisture content can be assured. But these conditions do not often prevail in jobbing foundries.

Applications of natural moulding and synthetic sands are given in Table 3.10.

Table 3.10 *Applications of natural moulding and synthetic sands*

TYPE OF SAND	APPLICATIONS	REASONS
Natural moulding sand	Light castings	Permeability is not important and only good surface finish may be required.
	Jobbing foundry	Only a few castings may be required; patterns may be of poor quality.
	Mechanised production of castings with few cores	There is little influx of sand from cores.
	Dry sand moulding	High permeability is not necessary as little gas is evolved; patching is easy.
Synthetic sand	Heavily cored castings	At shake-out, large amounts of clay-free core sand enters moulding sand; regular clay additions are possible.
	Mechanised production	Better hardness and uniform properties can be obtained.
	High pressure moulding	Results in good hardness and permeability, easy stripping, high strength, and toughness in mould.

Unit Sand In a steel or iron foundry, green sand moulding is quite common with the application of specially prepared *facing sand* over the pattern to a depth of 2 to 3 cm and subsequent layer covered with *backing sand*. But with the development of highly automated fast production moulding techniques, it became essential to supply a single moulding sand with consistent properties, eliminating the use of facing sand application, to cope up with the production speed. Here, return shake-out sand with appropriate addition of new sand and other additives with optimum workable properties is repeatedly cycled in the sand system. This unit sand caters to the need of the foundry, covering a wide range of product mixes with more or less constant addition of ingredients in the sand mixer.

In an iron foundry, unit sand comprises

(a) Return shake-out sand
(b) New sand
(c) Bentonite
(d) Coal dust or substitute of coal dust
(e) Water to correct temper

Return Shake-out Sand Characteristics of return shake-out sand will depend on

1. Surface area of the moulding sand in contact with the metal
2. Metal pouring temperature
3. Section thickness of the casting
4. Time taken from the time of pouring the metal till the moulds reach the shake-out station (red hot shaking out of castings is not preferable.)
5. Sand : metal ratio—if higher ratio is maintained, hot sand problem can be minimised
6. Storage capacity of the return shake-out sand bunker(s). It should be sufficiently large. If less, then in high production lines, number of circulations in the shift will increase, which will result in hot sand problem, if proper cooling devices are not incorporated in the sand system.
7. With different product mixes in the production schedule and with or without cored items, characteristics of the return sand will fluctuate over a wide range, which will call for strict control in the binder additions in the sand mixer.
8. When chemically bonded sand cores are used in the line, burn-out of the cores will vary depending on the core-making process employed and accordingly new sand addition in the muller is to be controlled.
9. Proper cooling arrangement in the sand system to bring down the temperature of hot shake-out sand to ambient temperature is essential.

Up to 40°C temperature of the return sand, and excellent control of the properties of the prepared green moulding sand can be maintained with minimum variation.

With 40 to 50°C temperature of the return sand, properties of the system sand can be controlled with extra precautions.

If the temperature of the return sand goes above 50°C, sand control will become erratic and inconsistent with abnormal fluctuations, resulting in increased casting rejection due to sand.

Hot Return Sand and Its Effect

With a sand-to-metal ratio of 5 : 1, the average shake-out temperature will be around 120°C and the total sand in the box will get dry and will require larger amount of water addition for tempering. The amount of heat retained in each cycle depends on the number of times the sand circulates in a day or a shift, sand to metal ratio, pouring temperature, retention time of the casting in the mould before shakeout, storage capacity of the hopper, layout of the sand handling system.

Hot Sand Defects

1. Difficult to control the sand properties.
2. Sand inclusions, washes, erosion scab, surface roughness, pinholes, crushes, broken moulds.
3. Cold cores placed in hot moulds, resulting in moisture condensation on core surface, thereby causing blow hole defects.
4. Sand sticking increases in storage hoppers which reduces effective holding capacity and further aggravates hot sand problem.

Effect of Hot Sand on Green Properties

1. Abnormal variation in moisture content
2. Variation in Density of 2″ × 2″ (i.e., 50 mm × 50 mm) specimen, and occurrence of soft spots in the mould
3. Slight reduction in permeability
4. Reduction in mould hardness
5. Reduction in green compression strength; more clay addition required for tempering
6. Reduction in sand deformation; brittle sand requires more additives to bring it back to desired properties
7. Reduction in dry compression strength
8. Reduction in hot compression strength, resulting in cuts, washes and inclusions

Only effective cooling system will result in getting return sand at ambient temperature and well below 40°C.

New Sand

High grade silica sand with SiO_2 content more than 98%, fusion point above 1700°C and minimum alkaline impurities is desirable. Most of our sands are *angular* or *sub-angular* or *sub-angular* to *rounded* grain shaped. As mined, the clay content varies from 0.5 to 2.0% and sometimes it is more than 2.0%. But for *core sands*, washed silica sand with less than 0.5% (preferably around 0.2 to 0.3%) clay is desirable. For shell resin coated sands and for no-bake process cores minimum clay (not more than 0.3%) and acid demand value (ADV) less than 6 cc of 0.1 N HCl per 100 grams of sand is preferred.

Though some foundries use unwashed new sand with clay content up to 1.5% in their moulding sand system, it is advisable to use clay-free sand (preferably clay below 0.5%) for better control. Besides, on sieve analysis, more than 85 to 90% should be retained on 4 adjacent sieves. Sand with 4 adjacent sieve distribution will resist thermal shock, will have better compaction and will be less prone to sand erosion. It may not be possible to obtain 4 adjacent sieve distributions all the time due to the mineralogical nature of the mined sands. But in any case 3 adjacent sieve distributions with 85 to 90% retention is essential. If not, on some configuration of castings scab defects will increase, and to correct the same, cereal addition to the sand system should be made or active clay-content level in the sand system should be increased by 1.0 to 1.5% more than the stipulated level. The desirable sieve analysis pattern of the sand is given in Table 3.11.

Table 3.11 *Desirable sieve analysis pattern*

US Sieve No.	*Aperture Opening (microns)*	*Retained on the Sieve (%)*
30	590	1.0 max.
40	420	5.0 max.
50	297	12–24
70	210	30–42
100	149	28–38
140	105	6–8
200	74	Less than 2.0
Pan	—	Less than 0.5
AFS Clay	—	Less than 0.3
AFS GFN No.	—	55 to 60

Sand retained above 140 mesh sieve will be considered as sand grains. Particles finer than 140 sieve will comprise silt, clay, etc.

For shell-resin coated sands, retention on 140 mesh can go up to 15% and more. But for cold box process cores, if retention on 140 mesh exceeds 8 to 10%, friable cores can result. As far as possible, in 140 mesh retention should be well below 10%. Otherwise, inert fines accumulation will increase in the system sand.

3.1.6 Additives to Moulding and Core Making Sands

In order to obtain specific characteristics in moulding and core-making sands according to the requirement of molten metal and base sand, suitable additives are mixed during sand preparation. The additives may be of reducing or fibrous nature, or may act as binding agents. These may also help in improving high-temperature plasticity and hot strength, produce anti-metal penetration properties and impart good surface finish to the castings. It is necessary to select the right type and determine the correct proportion of the additive for any given moulding and casting conditions so as to enable the production of flawless castings. The commonly used additives are the following:

1. Coal Dust It is commonly used in green-sand and dry-sand moulding for protecting mould surfaces against the action of molten metal and improving surface finish of cast-iron castings. When the molten metal comes in contact with mould surfaces containing coal dust, a gaseous envelope is formed which resists the fusion of sand to metal. Use of coal dust increases both green and dry strength, reduces expansion, tendency to scabbing and metal penetration. It, however, tends to reduce the permeability of sand. Good-quality coal dust suitable for foundry use should consist of finely crushed bituminous coal free from foreign material, and should have fineness of about 150 mesh BS sieve, equivalent to 106 micron IS sieve. It should have minimum 30% volatile matter, maximum 20% ash, 3% moisture, 1% sulphur and 0.2% phosphorus content. Specifications of coal dust for use in foundry are covered by IS: 1752–1973. Pitch and fuel oil are also used as reducing agents and have similar effect as coal dust. IS: 13100–1991 gives the specifications of pitch powder for use in foundries.

2. Iron Oxide Iron Oxide powder is used as an additive for both moulding and core-making sands to achieve high temperature plasticity, hot strength and anti-metal penetration characteristics. In core sands, it prevents veining or high-temperature cracking of cores. The use of iron oxide is common in steel foundries both for moulds and cores. In iron foundries, its use is restricted to cores only. Good-quality iron oxide should have iron oxide (Fe_2O_3) content not less than 93% and iron content not less than 65%. Its pH value in 10% distilled water solution should not be more than 9%. Its fineness should be 150 mesh BS sieve (106 micron IS sieve). IS: 10091–1981 gives specifications of iron oxide powder.

3. Dextrin It is used as binder to influence the bonding properties of sand. It increases air-setting strength, toughness and collapsibility and prevents sand from drying quickly. During pouring, it gasifies producing voids between sand grains and allowing their expansion without distortion. Dextrin is commonly used with core sand to increase dry strength and as a binder for mould and core washes. Two types of dextrin are available, yellow and white. Both should have fineness of 100 mesh, BS sieve (150 micron IS sieve) and moisture not more than of 10%. The yellow variety should have a minimum dextrin content of 85% and maximum ash content of 1%, whereas the white variety should have minimum dextrin content of 65% and maximum ash content of 0.5%. The specifications for dextrin for use in foundries are covered by IS: 4269–1981. Starch is also used for better expansion and scabbing resistance properties.

4. Molasses It is a commonly used additive both in moulding and core making for iron castings. It is a dark brown viscous liquid obtained as a by-product during sugar refining. It enhances the bench life of sands and imparts high dry strength and collapsibility. Due to high viscosity and wettability, it also increases green strength. Its decomposition at high temperature generates CO_2, which sets up a hardening action of the mould and increases hot compressive strength. On further heating the strength gets decreased, thus making the mould collapsible. However, due to the high hygroscopicity of the mix prepared with molasses, its use is not much favoured for good-quality castings.

5. Sulphite Lye It is a by-product of the cellulose industry and is used for imparting better dry strength, hot strength and collapsibility to moulds. Its use is more favoured in the production of large, heavy, iron castings like ingot moulds and iron rolls.

6. Linseed Oil (Core Oils) It is the most popular binder for core sand mixes. Linseed oil or other proprietary oils known as core oils, which are made by blending various ingredients such as vegetable, mineral and animal oils, natural resins and by-product residues from vegetable-oil based industries, are used either with cereal binders like dextrin or with dextrin and bentonite. The sand mix develops strength only when the cores prepared from the mix are heated to a temperature of 200–240°C for a specified time which may vary from 1 to 3 hours. The cores so prepared have very good baked strength, scratch hardness, permeability and collapsibility and can be stored for a long time. The specific gravity of core oils at 30°C should be about 0.90 and their acid value not more than 10. IS: 9009–1979 gives the specifications for foundry core oils. According to this, standard core oils are of two grades, fast baking and slow baking depending upon the baking time required at 220°C to attain peak tensile strength. Further depending on the maximum strength developed after baking, core oils are of two types, low strength and high strength.

7. Sodium Silicate (Water Glass) This the most common binder used in air-setting or self-hardening processes for moulding and core making. The CO_2 process, ferrosilicon process, cement process, dicalcium silicate process, and others make use of sodium silicate as a binder, along with a solid or gaseous hardener. IS: 6773–1978 (presently under revision), which covers the specifications for sodium silicate for use in foundries, provides 5 grades according to the physical and chemical characteristics. The variety suitable for the CO_2 process should contain total soluble silica (as SiO_2) 26 to 32%; total alkalinity (as Na_2O) 11 to 13%; mass ratio (SiO_2/Na_2O) about 2.2; relative density at 20°C, 1.50 to 1.60 (51–55° Baume); and total invert sugar content, 5 to 10%.

8. Fibrous Materials These materials are used to improve collapsibility and prevent scabbing and expansion defects. The commonly used materials are wood flour, peat, straw, chaff (dried grass), horsehair or cowhair, sawdust, manure and asbestos.

3.1.7 Mould Dressings

Moulds and cores are usually applied with a suitable wash or dressing to achieve a good surface finish. The surface finish is mainly achieved by the refractoriness of the coating and its ability to form an impervious layer on the mould or core surface. The layer so applied also helps in avoiding metal penetration and metal mould reaction.

The dressing may have either a water or alcohol base as carrier. The strength of the coating is developed either by baking or igniting the surface, according to the type of carrier used. Several types of refractory materials are used to form washes, such as silica flour, zircon flour, chamotte, bauxite flour and graphite.

Silica flour is a commonly used refractory dressing material, particularly in steel foundries. It is also used to obtain high temperature strength, high density and good resistance to metal penetration in cores. The silica flour should contain a minimum of 98% silica and not more than 1% moisture. Its fusion point should not be more than 1700°C. Its specifications are covered by IS: 3339–1975.

Zircon flour, being a highly refractory material, is primarily used in steel foundries. Good quality zircon flour suitable for foundry work should contain a minimum of 64% zircon oxide (ZrO_2), 30 to 35% silica and a maximum of 0.5% $TiO_2 + Fe_2O_3$. The fusion point should not be less than 2000°C, specific gravity about 4.5 and pH value of the water base wash not more than 9. Olivine flour possesses high refractoriness and low thermal expansion and is highly suitable in the production of manganese steel castings. Chamotte is used both as sand and flour in steel foundries. It consists of highly calcined flint clay and is particularly suitable for heavy steel castings.

Graphite washes are most commonly used for iron castings, as well as non-ferrous castings. The graphite used is naturally flaky type, silvery white in appearance, of a fine powder form and free from gritty particles. Good-quality graphite for foundry use should have ash content about 12 to 15% maximum; volatile matter 3% maximum; and moisture content 1% maximum. It should pass through a 150-micron IS sieve, 100% and 100 micron IS sieve 90%. IS:1305–1967 covers specifications of graphite in foundries. IS: 10033–1981 gives the specifications of zircon and graphite mould and core washes.

3.1.8 Parting Agents

Parting agents are used in foundries for easy release of moulds and cores from patterns and core boxes. Depending on the process of moulding, parting agents may be in powder or liquid form. The commonly used parting agents in powder form are graphite, soapstone and fine silica sand. The graphite should be the natural flaky variety, having fixed carbon content not less than 66% and predominantly micaceous non-carbonaceous matter. The fineness should be 100 mesh BS sieve (150 micron IS). Soapstone powder is used for steel-casting work. It has a very smooth, slippery feel. Its fineness is of the order of 200 mesh BS sieve (75 micron IS). Fine silica sand is also often used for steel castings.

Amongst the liquid parting agents, mineral oil or water-based silicone solutions are commonly used in case of shell and hot-box moulding. Silicone solutions can effectively withstand the high temperature of the pattern or core box, as encountered in case of shell and hot-box processes. The specifications of various parting agents are covered by IS: 8250–1988.

3.1.9 Core Gum and Core Repairing Paste

It is always necessary, in a foundry, to join two or more cores together before setting them in the mould. Often, cores also need repairing of defects like porosity, cracks, chipped-off portion, etc. The paste used for jointing or sealing has to be so chosen that it does not lead to any casting defects. The paste should set to a hard refractory mass on drying, without pealing off or cracking and should withstand metal flow without being washed away. Its gas content should be low. Two types of core gums are used:

1. The paste consists of refractory clay like plastic fireclay or china clay, a binder like bentonite, dextrin or sodium alginate, and water to a desired consistency. The gas content in this type is usually high and varies between 35 and 45 mL/g.
2. The paste is made up by thoroughly mixing sodium silicate with materials such as fireclay, china clay, soapstone, bentonite, silica flour, etc. This type is normally supplied by foundry chemical manufacturers, based on proprietary formulations. The gas content of this variety is low and not more than 25 mL/g.

SAND CONDITIONING 3.2

A good moulding sand should possess properties that permit easy formation of pattern details. It should have good flowability; the green strength required to retain its form when the pattern is removed; the necessary dry strength to resist collapse when heated by the molten metal at casting time; sufficient refractoriness to withstand the temperature of the cast metal without fusing; and enough permeability to allow the escape of gases generated from the molten metal. In addition, it should be sufficiently friable for ready removal from the solidified casting; economically available at the usage station; and durable.

Compromise in the foregoing requirements is undesirable, but when such is inevitable, appropriate application of moulding techniques often produces the desired effects—use of a venting wire may increase permeability, as also will the addition of certain organic substances to the sand mixture; extra dry strength may be acquired by surface dressings; better breakdown can be obtained by certain additives.

A sand that does not possess good flowability will require much more effort when packing the sand around the pattern to form the mould. In extreme cases, lack of flowability may result in moulds that are soft rammed, or of too low a rammed density. This is particularly so where the moulding machine has a predetermined cycle of automatic functions for producing the mould.

If the green strength of the moulding sand is insufficient, the mould may get distorted under its own weight when the pattern is withdrawn, and it is also more prone to damage and distortion prior to and during final assembly of the mould itself. Further, such sand may contribute to a dimensionally inaccurate and an unsound casting due to dilation caused by the pressure of the liquid metal when being cast; this is particularly so with cast iron, which has a peculiar phenomenon of expansion when solidifying. Insufficient dry strength will result in friability and premature breakdown of the mould surfaces, which in turn result in dirty and rough castings.

If the sand mould does not have the requisite permeability then the steam and gases generated by the heat of the molten metal and from the metal itself, will be unable to escape from the mould cavity and will tend to remain in the solidifying metal to form cavities in the casting known as *blowholes*. From this, it is apparent that the amount of moisture present and the gas evolution from the mould material have a strong influence on the tendency to form blowholes and necessitate different degrees of permeability.

In the case of naturally bonded sand, the used sand is cooled and cleaned of metallic pieces, such as springs, chills, find pieces of cast metal, after the solidified casting is removed. For lower-melting point alloys, such as aluminium, the sand as a whole will not be seriously burnt and, with the addition of the appropriate amount of water, will be suitable for repeated use. If the cast metal is of a higher melting point, such as bronze, cast iron and steel then the sand in the mould that comes into actual contact with the molten metal will be severely burnt and its bonding material rendered useless. All such sand should be segregated from the bulk at the knock-out station and discarded. In all cases, new sand should be added from time to time to maintain good working properties. Frequent quality-control tests ensure that the properties of the sand do not fall below the desired minimum standards.

Thus, in order to obtain good castings, the sand used for moulding must be correctly conditioned. Proper sand conditioning and preparation helps as follows:

(i) the binder is uniformly distributed around the sand grains;

(ii) the moisture is evenly dispersed in the sand mixture and the moisture content properly controlled;
(iii) the sand gets aerated, causing the sand grains to separate and increasing the flowability of sand;
(iv) the sand is delivered at the proper temperature; and
(v) the foreign particles are separated from the sand.

Conditioning of sand by hand being difficult and time-consuming, suitable equipment is required for this purpose. The various types of equipment used are described in Section 3.2.2.

3.2.1 Sand Preparation

1. Natural Bonded Sand Assuming that the texture of the supplied sand is acceptable, the preparation of a moulding or core-making mix should require only a short period of milling and the adjustment necessary to attain the desired moisture content (nominally 5% moisture content for general moulding in green sand).

After use, the casting, together with all metallic particles and burnt sand, should be removed and the remaining sand reconditioned as above. Where the contamination and deterioration is not heavy, as with aluminium casting usage, it may suffice to pass the sand through an aerator. Regular control tests should be made to determine the degree to which fines are being built up in the bulk of sand being used. If an excess of fines or silt is allowed to accumulate, green and dry strengths will be impaired and low permeability will tend to produce casting defects such as blowholes and surface blemishes.

Facing sand, i.e., the sand that is applied to the faces of the pattern forms the surfaces of the mould cavity, may require the addition of a material to increase the refractoriness and texture of the mould surfaces. For cast iron, fine coal dust 8–10% by volume or 2–4% by weight greatly improves the surface finish of the resultant iron castings. For light alloys of aluminium, a surface dressing of plumbago (powdered graphite) or talc applied to the mould cavity after the removal of the pattern, may be sufficient to give the desired surface finish to the casting.

2. Synthetically Bonded Sand (Moulding only) The unbonded sand should be weighed and placed in the sand muller and the appropriate weight of binder added. If bentonite is used, 4–6% by weight of sand should be added, followed by 4–5% water. Mulling should proceed to attain a complete distribution of bond and water throughout the mix. Better mixing is achieved by running the muller containing sand and bentonite for a few minutes before adding the water. A four-to-five minute mulling of the total mix should complete the operation. Excessive mulling time will increase the green strength to an extent that reduces mouldability and the bench life of the mix. If coal dust or wood flour is to be added, this should be done at the latest time possible, i.e., after the bond and water have been fully distributed. Thus, the coal dust or wood flour becomes part of the mix without being unduly coated with the blending ingredient.

3. Synthetically Bonded Sand (Core Making) Many combinations of bonding materials are used for inclusion in core sands. The selection of a particular bonding material and the requisite proportions are dependent on a consideration of the factors regulating the work in hand, viz., type of core, metal to be cast, method of core making, availability and cost of materials, and equipment available for any drying or curing process involved. A basic, general-purpose core sand can be made with a mixture of dried silica sand, 4–5% molasses, and 1–1.5% linseed oil by weight. Molasses will provide the green strength, and linseed oil the dry strength. Cores made with this mixture will need baking at about 280–300°C for a period of 1–2 hours, depending on the bulk and size of the cores.

Table 3.9 shows for general guidance, the sand practice for moulds and cores in case of various cast metals.

3.2.2 Sand Reclamation

Sand reclamation refers to the treatment of 'used' moulding sand so that it regains its original condition and can be reused again and again, with minimum addition of new sand. With the increasing cost of new sands and rising cost of transportation, it has become necessary for economical reasons to reuse the sand as much as possible. For environmental reasons also, it is desired that large heaps of used sands are not formed which may adversely affect vegetation and produce atmospheric pollution. Sand recycling has now become a necessity for all foundries.

Moulding and core sands consists of granular sand mixed with a natural or synthetic binder(s). After the casting is made and removed from the moulds, the lumps of sand left over from the mould need to be crushed into granular form and the bond coating over the surface of individual grains needs to be removed so that all the grains return to their original state. Essentially, the reclamation process consists of

(a) crushing of sand lumps
(b) removal of bond from the grain surfaces

The type of facilities or equipment required may depend on (i) quantity of sand to be handled, (ii) the kind of binder and its quantity, e.g., synthetic, organic no-bake, inorganic containing sodium silicate, cement, etc., (iii) extent of mechanisation used in the foundry, and (iv) overall economics of sand recycling.

Depending on the nature of binders used, reclamation may be done by mechanical, chemical or thermal means. Clay-bonded sands are easiest to handle, requiring a simple form of lump-breaking device after drying, followed by a rotating or vibratory screen to remove excess fines. Sands with chemical bond of organic nature are given chemical, thermal or mechanical treatment. Most of the bonds can be removed by washing in hot water. In mechanical means, which may be dry or wet, continuously flowing granular sand is thrown against a wear-resistant stationary surface so that the coating is separated. Equipment designed for the specific purpose of lump crushing and bond removal are available and proper selection of equipment is necessary. In a thermal system, sand is heated to 650–800°C to burn organic and carbonaceous materials. A combination of these methods is often employed.

Sand Reclamation of Chemically Bonded Sands

In the chemically bonded sand system, sand reclamation is very important. There are three basic requirements of such a sand system:

1. The sand should maintain a consistently acceptable LOI value by reducing thickness of resin coating on the sand grains, and Na2O must also be reduced as much as possible.
2. The reclamation system used should avoid excessive generation of fines caused by the fracturing of sand grains.
3. Fines should be maintained at low level by removing maximum amount of it generated during the metal-pouring operation and during reclamation itself. Lump crushing operation is found to be necessary prior to reclamation.

A diagrammatic representation of sand reclamation system is shown in Fig. 3.26.

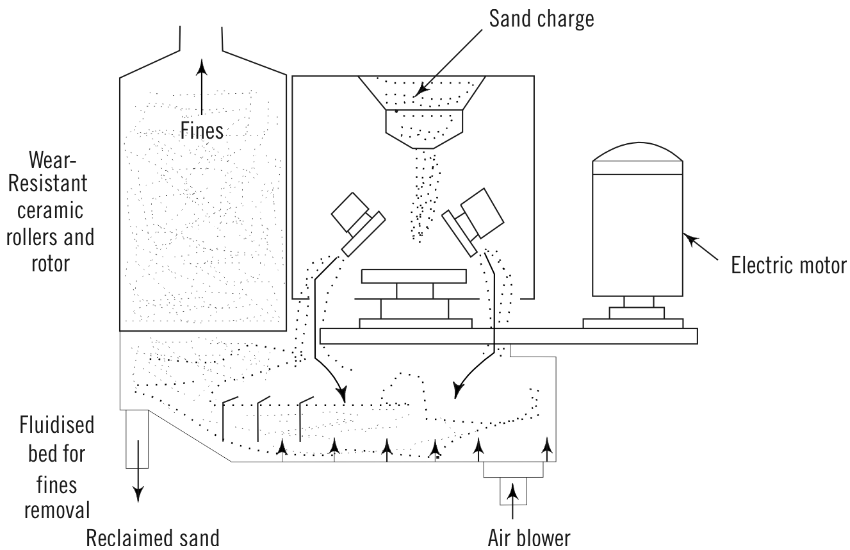


Fig. 3.26 *Diagrammatic representation of reclamation unit for chemically-bonded sands*

A novel reclamation process using cryogenic technology is presently under development for both clay-bonded sand and chemical-resin-bonded sand systems.

It has been established that sub-zero temperatures provide a convenient mechanism to separate sand from other unusable constituents.

Use of Silicate-based sand reclamation The processes of pneumatic, mechanical/ thermal sand reclamation and their combinations have been in common use. Due to large investment and huge energy cost, thermal sand reclamation has found much limited markets, though technically, it has proved to be the most versatile process to clean all types of sands to a high quality level without damage to the sand grains. Pneumatic and mechanical processes in combination due to their favourable economics have been more popular, though the quality levels and versatility are not to the level of thermal process. The sodium silicate sand process has been widely known and practiced by Indian foundries, as well as others. The process is found to be more user-friendly and less sensitive to climate vagaries, so also economically more viable. However, due to the non-availability of good sand reclamation process, its extensive use gets hindered. However, due to environmental problems, the trend is drifting back towards silicate sands from other no-bake processes.

3.2.3 Sand-Preparation Equipment

When mechanical equipment is not used for sand preparation, the sand moulds are shaken out manually on the pouring floor itself. After the flasks and casting are removed, new sand and the bond are added to the used sand, and the mixture is first wetted, and then shovelled into a triangular heap. Just before moulding, more moisture is added if necessary, and the heap is *cut* with a shovel so that the sand mix becomes completely homogenous. Beside involving a great deal of time and labour, this method does not guarantee fully homogeneous mixing. On the other hand, the sand mix when prepared by mechanical equipment has its moisture uniformly distributed, is free from lumps, and is delivered in a *silky* condition.

The equipment used for sand preparation includes

1. the magnetic separator;
2. the riddle;
3. the muller or mixer; and
4. the aerator.

1. Magnetic Separator The moulding sand coming from the shake-out station should be freed of all iron particles and foreign matter before being put to re-use. The function of the magnetic separator is to separate the iron pieces, wire nails, iron shots, and other ferrous particles from the sand. The magnetic separator consists of a magnetised pulley over which a flat rubber or canvas belt rolls. As the belt rolls over the pulley, the sand and non-magnetic particles fall freely off the belt in a vertical downward direction. The ferrous objects, on the other hand, tend to cling to the belt due to the magnetisation effect and drop off only when the belt has left the pulley. The pulley may be either a permanent magnet type or an electromagnet type carrying dc magnetising coils.

2. Riddle After the iron pieces are separated, the sand is usually passed through a screen or riddle where the pieces of dry sand cores, hard lumps of sand, and other refuse are eliminated. Mechanical riddles can screen the sand at a much faster speed than hand riddles and are a must in a production foundry. They may be operated by compressed air or electric motors. The compressed air riddle consists of an air cylinder, a reciprocating piston, and a screen connected to the end of the piston. The screening action is due to the reciprocating action of the piston moving through a very short stroke length.

In the case of riddles operated by electric motors, the action is caused by a gyratory motion. The screen is supported from a frame to which an electric motor is also attached. An unbalanced wheel is fastened to the shaft of the motor. As the shaft rotates, it causes the wheel to move out of balance, thus giving a wobbling motion to the screen. In production foundries, the riddles which have revolving or deck-type screens, can handle larger quantities of sand in a shorter time.

3. Muller The function of the muller is to condition the moulding sand for re-use. *Mulling* is a process of kneading and working the sand for the purpose of distributing the ingredients into a homogenous mixture. The muller (Fig. 3.27) generally consists of a cylindrical pan in which two heavy rollers roll in a circular path about a vertical rotating shaft. Two ploughs are also carried with the rollers, which scrape the sand from the sides and bottom of the pan and place it in front of the rollers. The rollers are set slightly off the true radius so that they move out of centre and produce a smearing action on the sand. The rollers are mounted on rocker arms to enable them to move up and down according to the quantity of sand in the pan. However, they are kept raised about 6 mm from the base of the pan in the lowest position to prevent crushing of the sand grains.

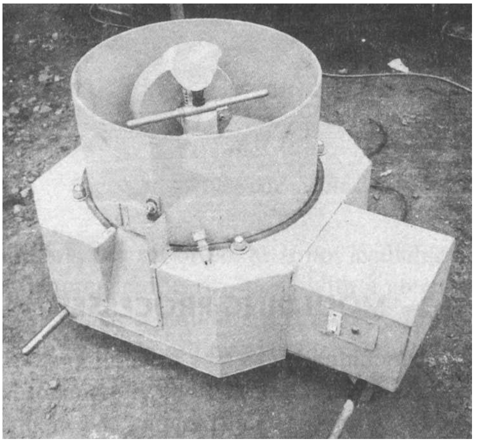


Fig. 3.27 *Sand muller*

The muller is generally equipped for cooling the sand and adding moisture, if required. Binders, etc., are also added to the moulding sand before mulling, if needed. After mulling, the sand is discharged through a door in the base of the pan. A mixer is generally used to prepare core sands and it consists of a cylindrical trough having a rotating shaft in the centre, with two arms, each having a blade fitted on to it.

4. Sand Aerator After the sand is conditioned in the muller, it is sent to an aerator where the sand grains are separated and each grain is made to flow freely and smoothly. The capacity of the moulding sand to flow freely around the pattern and get packed is termed *flowability*. Aerating helps in improving the flowability of sand and causes it to get *fluffed up*.

Usually, mechanical aerating is accomplished by an impeller or rotating paddles whirling the sand at a high speed towards the inner walls of the casing. The rotating paddles consist of a set of rods, each having a number of combing fingers arranged radially. The aerator may either be a separate unit in which the mulled sand is charged through a hopper or it may be attached directly to the outlet of the muller. In the latter case, the mulled sand passes through the aerator and is discharged through a door in the bottom of its casting. Figure 3.28 shows a portable type of sand aerator independently driven by an electric motor.

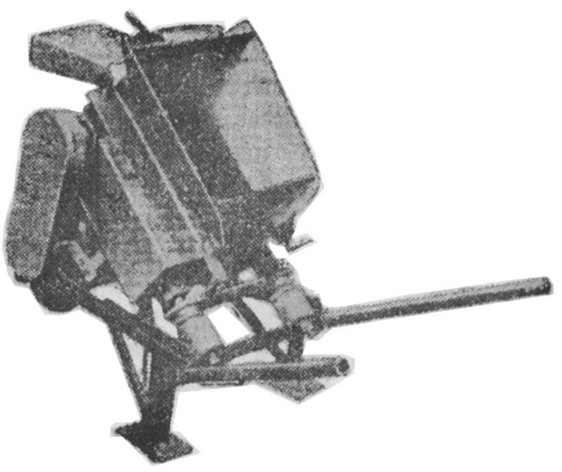


Fig. 3.28 *Sand aerator*

MOULDING PROCESSES 3.3

The moulding processes in common use may be classified according to different norms. When the common denominator is the method of preparation, the processes conducted with hand tools by the moulder are referred as hand moulding and those requiring the help of a machine are grouped under machine moulding. Hand moulding may be done either on the foundry floor or on a working bench. Accordingly, the process is termed *floor moulding* or *bench moulding*.

3.3.1 Floor Moulding

Floor moulds may be either the open-sand type or the one-box type. In *open-sand moulding,* the mould cavity is prepared in the floor and the molten metal is poured directly in the cavity; no passage is provided in the sand for the molten metal to reach the mould cavity. Such moulds are used for castings that do not require good surface finish on the upper face and are unsophisticated, such as floor plates, weights, mould boxes, manhole covers, and drain covers. To overcome the drawback, *one-box moulding* is used in which one part of the flask is placed atop the floor mould. This flask acts as a cope and carries the sprue and risers. For easy escape of gases from beneath the casting, especially in large moulds, a bed of coke ash should be made and the sides lined with bricks. Vent pipes can also be embedded into the floor beneath the coke bed.

3.3.2 Bench Moulding

Bench moulding is favoured for small-sized castings, which are light in weight and can be easily handled. The various techniques applied for preparing the mould in bench moulding are now discussed.

1. Two-box Moulding The two-box moulding method makes use of a pair of moulding boxes, the upper part being called *cope*, and the lower one, *drag*. The two parts are fitted with a suitable clamping and a locating arrangement. The clamping is required to prevent the cope from lifting due to the pressure of the molten metal when the latter is being poured. The locating device is essential for the two parts to maintain proper alignment at all times. Sizes of moulding boxes are standardised and are specified in IS: 1280–1967.

2. Three-box Moulding In case the pattern is of the flanged type, and flanges are to be moulded horizontally, it is very difficult to prepare the mould in two boxes. Then, the mould can be easily formed by the use of three boxes, the pattern being made in parts as required. The procedure adopted is illustrated in Fig. 3.29 for moulding a flanged type of rope pulley. The additional box in the middle is called *cheek*. During pouring, all the three boxes are clamped together.

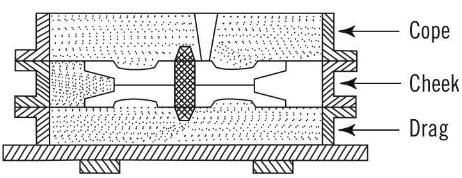


Fig. 3.29 *Three-box mould*

3. Moulding with a False Cheek If the three-piece set of boxes is not available or is not convenient to use, the mould may be prepared in two parts with a green sand core, often referred to as a *false cheek*. Such a mould is prepared by first ramming the cope half of the pattern in the cope and then rolling over the assembly. A parting is then formed around the pattern in the cope and a false cheek is prepared with green sand in the cavity so formed. Next, the drag is rammed over the false cheek. The drag is then drawn, the pattern removed, and the drag again replaced. The mould is completed by rolling over the assembly, drawing off the cope, removing the remaining pattern half, and finally choosing the mould. When the castings are required in large numbers, the green sand core prepared in the mould itself can be replaced by a dry sand core. The dry sand core is prepared separately in the core box and, after baking, it is inserted in the mould cavity (Fig. 3.30).

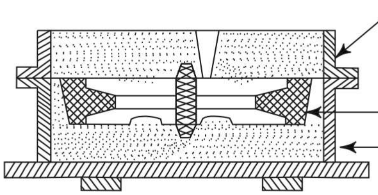


Fig. 3.30 *Moulding with dry sand core*

4. Plate Moulding When a large number of fairly simple castings are required, they are produced several at one time by this process. The form of a given part is divided into halves and the patterns (usually of metal or plastic) are attached to each side of a board or plate. One side is moulded in the drag and after it is turned over, the cope side is moulded. The two boxes are then separated and the boards and patterns are removed. On reassembling the two boxes, the moulded impressions match up and the mould is ready for pouring.

The plate moulding method is generally employed with moulding machines where the ramming of sand, pattern lifting, and rolling over are done mechanically.

5. Stack Moulding When the requirement is for a large number of castings of small size, each having one flat surface, it is convenient to make use of both the sides of one half of the mould and to stack these so that the lower face of each part is a cope face, and the upper face a drag face (Fig. 3.31). A common passage for the molten metal runs through the stack of intermediate boxes. Thus, a number of parts can be cast in a single pouring operation.

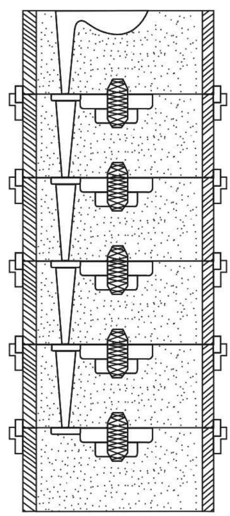


Fig. 3.31 *Stack moulding*

6. Odd Side Moulding In case where the solid or one-piece pattern does not have a flat face to rest on the moulding board and where it cannot be conveniently made into the split type, an *odd side* is first prepared by moulding in one of the moulding boxes. The odd side is thus a spare or dummy half-mould in which the pattern is embedded after filling in the sand. The sand is pressed hard all around the pattern by hand and is rammed. The actual drag part is then placed over the so-made odd side, and the half-mould in the drag is formed in the usual way. After the drag is separated, it is rolled over and put on a board. The pattern is then removed from the odd side and placed in the drag cavity. Finally, the cope is set on the drag and the moulding completed as usual. The odd side thus facilitates supporting the pattern and getting the required impression in the drag.

3.3.3 Types of Sand Moulding

Sand-moulding methods may also be classified according to the type of sand used for preparing the mould and the moisture content of the sample.

1. Green Sand Moulding When the mould is filled with molten metal while the sand is still moist, the method used is called green sand moulding. Due to the presence of moisture, the mould lacks permeability and strength and this may result in defects such as blowholes and pinholes in the casting. In spite of this drawback, green sand moulding is the most popular of all moulding methods and accounts for more than 90% of sand-moulded castings. With the use of a synthetic sand mixture, this method has gained further popularity. For all mechanised moulding, green sand moulding is largely employed due to its ease of adaptability and economical operation. The defects can also be minimised by a proper control of process parameters, particularly by keeping moisture initially low.

2. Dry Sand Moulding The dry sand moulding method is used when the mould requires greater strength to withstand the weight of a large volume of metal or if a hard surface is required to avoid surface erosion. The mould is prepared with a specially processed sand and is then dried in an oven.

The sand mixture for moulding may consist of moulding sand, burnt facing sand, clay, cinders (boiler ash), and moisture. The layer of facing sand surrounding the mould cavity is made up of fine moulding sand, river sand (new sand) of a fine-grained variety, and a bond such as pitch or flour and water. The water content in the dry sand mix is kept high (6–8%) so that green properties are satisfactory. After the mould is ready, its surface is sprayed with molasses water and the mould is dried in an oven maintained at 200–300°C, until all the moisture is eliminated. Alternatively, heated air may be circulated through or passed over the mould.

The castings prepared from dry sand moulds are found to be flawless. Dry sand moulds are more shrinkproof and more rigid and strong. However, the higher costs involved limit the application of this method to large castings where the maximum depth of pouring is more than 1200 mm and where a faultless and well-finished casting is essential. Dry sand moulds possess higher resistance to cooling contraction and so are unsuitable for light and intricate castings of metals such as steel; chills may be used to overcome this problem.

3. Skin-Dried Moulding This is a process that dries the moisture from the surface layer of the rammed sand to a depth of about 25 mm or more by using gas torches or heaters. It has the advantages of both green sand and dry sand moulding to a certain extent. Since the time required for drying is less than in the case of dry sand, the method is also less expensive.

4. Loam Moulding This method of moulding is used for large-sized castings where the regular moulding method in flasks would be too expensive and inconvenient. The loam sand mould is constructed of porous bricks cemented together with loam mortar, which is a mixture of equal amounts of sand grains and clay wetted to the consistency of mud. The inner side of the brick structure forms the rough contour of the casting and it is faced with a 6–12 mm layer of loam sand. It is then swept by a strickle to get the required shape, eliminating the need for regular patterns. Skeleton patterns or templates are also used with loam moulding.

5. Oil Sand Moulding In this process, linseed oil, or a blend of oils consisting of vegetable oils, mineral oils, animal oils, natural resins, etc., known as core oil, are used as binder with sand, along with dextrin and bentonite. The process is commonly used for the manufacture of cores but it can be used for moulds as well. The composition of the mix may be

sand: 100 kg, core oil: 1–2 kg, dextrin: 0.5–1 kg, bentonite: 0.5–1 kg, water: 2 kg.

The cores prepared from the sand mix are to be baked at 220–230°C for 1 to 3 hours, according to the type of core oil, so as to develop the peak strength.

The mix may have

green permeability, 200 –220; green compressive strength, 400–500 g/cm^2 (0.004–0.005 MPa); baked tensile strength, 5–15 kg/cm^2 (0.5–1.5 MPa) minimum, scratch hardness, 70–80, baked gas content $25 \times 10^3 = 3010^3$ mm^3/g (maximum).

3.3.4 Tools for Hand Moulding

The hand tools generally used for moulding work are as follows:

1. Trowels Trowels are used for filling sand, cutting the in-gates, making joints or partings, and for repairing and finishing the mould. A trowel consists of a steel blade, which may be rectangular, triangular or heartshaped, with a wooden handle fitted at one end.

2. Heart-and-Square Tool The heart-and-square tool combines the functions of a small-sized heart and square trowel. The two shapes, heart and square, are formed on the two ends of a rod. This tool is also used for finishing the mould surface after the pattern has been withdrawn.

3. Rammers Rammers are employed for pressing the sand in the moulding box to make the mould become sufficiently strong and dense. Rammers are commonly of two types—the *pin rammer*, which has a conical or wedge-shaped end, serves to press the sand into corners and pockets and is generally used first so that the sand becomes uniformly dense in all parts of the mould; and the *flat rammer*, which has a flat circular end, and is designed for final pressing of the sand after the flask has been completely filled with sand. Rammers generally have a wire handle of convenient length. At one end of the handle, a ramming block of cast iron or wood is attached. In the case of large moulds, pneumatic rammers are used to save time and labour.

4. Cleaners and Lifters These are made from a steel plate, having one end flat and straight and the other end bent at 90°. The function of the cleaner and lifter is to lift the dirt and sand particles out of the mould and repair the broken mould faces. Generally, the straight end is used for cleaning and repair work and the bent end for lifting sand particles.

5. Gaggers Gaggers are iron rods bent at one end or both ends. They are used to reinforce the sand, especially in the cope, and to support the hanging and unsupported portion of the sand.

6. Vent Wire This is a piece of wire having one end pointed and the other end fitted with a wooden handle. It is excellent for piercing holes in the rammed sand so as to allow easy escape of water vapour and gases when molten metal is poured into the mould.

7. Slick Slick is used chiefly for repairing the mould. It is a double-ended tool having one end flat and a spoon on the other end.

8. Swab The swab is a small brush with long hemp fibres. It is used for moistening the sand around the edge of the mould before the pattern is removed. A bulb swab has a rubber bulb to hold the water at one end and a soft hair brush at the other.

9. Drawspike The drawspike is merely a pointed steel rod with a loop at one end. It is used for withdrawing the pattern from the mould. The pointed end is driven into the top face of the pattern and then is gently raised. In the case of metallic patterns, the drawspike has the lower end threaded, and this threaded end engages in internal thread cut in the pattern face. Wooden patterns may also have a lifting plate with a threaded hole sunk into its top face.

10. Riddle The riddle serves to remove the lumps and foreign particles from the sand. It has a wooden frame with a screen of suitable meshes on one side. Where large volumes of sand are handled, power riddles are suitable.

11. Smootheners and Sleekers These tools are designed for smoothening out and finishing corners, recesses, bends, etc., and are made in a wide variety of shapes and sizes.

12. Runner Pegs and Sprue Cutters Runner pegs are used for forming the sprue in the cope and are generally made of wood. They may be cylindrical, square or rectangular. The purpose of the sprue cutter is the same as that of the runner peg. It differs from the latter in that it is a tube of steel and is forced into the sand after the sand has been rammed in the cope to trepan a hole for the sprue. A gate cutter is made from a thin sheet by bending it to U-shape.

13. Brush A brush is used (i) to sweep away the parting sand from the mould joint, (ii) to apply the plumbago on the mould surfaces, and (iii) to smoothen the mould surface by applying a paint.

14. Straight Edge The straight edge is a bar of steel of rectangular section, bevelled on one side. Its purpose is to strickle away the excess sand from the mould after it has been rammed so as to provide a level surface.

CORE SANDS AND COREMAKING 3.4

A core may be defined as that portion of the mould which forms the hollow interior of the casting or a hole through the casting. Generally speaking, the word *core* means the mass of dry sand that is prepared separately by being baked in an oven and then placed in the mould.

3.4.1 Characteristics of Cores and Core Sands

(i) Cores must have sufficient hardness as well as strength in both dry and green states. Without these properties, the core will not be able to support its own weight and withstand the force of molten metal.
(ii) Cores must be permeable to allow the core gases to escape easily.
(iii) Cores should be able to withstand the high temperature of molten metal.
(iv) The core sand should produce a minimum amount of gas when in contact with molten metal so that very high permeability is not needed and greater strength is imparted to the core.
(v) Cores when prepared should be collapsible, i.e., they should disintegrate and collapse after the metal solidifies. If the core does not collapse, difficulty may be experienced in removing it from the casting.

The ingredients of core sands are sand and binder. Generally, a high silica sand containing very little, if any, clay is found best suited as it can withstand high temperature. Excessive clay reduces not only permeability but also collapsibility.

In choosing core sand for a given core, the important factors to be considered are the shape, size and distribution of sand grains, the clay content, and the mineralogical composition of clay particles.

The function of a core binder is to cement the grains of sand into the desired shape and to impart sufficient strength to cores to prevent breakage, distortion, and erosion in the coremaking, moulding, and casting processes. The sand mixture should possess not only strength but also permeability, collapsibility, and heat resistance. Various commercial binders are available in the market which consist mainly of oils, cereals, resins, sulphite-liquor, molasses, and proteins. Core oils are, as mentioned earlier, more popular as they are very economical and produce better cores. The chief ingredient of these core oils is vegetable oil, for instance, linseed and corn oils. Sometimes, specially processed mineral oils are also added to achieve specific properties.

The action of thermoplastic binders, such as rosin and pitch, depends on the amount of heat which liquefies and disperses the binder in the sand. The powdered binder is mixed with sand and formed into cores. When heated, the binder liquefies and coats the grains of sand. After cooling, the dispersed liquid binds the sand grains together to form a united mass. Rosin is a form of resin and is obtained by distillation and extraction from pinewood.

Thermosetting resin core binders are also becoming common owing to their high strength, low gas formation, collapsibility, and resistance to moisture absorption. The resin binders usually favoured are of phenol, urea, and furan.

3.4.2 Types of Cores

The cores used in foundries are named according to their shape and their position in the mould (Fig. 3.32). The most common type is the *horizontal core*. This core is usually in a cylindrical form and is laid horizontally in the mould. The ends of the core rest in the seats provided by the core prints on the pattern. Horizontal cores may be made in one piece, using a split core box, or in two halves, using a half core box. In the latter case, the two halves have to be pasted together, using a core-pasting gum. Selection of one type of core, e.g., full core or half cores depends on the quantity of cores required, the material and process used for core-making and accuracy of hole. Full cores, if not having a flat surface for support while transferring from the core box to the core oven, have to be laid on a metallic core carrier, which has a shaped cavity matching with the core surface.

The core when required to be placed along a vertical axis in the mould is referred as a *vertical core*. The ends of the core at the top and the bottom fit into the seats provided in the cope and drag halves of the mould. Both the horizontal and the vertical cores are used more frequently than other cores in foundry work; for this reason, they are called *stock cores* and are kept ready in various diameters and lengths. For mass production work, the stock cores are made in a continuous core-making machine where the core sand is forced into a tube by means of a tapered screw. A thin rod protruding from the centre of the screw forms a vent in the core as it is extruded from the tube.

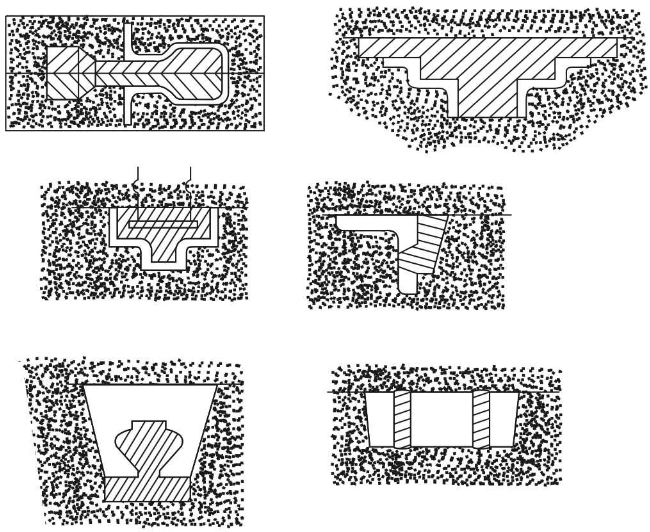


Fig. 3.32 *Different types of cores*

(A) Balanced core *(D) Wing core*
(B) Cover core *(E) Ram-up core*
(C) Hanging core *(F) Kiss core*

When the casting is to have an opening only on one side and only one core print is available on the pattern, a *balanced core* (Fig. 3.32(A)) is suitable. The core print in such cases should be sufficiently large to support the weight of the core, which extends into the mould cavity, and it should be able to withstand the force of buoyancy of the molten metal surrounding it. To support the core in the mould cavity, chaplets are often inserted. Chaplets are small pieces of metal, specially shaped to suit the cavity. Since the chaplets finally go into the casting, they should be of the same metal as the casting.

When the entire pattern is rammed in the drag and the core is required to be suspended from the top of the mould, a *cover core* (Fig. 3.32(B)) may be employed. Unlike the balanced core, which extends horizontally in the mould cavity, the cover core stretches vertically downwards.

If the core hangs from the cope and does not have any support at the bottom in the drag, it is referred to as a *hanging core* (Fig. 3.32(C)). In this case, it may be necessary to fasten the core with a wire or rod, which extends through the cope to a fastening on the top side of the cope.

A *wing core* or *stop-off* core (Fig. 3.32(D)) may be used when a hole or recess is to be obtained in the casting either above or below the parting line. This kind of core is necessitated when it is not possible to place the pattern in the mould such that the recess can be cored directly or with the other types of cores. As a part of the core placed in the seat becomes a stop-off and forms a surface of the casting, it is referred as stop-off core. The same core is at times also designated by other names, such as tail core, chair core, and saddle core, according to its shape and position in the mould.

Sometimes, the core is set with the pattern in the mould before the mould is rammed. Such a core, called a *ram-up core* (Fig. 3.32(E)), is favoured when the cored detail is located in an inaccessible position. It may be used for both interior and exterior portions of a casting.

When the pattern is not provided with core prints and no seat is available as a rest for the core, the core is held in position between the cope and drag simply by the pressure of the cope. Such cores are termed *kiss cores* (Fig. 3.32(F)). They are excellent when a number of holes are required in the casting and where dimensional accuracy with regard to the relative location of the holes is not important.

3.4.3 Core Drying

After the cores are prepared and placed on supporting plates or core carriers, they are transported to ovens for baking to dry the moisture and to harden the binder. According to the kind of production for which they are built, the core-drying ovens are classified as batch type or continuous type.

The *batch-type oven* makes use of portable racks. The racks, loaded with cores, are transported to the oven by lift trucks, trolleys or suitable conveyers. (Large cores may be moved directly into the oven.) The racks are admitted into the oven either through two doors, which swing open on hinges, or through a single sliding door of a counter-balanced type. The batch type ovens may be also the drawer kind in which the cores are placed in a number of sliding drawers. The drawers are operated by an overhead puller which engages any one or all of the *drawers* at one time. The batch type ovens are generally operated in foundries engaged in jobbing and batch production of castings.

Continuous-type ovens are designed for high production work. The core racks move slowly through these ovens on a continuous chair or rail. The loading and unloading is continuous, with the baking time controlled by the rate of travel of the conveyer. Continuous ovens are especially suited for small cores which are of approximately the same size. The temperatures of the various parts of the oven and the speed of the conveyer are so coordinated that the core emerges from the oven not only baked but also cooled. To save floor space, in some designs, the cores get baked as they move vertically upwards through the oven and get cooled on their return trip downwards.

Core-drying ovens may be heated by coal, coke, oil, gas, or electricity. The choice of the fuel depends on its availability, cost and the quality of cores required.

The temperatures used for baking may vary from 150°C to 400°C, depending on the type of binder used, the size of the cores, and the length of baking time. The ovens are generally of the air-circulated type which distribute the heat uniformly all over and carry away the air saturated with the moisture oozing from the cores. In modern core ovens, dielectric heating is also employed for high-quality cores made from resin binders. The material to be heated dielectrically is placed between the parallel plates or electrodes and a high-frequency current is passed through it. The high-frequency current tends to deform the sand molecules. The resistance of the molecules to this deformation produces the required heating effect. The core ovens should be equipped with adequate control of temperature so that correct temperature can be maintained, according to type, size and shape of cores.

3.4.4 Use of Chaplets

Chaplets are often required to be placed between the mould wall or base and core, in order to avoid deflection of the core and achieve the exact section thickness of the casting. As far as possible, chaplets should be of the same composition as the cast metal so that a homogeneous structure is obtained and no internal flaws are developed. For ferrous castings, steel chaplets are available as hardware items in different shapes and sizes. IS: 5904–1978 covers the requirements for steel chaplets and gives dimensions of 11 types of chaplets as follows:

Type 1 Single-column chaplets, round-headed, with or without collars, with or without groove in columns

Type 2 Single-column chaplets, with round or rectangular column and square heads

Type 3 Two-column chaplets with rectangular heads, round or rectangular columns; round head, round column and rectangular bottom plate

Type 4 Three-column chaplets with flat rectangular or flat radial heads

Type 5 Four-column chaplets with round or rectangular columns and rectangular heads

Type 6 Stem chaplets with flat-plate or curved-plate heads, stem being plain or grooved

Type 7 Two-column chaplets with flat, rectangular, stamped heads

Type 8 Bridge-type chaplets made from steel plates by pressing in one piece

Type 9 Spring-back chaplet, made in C shape in one piece by pressing

Type 10 Box-type chaplets, rectangular or radial, with inserting end or central rib

Type 11 Wire chaplet with single or double supporting spiral

The chaplets are to be given anticorrosion treatment or coating, such as passivation, copper coating, tin coating or nickel coating. Hot-dip turning is often used. It must be ensured, during use, that chaplets are clean, not rusted, and free from moisture. Figure 3.33 shows the above-mentioned 11 types of chaplets.

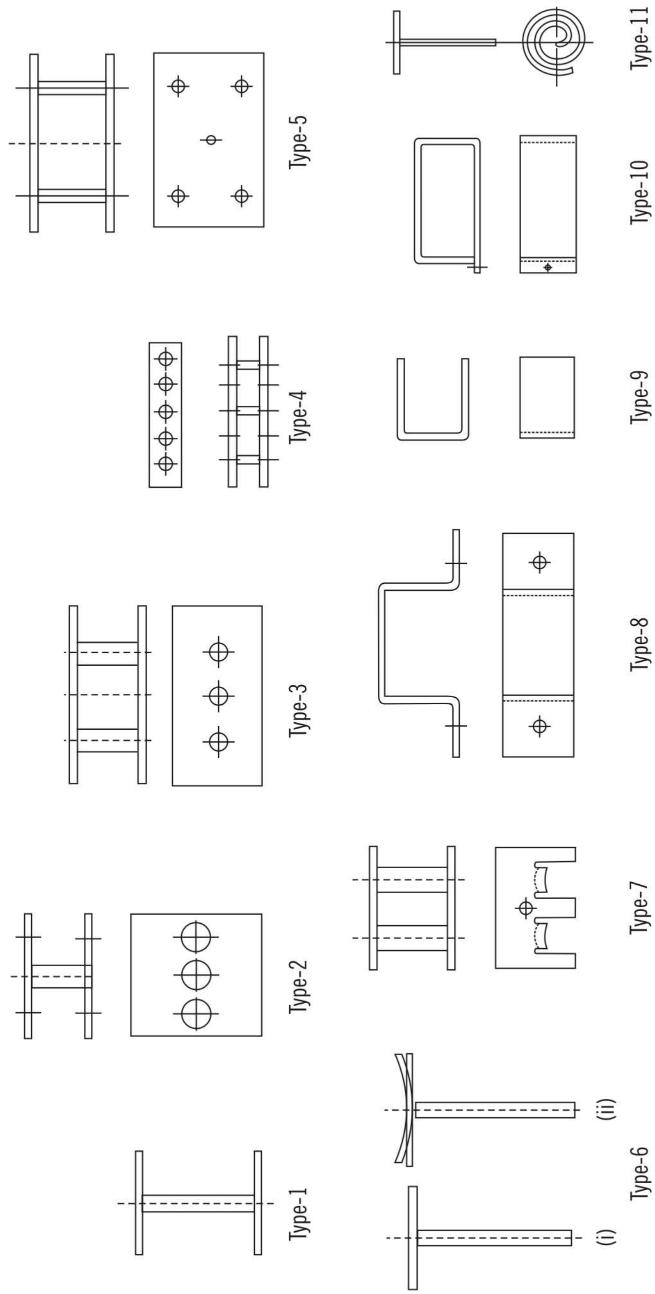


Fig. 3.33 *Various types of chaplets used in foundries*

MACHINE MOULDING 3.5

Moulding processes may be classified as hand moulding or machine moulding according to whether the mould is prepared by hand tools or with the aid of some moulding machine. *Hand moulding* is generally found to be economical when the castings are required in a small number. On the other hand, when the castings are required in large quantities, hand moulding is more time-consuming and laborious and becomes expensive. Considerable skill is also needed to make good moulds by hand. In such cases, *machine moulding* is generally employed.

The main advantages of machine moulding are as follows:

(i) It affords great saving in time, especially when a large number of similar castings in small sizes are required.

(ii) When the number of castings is substantial, the additional cost of metallic patterns and other equipment is compensated by the high rate of production, and the overall cost per piece works out lower than in the case of hand moulding.

(iii) The castings obtained are more uniform in size and shape and more accurate than those obtained by hand moulding due to steadier lift of the pattern.

(iv) A semi-skilled worker can do the machine job whereas hand moulding requires skilled craftsmanship.

3.5.1 Moulding Machines

Moulding machines may be broadly classified as (1) hand-operated moulding machines, and (2) power-operated moulding machines.

1. Hand-operated Moulding Machines

In the case of a hand-operated moulding machine, generally referred as a hand moulding machine, one or more of the operations, such as ramming, pattern drawing, and mould rolling-over, are performed by the machine which is manually operated either by a hand lever or a pedal control. These machines do not make use of any external power. Depending on the type of operation performed, the hand moulding machines may be of the pattern-draw type or the pattern-draw and squeeze type. The pattern-draw machines make use of a plain stripper type, a pin-lift type or a roll-over type of mechanism for withdrawing the pattern from the mould after the sand has been rammed. Figure 3.34 shows a pattern-draw and squeeze-type hand moulding machine.

2. Power-operated Moulding Machines

The power-operated moulding machines make use of hydraulic or pneumatic action to perform various operations during the moulding process, such as raising or lowering the table for pattern withdrawal, ramming the sand by squeeze, jolt, or combined squeeze and jolt actions, and rolling over the moulding boxes. Owing to the use of external power, manual labour and fatigue are markedly reduced and the production rate of moulds is increased.

Like the hand-moulding machines, the power-operated machines are also named after their principal functions. For example, a pneumatic jolt roll-over moulding machine is that in which the sand is packed or rammed by a jolting action with the help of compressed air, the mould is inverted by rolling it over, and the pattern is drawn out mechanically. Moulding machines that work on a pre-set automatic cycle are also available. Various operations needed to prepare the mould are performed automatically one after the other in proper sequence, and the moulds ready for assembly are passed on from the machine to a conveyer, which transports them to the mould assembly and pouring floor.

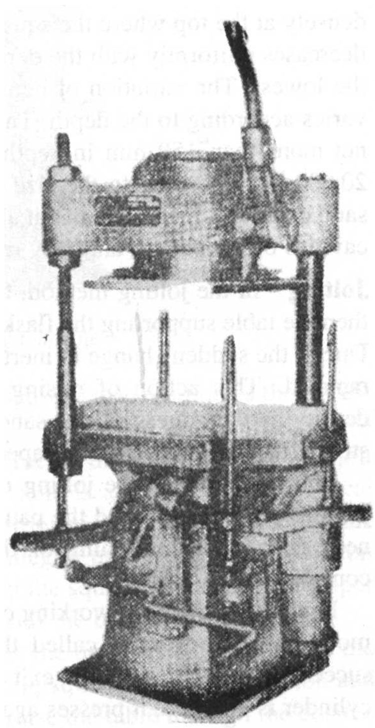


Fig. 3.34 *Hand-operated moulding machine*

For pattern-draw, the arrangement used in these machines is basically similar to that used in hand moulding machines, e.g., pin-lift type, stripper type, or roll-over type. For ramming the sand, three principal methods are employed: (i) squeezing, (ii) jolting, and (iii) slinging.

Squeezing In the squeeze method, the flask is filled with the moulding sand, and the sand is squeezed against a pressure board pneumatically or hydraulically until the mould attains the desired density. In some cases, the squeeze action may be obtained by means of electromagnets.

The main limitation of this method is that, by squeezing, the sand is packed more densely at the top where the squeeze board presses against the sand and the density decreases uniformly with the depth. At the parting plane, the density is found to be the lowest. The variation of density affects the hardness of the mould which thus varies according to the depth. The squeeze method is therefore restricted to moulds not more than 150 mm in depth. The squeeze pressures used vary from 3000 to 20,000 kg according to the size of the machine. Where the moulds contain green sand cores, this method is not at all satisfactory as the sand cannot flow into the core cavities of the pattern and may remain loose near these cavities.

Jolting In the jolting method, the flask is first filled with the moulding sand and then the table supporting the flask is mechanically raised and dropped in succession. Due to the sudden change in inertia at the end of each fall, the sand gets packed and rammed. This action of raising and dropping the table is called *jolting*. The density and hardness of the sand can be controlled by varying the height of the stroke, the amount of sand heaped above the mould, and the number of strokes.

The drawback in the jolting method is that the sand is rammed hardest at the parting plane and around the pattern and remains less dense in the top layers. This necessitates hand ramming of the mould at the back after the jolting action is completed.

In a jolting machine working on compressed air, the table supporting the flask is mounted on a cylinder called the jolt cylinder which is raised and dropped in succession by the entry and exit of compressed air underneath its base. When the cylinder is dropped, it presses against a valve which causes it to open and allow the air to enter the space beneath the base of the cylinder. The high-pressure air induces the cylinder to rise till it uncovers an exhaust port when the air rushes out and pressure falls down. Due to the fall in pressure, the cylinder drops down and it again presses against the valve and opens the air entry. The jolt cylinder together with the table are thus raised and lowered in quick succession producing the desired jolting action. The jolting load exerted during moulding varies from 200 kg to 1000 kg according to the size of the machine.

Jolt and Squeeze In order to overcome the drawbacks of both the squeeze and the jolt principles of ramming and to achieve uniform density and hardness in all portions of the mould, a combination of squeeze and jolt actions is often employed. The machines that bring about this combined action are referred as *jolt-squeeze moulding machines* (Fig. 3.35). A jolting action is used to consolidate the sand on the face of the pattern and it is followed by a squeezing action to impart the desired density in the upper portion of the mould. This squeeze action eliminates the necessity of any hand ramming.

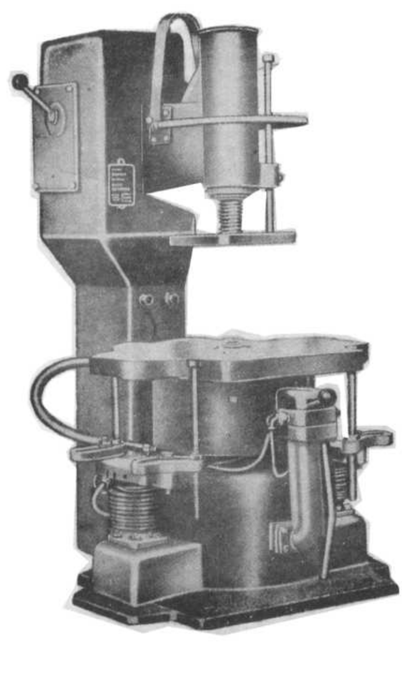


Fig. 3.35 *Pin-lift moulding machine*

The jolt-squeeze moulding machine is so constructed that both squeeze and jolt actions can be obtained one after the other. The table is attached to a cylindrical piston, called the jolt piston, which is raised and dropped in the jolt cylinder by the action of compressed air. The jolt cylinder is an integral part of the squeeze piston which can move up and down due to air pressure in the squeeze cylinder. The upper surface of the squeeze piston remains in contact with the bottom of the table.

During jolting, the squeeze piston lies solidly on the base of its cylinder, and the lift of the jolt piston causes the table to rise. During squeezing, the jolt piston and cylinder move along with the squeeze piston and raise the table through the desired height. Figure 3.36 shows a pneumatically operated jolt-squeeze pattern-draw turn-over type of moulding machine.

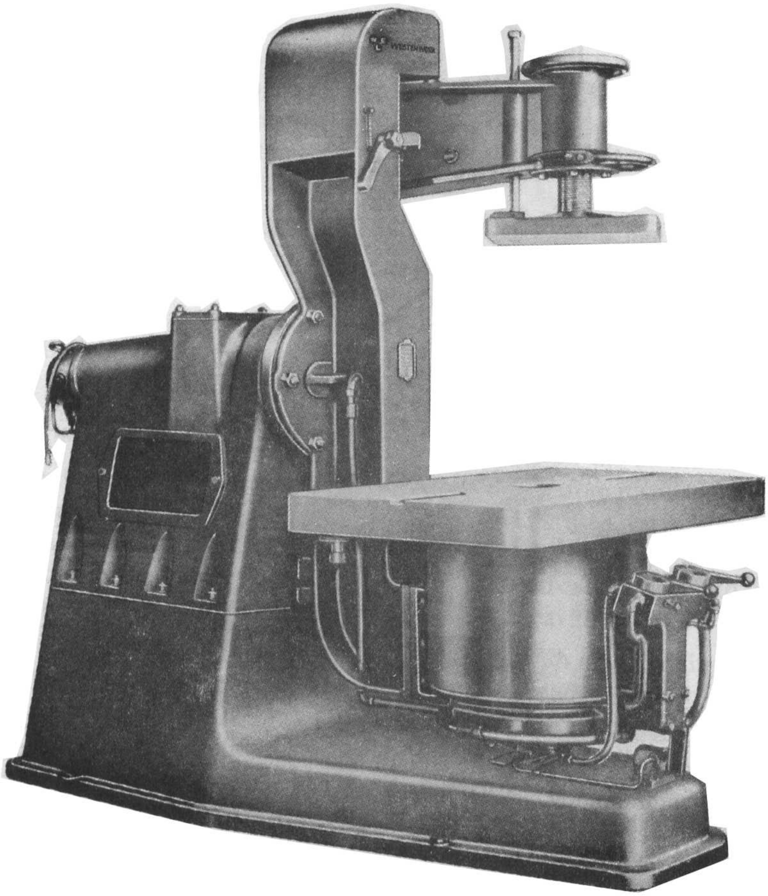


Fig. 3.36 *Turnover moulding machine*

The typical specifications of a jolt-squeeze moulding machine of medium size accommodating a moulding box of maximum 800 mm × 630 mm size may be

squeeze pressure	:	7000 kg
jolting load	:	350 kg
pattern draw	:	300 mm
table size	:	900 mm × 630 mm
squeeze stroke	:	100 mm
air pressure	:	6.3 kg/cm^2

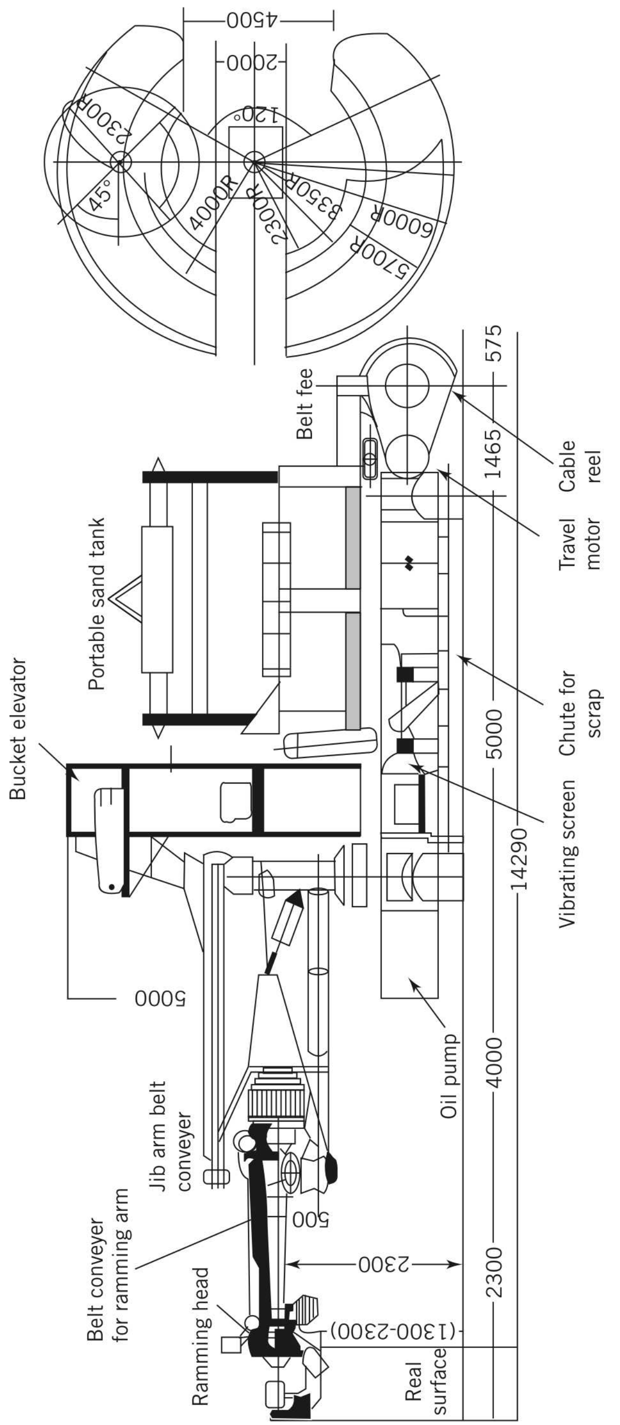


Fig. 3.37(A) *Dimensions of sand slinger having a capacity of 8 m^3/h*

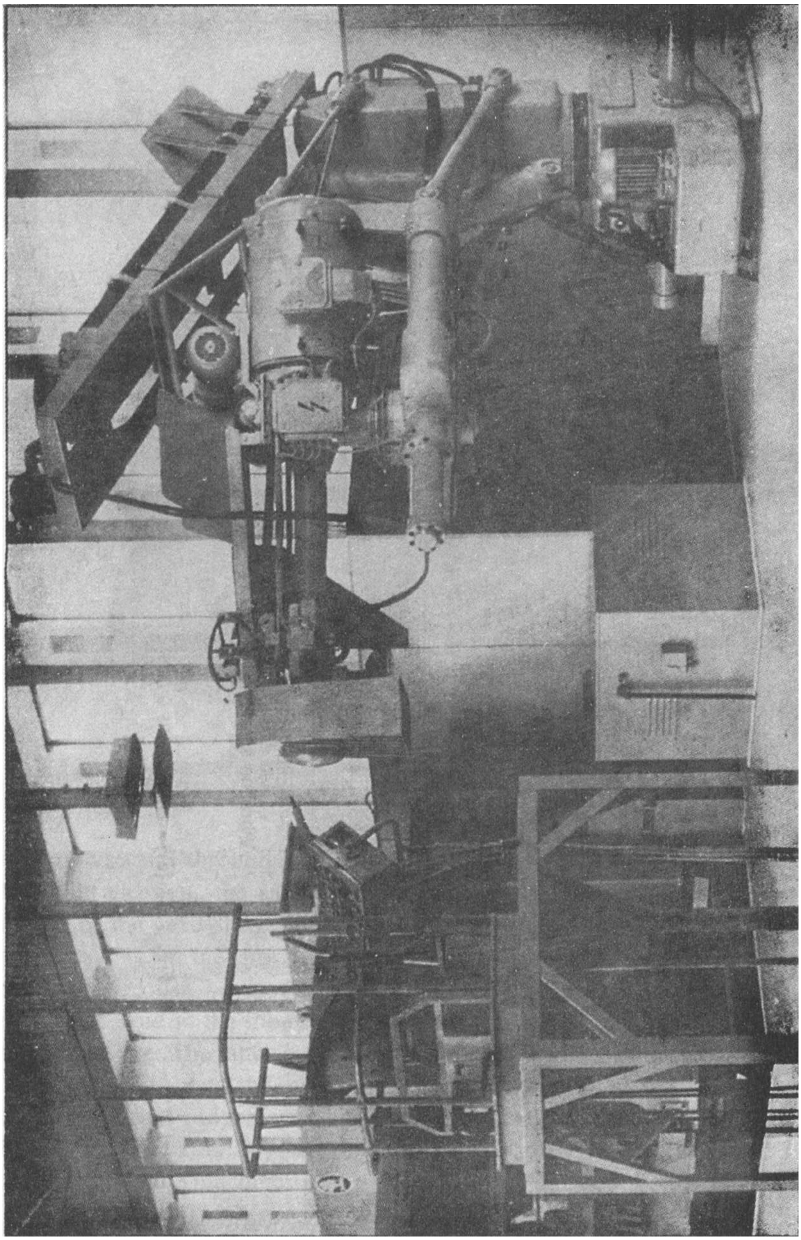


Fig. 3.37(B) *A stationary type sand slinger*

Slinging In the slinging operation, the consolidation and ramming of sand is achieved by means of impact with the pattern. Basically, the sand slinging machines, commonly known as *sand slingers*, are equipped for throwing a stream of sand downward, through a slinging head, onto the pattern at high velocity. Due to the rapid ejection, the sand particles settle down instantly and get rammed. The design of the sand slinger incorporates a high-speed rotary impeller, pipes, band conveyer, bucket elevator, and an ejecting head attached to a swivelling arm. The ejecting head can be moved all over the moulding box so as to attain uniform density of sand in the mould. The sand slinger may be either the stationary or the travelling type. The latter may again be the motive or the console type.

Figure 3.37(A) shows the main part of a motive type of sand slinger. The ramming capacity of sand slingers varies from 0.15 m^3/min for a small size to 0.85 m^3/min for a large size. Similarly, the ramming range varies from 4500 mm to 10,000 mm radius around the machine.

High-Pressure Moulding

High-pressure moulding uses a compacting process for the production of green sand moulds. The force of compaction required is much higher (about 5–10 times) than that for conventional moulding machine work. The squeeze force is usually applied hydraulically as this enables high production rates and noiseless operation. Since the process has been found to offer technical and economic advantages for both the producer and the consumer, special machines have been developed to achieve the necessary high compaction pressures. It is worthy of note that once the machines and related equipment are installed, production can be carried on uninterruptedly with the same moulding materials as are used in ordinary moulding work, abiding by green sand practice. Figure 3.38 shows the construction of a high pressure moulding machine.

The process is highly flexible and is suitable for all types of cast metals, both ferrous and non-ferrous. Closer dimensional tolerances can be maintained and less machining allowances are required, causing casting to be lighter by 3–7%. But since the initial cost of the equipment is high and the sand-control requirements precise, high-pressure moulding is considered worthwhile only for mass production work using close cycle operation. Flaskless moulds are generally used with high-pressure moulding (Fig. 3.39). The moulding boxes, in which the moulds are made, are not fixed but of the hinged type so that moulds can be removed from the box after they are compacted. To protect these moulds from damage or distortion, a sheet metal jacket is placed around them. The boxes used are snap flask moulding boxes and their design and specifications are covered by IS: 10518–1983. The use of flaskless moulds helps in considerably reducing the inventory of regular moulding boxes, reduced weights to be transported over conveyers, easier shake-out, saving of foundry space and reduced transportation.

Fig. 3.38 *Matchplate-sand-molding-machine*

The range of squeeze pressures used in conventional jolt-squeeze moulding machines is from 1.5 kg/cm^2 to 5 kg/cm^2. In high-pressure moulding, however, pressures vary from 7 kg/cm^2 to 25 kg/cm^2 and may be as high as 40 kg/cm^2. Contrary to the common belief that mould hardness increases in proportion with the increase in squeeze pressure, in practice it is seen that hardness increases at a steep rate with pressure only up to about 4.6 kg/cm^2. Any further exertion of squeeze pressure causes negligible rise in mould hardness. Properly controlled sand composition, which is a prerequisite, enables just adequate permeability for the gases to escape, coupled with sufficient strength, hardness, and other characteristics. The moisture content used in sand mix is usually not more than 2.5%. Comparatively higher clay content is used with suitable additives such as dextrin so as to control the spring-back tendency of sand and prevent mould distortion.

For uniform composition of sand all over the pattern, especially when the latter is of varying height, a contoured squeeze head is used. A self-contoured squeeze head, which can automatically adjust itself, is found ideal for overcoming the difficulty of preparing a squeeze head of a fixed contour for each pattern. The head consists of a large number of squeeze feet, each with its own piston and hydraulic cylinder. Each cylinder is hydraulically connected through one or more manifolds. During the squeeze operation, the pistons are fully extended and

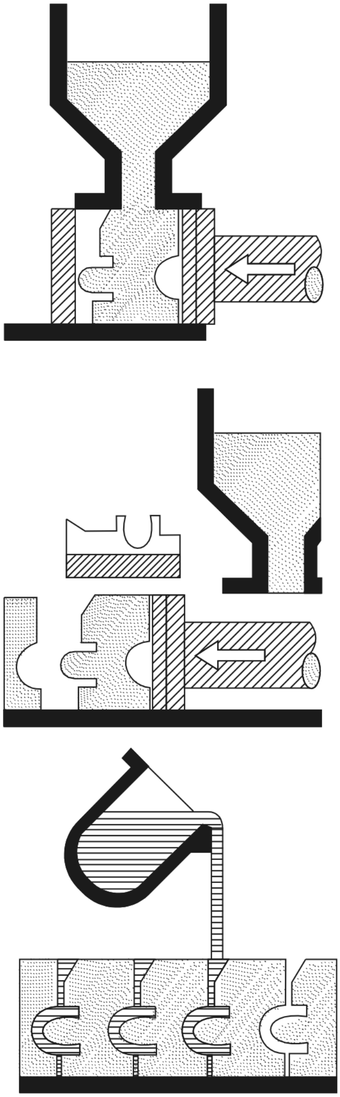


Fig. 3.39(a) *Automatic flaskless HP moulding*

Fig. 3.39(b) *Flaskless moulding machine*

apply pressure on the sand. Each piston continues the squeeze action through its squeeze feet till a pre-set value of pressure is reached. At this instant, the cylinder is no longer capable of resisting any further pressure and a relief valve operates causing the pistons to yield and a contoured squeeze head is formed to suit the shape of the pattern.

It is essential for patterns used in high-pressure moulding to have fine finish and polish, high strength and rigidity, so as to enable easy stripping, good wear resistance and hardness, and accuracy. The patterns are made of cast iron, steel, or epoxy resin. Sometimes, aluminium patterns are also used; wooden patterns are not favoured. Large patterns are provided with suitable ribs and may also have supporting plates. Wear strips may also be inserted at places where greater wear is expected. In the case of cast-iron patterns, chrome-plating ensures good finish.

Various processes used to achieve compaction in high-pressure moulding are the following:

1. Blow Squeeze The most common practice followed in high-pressure moulding is blow squeeze where the moulding sand is blown pneumatically over the pattern and then the squeezing of sand is carried out. The process is satisfactory, producing good-quality rigid moulds and is quieter in operation than the jolt-squeeze machine, but the precompaction obtained by blowing is limited and not uniform in large moulds. Improved methods have been lately incorporated in the new generation moulding machines which are more efficient and productive.

2. Impact Moulding This process uses either an air impulse or a gas-injection system in order to use impact force to achieve a high degree of compaction in a very short time, the latter being controlled by the fast build-up of pressure in a closed moulding chamber. Gas injection utilises combustion of a gas/air mixture (natural gas, methane or propane), as in case of an IC engine. In an air-impulse system, the pressure build-up is caused by releasing compressed air at high pressure on the back of loosely filled sand.

Both systems are effective and allow compaction in one operating cycle, have high operational reliability, less down time, reduced maintenance costs, reduced noise and dust emissions and controlled shock-free movements. However, the compaction at the edges in the fast may be low, due to which the pattern plate cannot be fully utilised.

3. Shoot Squeeze The sand in this system is ejected from a shorter head and is made to impinge on the pattern under heavy force. The shooting operation, thus causes pre-compaction of sand, which is then followed by a high-pressure squeeze for full compaction. The process is efficient and productive, less noisy than blow squeeze machines and incurs lower operating costs. The machine can produce moulds weighing 500 kg in a cycle time of 45 to 60 seconds.

4. Vacu-press In this process, vacuum is created in a moulding chamber and simultaneously the sand is shot, enabling considerable improvement in filling and compaction as the incoming sand has only a small amount of air to displace. The sand so pre-compacted under the action of vacuum is then squeezed to achieve complete compaction. This process is highly effective in producing extremely intricate castings consistently to close tolerances at high production rates. The operation is quiet and involves low operating cost, though the initial investment is fairly high. Given a close control on the sand quality, the rejection rate can be as low as 1% during production of automobile castings.

Selection and Evaluation of High Pressure Moulding Machines

The criteria for selection and evaluation of a high pressure moulding machine largely depends upon the requirement of the individual foundry and the type of casting with respect to weight and size which are planned to be produced. In the present-day context, the saving of even a marginal weight in the finished casting, could go a long way in the economical operation of the foundry. This coupled with the need for close tolerances and reduction in machining time are the other factors which determine the selection and evaluation of moulding machines. Still other criteria to evaluate moulding machines include the ability to draw the pattern with minimum draft, the capacity to utilise the maximum pattern surface area and the ability to produce uniform hardness throughout the height of the mould. It is possible to locate the pattern as close as 20 mm from the moulding box walls and still prevent soft pockets to high green strength achieved during moulding. The variation in hardness may be less than 5% even in moulds with a height of 350 mm and the total rejections both in the foundry and machine shop may be well within 1–2%.

3.5.2 Core-making Machines

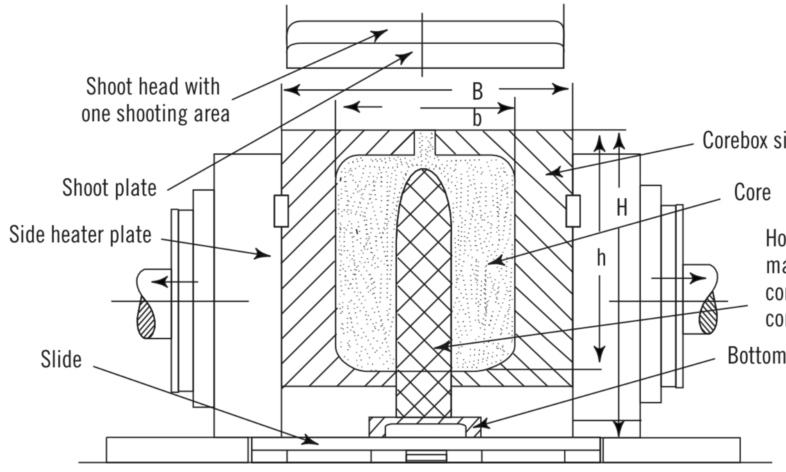
A number of types of machines have been developed for the rapid production of cores as well. Suitability of a particular type depends on factors such as the number of cores required, the size of the cores, and the intricacy and design of the cores. The commonly used core-making machines are now discussed.

1. Core-blowing Machine The core-blowing machine is indispensable for core making in a production foundry. The core sand is forced into the core box from a sand reservoir with a stream of high velocity air at a pressure of about 6–8 kg/cm^2. The core box has a number of vent holes suitably located so that as the sand is introduced, the air is ejected through these holes. Due to the high velocity air, the sand is passed instantly in the core box.

A core shooter is another version of a core blower in which the core sand is ejected from the shooter head and is made to impinge into the core box cavity under impact (Fig. 3.40).

2. Core-drawing Machine The core-drawing machine facilitates in drawing off the cores from the boxes especially for core boxes having deep draw. The core box, with core sand duly rammed in, is placed on a core plate, which is supported on the machine bed. From one side, the core box is placed in contact with another vertical plate and this vertical plate is vibrated so as to produce a rapping action on the core box. After rapping the core box is raised leaving the core on the core plate. The ramming of the sand in this case is done by hand either with a hand rammer or a pneumatic rammer.

3. Continuous Core-Making Machine A continuous core-making machine is used for preparing cylindrical cores of uniform section in various sizes which are called stock cores. Cylindrical cores, which are most commonly used, are prepared in long length on these machines and are kept in stock. When a core of a certain diameter and length is required, it is taken out of the stock, cut to the desired length, and used after tapering down the ends. For preparing the stock cores, the core sand is filled in the hopper of the core-making machine from where it comes



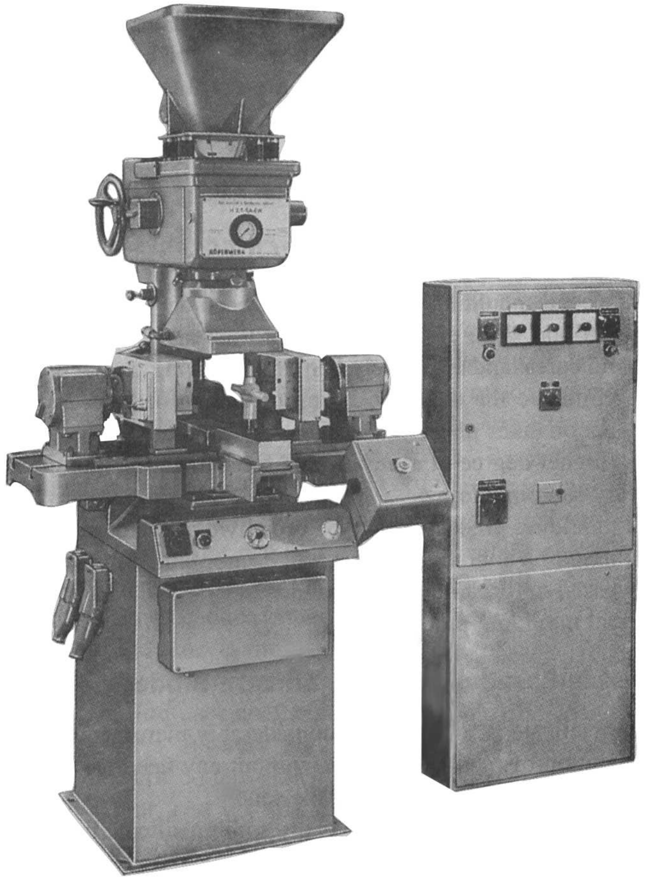


Fig. 3.40 *Core shooting and curing machine*

into a cylinder. It is then forced from the cylinder through a die of the size desired by means of a horizontally rotating screw.

4. Roll-over Core-Box Draw Machine This machine is similar to the roll-over pattern-draw hand moulding machine, except that it is smaller and is used for withdrawing the core box from the core.

5. Jolt Roll-over or Jolt Pin-lift Core-Box Draw Machine These machines again are similar to the corresponding moulding machines described earlier. In general, these machines are smaller in size and often the various operations such as jolting, roll over, and drawing, are performed manually.

6. Sand Slinger For medium- and large-sized cores, sometimes a sand slinger, similar to the one used for moulding work, is required. This is usually of the stationary type and smaller than the one used for making moulds.

'SPECIAL' SAND MOULDING PROCESSES 3.6

In recent years, special moulding processes have been developed to enable moulding with less effort and skill, effect a saving in time and expense, produce better quality moulds and cores, and effectively help in improving productivity. Generally, these processes eliminate the need for drying or baking of moulds and cores, and rapid hardening action takes place due to chemical reactions. Also, the castings can be produced to a higher degree of accuracy and finish than that possible by conventional green or dry sand moulding.

Special sand-moulding processes may be broadly classified under three heads:

(1) Processes based on sodium silicate or other inorganic binders;
(2) Processes based on organic binders; and
(3) Other special moulding processes.

3.6.1 Processes Based on Sodium Silicate Binder

The use of sodium silicate as a binder has considerably increased in recent years. It enables the preparation of mould and cores without any need for drying or baking and in certain cases even without ramming the sand.

Differences amongst various processes using sodium silicate lie in the quality of hardener used, the type of catalysts or other additives, and in the nature of the chemical reactions that cause the hardening. These processes are being widely used for the production of cast iron, steel as well as non-ferrous castings required in small, medium, and heavy sizes alike as they provide easier sand control and can be adapted with more ease and flexibility than other processes.

Patterns used with these moulding processes may be made of wood, metal, or plastic. Wooden patterns if painted with synthetic enamel paint are difficult to strip. Such patterns should only be given a coat of shellac or varnish. If paint is essential, a nitro-cellulose base aluminium paint may be used. Greater draft allowance on the patterns may have to be given if the stripping problem persists.

(1) Carbon Dioxide Process The development of the carbon dioxide (CO2) process of moulding and core making about thirty years ago marked the advent of an epochmaking era in foundry practice. The method has not only cured the problems of foundrymen caused by the need for greater skill and care during moulding and baking, it has also removed serious bottlenecks before the management in planning a regular and streamlined production of castings at a low rejection rate.

The principle of working of the CO2 process is based on the fact that if CO2 gas is passed through a sand mix containing sodium silicate as the binder, immediate hardening of sand takes place as a result of the chemical action between sodium silicate and CO2. The bonding strength obtained by the hardening action is sufficient to eliminate the need for any drying or baking of the mould and the metal can be immediately poured. The chemical reactions taking place are of complex nature, though the main reaction can be represented in simplified form as

$$Na_2O \times m SiO_2 \times x H_2O + CO_2 \rightarrow Na_2CO_3 + m SiO_2 \times x H_2O$$

The sodium silicate used in this process, as also in the others described later, is based on the $Na_2O.mSiO_2.xH_2O$ system where the ratio of total alkalinity (Na_2O) to the total soluble silica (SiO_2), called mass ratio, or its inverse, called *molar ratio* or mol. ratio, is a variable factor affecting the characteristics of the process. The common sodium silicate used for the CO_2 process in foundries should have a mass ratio varying from 2.1 to 2.3. The ratio of soda to silica can be raised by adding a suitable quantity of NaOH. The specific gravity of the liquid depends on the mass ratio and its water content, which for foundry use may vary from 1.55 to 1.71 (52–60° Baume). Without changing the mass ratio, the specific gravity of the liquid can, if required, be reduced, from 58° Baume to 53° Baume by adding an invert sugar content in the range of 5–10%. IS: 6773–1978 relates to the specifications of sodium silicate for use in foundries.

The SiO_2 obtained from the reaction contains a certain number of water molecules and is represented as $SiO_2.xH_2O$, which is called silica gel. This silica gel is responsible for giving the necessary strength to the mould.

The sand used for the process must be dry and free of clay. This sand is usually mixed in a sand mixer with about 3–5% of sodium silicate. Suitable additives, such as coal powder, wood flour, sea coal, dextrin, and iron oxide, may be introduced to obtain specific properties. As very high compressive strength is reached in CO_2 moulding, the problem of collapsibility is generally encountered. Dextrin as also coal powder, wood flour, and sea coal improve collapsibility. Iron oxide prevents hot deformation of cores and produces a smooth interface between the mould and the metal, thus helping to prevent metal penetration and achieve good surface finish. Kaolin clay is added to promote mould stability and is often used in steel casting work. Various proprietary compounds are also available as additives. Invert sugar is often mixed in these proprietary compounds as it is an effective breakdown agent and an aid in bettering collapsibility.

It is essential to pass CO_2 for a predetermined length of time. The reaction proceeds rapidly in the early stages of gasification and the compressive strength of the sand mixture reaches a maximum value when a certain critical amount of gas is passed. If gassing is continued further, the strength of the bond gets impaired. It is also found that a given quantity of gas produces higher strength when applied at low pressure and for a longer time. The volume of CO_2 required can be calculated if the quantity of sodium silicate present is known. As a thumb rule, for every 1 kg of sodium silicate, 0.50–0.75 kg of gas is required.

A single cylinder with a pressure-reducing valve can be used for small installations. The vaporising capacity from such a source is about 2 kg per hour. Gas tends to freeze if the rate of draw is increased. Where the requirement of gas is large, a cylinder manifold system along with an electric vaporiser is used. With this arrangement, a vaporising capacity of 75 kg per hour can be obtained. For a still larger requirement, liquid CO_2 from syphon-tube cylinders or bulk-storage tanks can be used.

The gassing can be carried out by a probe having a number of holes at the base. In the pipelines and fittings, the same diameter should be used. The minimum diameter of the pipe is 12 mm. Gas leakage should be avoided by frequent testing. If several probes are used, flow rates in all of them should be the same as in a single probe. The flow rate of CO_2 gas depends on the depth of penetration desired.

Advantages of CO_2 Moulding

(i) There is considerable saving in labour as moulds and cores for heavy castings need not be carried to the oven and from there to the pouring station. Manual work is thereby greatly reduced. Costs too are cut as rush orders can be quickly fulfilled and floor space is saved.

(ii) High accuracy and good surface finish on castings are possible. The process can serve as an inexpensive substitute for dry sand moulding where close tolerances are specified.

(iii) Withdrawal of pattern is facilitated since the moulds may be hardened before extracting the pattern.

(iv) The likelihood of rejections is less whilst productivity is higher. Mould cracking and deformation are also prevented.

(v) The process can be mechanised and adapted even for mass production.

(vi) Less moulding skill is required than for dry sand moulding.

(vii) Reduced machining allowances are required.

(viii) The method is versatile as it can be easily used by small, medium, and large foundries for light and heavy castings and for ferrous and non-ferrous foundries alike. All materials required are indigenously available.

In view of its overwhelming advantages and versatility, the CO_2 process has proved successful for large and diversified applications, such as parts of valves, pumps and compressors, machine tools, wheel castings, railway components, diesel engine parts and reduction gear castings.

(2) Ferro-silicon Process In this process, silica sand is hardened and bonded with the reaction product obtained by exothermic reaction between sodium silicate and ferro-silicon powder. The method is based on the principle that if sodium silicate and powdered ferro-silicon are mixed in a weight ratio of 2.25 : 1, foaming action takes place and the temperature rises simultaneously, reaching a boiling condition at about 90°C. During the chemical action, steam and hydrogen are liberated. The reactions taking place are

$$Na_2O.nSiO_2 + H_2O \rightarrow 2NaOH + nSiO_2$$
$$mSi + 2NaOH + H_2O \rightarrow Na_2O.mSiO_2 + 2H_2$$

The reaction continues as long as silicon and water are present. If silicon is supplied a little in excess, almost all the water is dispelled by decomposition and evaporation. At room temperature this reaction takes place slowly, but once the temperature is increased, the reaction accelerates and finally the products of reaction form a hard spongy mass. No baking of the mould or cores is necessary.

The sand used in the mix should be dry and should have a grain size to suit the requirements of the metal to be cast. Normally, for ferrous castings, silica sand of 65 mesh is suitable, and for non-ferrous work, 100 mesh is used. The sand is first mixed with about 2% of its weight of ferro-silicon, containing 75–80% silicon, which should be duly powdered to 3–3.5 micron size. Sodium silicate of the correct grade, specific gravity, and mass ratio is then added (about 5% of the weight of the sand) and the mixing continued. The specific gravity and mass ratio suitable under moderate climatic conditions are 1.3–1.35 and 1 : 2.0–1 : 2.3, respectively. In order to impart specific properties, such as collapsibility and bench life, suitable additives may be used. A precise control of the mixing cycle and ingredients is necessary to obtain the desired mould characteristics. As the bench life of such sand mixes is usually short, moulding must be completed as early as possible and within the period of the bench life. The moulds have to be coated with a suitable wash before they are closed.

When using ferro-silicon, the same process may be modified by adjusting the basic ingredients and mixing a foaming agent to enable use of the mixture as a flowable slurry in the mould. The slurry is poured over the pattern into the flask and, by virtue of its easy flowability, it occupies all the areas uniformly. Ramming of sand is thus largely eliminated.

Advantages of Ferro-Silicon Process

(i) Mould drying or core-baking is eliminated.

(ii) Due to exothermic reaction, residual moisture in moulds is much smaller than in the CO_2 process.

(iii) Moulding requires much less skill and the hardening time can be controlled.

(iv) Cracking and deformation of moulds is prevented as no drying is done.

(v) A lesser number of moulding boxes is required and the moulds can be easily poured on the same day they are prepared.

(vi) Better accuracy of casting, dimensions and finer finish are possible.

(vii) Defects in castings, attributable to mould, such as blow, contraction, and seizure, are largely eliminated.

(viii) Production of castings from a given floor space is higher.

(ix) No core bars and reinforcements are generally required.

(x) Cost of casting is reduced.

(xi) The process is versatile. It can be used for small or large castings, ferrous or non-ferrous, and moulding can be done with all types of patterns, viz., solid, sweep or strickle. It is particularly suitable for medium and large castings, such as pump castings, motor housings, gear boxes, and machine frames.

(3) Dicalcium Silicate or Fluid Sand Process Dicalcium silicate has been found to be a very effective hardening agent when used with sodium silicate as a binder. Unlike the Fe–Si process where hardening is due to exothermic reaction, the chemical reactions taking place in this process do not cause any evolution of heat. Synthetically produced dicalcium silicate can be used for the purpose. Slags from certain melting or reduction processes, such as basic-lined hot blast cupola, open-hearth furnace, and ferro-chrome production, contain an appreciable quantity of dicalcium silicate and are quite suitable. The rate of hardening depends on the grain fineness of the silicate and the temperature of the sand. The fineness of the silicate grains should not be less than 200 mesh. The higher the temperature, the quicker the reaction and the shorter the bench life.

To prepare the mix, about 2–3% of dicalcium silicate and 5% sodium silicate are mixed with sand, along with suitable foaming chemicals. The mix can flow easily in the mould, thus eliminating any need for ramming. Mixing time is from 3–5 minutes, and the bench life in temperate climate, as in this country, is not more than 25–30 minutes. The sodium silicate used in this process should have a high mass ratio (1 : 2.3 to 1 : 2.8) and specific gravity of 1.48 to 1.50.

The fluid sand process finds its main application in medium and heavy castings, both in grey iron and steel, such as ingot moulds, heavy machine tool castings, steel-mill rolls, castings for cement and the mining industry, and pump castings. The main advantage of the process is the great saving in labour input and moulding equipment. No drying or baking facilities are needed and high-quality defect-free castings are produced. The process has gained wide popularity in many European countries, the USSR, and Japan, and has been introduced in Indian foundries also.

In order to guide foundries to adopt the fluid sand process, test methods have been laid down in IS: 9674–1980. Tests are prescribed for flowability, bench life, bulk density, compressive strength, permeability, sagging tendency, collapsibility, hardener fineness, water-absorption capacity, hardener activity, foamability, and residual water content.

(4) Cement Moulding Process Portland cement may be used as an inorganic binding material to bind sand grains together. Efficiency, however, is further increased and a good combination of strength, permeability, and flowability achieved by using cement along with sodium silicate. The sand mix may consist of about 2% cement, 4–5% sodium silicate, and 1% pitch or molasses. The mix has a useful bench life of about 15–20 minutes and large-sized moulds can be produced for ferrous castings with good shake-out properties. By using foaming chemicals in the sand mix, flowable cement slurry can also be produced so that the ramming of sand is considerably reduced.

(5) Chamotte Process Burnt fire clay, ground to a fine mesh size, called 'chamotte' can also be an effective hardener when used with a sodium silicate binder. The process, using about 2% chamotte and 4–5% sodium silicate (2.5 mol. ratio) with high silica sand, named as chamotte process has been used in many steel foundries for producing heavy castings at low cost, free from defects like sand fusion, hot tears, cold cracks and scabbing.

3.6.2 Processes Based on Organic Binders

Various types of organic binders have long been in use and have lately become very popular for the production of high-quality castings of small to medium size. These processes were initially developed for making cores, but in spite of the high cost involved, they have found use in mould making as well. This is because they produce castings of superior quality and can considerably shorten the production cycles. The processes using organic binders include

(1) shell moulding;
(2) hot-box moulding;
(3) cold-box moulding;
(4) alkyd and phenolic no-bake processes;
(5) furan process; and
(6) gas-setting resin process.

(1) Shell Moulding

The process entails making moulds and cores as relatively thin shells from a mixture of fine sand (about 100–150 mesh) and thermosetting resin. When this mixture is placed against a heated metal pattern, the resin cures, causing sand grains to get bonded to each other and forms a shell around the pattern. The inside of the shell conforms exactly to the dimensions and shape of the pattern and constitutes one half of the mould. Two halves so prepared are placed together (after setting cores, if any, inside) to form the mould assembly. When the mould is ready for pouring the molten metal, the assembly is placed in a flask and back-up material is placed around it. Cores can also be prepared in the same way.

Figures 3.41 and 3.42 show the mode of preparing a shell mould and shell core. In actual practice, the pattern is heated under controlled conditions such that it maintains its temperature within a small permissible range. The sand–resin mixture is dumped or blown on to the heated pattern and, after a pre-set time, the pattern is turned over to allow the unbonded sand to be removed, leaving the shell on the pattern. The shell is then stripped mechanically and, if required for complete curing, it is further heated.

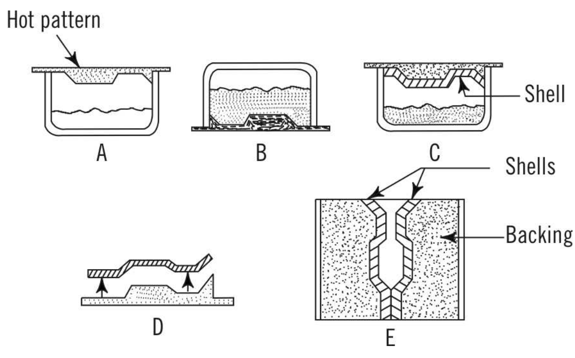


Fig. 3.41 *Shell moulding process*

(A) Sand resin mix in a box
(B) Sand-resin mix dumped over a heated pattern
(C) Shell formed over the pattern
(D) Shell stripped from the pattern
(E) Two shells joined together to form a complete mould and supported in backing material before pouring molten metal

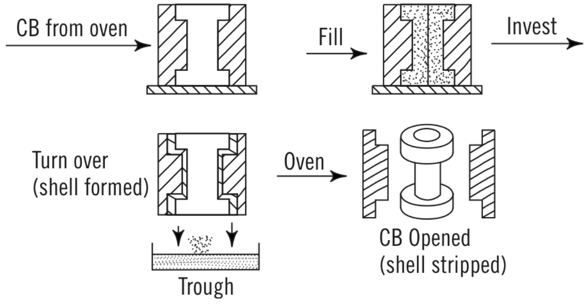


Fig. 3.42 *Preparation of shell core*

Machines are available, both for core making and moulding, where the operation can be carried out manually, semi-automatically, or on a fully automatic cycle. Two types of machines are in use: (i) the dump-box type, which relies on gravity alone to apply the sand–resin mixture on to the pattern and is ideal for low production rates where high dimensional control is not required; and (ii) the blow type where the mixture is blown on the pattern and the machine is set to work on a predetermined cycle of operation for high production rates; the pattern is heated on either electricity or gas.

The resins used are basically of the thermoplastic type, to which polymerising agents have been added to produce thermosetting characteristics. Phenol formaldehyde is the most popular resin. To control the hardening action of the resin and accelerate it, hexamethylene tetramine (abbreviated to hexamine or hexa) is added to the mix. The usual measure of resin is 4–6% of sand by weight, and the proportion of hexamine is 14–16% of the resin. The quantity of resin increases with the fineness of the sand. The sand must be dry and, as far as possible, free of organic materials and clay. The rounded type of sand grains are recommended for cores and the sub-angular type for moulds. When additives such as coal dust, MnO_2, ammonium borofluoride, lignin, and iron oxide are used, the shell acquires special characteristics, for instance better surface finish, resistance to thermal cracking and distortion, and substantial strength. A lubricating material is also sometimes added to the resin or the sand mix to permit easy release of the mould from the pattern and to improve the flowability of sand. Calcium stearate, zinc stearate, and carnauba wax are common lubricating materials.

The sand-resin mix may be prepared in three different ways. The selection of the process depends on the type of equipment available and the variety of resin, which may be water-borne, flake, or of the granular type. The specifications of liquid, flake and powder resins for shell moulding are covered in IS: 8246–1976, IS: 11266–1985 and IS: 10979–1981 respectively. The selection of resin should be made according to the requirements of castings, keeping in mind the resin manufacturers' recommendations.

1. Hot-Coating Process The curing of resin takes place due to the dual effect of heat and chemical action of an acid catalyst such as hexamine. It entails

(i) heating the dry silica sand to a temperature between 120°C and 175°C;
(ii) mixing the heated sand thoroughly with the resin and hexa so that the sand grains get uniformly coated with the resin;
(iii) screening the sand mix to eliminate lumps and agglomerates which may have been produced during mixing;
(iv) cooling the sand mix to about 45°C to prevent lump formation and to impart flowability; and
(v) aerating the cooled sand mix to further improve its flowability and power to quickly form the shell.

The hot-coating process is customary where shell moulding is undertaken for mass production of castings. It is the most economical method for large-scale production since less resin is required and a free-flowing mixture, which can also be stored, is obtained. The shells produced are stronger. Further, the process is safe as no alcohol is used and there is no explosion hazard.

2. Warm Coating Process In this process, the catalyst is used with a different resin formulation so that curing can take place only by using warm sand at about 80°C. The resin is in the form of a liquid solvent solution. Preparation of the coated sand takes longer and, even then, the mix is prone to lump or cake formation during storage. The quantity of resin consumed is larger than in the case of the hot-coating process. However, the simplicity of the process renders it suitable for medium-sized foundries.

3. Cold-coating Process When heating of sand grains is not required, the sand is first mixed with the requisite quantity of hexa and then resin, duly dissolved in alcohol, is added to the mix. The mixing operation is carried out at or in the region of room temperature. The method is more expensive than the other two as a greater quantity of resin is required, larger quantities of liquid have to be handled, and the mixing cycle is longer. The alcohol, which acts as carrier for the resin, has to be eliminated during the mixing operation itself by blowing air. The strength of the shell produced is also relatively less. With the development of newer types of resin composition, however, the process is gaining popularity as no special equipment is required and small quantities of sand mix can be prepared as and when needed.

Pre-coated Resin Sand The three methods described above are meant for preparing the sand–resin mix just before the moulds or cores are required to be made. Another variety of resin sand, known as 'pre-coated' sand, is available from the suppliers of foundry raw materials in a ready-mix form. This pre-coated sand can be stored for a long time (up to about three months) and can be used whenever required for preparing shell moulds or cores. Such precoated sands are particularly suitable in small foundries which cannot afford to instal the equipment for hot or warm coating.

Like other foundry procedures, a close control is required on the quality of basic materials, as well as on the sand mix prepared for working. In case of a sand mix, control is required both in the laboratory and during the production of shells. Thus, there are three sets of process tests used in shell moulding.

Production control tests on the sand mix

(i) Hot Tensile Test Tensile strength is measured 1 minute and 5 minutes after the coated sand is heated to a specified temperature. The strength at 1 minute isindicative of the mix performance from the physical standpoint since the cores are usually ejected from the machine and handled within a minute. The strength at 5 minutes indicates the final strength of the mix for its performance during

the pouring operation. The percentage of resin and the characteristics of base sand considerably affect the hot tensile strength. Figure 3.43 shows a hot tensile tester.

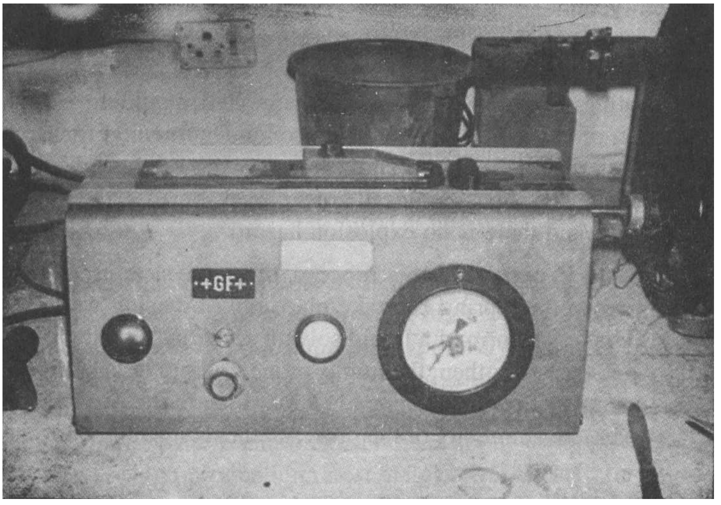


Fig. 3.43 *Hot shell tensile strength tester*

(ii) Melt-Point or Stick-Point Test The melt point indicates the rate of build-up of the shell on the pattern. The lower the melt point, the higher the tensile strength, the greater the tendency to form lumps or cakes in storage and for peel-back defect, the faster the melting rate of resin, and eventually, therefore, the higher the shell thickness obtained. The normal value of melt point is 95–100°C.

(iii) Hardness The hardness of cured shell moulds or shell cores provides a good index of uniformity in production. This property is measured with a dry hardness tester, using either the indentation, scratch or rotary methods.

Laboratory control tests on the sand mix

(i) Shell tensile strength or shell transverse strength and deflection
(ii) Shell permeability
(iii) Hot shell deflection

Laboratory control tests on basic materials

(i) Screen analysis
(ii) Specific surface and coefficient of angularity
(iii) Sintering point

Pattern Equipment for Shell Moulding The pattern and core box equipment used for shell moulding not only helps in forming the shape of the mould and core but also assists in curing them. The material used for patterns should therefore be capable of operation at temperatures in the range of 175–300°C. The pattern itself must be capable of transferring heat evenly from all over its surface to the resin–sand mix. It must also possess and maintain the required degree of dimensional accuracy and stability demanded by the finished as-cast dimensional tolerances of the casting. Moreover, an even amount of heat must be sustained from one cycle to another at the required rate of production. Thus, it must have a high rate of temperature recovery. These characteristics require sound application of thermodynamic principles with due regard to economic factors.

The materials used in the construction of shell patterns and core boxes are cast iron and aluminium alloy.

(i) Cast Iron This can produce as many as 250,000 castings and it satisfactorily fulfils the requirement of heat flow. It is also most economical to manufacture due to its ease of casting and machining. On repeated use for long periods, fatigue cracks may develop. Cast iron patterns are often manufactured by investment casting or the ceramic process so that the need for subsequent machining is minimised.

(ii) Aluminium Alloy This material is suitable for short to medium runs as it cannot withstand much abrasion and wear and is very easily damaged. Shell sand also tends to adhere to aluminium patterns and the high coefficient of thermal expansion may lead to warping and distortion of the pattern. However, its good heat conduction, lightness, good machinability, and low cost place it second only to cast iron for patternmaking. In order to improve its resistance to wear and abrasion, it is sometimes chrome-plated, though this increases the cost.

Conforming to certain basic principles underlying the design of shell patterns and core boxes ensures uniform and consistent quality of shell moulds and high speed of production:

(i) The surface area on the underside of the pattern or pattern plate which directly receives heat should as far as possible be equal to the surface area of the heat-dissipating surface (surface in contact with the sand–resin mix).

(ii) The heat-recovery time of different parts of the pattern should be equalised by suitably proportioning the section sizes. Patterns are often made hollow to satisfy these requirements. Special heat-conducting devices (finned heat exchangers) are also provided to aid uniform heat recovery all over the surface and even build-up of the resin shell. Sometimes, the casting design may have to be modified to make its production by shell moulding easy.

Applications The shell moulding process is useful for the production of castings that may range in weight from 200 g to as high as 200 kg in both ferrous and non-ferrous metals. The most common application is for automobile castings in grey iron and aluminium. For steel casting work, the resin should be nitrogen-free, and the sand of high refractoriness. The process is particularly suited where the greater dimensional accuracy, which it attains, can help to reduce the amount of machining required and where smooth surface rather than as-cast dimensions is the main requirement.

Advantages and Limitations of Shell Moulding

The chief advantages of shell moulding are given here:

(i) The sand prepared can be stored and transported easily.
(ii) Less sand is required. Cores can be made hollow.
(iii) Good accuracy of dimensions and finish can be achieved. Very small taper (not more than 1°) on the pattern walls is sufficient.
(iv) High rate of production is possible with limited floor space.
(v) Moulds and cores can be stored for future use. They are non-hygroscopic.
(vi) The process can be used for all cast metals.

The main limitations of the process are given here:

(i) The maximum casting size and weight are limited due to economical reasons and practical limitations of equipment.
(ii) High cost of pattern equipment and resin binder.
(iii) Relative inflexibility in gating and risering as these have to be provided in the shell itself.
(iv) Shrinkage and distortion of the shell cores and moulds may affect casting accuracy.
(v) The need of expensive equipment for preparing shells.

Defects in Shell Moulds and Cores and Their Causes Shell cores and moulds cause few casting difficulties but there are still some problems which may appear at times and these are discussed below:

Problem-1 *Bonding defects*

Appearance Castings fins, possible run-out of metal when weakness is extreme
Possible causes

1. Too viscous a bonding resin can cause the mould to close improperly
2. A resin has much too fluid to have good surface adhesion
3. Resin which sets up too fast
4. Machine, if out of alignment, causes invisible cracks in the mould surface which spread when contacted by hot metal
5. Delay in bonding can also cause the mould to close improperly

Problem-2 *Bubbles on back of shell*

Appearance Resin 'bubbles' or 'beads' appear on the back of moulds
Possible causes

1. Poor distribution of resin in sand (in dry mixes)
2. Inadequate melt of resin on hot-coated sand
3. Additives not properly dispersed
4. Over-mulling of coated sand causing resin to break loose

Problem-3 *Distortion*
Appearance Cores or moulds out of shape
Possible causes

1. Too much plasticity due to insufficient care
2. Too little hexamethylene tetramine (hexa)
3. Ejection or moulding pins may be out of adjustment causing uneven pressure with resulting distortion on removal

Problem-4 *Drop off*
Appearance Sections of the shell break off (differs from peel in that drop-off leaves pattern or core box clean, whereas peel is characterised by partially set sand falling off while the remainder is still adhering to the pattern or corebox).
Possible causes

1. Over-lubrication preventing proper adhesiveness of resin–sand mix to pattern
2. Too much resin
3. Pattern temperatures below those needed to bond resin and sand properly

Problem-5 *Lack of uniformly in shell*
Appearance Low density areas, solid resin chunks
Possible causes

1. Agglomerated sand or moist sand restricting flowability
2. Low stick point (melt point) of coated sand
3. Plugged vents or improper venting
4. Core-box blow pressure too low or too high

Problem-6 *Peel-back*
Appearance Pattern set sand breaks off leaving weak spots. Moulds break and cores collapse when poured
Possible causes

1. Pattern temperature too high or too low
2. Time in contact with pattern too long
3. Too much resin
4. Sand mix stick point too low
5. Hot or cold spots on plate or core box
6. Too much vibration
7. Wrong resin for the job
8. Pattern and dump box improperly designed for clean separation

Problem-7 *Seizure*
Appearance Cores and moulds difficult lo remove though there is no sand adhesion to the pattern (as in sticking).
Possible causes

1. Insufficient or improper lubricant

2. Resin is too high in hexa, shell is too rigid when cured causing seizure
3. Excessive resin shrinkage during cure
4. Temperatures too high
5. Cure time excessive

Problem-8 *Sticking*
Appearance Mould or core will not release easily from pattern or core box
Possible causes

1. Surfaces of pattern or core box rough
2. Insufficient or improper lubricant
3. Design of pattern or core box with undercuts or backdraft
4. Free resin from segregated or abraided sand mix

Problem-9 *Thermal shock*
Appearance Cracks in mould before metal solidifies causing run-out. If metal reaches plastic state before cracks open, veining will result.
Possible causes

1. Sand grain expansion during pouring causes thermal shock and the cracks which stem from it. Round grain sands are more prone to shock, sharp or angular sands less inclined Blending sands can help to correct. Addition of vinsol to the mix at about 1% of weight of sand helps. Modified phenolic resins resist shock and eliminate cracking.
2. Pattern design may contribute to the problem.

Problem-10 *Thick Shells*
Appearance Excessive wall thickness
Possible causes

1. Dwell time excessive
2. Temperature too high
3. Resin stick point too low

Problem-11 *Thin shells*
Appearance Shells thinner than normal in a given dwell time
Possible causes

1. Dwell cycle too short
2. Pattern temperature too low
3. Resin flow may be too short for the job; long flow specification may work well under same cycle and temperature

Problem-12 *Warping of Mould*
Appearance Moulds distorted when compared to pattern from which they are made.
Possible causes

1. Temperature differential between pattern and oven may be too great.
2. Resin may be too slow or may not cure rigid enough.

Problem-13 *Weak Shells*
Appearance Lack of strength
Possible causes

1. Not enough binder
2. Too much moisture
3. Uneven distribution of resin
4. Insufficient hexamethylene tetramine (hexa) in sand mix
5. Undercure (light-coloured shells)
6. Overcure (dark brown or black appearance)
7. Pattern and oven temperatures or oven cycle needs adjustment if cure is not right
8. Resin melt point too high

(2) Hot-Box Moulding This process is a refinement of shell moulding. A resin similar to that used in shell moulding is applied for coating the sand grains. Then the resin–sand mix is blown over the heated pattern or core box, which in this case is not turned over to allow shell formation, but instead the bulk of sand in the mould is heated and allowed to form a solid mass. The cores or moulds obtained are relatively free from distortion or shrinkage and the accuracy of dimensions is greater than in the case of shell moulding.

For small sizes, for which the method has been largely adopted, very high rates of production are achieved. The process has been applied particularly in core making. Today, there are special hot-box machines where the sand mix is blown over the heated pattern, the blown sand cured, and then the mould or core stripped from the pattern or core box. Proprietary resins are available for hot-box work for cast iron, steel, and non-ferrous metals. Those for cast iron are usually the phenolic thermosetting type, modified with urea. For steel, SG iron, etc., zero nitrogen furan resin is excellent and for non-ferrous work, a straight furan type resin is found suitable. Hot box resins are covered by IS: 12424–1988.

(3) Cold-Box Moulding This method is the latest development in moulding using organic resin binders and is now tending to replace even the hot box process. Its overwhelming advantage is that no heating of patterns is required, the curing being obtained simply by passing a gaseous catalyst through the blown mass of sand in the core box. The process is excellent for mass production as its production rate is much faster than that of the shell or the hot box method. Besides saving heat energy and its high productivity, this process gives lower gas evolution, higher dimensional accuracy and better surface finish to the casting, good collapsibility, better resistance to erosion and lower scrap rate. The resins for the cold-box process are proprietary and are available under different brand names.

The difficulty with the process is that special equipment, which is expensive, is required for blowing the catalyst gas through the core box. Further, the gas is toxic and poisonous and is dangerous if inhaled and, therefore, it must not be allowed to leak into the atmosphere. Still, the process is extremely suitable for small-sized castings required in big quantities. The total time to prepare a core could be well within 20–30 seconds.

The cold-box process for core making involves mixing fine dry sand with a polyisocyanate binder and an alkyd phenolic resin, blowing the vapour (TEA liquid atomised in air) through the core box. After the excess gas passes through the core box, it is introduced into a scrubber solution where all of it is dissolved to prevent it from escaping into the air (Fig. 3.44). After gassing, air or CO_2 is passed through the system to remove unused gas and pump it out through the exhaust manifold. The cured core is then ready for ejection from the core box.

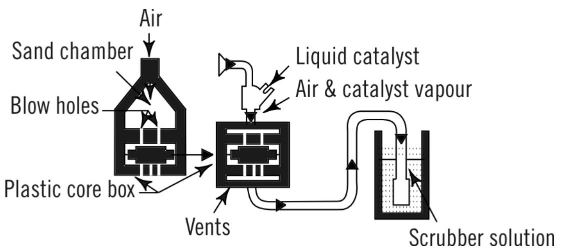


Fig. 3.44 *Cold box core making process*

The cores made by the cold-box process do not require dressing, provided the base sand is of good quality. However, if dressing is absolutely necessary, a water-based type is desirable. It is applied after curing, and is torched thoroughly.

The shell, hot-box and cold-box processes are essentially for mechanised production of small castings required in large quantities. In fact, these processes are economical only when they are used with an adequate degree of mechanisation. There remain a large range of castings which, though not ordered in bulk, are required to achieve a high degree of accuracy and finish at short notice with low fettling and machining costs. For fulfilling the need of such castings, no-bake, cold curing processes using liquid catalysts have been developed.

(4) Alkyd No-Bake Sands With normal drying oils, resins (which are rigid and brittle materials) are added to strengthen and harden the drying oil film. Resins are derivatives of petrochemicals. The alkyd resins, used in core oils, are formed by the reaction of phthalic anhydride with glycerol). The hydroxyl groups in the glycerol react with the acid groups in the anhydride to produce long chains. These chains act to bond the aggregate further and will produce three dimensional structures. These resins can be modified by substituting fatty acid for some of the phthalic anhydride to get more plasticity. Solvents like turpentine, kerosene or mineral spirits are added to resin-oil mixtures to improve flowability. Some alkyd resins are accelerated by isocyanate to harden into a solid sand mass more quickly. The cold-box process uses this type.

As in the case of air-hardening process, the alkyd no-bake system consists of a binder, hardener and catalyst.

- The **binder** is drying oil containing some oil-modified alkyd resins, which is of proprietary nature. Manufacturers can formulate different grades suiting to the customer's need.
- The **hardener** is cobalt- or lead-napthanate which is the reacted product between cobalt/lead salts and napthanic acid.
- The **catalyst** is isocyanate.

In this process, curing of the binder takes place in two stages. Initially the isocyanate reacts with the reduced moisture in the sand and with hydroxyl groups of the oil modified alkyd resin to give a bond, which is relatively weak, but strong enough to allow the stripping of the core from the pattern.

The second stage of the curing involves reaction of the unsaturated drying oils with oxygen in the air, resulting in polymerization as in the core oil system. Metallic napthanates will also catalyse the oxygen cross-linking in combination with isocyanate.

A 3-part alkyd system for a particular recipe can be described as "2.5 : 5 : 20".

(i) Part-A The first figure is the proportion of **binder** (i.e., Part-A) in percentage. It is based on the weight of sand.

(ii) Part-B The middle figure is the proportion of accelerator or hardener (i.e., Part-B) in percentage. It is based on the weight of **binder** (i.e. Part-A).

(iii) Part-C The last figure is the proportion of catalyst or cross linking agent (i.e. Part-C) in percentage. It is also based on the weight of **binder** (i.e., Part-A).

Such a recipe will work better and give best results when used in that proportion only. Any deviation from this will give poor results. In this regard, the major role is played by Part-C. Thus, an alkyd designed for 20% Part-C (no-bake), when used as semi-Bake (8% Part-C) will give slower setting. If the proportion of Part-C is increased, it will result in drastically reduced bench life and the final strength will also be lower.

Order of Addition of Ingredients While mixing sand, Resin Binder Part-A and Accelerator Part-B should be premixed first and added to the sand, and then the addition of Cross-Linking Agent Part-C should be made. In this case, the initial strength development will be relatively slow and steady. The final strength development will be good.

But, if Binder Part-A and Cross-Linking Agent Part-C are pre-mixed and added to the sand, followed by Accelerator Part-B, the initial strength development will be faster, sacrificing the final strength. The reason could be due to the following:

1. Alkyd is the binder for sand grains and the cross-linking agent is the active hardener. When the cross-linking agent is added first to the sand, the initial coating of the sand grains is done with the cross-linking agent. The bond strength of cross-linking agent and sand is lower and so is final strength.

2. Initial faster rate of reaction can be explained by the fact that in this system, mulling time after addition of the cross-linking agent is more than with conventional mixing, resulting in initial high strength.

Hence, it is advisable to pre-mix Part-A and Part-B and add to the sand, followed by Part-C. After adding Part-C, i.e., the cross-linking agent excess mulling should be avoided as it will lead to friability and low final-strength development. Optimum mixing/mulling time should be determined and followed.

Effect of Process Variables

Moisture in the Sand Moisture in the sand acts as *poison* in an alkyd no-bake system. The active constituent of Part-C, i.e., isocyanate, reacts with water, thus reducing the effective cross-link density of the system. In the presence of moisture, two parallel reactions take place in the system. One is the desired cross-linked product and the other is the undesired reaction. Thus, it becomes complicated and the strength falls drastically, the reason being probably the formation of solid diamine particles which act as weak points on the system.

Effect of Part-B (i.e., Accelerator) The role of Part-B is to help the reaction between NCO group of cross-linking agent and OH group of alkyd in a controlled way in order to build up a three-dimensional structure. In general, 5% of Part-B (on the basis of Part-A) is optimum for the system. Increase in quantity of the same increases the rate of reaction and naturally affects the final strength due to build-up of irregular cross links.

Effect of Part-C (i.e., Cross-linking Agent) Being a cross-linking agent, increase of Part-C addition increases the final strength substantially and also increases the rate of setting to some extent. However, after an optimum level (slight excess than stoichiometric amount), the effect becomes insignificant. Alkyds used as no-bake formulations normally requires 20% Part-C (based on Part-A) for optimum results in good weather conditions. But in humid conditions, the same can be used up to 25% to get rid of drastic strength reduction to some extent.

For successful working of the alkyd system, the following points are important:

(i) The base sand should be completely dry, having minimum clay (preferably below 0.5%). Temperature of the sand in any case should not exceed 40°C. Four adjacent sieve distribution sand will give better packing density.

(ii) Moisture/humidity is the greatest single factor which adversely affects the system. In the rainy season, slight baking of the moulds and slightly increasing proportion of cross-linking agent will be effective. Storage of cores and moulds for a long period should be avoided.

(iii) Excess heat should not be generated during the mulling/mixing cycle, as this will drastically reduce the bench life of the sand.

(iv) An alkyd designed for no-bake system does not perform well as that for air-set system and vice versa.

(v) Rapidly accelerating the setting characteristics with the excessive use of Part-B and Part-C, will lead to a drop in final strength. Nitrogen porosity will also increase.

(vi) Initial setting rate and final strength development oppose each other.

Useful Information about air-hardening process

(i) In the air-hardening process, the cores or moulds have to be baked in an oven for attaining the final baked strength. But in alkyd no-bake system, moulds or cores are not necessarily baked in an oven, and when water-base wash is applied on the moulds or cores, they are dried in a hot-air oven at a lower temperature of 140 to 150°C which gives slightly enhanced baked strength.

(ii) Mixing can be done in a batch-type revolving arm mixer or a speed muller with a total cycle time of 4 minutes and 1 minute respectively. Bench life of the sand mix can be adjusted by controlling the addition of the hardener. Quantity added is to be judged depending on the atmospheric temperature, humidity, etc. Base sand temperature should not exceed 40°C.

(iii) As the bench life of the prepared sand mix in an alkyd no-bake system is not more than 20 to 25 minutes, moulds or cores should be filled up as quickly as possible.

(iv) In an air-hardening system, sodium perborate or isocyanate liquid catalyst can be used, but in an alkyd no-bake system, only isocyanate is used as a catalyst. (The reactivity of binder in an air-hardening system is kept at a lower level during manufacturing, in comparison to an alkyd no-bake system.) Hence bench life of air-hardening system is longer.

(v) In steel foundry, many of the thermocole patterns are filled with alkyd no-bake sand and good-quality castings are made. When using a thermocole pattern, the entire mould has to be filled with no-bake sand, as backing sand slung by a speed slinger will distort the thermocole material. Before filling the mould with no-bake sand, the thermocole pattern is given a coat of thin sodium silicate solution after protective paper wrapping over the pattern. Otherwise, the thermocole pattern will shrink due to the heat reaction evolved from the alkyl no-bake sand mix and dimensional accuracy of the resultant casting will be affected.

(vi) For some castings, weighing up to 7 to 8 tonnes, the initial facing layer of the sand is either 100% zircon sand or 50% zircon + 50% silica. The rest of the mould or core is filled with ordinary no-bake sand or silica sand. Also, for heavier castings, 10% silica flour addition in the sand mix gives good results. (Refer Table 3.11 for sand composition.)

Table 3.11 *Alkyd no-bake sand composition (for steel castings)*

		Ordinary No-Bake	50% Zircon No-Bake	100% Zircon No-Bake	No-Bake for Heavy Castings	No-Bake for Roller Castings
Allahabad Sand	(kg)	200	150	—	80	30
Zircon Sand	(kg)	—	150	300	—	50
Silica Flour	(kg)	—	—	—	20	70
Alkyd No-Bake Binder (Part-A) Liquid	(kg)	5.0	6.75	6.0	2.8	5.5
Iron Oxide Powder	(kg)	1.0	0.75	1.5	0.5	0.75
Hardener (Part-B)	(cc)	150	125	70	85	165
Liquid Catalyst (Part-C)	(cc)	1000	1000	900	500	1100
Mixing time in Speed Muller	(sec.)	60	60	60	60	60
Bench Life of the prepared mix	(min.)	25 to 30	40 to 50	35 to 40	25 to 30	25 to 30
Air-Set Compression/Shear Strength (psi)						
Compr. Strength after 1	hour	2.0	0.1	0.6	14	28
Compr. Strength after 2	hours	55	0.3	2.1	55	65
Compr. Strength after 4	hours	160	18.5	140	120	120
Compr. Strength after 24	hours	> 270	> 270	> 270	> 270	> 270
Shear Strength after 24	hours	80	180	200	75	100

Notes (1) Binder (Part-A) is based on the weight of the sand, (2) Part- B is based on the weight of the binder, around 3.0% (minimum), and will vary from 3 to 5% to adjust bench life. (3) Part-C is based on the weight of the binder (around 15 to 20%) (4) Part-A and Part-B are pre-mixed and added).

(5) Phenolic No-Bake Sands

Phenolic no-bake binders were introduced around 1960. This 2-part system works well for both smaller and larger castings. Continuous mixers are used to get desired work/strip time and the production is faster. There is no need to bake the moulds or cores in the oven. The binder gives better hot strength.

Phenolic no-bake are alkaline condensates of *phenol* and *formaldehyde*. The phenolics are also completely nitrogen free and are well suited for the production of steel and iron castings, where pin-hole avoidance is necessary. With the introduction of strong acid catalysts based on sulphonic acids, some of the problems associated with curing and deep-set properties were overcome.

1. Acid Catalysed Phenolic System The phenolic system consists of two liquid parts.

The **binder** is phenolic resole resins containing numerous reactive methylol groups and these are involved in auto-polymerization reactions at ambient temperatures or at slightly higher temperatures.

The **catalyst** for the phenolic no-bake resin can be either (paratoluene sulphuric acid or benzene sulphonic acid. Phosphonic acid which is an excellent catalyst for furan binders will not act or cure phenolic resin at the rate required for foundry use. The acid strength of phosphoric acid is not sufficient to trigger a rapid polymerization of phenolic resin. Paratoluene sulphonic acid, benzene sulphonic acid and phenol sulphonic acid have sufficient strength to function as ideal catalysts for phenolic resins.

The main function of the catalyst is to initiate further condensation of the resin and advance the curing by the cross-linking action. The acid-catalysed curing reaction of the phenolic resins proceeds by further condensation of methylol and methylene ether groups, with reactive phenolic ring positions in the resin. The condensation reactors produce water which results in a dilution effect on the acid catalyst which tends to slow the rate of cure. Because of this effect, high concentration acid catalysts are required to ensure reasonable rate of cure and good deep-set properties. At times, 60 to 75% concentrations are used.

The addition of the resin binder is normally 1.0 to 3.0% by weight of sand, and the catalyst from 30 to 50% by weight of the resin binder. In a *batch-type sand mixer*, the catalyst is added to the dry, clay-free synthetic sand and mixed for 4 minutes and followed by resin binder and mixed for 2 more minutes. The bench life of the sand mix will be around 7 to 8 minutes. Hence, it is essential to make the core/mould as quickly as possible before the bench life is over. But if sand mixing is done in a *continuous mixer*, the bench-life lapsing problem will be minimised and any type of large size cores can be made as per need. Low bench life is one of the factors which has affected the introduction of this process on a large scale in our foundries. Alternatively, foundries can opt for *alkyd no-bake system* in which bench life can be prolonged from 15 to 20 minutes using a *batch-type mixer*.

Advantages of this Process

(i) Rapid core-strength development
(ii) Low odour
(iii) No nitrogen
(iv) Faster use of cores to produce casting with 3 to 4 hours of core making
(v) Good stripping property
(vi) Good deep-set properties
(vii) High hot strength

Limitations

(i) Strong acid for the curing action
(ii) Sensitive to sand temperature, particularly to cold sand
(iii) Limited shelf life of the resin on storage
(iv) Cores prone to veining defects

2. Alkaline Phenolics The alkaline phenolics system is getting popular abroad because of the superior characteristics and good working environment which is insisted by government agencies. Sand-related defects are considerably lower with this system of sand. As the bench life of the sand mix will be lower as compared to other cold setting processes, it is essential to go in for a continuous sand mixer to get the maximum advantage of the process.

The resin and hardener used in this process, like all other chemical binder processes, are of proprietary nature. In a simple language, the reaction can be described as

$$\text{Resin + Hardener} \rightarrow \text{Cured Resin}$$

(group of chemicals known as 'esters')

In a conventional no-bake binder, the addition of catalysts/accelerators can be increased or decreased to the desired level to get fast or slow cure, to take care of the temperature variations, humidity factors, etc.; thereby adjusting the bench life of the sand mix and also strip time as per the need. But in the alkaline process, increasing the percentage of hardener results in faster strip, but the excess addition does not get utilized and is wasted. While reducing the percentage of hardener, strip time increases but the resin does not get fully cured and results in friable and weak moulds and cores. However, an appropriate grade of the hardener to take care of bench life, strip time and seasonal variations is to be selected from the manufacturers, who provide different grades. They can supply different grades to suit the bench life and strip time requirements.

In alkaline phenolics, a selected grade of hardener gives the specified bench life, say 8 minutes and the curing action is triggered immediately after the bench life, which means the sand should be used well before the bench life is over (i.e., before 8 minutes).

When executed in a systematic manner, alkaline phenolics will give higher productivity, many of the defects will be minimised and will result in good working environment.

While producing large moulds for heavy castings, a facing layer over the pattern is done by hand tucking the sand and ramming by a flat mallet to get a fairly good compaction. It is not enough if the sand is simply poured on the mould without proper packing. After allowing the sand to harden and set well for at least 4 to 6 hours, backing sand is poured and rammed pneumatically or by a speed slinger machine. In case the entire mould is to be filled with facing sand only, then the first layer of the facing is made with non-urea blow-hole free resin binder, and subsequent layers with urea-type resin binder sand. In this way, in-depth curing, which gets affected sometimes with non-urea resin binder sand, can be solved as this sand cures much better uniformly.

Table 3.12 shows the comparison between alkyd resin, acid catalysed phenolics and alkaline phenolics binder systems. Table 3.13 shows bench life and strip time suggested for different production conditions.

Table 3.12 *Comparison of alkyd resin, acid catalysed phenolics and alkaline phenolics binder systems*

CHARACTERISTICS	ALKYD RESIN SYSTEM (3 PART SYSTEM)	ACID CATALYSED PHENOLICS (2-PART SYSTEM)	ALKALINE PHENOLICS (2-PART SYSTEM)
Normal Addition Levels			
Resin (% based on sand)	2.5	2.0	2.3
Catalyst (% based on resin)	20	40	20
Accelerator (% based on resin)	5.0	—	—
Bench life at 30°C (min.)	10	7	8–10
Strip time (min.)	50–55	28–30	24–30
Bench life/strip time (Ratio)	1:5–1:5.5	1:4–1:4.5	1:3–1:3.5
In-depth through cure and sagging resistance on stripping.	Poor	Poor	Good
Curing time required before metal pouring (Hours)	16-18	8-12	4-6
Core storage property	Fairly good	Fairly good	Fairly good, but slightly friable in humid condition
Reclamation	Poor (up to 50%, but N_2 build-up takes place)	Good (80 to 85%)	Medium (50 to 60%)
High temperature properties	Poor	Good	Excellent
Veining	Possible	Lesser	The least
Scabbing and inclusions	Prone	Lesser	The least
Hot tearing	Possible tearing	Known to give	The least
Fumes at pouring and mixing stations	Present to some extent, pungent and eye irritant.	Present, pungent and eye irritant	Absent. no obnoxious smell
Effect on skin	MDI can cause dermatitis with constant contact.	Strong acids being used as Catalyst can cause skin burns with constant contact.	Resin being alkaline, can cause skin irritation.

Table 3.13 *Bench life and strip time under different production conditions*

Production Need	Bench Life (minutes)	Strip Time (minutes)
For rapid production	2–3	9–12
For medium production	8–10	30–50
For slow production	15–20	75–100

(6) Furan Process

Furan resins are a family of resins produced with furfuryl alcohol and polymerized with sulphonic or ortho-phosphoric acid to produce cores and moulds. Commonly, there are three grades of furan resins:

Grade	%Furfuryl alcohol	%Nitrogen
Low furfuryl alcohol	40–60	5–11
Medium furfuryl alcohol	60–80	2–8
High furfuryl alcohol	>80	0–3

The most important advantage of the furan system is that the strip time of mould and core can be varied anywhere from 2 minutes to 1 hour or even more, depending on the size and weight of the casting. Other advantages of furan resin process are

- Highly reclaimable used sand (a large percentage (more than 95%) can be effectively reclaimed even by mechanical sand reclamation
- Higher hot strength is achieved as compared to alkyd or other resin systems
- Physical properties achieved in this process are superior to other resins
- Very high productivity can be achieved, strip time being as low as 2 to 3 minutes
- The production of moulds and cores is highly economical, especially when used in conjunction with continuous mixer and sand reclamation plant
- If fine sand is used (85 to 100 GFN), excellent surface finish can be obtained on the castings, however, even sometimes without the use of mould coating. Using somewhat coarser sand, along with mould coating the binder cost can be reduced. Finer sand will consume more binder and will generate more gas.

Apart from other factors like (i) moulding material, (ii) sand/metal ratio and (iii) foundry technology, process control is an important aspect in order to get consistent results and high output at minimum overall cost and for effective use of the furan binder system as well as any chemically bonded sand system. The main requirements for process control are

- Sand used should be of same grain size, shape and distribution and should be of same origin
- Sand temperature of sand should be maintained within 638

- Chemicals used should be same throughout the process and their physical properties should not vary
- Variations in sand compaction must be avoided as far as possible; uneven compaction of sand in the mould can lead to casting defects like penetration, burn-on, hot tears and scabbing along with sand erosion

The routine checks to be used as a part of process control are calibration of sand mixing, calibration of binder/hardener and sand flow calibration with binder/without binder

Gating is also an important criterion in no-bake moulding. To achieve proper compaction in a critical runner system, a V-shape with generous radius at the bottom is helpful. A safe practice is to fill the mould with molten metal in the shortest time. The pouring time should therefore be as small as possible. Venting should be used generously. Zig-zag vents can be used on the parting line to avoid the chances of run-outs. Use of flow-offs is also desirable in this process. They prevent air to be trapped by the molten metal as it fills the mould. The cross sectional area of flow-offs should be at least 10% of the total in-gate area.

Furan resins also form an important class of foundry core binders. Among the various types of furan resins are urea-furfuryl alcohol formaldehyde and phenol furfuryl alcohol formaldehyde. The catalyst commonly used with these resins, which causes the hardening action due to polymerization, is phosphoric acid. The strength of phosphoric acid varies from 70–90% according to climatic conditions. The method of use is extremely simple and quick and is suitable for all sizes. Since the process of furan sand is expensive, it is generally restricted to core making, but it can also be used for moulds when good finish is essential. Moulds, especially large ones, can also be prepared in composite form, using furan sand for the facing and CO_2 sand for the backing.

The accepted ratio of resin to sand is 2.0–2.5%. The catalyst recommended is 30% of the resin. The resins and the catalyst are available under proprietary brand names. The stripping time ranges from 1 hour to 2 hours and the bench life is about 30 minutes. The stripping time, bench life, and compressive strength depend largely on the temperature of the environment. These can however be adjusted according to the prevailing temperature by varying the proportion and strength of the catalyst.

The sands using furan resin have high collapsibility and, therefore, the fettling cost of castings made by the furan process is always much lower than that of similar castings produced with inorganic binders such as in the CO_2 process. Moulding costs with these sands is also low as baking of moulds and core is not required and ramming requirements are also substantially reduced. The method is non-toxic and non-inflammable and no heat is produced when chemical reactions occur. The urea type of furan sand is cheaper and is satisfactory for grey cast iron. This type cannot however be used for steel casting as the mould gets affected by high temperature and metal penetration is caused and, due to the presence of nitrogen in the resin, pinhole-porosity may be produced. For steel casting, phenol type furans are suitable though they are more expensive. The specifications of organic no-bake resin binders are covered by IS: 10032–1981.

(7) Gas-Setting Resin Process

This method, developed as a substitute for the CO2 process, overcomes the difficulty of collapsibility and reduces the fettling work which involves high labour input. It is suitable for heavy and simple castings and may be used for all cast metals. Saponified ammonium acrylic ester or water-soluble phenolic resin is used as a binder with dry sand and, after preparing the mould, gassing is done with CO_2 to accelerate the hardening reaction. Lime is also mixed along with the resin to act as binder-cum-activator. The moulds have high collapsibility and reasonably good strength.

(8) SO_2 Process

Though, a versatile process offering several advantages, including a high bench life, high strength and good collapsibility, it has not been adopted by many foundries due to the environmental problems created by SO_2 gas and the difficulty in handling sands and moulds containing sulphuric acid and other toxic materials. The process consists of generating sulphuric acid within the compacted sand mixture in the mould or core box, as the case may be by blowing heated SO_2 gas diluted with air through a sand-furan resin-methyl ethyl ketone peroxide mixture. The acid formed *in situ* instantaneously catalyses the resin binder into a highly cross-linked polymer, imparting high strength and rigidity to the mould or core. After SO_2 gassing, the mould is purged with dry air to remove any traces of SO_2 left behind.

3.6.3 Other Special Moulding Processes

The processes significantly different from conventional moulding processes and finding considerable scope for specialised applications are

(1) investment casting;
(2) full mould casting;
(3) plaster moulding;
(4) ceramic moulding;
(5) vacuum moulding;
(6) VRH process; and
(7) graphite mould casting.

(1) Investment Casting

Investment casting, also called the *lost wax process*, the *precision casting process*, or the *cire-perdue*, uses a pattern of an expandable material, such as wax or polystyrene. The mould, called the *investment*, is prepared by surrounding the pattern with a refractory slurry that can set at room temperature. The mould is then heated so that the pattern melts and flows out, leaving a clean cavity behind. The mould is further hardened by heating, the procedure being called *firing*, and the molten metal is then poured while it is still hot. When the casting is solidified, the mould is broken and the casting taken out.

Pattern Preparation The patterns are generally prepared by injecting a suitable grade of wax composition into a metal die which is given the shape of the pattern. If the dies are required for large scale production, they are made by machining or casting in aluminium alloy, magnesium alloy, brass, or low carbon steel. For the production of small number of patterns and where wax is not injected at very high pressure (not higher than 20 kg/cm^2), low melting point alloys, such as tin-bismuth alloy (cerro-alloy) and zinc alloy, which can be quickly melted and used in as-cast form without any finishing, are most suitable. Silicon-rubber dies are also used for small quantities and intricate shapes.

Wax patterns are prepared by injecting liquid or semi-solid wax into the pattern die. If each pattern is small in size, several such patterns can be joined together about a common wax sprue through in-gates and then the investment prepared about the assembly of patterns. Wax is expected to have low ash content (up to 0.05%), good hardness, tensile and impact strength in solid state, wettability, resistance to oxidation, adhesiveness (weldability), solubility in specific solvents, resistance to chemical action when binders are used in the investment process, and low shrinkage during solidification. To fulfil all or most of these requirements, special wax blends have to be formulated for pattern work. It is a good practice to lightly heat the dies, inject the wax at relatively low temperature, and use moderate to high injection pressures.

Patterns made from solid or expanded polystyrene are also used in the same way as wax, i.e., by injecting it into the die, but they present problems such as pattern deformation and dimensional variations and are non-recoverable.

Investment Preparation Two methods of investment (Fig. 3.45) are usual, viz., solid investment and shell investment.

In *solid investment*, a primary coat (pre-coating) of binder mixed with fine refractory, such as silica flour and zircon flour, is applied to the pattern which is then placed, complete with gating in a metal flask and is surrounded by refractory slurry. The method is speedy but a large quantity of expensive ceramic materials is necessary for preparing the slurry. The pre-coating is not essential for non-ferrous metals. The binder used in preparing the primary coat and investment slurry is ethyl silicate. The chemical reaction gives rise to the formation of silica gel in a hydrolysed solution of water, which imparts a permanent siliceous bond:

$$\underset{\text{(ethyl silicate)}}{Si(OC_2H_5)_4} + \underset{\text{(water)}}{4H_2O} \rightarrow \underset{\text{(ethyl alcohol)}}{4C_2H_5OH} + \underset{\text{(silicic acid)}}{Si(OH)_4}$$

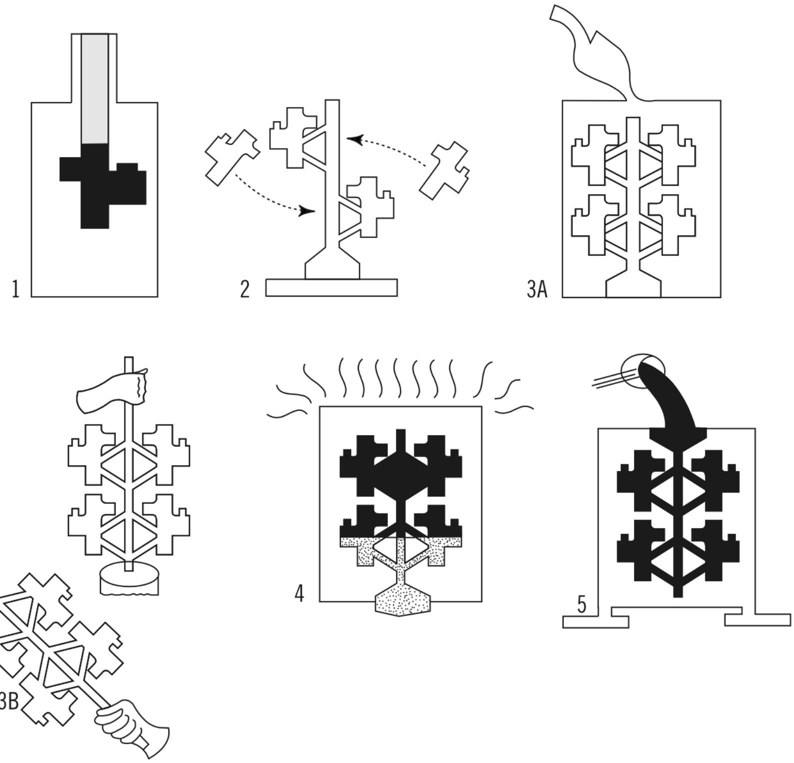


Fig. 3.45 *Investment casting process*

As water is insoluble in ethyl silicate, methylated spirit is used as a mutual solvent. Dilute 10% HCl also serves as a catalyst and stabiliser.

Silicic acid produced by the foregoing reaction gets converted, when heated during the firing stage, into silica gel, which is a hard, strong, and permeable mass. Gelation and hardening can also be accelerated in the investment by the addition of an alkali or by keeping the investment in an ammonia chamber. The proportions of various constituents that form the investment may be as follows:

refractory grains for investment	100
ethyl silicate	5
10% hydrochloric acid	1
methylated spirit	1
water	9

Other binding materials that have been used are (i) sodium silicate; (ii) a mixture of ethyl silicate and sodium silicate; (iii) phosphate-bonded materials, such as gypsum phosphate, ammonium dihydrogen phosphate, mono-ammonium phosphate, mono-magnesium phosphate; and (iv) colloidal silica.

In the *shell-investment process*, after applying a pre-coating as in the case of solid investment, the pattern assembly is alternately dipped in a coating slurry and *stuccoed* with granulated refractory, either by sprinkling or by suspending in a fluidised bed, until a shell is built up to the desired thickness. The grain size of refractory particles varies from 20 mesh to 100 mesh. A fine grain size is used for the initial coat and coarse grains used progressively for subsequent coats. Each coat is air dried before applying the next coat. Refractory grains of high refractoriness, such as zircon, are better suited for high-melting-point metals, like steels and alloy steel.

The binder used in the shell-investment method is the same as in the case of solid investment. All operations, apart from the preparation of the shell investment, are also the same. The selection of the investment method depends on the size and shape of the casting, the metal composition, and relative costs.

In case it is necessary to use cores in the investment moulds, these are to be so placed within the wax pattern that they do not collapse when the investment is dewaxed. Ceramic cores are often used and are either placed in the pattern die itself or a hole is obtained in the wax pattern by keeping a metal insert or core in the die and then putting a ceramic core in the hole. Soluble cores made of materials like nitre are also used.

Gating and risering practice depend on the metal to be cast. However, as the moulds are poured while hot, not much risering is required. The principle of gating is the same as that applied in conventional methods. Gate sizes and locations should be such that the metal enters with a minimum of turbulence with uniform pressure, and at a steady rate. Castings required in extremely high metallurgical quality are poured under vacuum to keep the metal completely out of contact with air.

Dewaxing After the investment is prepared, the next step is dewaxing, or removing the pattern material, and then pre-heating. Pre-heating is done to remove all residues of wax or plastic. It also helps to minimize both the size of risers and hot tears in the casting, and permits filling of mould sections that are too thin to be filled in a cold mould. The actual time and temperature cycle for dewaxing and pre-heating depends on the type of binder and refractory materials used, the metal composition, and the method of investment. In general, however, for making steel castings, the temperature is first gradually raised from room temperature to 350°C in about 4 hours for dewaxing, then raised to 750°C in another 4 hours for firing, again raised to 980°C in the next 3 hours for pre-heating, and finally held at that temperature for about 4 hours for holding. The moulds are poured just after removing them from the furnace, and both the mould and metal are allowed to cool down simultaneously at a slow rate, keeping them out of contact with open air.

A modification of the investment casting, which uses frozen mercury as pattern material, is called the *Mercast process*. Mercury patterns are obtained by pouring mercury into pattern dies, which have been cooled to –56°C or even lower, and allowing the mercury to solidify. The investment mould is then prepared by using the frozen mercury pattern at a temperature around –38°C in the usual way. When the investment is brought out at room temperature, the mercury melts by itself and is drained, and the moulds are then fired and poured. The most important advantage of this process is that the highest dimensional accuracy is possible as the pattern material does not expand or shrink during change of state from liquid to solid and vice versa. No injection equipment is required as mercury is merely poured by gravity. The main drawbacks are the expensive equipment required for creating low temperature conditions, the high cost of mercury itself, its handling problems, and its poisonous nature.

CLA Process A further modification of ceramic shell-investment casting introduced by Chandly and Lamb in the USA, is the CLA process. The process consists of (i) placing the ceramic shell mould upside down in a closed chamber; (ii) submerging the sprue portion of the mould, protruding out of the chamber, in a molten metal bath; (iii) sucking the molten metal into the mould cavity by creating a vacuum in the chamber by connecting it to a vacuum pump; (iv) releasing the vacuum when the casting is solidified, allowing most of the molten metal in the sprue to return to the bath. In practice, it is to be ensured that when vacuum is released, the metal in the mould has solidified but that in the sprue is still molten.

Mould filling is achieved fast and it can be precisely controlled. There is practically no turbulence, and castings as thin as 0.3 mm have been easily produced. Since no ladle is employed for transporting the molten metal, much less superheating of the metal is required and lower casting temperatures are possible, enabling fine as-cast structure of the metal. Castings are also free from dross and inclusions. Casting yield as high as 90–92% can be achieved and rejections can be largely eliminated.

Advantages and Limitations of Investment Casting

Investment casting has several advantages.

(i) A high degree of accuracy and fine surface finish are possible. Tolerances close to ± 0.1 mm can be achieved on small components and a surface finish around 1–5 microns (Ra value, IS: 3073–1967) are possible. Thus, the machining can be largely reduced or eliminated.

(ii) The process can be adapted for all types of metals and alloys that can be melted and poured. Bimetallic castings can also be produced.

(iii) Complex shaped parts, difficult or even impossible to cast by other methods, and metal parts that are difficult to machine, can be conveniently made by this process.

(iv) Close control of mechanical properties, such as grain size, grain orientation, and directional solidification, is possible and as such high-quality castings free of external or internal flaws, can be obtained.

(v) The process can be adapted for mass production.

The main drawbacks of the process, which restrict its use to high quality and small-sized castings only, are the following:

(i) The limitations of size and weight by physical and economic consideration render the process best applicable to castings weighing from a few grams to 5 kg.

(ii) Precise control is required at all stages of production. Special equipment is required for preparing patterns, making investment, etc., for efficient use of the process.

(iii) The raw materials, special tooling, equipment, and technology required are expensive.

(2) Full Mould (Cavityless) Casting

In this method, the pattern, complete with gates and risers is prepared from expanded polystyrene (EPS) slabs by machining and fabrication, then coated with a suitable mould wash, and finally embedded in a no-bake type of sand. Organic no-bake sands, such as furan or alkyd isocyanate, may be used for small-sized castings and CO_2, ferrosilicon, or fluid sand for medium and large-sized castings. While the pattern is inside the mould, molten metal is poured through the sprue. The heat of the molten metal is sufficient to gasify the pattern and progressive displacement of pattern material by the molten metal takes place. The amount of gas produced is so small that it can easily escape through the sand without causing any back pressure. To allow easy gasification of the pattern, the temperature of the metal when it is poured should be about 25–30°C higher than that required for sand casting.

Unbonded sand, viz., sand grains only without any binder or moisture, has also been successfully used for full-mould casting. Proper selection of grain shape and size, correct gating system design, correct pouring temperature and pouring rate are important considerations in unbonded sand practice. These have to be established by trial and experimentation.

It is thus possible to quickly and inexpensively cast shapes with high dimensional accuracy and metallurgical quality. As there is no air in the mould at any time, defects such as blowholes and pinholes are prevented. Pattern removal is not required and so dimensions are better maintained and defects due to parting line are eliminated. Further, there is no limitation as regards size, shape, or complexity. The method is best suited for one-off castings required at short notice or for prototype castings. It can be used for both ferrous and commonly cast non-ferrous metals.

This method, which can be varied to suit large-scale production of small castings, is an economical substitute for investment casting where the pattern is prepared from pre-expanded polystyrene granules. Such granules are injected or gravity-filled in thin-walled aluminium or copper dies and heated either under steam or in hot water. Heat causes granules to fully expand and consequently join together, forming a solid shape conforming to the die cavity. The rate of production is very quick as a large number of patterns can be moulded together. The method can also be mechanised.

A still further sophistication of the method is that where the pattern is embedded in iron sand containing fine iron shots, iron oxide powder, or grinding swarf. The flask carrying the iron sand and pattern is surrounded by an electromagnet and a magnetic field of about 2000 gauss created (for a flask size of 600 mm × 600 mm × 200 mm). The magnetic field causes easy flow of moulding material into and around the pattern recesses and enables it to get fully consolidated. The mould is highly permeable as it is completely dry. The molten metal is then poured as in full mould casting. When the casting has solidified sufficiently, the magnetic field is broken by switching off the current to the electromagnet. The mould instantaneously disintegrates and the casting becomes available without requiring any cleaning or fettling. The same iron sand can be used over and over again after cooling. This process, called ***magnetic moulding***, has been adopted in some foundries for the production of automobile components.

(3) Plaster Moulding

The mould is prepared in gypsum plaster. Plaster is mixed with the right quantity of water (add plaster to water), additives such as asbestos, talc, and silica flour added if required for imparting more strength, permeability, and refractoriness, and the slurry so prepared is poured over the pattern placed in a flask. The mould is vibrated and the slurry allowed to set. In about 30 minutes when setting is complete, the pattern is withdrawn and the mould dried by slowly heating it to about 200°C. When the moulds are fully dehydrated, molten metal is poured.

One of the main drawbacks of plaster is its low permeability. To overcome this, it is advisable to prepare the mould and also pour the molten metal under vacuum. Another alternative is to pressure-feed the metal into the mould by using compressed air.

Plaster moulding, though limited only to the casting of non-ferrous metals owing to low refractoriness of plasters, possesses certain typical advantages. Plaster has a very low rate of heat conductivity and so the metal does not solidify quickly. This helps in eliminating the chilling tendency, thereby enabling thin sections to be easily cast. Moreover, molten metal can be poured very slowly, thus allowing the gases to escape from the mould. A high degree of dimensional accuracy is obtained. The high surface finish it acquires effects saving in subsequent fettling and machining costs.

Till the development of ceramic moulding, plaster moulding appeared to be the best method for the reproduction of fine form and detail. Besides being used for engineering components the method is still very popular for ornamental castings, statues, jewellery, etc.

(4) Ceramic Moulding

This process employs chemical and ceramic slurries for moulds to produce metal castings of the highest precision and extremely fine finish. It has been found suitable for all types of cast metals and even for highly reactive metals, such as titanium and uranium. The castings do not normally require any risers, venting, or chilling as the cooling rate is very slow. The process is particularly suitable for producing forging dies, tyre moulds, dies for plastic moulding, dies for drawing, extrusion, die casting and glass making, pattern for shell moulding, impellers of pumps having very narrow passages, parts for atomic reactors, etc. Any ordinary pattern of wood, metal, or epoxy may be used. What is of consequence is the finish and accuracy of the pattern, since the same pattern is reproduced as a casting.

A refractory slurry is prepared by mixing specially developed ceramic aggregates and a liquid chemical binder, which is a modified alkyl silicate (alcohol-based silicon ester). Ceramic aggregates consist of critical blends of ceramic refractories according to the properties required, for instance, strength, surface finish, and permeability. When the binder begins to set, refractory particles hitherto in suspension are locked together. The slurry so prepared is poured over the pattern kept in a flask. It sets in about 3–5 minutes time. Slurry fills up all the cavities and recesses by itself; no ramming or even vibration of the mould is required. The pattern is then withdrawn, and the ceramic mass removed from the flask and treated with a catalyst or hardener to promote full chemical stabilisation. The mould is then heated at about 980°C in a furnace to expel the liquid binder completely. The duration of heating depends on the size and sectional thickness of the mould. The metal is then poured and the mould allowed to cool down slowly as in the case of investment casting.

Figure 3.46 shows typical precision steel castings made by ceramic moulding process and fig. 3.47 the ceramic cores and mould for these castings.

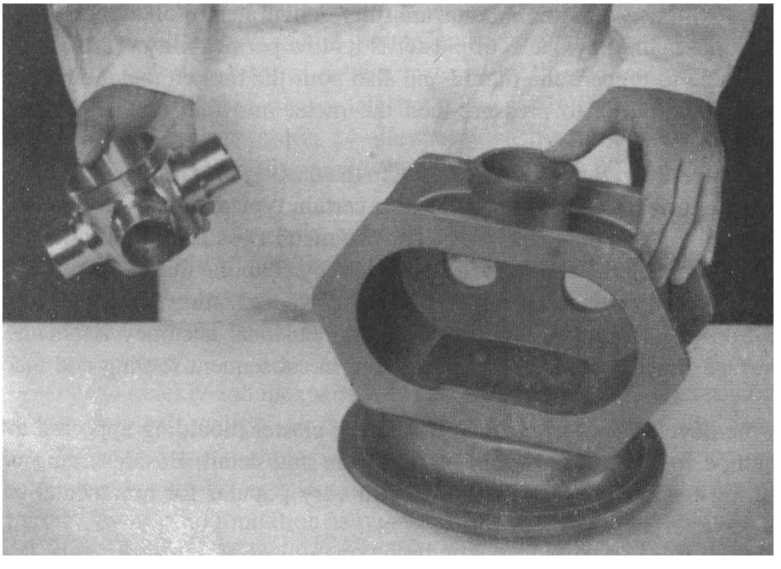


Fig. 3.46 *Typical precision stainless-steel casting made by the ceramic moulding process*

Left, valve body for the dairy industry. **Right**, heavy pump housing for the chemicals industry. Extreme accuracy, high metal density, and minimal finishing requirements make ceramic moulding ideal for producing these parts.

(5) Vacuum Moulding

Vacuum molding was developed a few years ago in Japan. Its main advantage is that it does away with the use of binders and moisture as sand ingredients. The mould is prepared with dry sand and the required compaction and the shape of mould cavity are obtained by using vacuum. The procedure used to prepare the mould is shown schematically in Fig. 3.48. As neither binder nor water is required in the mould, a clean environment is possible, fettling problems are eliminated, and no sand conditioning is necessary. Mould production is quite fast and moulding machines can produce 90 to 100 moulds per hour.

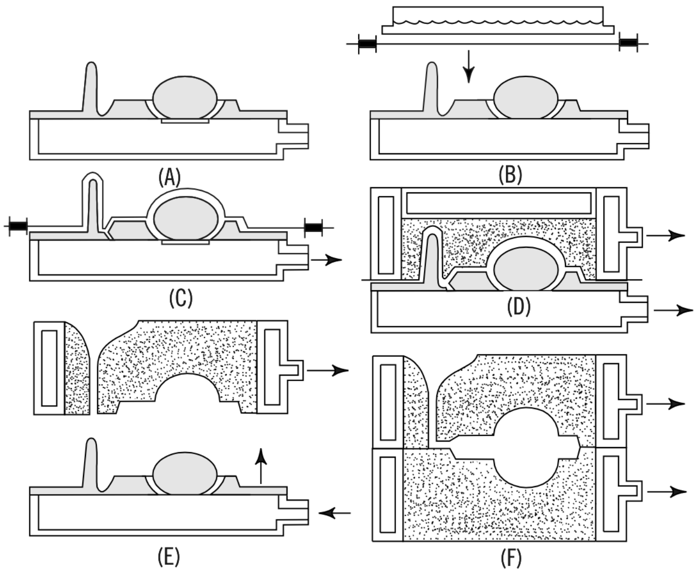


Fig. 3.48 *Steps in vacuum moulding process*

(A) Pattern set on hollow carrier plate.
(B) Thin plastic sheet softened by heater.
(C) Softened-sheet dropped over pattern and vacuum created in carrier plate.
(D) Double-walled flask set on pattern, flask filled with dry sand and vibrated, sprue formed, mould levelled. Sprue opening and mould top covered with plastic sheet. Vacuum applied to flask. Sand gets compacted.
(E) Vacuum in carrier plate released and mould stripped.
(F) Cope and drag moulds assembled, having plastic-lined cavity. Vacuum in flasks maintained during pouring and later, till casting solidifies. On releasing vacuum, sand drops leaving clean casting.

The process however requires special pattern plates and double-walled flasks for effecting vacuum, efficient venting system in the inner face of flasks to prevent the sand particles from being sucked by the vacuum pump, a device of stretching and heating plastic sheet and a powerful vacuum pump. Sand grains must be carefully selected for successful operation. For maximum compaction, a two-screen sand (70% of 70 mesh size and 30% of 270 mesh size) is employed. A vibratory frequency of 3000 cycles per minutes is used for a few seconds to cause compaction.

A modified V process makes use of an EPS pattern, duly applied with a refractory coating. Loose dry sand grains are poured around the pattern and compacted by vibration followed by application of vacuum to achieve full consolidation of sand. Thus, vacuum in the process needs to be applied only during pouring and for a short time thereafter. While a plain V process is suitable for simple-shaped castings needing minimum coring, the modified process can be applied for complex-shaped castings as well.

(6) VRH Process

The VRH process, developed in Japan during 1990, is an ingenious and practical application of basic chemistry principles on the mechanism of conventional CO_2 process. In principle, it uses dehydration of CO_2 moulds and their hardening under reduced pressure. The flask containing sand duly compacted over the pattern is placed inside a VRH vacuum hardening box. After closing, suction is applied and the resulting reduced pressure promotes the evaporation of water present in sodium silicate. During chemical reaction which causes bond formation, removal of water induces the development of silica gel around and between the sand grains.

Vacuum replacement is accomplished by injection of CO_2 gas. In the absence of air or other gases, reaction of CO_2 with sodium silicate is fast and efficient. The mould hardness is also increased further. Inside the vacuum-hardening box, pressure changes as a function of time, following a certain pattern which is essential for hardening of the mould. It has been established that through the use of vacuum, moulds can attain desired strength using only about half the quantity of sodium silicate. The bond developed is fine and setting is uniform all over the mould. Due to reduced consumption of sodium silicate, collapsibility is improved considerably and further, lower amount of residual Na_2O produced results in economical, technical and environmental benefits. The process is carried out in four stages:

(i) Moulding box setting on a vibrating table
(ii) Filling and compaction of sand and releasing the box
(iii) Hardening the mould, lowering the hardening box and applying suction, injecting CO_2 and raising the VRH box
(iv) Box removal

The desirable requirements of the VRH process are

(i) Sodium silicate should have a mol ratio of 2.0 to 2.2 and viscosity 50° Be.
(ii) Sand % silica to be $\geq 96\%$, water content to be $\leq 0.5\%$ and fines to be of size – 200 mesh and $\leq 1.5\%$.
(iii) Reclaimed sand to have $H_2O \leq 0.3\%$, residual Na_2O to be $\leq 0.5\%$ and fines to be ≤ 0.55 of size –200 mesh.
(iv) *Mould strength:* just after hardening: 5–8 kg per cm^2
2 hours after hardening: 8–12 kg per cm^2
24 hours after hardening: 20–30 kg per cm^2

(v) *Mould collapsibility:*

Temperature°C	Compressive strength
200	30–40 kg/cm^2
600	5 kg/cm^2
800	15–25 kg/cm^2

(7) Graphite Mould Casting

Graphite has been successfully used as a mould material for producing steel castings, particularly wheels for railway wagons and coaches. Graphite does not fuse with molten steel at high temperatures, has high resistance to burn-in allowing clean withdrawal of the casting from the mould, high resistance to thermal shock, low coefficient of expansion and ability to resist distortion. Thus, the mould once prepared from graphite blocks by machining can be used repetitively, though special measures, such as pressure pouring have to be adopted to prevent erosion of mould walls and to regulate the rate of entry of metal into the mould.

Review Questions

1. What are the principal ingredients of moulding sands? How are they specified?
2. What basic tests are prescribed for testing moulding sands? How are they performed?
3. What advanced tests are recommended for moulding and core sands? What is their significance?
4. What is permeability? How is it measured in case of dry and wet sands?
5. What is compatibility? What factors affect its evaluation?
6. Prepare a test-reporting programme for a medium-scale batch-production foundry producing grey-iron machine-tool castings.
7. What are the specifications of high-silica sands? For what conditions of working, is it most suitable?
8. What are the various types of 'special sands'? Give their typical properties and uses.
9. What is the role of bentonite in moulding and core-making operations? What are its important specifications?
10. What is the effect of moisture and clay content on green compressive strength of sands? Explain.
11. What different methods are used for reclamation of sands? What operations are involved in sand conditioning and preparation?
12. Explain various types of moulding methods and show their uses.

13. What are the characteristics of core sands? What different types of cores are used?
14. Write an explanatory note on alkyd no-bake sands and their uses. What are their advantages and limitations?
15. What is VRH process? How is it carried out? What are its merits over other sand-casting processes?
16. Explain with the help of a flow diagram, how sand reclamation of chemically bonded sands is carried out.
17. Write short notes on
    (i) Use of chaplets
    (ii) Graphite moulds
    (iii) Full mould casting
18. Explain the working of a pneumatic moulding machine. What is high-pressure moulding? What are the important characteristics of this process?
19. Explain the various processes of moulding and core-making, which are based on the use of inorganic binders. Give a relative evaluation.
20. What is shell moulding? How is it performed? Explain its process characteristics. How are patterns prepared for shell moulding?
21. What are alkyd resin processes? Explain their uses.
22. Describe the process of investment casting. How are patterns prepared for this process? What process controls are necessary in this case?
23. Explain (i) ceramic moulding, and (ii) vacuum moulding process. What are their applications?
24. Explain the basic principle of the VRH process and bring out its distinctive features, showing its superiority over CO_2 process.
25. What is the effect of shape and size of sand grains on the characteristics of moulding sands? Discuss.
26. Explain the typical characteristics of true clay, effective clay and MB clay. How are these three types of clay evaluated?
27. Discuss the use of compactability and mouldability tests in sand control and highlight their effect on casting quality.
28. Explain how the high-temperature characteristics of moulding sands are evaluated. What is their role in high-pressure moulding?
29. What tests are essential to perform for sand control during machine moulding?
30. What is a standard sand mix and how is it prepared? How is standard testing data maintained in foundries?
31. "In order to produce good quality casting, the sand used for moulding must be correctly conditioned". Discuss the statement.
32. What are the major advantages and limitations of CO_2 moulding process over other self-hardening processes? For what types of castings is this process most suited?

Chapter 4

Technology of Metal Mould–Casting Processes

Metal mould-casting processes are different from sand casting in that the moulds, being metallic, are of a permanent nature and are used repeatedly. These metal moulds are also called *dies*. Unlike sand moulds, metal moulds have superior surface characteristics and can produce castings to close tolerances and with distinctive surface finish. Besides, the processes using metal moulds have been remarkably mechanised with the result that extremely high rates of production are achieved with as small as 15 seconds as cycle time.

The types of metal mould casting processes briefly discussed here are permanent mould casting; pressure die casting; low-pressure casting; squeeze casting; centrifugal casting and continuous casting.

4.1 PERMANENT MOULD CASTING

Although the greatest tonnage of castings in modern industry is produced by sand casting, a large quantity of small-sized castings, particularly those in aluminium and magnesium, is cast by means of permanent moulds. These moulds, which are metallic, are ideal when numerous identical castings are required. Unlike sand moulds which are serviceable only once, as they have to be destroyed to extract the casting, permanent moulds are used many times without getting damaged.

Permanent mould casting is also referred as *gravity die casting*. Since metal is fed into the moulds by the force of gravity, no external pressure is necessary. The moulds require repair and renewal only after long periods.

The operations involved in permanent mould casting form a cycle which, when repeated in a certain rhythm, can determine the output rate of the equipment used. The cycle of work is as follows:

The dies are closed and mechanically clamped; molten metal poured; the metal allowed to solidify; the dies opened; the casting taken out; and the dies cleaned for the next cycle of operation.

All this work may be done manually. However, to increase the rate of production, some operations may be carried out in mechanised form, i.e., they may be performed semi-automatically with minimum manual control.

4.1.1 Dies for Permanent Mould Casting

Dies are usually in a pair, so arranged that when both halves are placed together the cavity for the complete casting is obtained. The dies are equipped for feeding the molten metal, and they have vents for gases to escape and a mechanism for clamping and ejection. The joint or parting on the dies is either straight (i.e., vertical or horizontal) or curved according to the shape of the casting. For a complex shape, the die may also be an assembly of multiple pieces with numerous joints.

Dies are provided with a generous taper allowance to facilitate extraction. There is allowance for thermal expansion of the dies in addition to the usual contraction allowance for the casting. After pouring, the casting should be ejected as soon as possible to prevent hindered contraction. For reducing the cycle time, the dies may be air-cooled or even water-cooled.

Four types of dies are normally used:

(i) Simple Die Two-part die or block die

(ii) Recessed Die The die is made hollow to reduce weight and improve thermal balance. Ribs may be provided for strength and stiffness.

(iii) Hinged Die Two halves open about a hinge. Small dies for simple and shallow castings are easily opened and closed manually if they are hinged.

(iv) Multi-staged Die The die is made up of a number of pieces which are either joined together firmly or kept loose to facilitate sliding or lifting. It is suitable for complex shapes which cannot be obtained by simple construction.

Cores used for obtaining holes, cavities, and undercuts in the casting may be either of sand or metal. Sand cores simplify the die construction and are therefore the appropriate choice where the number of castings is small or where the shape required is too complex for the working of a metal core. Metal cores are either fixed or movable and may be made of grey cast iron or steel. Movable cores are withdrawn by means of a rack and pinion, or a screw or lever system, or by hydraulic or pneumatic mechanism. Further, the cores may be solid or hollow. Solid cores are easy to prepare and are suitable for small castings. Hollow ones weigh less, get heated and cooled easily, and are excellent in large castings. These may also be water-cooled if a higher cooling rate is desired.

The choice of material for dies depends on the dimensional accuracy required, the method of closing used, the complexity of shape, and economic considerations. The most favoured material is pearlitic grey cast iron. Meehanite (high duty) iron is also popular. Steel dies (forged die steel) are used in a limited way for large scale production. Steel dies should first be stabilised by heating them at 550°C for about 10 hours and then cooling slowly. A nickle-chrome alloy, Nimonic 80, has been used for casting cupro-aluminium and other non-ferrous alloys.

4.1.2 Metals Cast by Permanent Mould Casting

All cast metals, with the exception of steel, can be cast by the permanent mould method, which ensures better mechanical properties, resistance to corrosion, and fine surface finish. Aluminium alloys used for pistons (for light automobiles), cylinder heads, and blocks, gear-box housings, compressor parts and agitators for washing machines are most often cast by this method. Copper alloys which are sufficiently fluid in the molten state and used for gears, pinions, impellers for small pumps can also be cast by this process. Lead alloys, in the form of parts of lead storage batteries and also other components, respond positively to the method. Zinc castings though commonly produced by pressure die casting, can also be made by the permanent mould method where the quantity of production is not enough to justify the use of pressure die casting. Grey-iron castings can also be produced by this process, though a thin refractory lining or coating has to be given to the mould surfaces so as to withstand the high temperature of molten metal. The coating usually has a base of sodium silicate or phosphoric acid. Cores, if required, are made in sand. The castings made by the process are generally limited to piece weights up to 10 kg.

PRESSURE DIE CASTING 4.2

Die casting provides the foundryman with one of the fastest means of producing castings with a much higher degree of accuracy than that normally obtained by conventional sand casting. In fact, this method is unexcelled for mass production work as numerous castings can be produced very rapidly at low cost. Further, the castings can be made to very close tolerances and with a fine surface finish. The process is however suited only to certain non-ferrous metals and for small-sized castings.

4.2.1 Die-Casting Dies

Die castings are prepared by forcing molten metal under high pressure into a metal mould called a *die*. The die resembles the common type of permanent mould in that it too has two halves which open and close along a vertical parting. On a die-casting machine, the die half called the *cover die* is stationary. The other die half, which opens and closes, is known as the *ejector die*.

Die-casting dies are usually made of an alloy steel, which should be dimensionally stable, withstand heat checking, not get soldered to the cast alloy, be tough, and resist erosion.

Die cavities have to be machined with great accuracy. Sometimes die cavities are machined by a process known as hobbing. A hardened steel master, called a *hob*, is forced into an annealed alloy-steel die block. Once a hob has been made, a number of die cavities can be duplicated from it. Since no coating is applied to the die cavities, this method produces smoother castings and maintains closer tolerances than those resulting from permanent mould casting.

4.2.2 Die-Casting Machines

The major functions of die-casting machines are as follows:

(i) Closing the two halves of the die by moving the movable half (ejector die) towards the fixed half (cover die);

(ii) Securing the two die halves firmly together, so that they do not separate due to the pressure of molten metal;

(iii) Forcing the molten metal into the die; and

(iv) Opening the die by moving the ejector die away from the fixed die.

A die-casting machine must have a sturdy frame designed to support and open the die halves in correct alignment. The frame must be of lasting strength, since the weight of an assembled die often exceeds several tonnes. Further, the locking force required to hold the die halves together must adequately exceed the maximum force developed by the molten metal to ensure leakproof clamping at the die parting. In some modern die-casting machines, the locking force may approximate as much as 1000 tonnes, depending upon the die size and the molten metal pressure employed.

The maximum force tending to open a die will equal the maximum molten metal pressure times the total projected area of the mould cavity and gating.

4.2.3 Methods Used for Closing and Locking the Dies

The methods used to close and lock dies may be straight hydraulic, hydraulic and mechanical, or purely mechanical.

(1) Straight Hydraulic When hydraulic clamping is directly applied to the die and maintained continuously, line pressure constantly backs up the die when it is closed.

(2) Hydraulic and Mechanical Here, the die is closed both by hydraulic pressure and considerable impact caused by the simultaneous straightening out of the toggle links which are set in motion by the movement of the piston in the hydraulic cylinder. Thus, as long as the toggle-clamping mechanism is correctly adjusted, the dies can be kept securely locked.

(3) Mechanical The mechanical method docs not make use of any hydraulic pressure but relies wholly on a mechanical facility for closing and locking the dies.

4.2.4 Types of Die-Casting Machines

The machines for feeding metal into dies under pressure are

(1) hot-chamber machine;
(2) cold-chamber machine; and
(3) air-blown or goose-neck machine.

(1) Hot-Chamber Machine This machine (Fig. 4.1) has a suitable furnace for melting and holding the metal. Submerged below the surface of the molten metal, a plunger operates within a cylinder. When the plunger is raised, it uncovers an opening or port in the cylinder wall through which the metal spills into the cylinder. After the cylinder is filled, the plunger is forced downwards, pneumatically or hydraulically closing the opening and then forcing the confined metal up through a channel and nozzle into the die. After a predetermined time, the plunger is again raised, allowing the surplus molten metal in the channel and nozzle to drop back into the cylinder. The die is then opened and the solidified die casting ejected. Metal-injection speeds and pressures are controllable to suit different metals and casting.

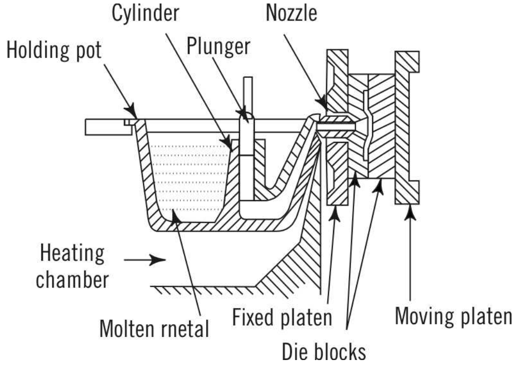


Fig. 4.1 *Plunger type hot-chamber die-casting Machine*

Generally, these machines work at pressures below 150 kg/cm^2 as higher pressures have not proved advantageous. In order to attain uniformity and maximum speed of operation, it is necessary to use a predetermined and automatically controlled cycle for various operations. The operator is however required to manually remove the casting from the die, and inspect and sometimes lubricate it.

(2) Cold-Chamber Machine The cold chamber is a horizontal steel cylinder into which molten metal is quickly introduced (Fig. 4.2). This metal is normally ladled by hand from a nearby holding furnace. After feeding the chamber with slightly more metal than is needed to fill the die, the operator pushes a button which starts an automatic cycle. First, the plunger rapidly advances, forcing the metal into the die; after allowing sufficient time for solidification, the die is automatically opened; as the die opens, the plunger pushes out the so-called *biscuit* of excess metal from the cold chamber; finally, the die casting is removed.

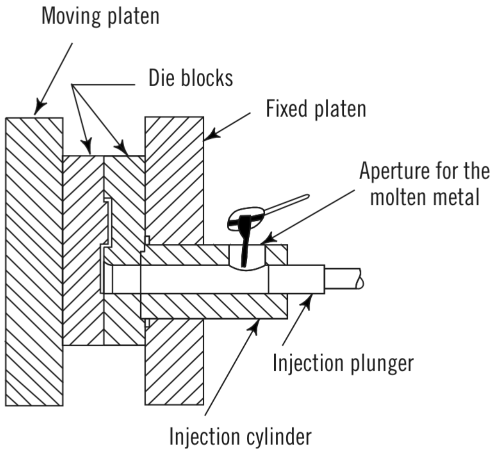


Fig. 4.2 *Cold-chamber die casting machine*

The cold-chamber machine is ideal for metals such as aluminium alloys which cannot be cast in hot-chamber machines due to the high reactivity of molten aluminium with steel. High melting temperature alloys of the non-ferrous type are also best die cast in cold-chamber machines. The pick-up of iron by aluminium in the cold chamber is negligible as the actual contact between the molten metal and the chamber and its plunger is only momentary.

Pressures in cold-chamber machines range from 300 kg/cm^2 to 1600 kg/cm^2.

Modern cold-chamber machines usually provide for multiphase injection of molten metal (Fig. 4.3) to ensure complete and uniform filling of die cavity and preventing porosity in castings. Injection speeds and pressures are variable. Regulation of locking force is done automatically and ladling of metal from the furnace to the die-casting machine is also arranged mechanically to work on a closed cycle operation. Figure 4.4 shows an automatic ladle operated electro-mechanically, fitted to a cold chamber die-casting machine. All these features result in better-quality castings, maximum reliability, high production and high standards of operator safety.

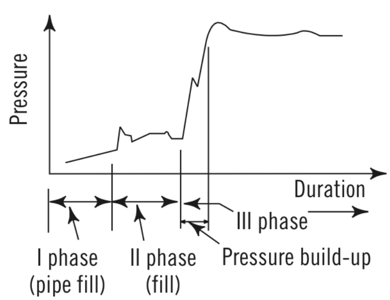


Fig. 4.3 *Multi-phase injection*

In a modified form of the cold-chamber process, developed by General Motors Corp., USA, the die cavity is first filled slowly by a moving plunger assembly in the injection cylinder. Then, high-compaction pressure is applied by a secondary plunger as shown in Fig. 4.5. The castings produced are accurate, rate of

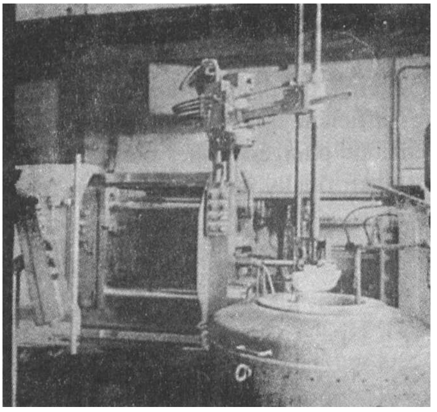


Fig. 4.4 *Automatic ladle fitted to a cold-chamber die-casting machine*

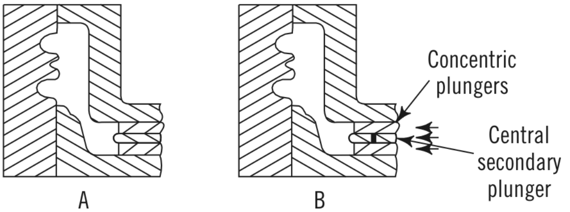


Fig. 4.5 *ACURAD process: (A) Slow filling of die cavity (B) Applying high-compacting pressure*

production is rapid and the structure is dense and, the process has been named as ACURAD process.

(3) Air-blown or Goose-neck Machine This machine differs from the hot-chamber machine in that it makes use of compressed air to force the liquid into the dies (Fig. 4.6). Since the bottle has a goose-neck shape, it can be tilted about trunnions

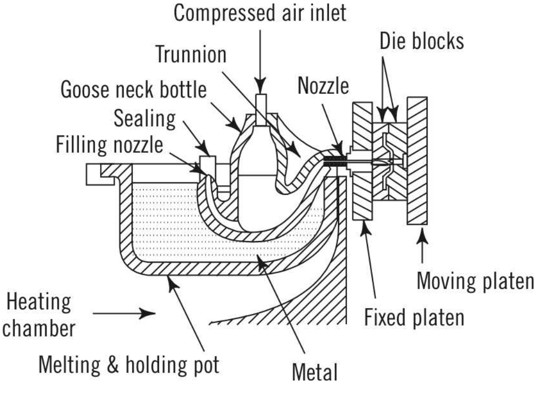


Fig. 4.6 *Air-blow type die-casting machine*

from the air-blowing position to the filling position and vice versa. The metal can thus be simply filled into the bottle.

The air-blown machine is much simpler in operation and construction than the plunger type as it has no moving parts. However, it requires greater attention from the operator since the work is mostly manual. It is being largely replaced by the hot chamber machine which currently records a much higher rate of production and is favoured primarily because of its easy adaptability to mass production. Modern cold and hot-chamber die-casting machines are illustrated in Fig. 4.7.

4.2.5 Metals for Die-Casting

Due to lack of die material that can withstand the high pouring temperature of molten metal, it is not practicable to die cast metals such as iron and steel, which are otherwise suitable for the job. So far, only non-ferrous alloys have been die cast. Zinc alloys with melting point around 380°C are most easily die cast. Other die-casting alloys in order of importance are aluminium, magnesium, copper-base alloys, tin-base alloys, and lead.

4.2.6 Design of Die-Casting Dies

While designing dies, the crucial consideration is the arrangement of the die cavity or cavities and the location of the parting line. It is always desirable to have a regular flat parting line, but an irregular one is often required to facilitate extraction of the casting. Here also, cores are used to form holes and recesses and to avoid thick sections. Cores may be integral with the dies in the shape of projections in the cavity or they may be placed separately. Again, they may be fixed, moving, or collapsible, depending on the nature of requirement and the design of the casting.

The fixed core is one that is placed separate in the die cavity but cannot be removed when the casting is ejected. The moving core is one that can be withdrawn from the die cavity so as to facilitate the ejection of the casting. The mechanism for withdrawing the core may be operated hydraulically or by levers or cams. The collapsible core made is up of a number of pieces which can be kept in an assembled form in the die cavity to act as a solid core. To allow the casting to be ejected, the core is collapsed by causing the pieces to first disintegrate and then draw together. Usually, cores used for die casting are made of alloy steel.

Design Considerations In addition to the considerations for sand-casting design, the following points should also be kept in view when designing die-casting dies:

(i) Fixed cores can be placed in either the ejector or the cover (fixed) portion of the die. A fixed core must have its axis parallel to the direction of motion of the die. Movable cores must be provided with positive means

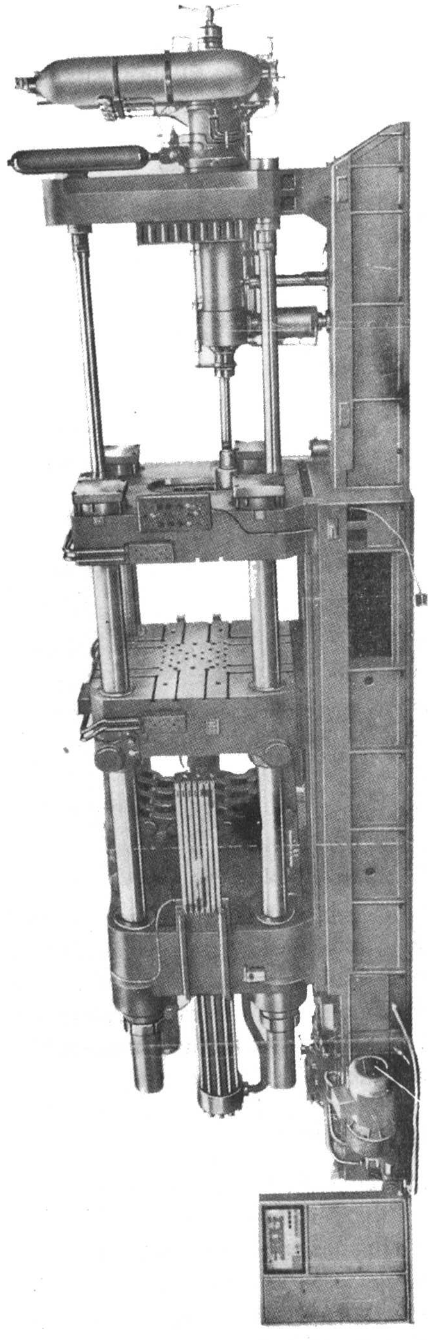


Fig. 4.7 *Cold chamber die casting machine*

for moving and locking in place when the die closes. A rack-and-pinion system operated by a lever admirably fulfils the purpose. But where a short motion is required, it is simple to set a pin at an angle engaging with a hole, such that the piece containing the hole moves transversely when the pin is moved longitudinally.

(ii) A loose core or knock-out is essential for forming a shape having an internal undercut or recess which cannot be produced by a core attached permanently to the die. In such cases, loose pieces which come out along with the casting when the latter is ejected, are also suitable. They are then knocked out and can be used again.

(iii) The casting must invariably cling to the ejector portion. Ejector pins should be made to bear at such points on the casting where the pin marks will not be noticeable or objectionable. As far as possible, the pins should be made to bear on the runners, flash, or other projections which are subsequently cut off. Pins should also be so placed that the casting is not deformed.

(iv) If the side walls of the casting are undercut or contain recesses that cannot be formed by the dies, the introduction of movable slides is recommended. Each slide is provided with a guide in the block with its own operating and locking mechanism.

(v) Vents are fitted on the die parting to allow the air to escape when the molten metal is injected. Vents are normally formed by machining grooves about 0.2 mm deep.

(vi) Sprues, runners, and gates should be so provided that they facilitate the removal of the casting. Sprue holes are always tapered. A sprue pin is usually fixed at the inner end of the sprue to deflect metal into the runner. Runner or runners are cut at the die parting. Gates join the runner with the die cavity. The dimensions of the gating system affect the soundness and surface finish on the casting; these should therefore be decided with due care.

(vii) Overflow wells are sometimes included. They collect the extra metal and facilitate escape of air, thus contributing to the soundness and uniformity of mechanical properties in the casting.

(viii) Large dies required for mass production are usually watercooled. Holes are drilled through the dies for the circulation of water. Large cores may also need water-cooling.

(ix) The provision of several die cavities in the same die increases productivity. Where the shape and size permit such an arrangement, it is worthy of attention.

Advantages of Die-Casting Process

(i) Very high production rates are possible, e.g., with the hot-chamber type, 300–350 castings per hour and with the cold-chamber type, 75–150 castings per hour. Cycle time varies from 3 to 12 seconds in modern die-casting machines.

(ii) Close dimensional control can be maintained. In zinc, a tolerance of ± 0.075 mm on dimensions up to 25 mm size and ± 0.025 mm for each additional 25 mm can be easily achieved.

(iii) Thin sections can be cast. Under favourable conditions, minimum thicknesses are about 0.50 mm for zinc and 0.80 mm for aluminium.

(iv) Details are reproduced faithfully with a high degree of precision.

(v) Surface finish of 0.80 microns (Ra value) can be obtained. It may vary from 0.80 micron to 3 microns according to the types of cast metal and the controlling parameters.

(vi) Die-casting dies retain their accuracy and usefulness for a long time. Dies for zinc alloys may produce as many as 5 million castings.

(vii) The saving of labour and lime and the elimination of machining renders it extremely economical for large-scale production.

Disadvantages of Die-Casting Process

(i) Only certain non-ferrous alloys (discussed earlier) can be economically die cast.

(ii) The maximum size is limited by the size of the dies and the capacity of the die casting machines available. So far, the maximum sizes reportedly cast are 90 kg in zinc and 30 kg in aluminium using a locking force of about 2,000 tonnes.

(iii) The high cost of dies and die-casting equipment requires sufficiently large production quantities to make the process economically feasible. The minimum economic quantity for die casting is considered to be about 20,000.

(iv) Die-castings usually contain some porosity due to the entrapped air.

(v) Die-casting process is prone to metal loss due to several reasons.

Metal Loss in Die-casting

The term metal loss is an emotive term which tends to mean different things to different individuals, depending on their functions in the die-casting unit. Metal loss occurs because of badly adjusted burners, poor fluxing practice, over-weight or badly-flashed castings and poor storage conditions.

A tightly locked die and too high a metal velocity will produce a pressure die-casting with porosity, whereas a slackly locked die and high packing pressure on the metal will increase the component thickness and hence its weight. The use of the correct machine settings, obtained with the use of optimum instrumentation, will give the correct component weight with the optimum mechanical and physical properties.

Metal losses arise from many causes. A few of the more obvious and most serious causes are

(i) The inevitable process loss caused due to metal oxidation during the conversion of metal from the solid to the liquid state
(ii) The inadvertent manufacture of material
(iii) Overweight components
(iv) Material loss during secondary operations such as turning, tapping or drilling, which produce material that cannot be economically recovered
(v) Poor storage conditions for alloys, castings or scrap

Total Metal Loss is the difference between the weight of the metal charged into the furnace and the weight of saleable castings. But melting loss is the difference between the metal charged into the furnace and the output of accounted molten metal.

Metal Loss It is the metal weight unaccounted for in a metal material balance struck between two points in time. It is usually expressed as a percentage of the weight shipped.

Melting Loss It is that portion of metal loss which occurs during a melting and holding operation. It is normally expressed as a percentage of the total weight of the metal melted, both ingot and scrap.

Metal loss depends on the following factors:

In order to anticipate losses in an aluminium die-casting Plant, it may be assumed that total aluminium losses arising from the melting operations should range from 5 to 8% of castings sales weight. The figure depends upon

(i) Casting process employed
(ii) Amount of unavoidable extra metal around the actual component
(iii) Melting process
(iv) Metal and component storage conditions
(v) Scrap rates in foundry and trimming shop as also the components returned by the customer

Casting Process Of the various casting processes available for aluminium alloys, it is reasonable to expect that low-pressure die-casting will normally provide the least loss because the crucible is sealed, the sprue is small and flash tends to be minimal. Pressure die-casting is usually in the mid-position, although one can encounter high scrap rates. Gravity die casting, with its higher casting temperatures, tends to produce greater pot losses, giving it the third position.

Extra metal in and around the component should be minimised by careful attention at the design and planning stages. Running systems should conform to standard practices in respect of direction and cross-sectional areas, and particularly with cold-chamber pressure die-casting, the shot sleeve diameter should be the smallest that will adequately contain the metal dose. Although, in order to save later expenses, overflow wells or headers should initially be milled into the cavity inserts, they should not be connected until die tests prove their necessity, and that too only in specific locations as required.

Ingot Loss Primary melting and recovery melting systems play the greatest part in metal loss prevention since poor initial melting can cause ingot loss of up to 1.5% with a further loss of about 5% on scrap returns. Thus, depending on the ratio of cast to sale weights and the melting system, total metal losses may range from about 4% at 70% casting yield to about 13% at 30% casting yield.

The reason for very high losses at low yields is that more metal is returned to the furnace for remelting with melt losses occurring on each occasion. A simple explanation of this could be illustrated by the following hypothetical examples:

(i) With a component made without any excess metal (some low-pressure die-casting methods approach this idea) and with an expectation of 100% saleable castings, there will be no scrap returnable for remelting and the sole loss of 0.25 to 0.5% would arise from the initial melting of the ingot.

(ii) At the other end of the scale, a component with 100% scrap rate would be continually recycled through the remelt system, melt losses taking place on each occasion. All the initial metal would thus be turned into dross with no viable production ever being achieved.

All casting systems must inevitably come between these two extreme instances, according to the ratio of the sale weight to the cast weight (termed as casting yield). *The lower the yield, the greater is the final metal loss*.

Secondary Operation Scrap Shop returns consist of scrap castings, sprues, runners, gates, overflows, machine dribble, general spillage and flash. Any step which reduces the amount of any of these items will pay for itself many times over, and the greatest attention should be given to very thin material where the surface area is large in relation to its weight. Reduction in the proportion of runners and overflow—consistent with the production of sound castings—reduces the metal loss as well as the cost of melting.

Secondary operation scrap such as turnings or drillings, can be separated into particular alloys, the sales of such segregated arising being more profitable and more easily arranged. In any event, they are not easily or satisfactorily remelted in normal foundry plant.

Most of the metal loss in melting shop returns is caused by the oxidation of thin sections of scrap. By contrast, there is comparatively little loss due to oxidation when ingot alloy is melted. Out of an overall melting loss in a die casting works of 5%, probably only about one-tenth arises in the melting of ingots and nine-tenths in the melting of shop returns. Consequently, any reduction in the proportion of shop returns or in the oxidation that occurs when this material is remelted should show worthwhile savings.

As stated before, oxidation is a surface effect; the chunkier the metal, the smaller is the proportional loss. In case of aluminium and magnesium (and zinc, to a much lesser degree) it is not worthwhile attempting to remelt thin, light-weight arisings under normal foundry conditions.

In all melts, the surface condition of the ingot or scrap has a direct bearing on metal loss and it is essential to ensure that all metal stock is contained in satisfactory, dry storage conditions because any dampness will affect metal surfaces, producing a further increase in loss when melting takes place. Damp surfaces on metal being melted present a considerable safety hazard and, in case of aluminium alloys, dampness may give rise to gassy metal and possible spoilage of production.

The inadvertent manufacture of material uneconomic recovery includes flashings, sweepings or other material from the foundry which has an exceptionally high surface area to low weight.

Factors Contributing to Melting Loss

Aluminium Oxide or Dross During melting, all die-casting alloys combine with atmospheric oxygen, and some with nitrogen, to produce metal loss to a greater or lesser degree. The metal content of the dross so formed is not equal to the total weight of the dross. For example, ten tonnes of aluminium dross, which have been fully converted to oxide, will contain only 5.3 tonnes of original aluminium, the balance being the weight of atmospheric oxygen which had combined chemically with molten aluminium.

For those die-casters using *reverbaratory furnaces*, the first area to examine for possible reduction of metal loss is the melting operation. Aluminium, of course, in either the liquid or solid state, reacts very readily with oxygen to form aluminium oxide on its surface. Once this oxide has formed, it cannot for all practical purposes be converted back to metallic aluminium. In order to keep to a minimum the amount of aluminium oxide or dross formed inside a reverbaratory furnace, the die-caster should adopt the following practices:

(i) Set the burner to a slightly reducing flame. A 5% excess fuel mixture is sufficient. Since burner settings that are excessively reducing are both unnecessary and inefficient, the dia-caster may monitor his flame with an oxygen–hydrocarbon analyser.

(ii) Maintain furnace integrity, particularly with respect to air leaks. Maintain, repair or replace skim gates and clean-out doors as required to insure a minimum of ambient air leakage into the furnace during low fire conditions.

(iii) In addition to maintaining the furnace integrity, the amount of air inspired during low fire conditions can be further reduced through the use of furnace pressure controllers such as mechanical dampers which provide a counter-pressure to the natural updraft of the flue. In addition to reducing oxidation losses, pressure controllers also improve fuel efficiencies.

The aluminium oxide or dross that collects on the surface of the bath in a reverbaratory furnace has entrapped within it a considerable amount of free aluminium. To keep as much of this free aluminium as possible from being skimmed off along with the dross, it is necessary that a salt flux (1 kg per sq. metre of surface area) be rabbled into the dross before skimming. The flux will release much of the entrapped free melt back to the bath. Further reduction in metal content of the dross can be accomplished through the use of a dross reclamation unit.

Typical untreated dross contains up to 80% free aluminium. The use of a salt flux will lower that to 35% and the use of a dross reclamation unit will reduce it even further to 15%.

Sludge Another contributor to metal loss is sludge. In addition to causing inclusion problems and melting difficulties, sludge obviously also represents metal loss. Sludge is an intermetallic compound of aluminium, silicon, iron, manganese and chromium; and is frequently found at the bottom of die-casting furnaces, particularly ones that are used for both melting and holding. The formation of sludge on the bottom of a furnace depends on two variables—composition of the metal and temperature of the bath.

The relationship between composition and sludge formation is representated by the formula

$$\text{Sludge Factor} = (1 \times \%\text{Fe}) + (2 \times \%\text{Mn}) + (3 \times \%\text{Cr})$$

The coefficients in the formula indicate the relative importance of the three elements as sludge formers. Naturally, the higher the sludge factor for a heat of metal, the greater will be its tendency to form sludge.

Die-casters who are concerned about the possibility of developing sludge in their furnaces often specify a maximum sludge factor on their alloy specification. In such cases, a typical sludge factor for ingot is 1.85 and for molten metal, it is 1.95.

Besides composition, the other big factor influencing sludge formation is metal temperature during the melting operation. In the solid material (ingot, scrap etc.) that is charged into the furnace, the sludge-forming elements exist as fine particles of the intermetallic compounds. If the temperature of the metal bath is not sufficiently high, these fine intermetallic particles in the charge material never dissolve, but instead coalesce and sink to the bottom of the furnace as sludge. This problem is particularly severe when ingots are charged directly into the furnace located at the casting machines. Since the pyrometers of these furnaces are usually set at the optimum *casting temperatures* and not at the optimum *melting temperatures*, and because the ingot (due to its size) has a considerable chilling effect on the melt, the intermetallics are never exposed to temperature sufficiently high to dissolve them. In the case of *electric induction furnaces*, serious sludging problems rarely occur because of the uniform stirring action of the melt.

It is also possible for sludge to form from molten metal, particularly in holding furnaces where there is a drop in temperature and the amount of sludge-forming elements present (iron, manganese and chromium) exceeds the solubility for the lower temperature. When this occurs and given a suitable period of quiescence, sludge particles will form, coalesce and because of their higher specific gravity sink to the furnace bottom.

When confronted with a sludging problem, a die-caster should consider employing the following practices:

(i) Specify a sludge factor consistent with both his needs and the inherent nature of secondary aluminium alloys.
(ii) Melt the metal in a central breakdown furnace at a minimum temperature of 730°C.
(iii) Avoid charging a large proportion of ingot and scrap into the melting furnace at one time; instead make smaller additions on a more frequent basis.
(iv) Preheat the solid material before charging.
(v) Maintain a minimum temperature of 650°C in the holding furnace.

As for sludge that has already formed on a furnace bottom, the particles are normally quite coarse and difficult to dissolve. If any of these hard particles should find their way into castings that are to be machined, they could cause excessive tool wear or even tool breakage and produce a machined surface of non-uniform appearance. Therefore, the best practice is to scoop out sludge that has already formed and discard it.

Casting Yield Another major factor influencing aluminium melting loss is casting yield, which is defined as the ratio of net casting weight to total weight cast (i.e. shot weight).

Due to the inherently higher melting loss associated with scrap, the more run-around scrap (biscuits, runners, gates and flash) that is produced, the greater will be the overall melting loss. Using a figure of 2% for the melting loss of aluminium ingot, and 7% for the melting loss of scrap, *Found* and *Lapin* developed the curve shown in Fig. 4.8 relating to casting yield to overall melt loss (total melting loss as a per cent of net casting weight).

As an example, it can be seen from the curve that increase of casting yield from 50 to 60% will reduce the melt loss from 8.5 to 6.5%, i.e., a decrease in the melt loss of 24%. If melting practices and furnace conditions are such as to provide higher losses on ingot and scrap melting than those used by *Found* and *Lapin*, the curve rises even more rapidly. In other words, high melting loss compounds low yield.

The yield on a die-casting may be improved by reducing runner, gate and overflow weights where possible. Using proper gating principles often results in increased casting yield. It should not be overlooked that increased casting yield

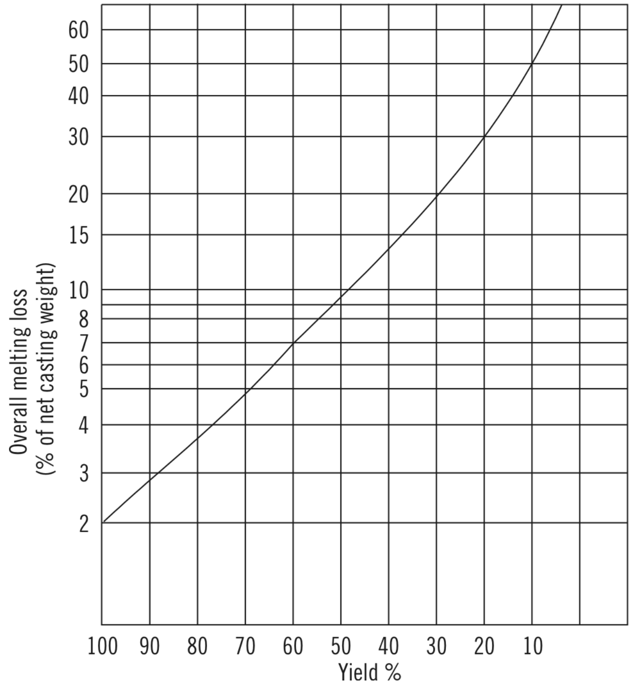


Fig. 4.8 *Overall melting loss as a function of casting yield for aluminium alloys*

will not only save in metal costs and melting capacity, but will also reduce the fuel requirements for each kg of casting produced.

Determining Metal Loss

One then comes to the all important question, "*How to determine metal loss*?"

There are systems of great complexity but the simplest method is to take the delivered weight of alloy in a given period and add the opening stock of metal together with the weight of castings and scrap stocks. From the total, the sales weight of the castings and the closing stock weights of castings, scrap and ingot are subtracted. This should leave a shortage which can then be expressed as a percentage of sales weight or alternatively, as a percentage of metal used.

It has been known for systems using a straightforward weight-in/weight-out procedure to show slight metal losses, to accord with the expected shortfall, but when the estimated metal contents of drosses and residues have been derived and produced, it has been found that there should have been a great surplus of metal, which is in fact nowhere to be found. Therefore, the metal accounting side also needs education in this matter and weight-check, wherever possible, is required on components and stocks to obtain accuracy of answers.

The possibility of the production of overweight components may be avoided by checking the weight of castings at least once during each run and taking action if a departure from the original or subsequently agreed weight is discovered.

As to how well a die-caster is doing, comparatively speaking, values for metal loss in the aluminium die-casting industry vary anywhere between 4 and 12%. To provide an idea of possible savings, it is necessary to quote a range of melt losses for comparison purposes. These are shown in Table 4.1.

Table 4.1 *Metal loss performance*

Total Dross and Sweeping Loss (% metal content)	Performance Rating
4	Excellent
5	Very Good
6	Good
7	Indifferent
10 and above	Bad

Controlling Metal Loss

1. Metal Loss Taking the following steps will reduce the metal loss:

1. Design cast component and tooling for minimum surplus weight.
2. Control metal temperature at the casting station as low as possible, consistent with casting quality requirement.
3. Use correct machine and/or die operating conditions.
4. Avoid making scrap and do not return any scrap to the melt bath.
5. Check weight castings from each run.
6. Segregation of re-run alloys in a dry storage area.
7. Avoid metal mix-ups in foundry and trim shop.
8. Avoid overheating re-run melts.
9. Use adequate flux on re-run melts and rabble well in to produce dry drosses.
10. Allow surplus metal to drain away from skimmed dross.
11. Transfer liquid re-run alloy to the holding furnace.
12. Ensure that residues are correctly sorted and properly disposed of.
13. Determine metal loss by weight calculation and run a metal balance to check on losses.

2. Melting Loss Melting loss has been accepted by foundrymen as an inevitable part of melting, and sufficient attention is not paid to the same. Many times the melting losses exceed the cost of labour, fuel, crucibles, refractory, maintenance and depreciation at present costs in oil-fired melting. The aspect itself determines the immediate need to control melting losses. The following general conclusions can be drawn based on the data on melting losses.

1. Melting loss depends upon the composition of the alloy, especially on the presence of reactive elements.
2. Melting loss can be controlled by ensuring quiet melting without excessive agitation.

LOW-PRESSURE DIE CASTING 4.3

Low-pressure die casting has been lately developed to enable production of castings that are flawless, have very thin sections, and register a yield approaching 100% even in metals such as aluminium and magnesium. The mould, which is made in metal (usually cast iron), is filled by upward displacement of molten metal from a sealed melting pot or bath (Fig. 4.9). This displacement is effected by applying relatively low pressure of dry air (0.5~1.0 kg/mm^2) on the surface of the molten metal in the bath. The pressure causes the metal lo rise through a central cast iron tube and move into the die cavity. The dies are provided ample venting to allow the escape of air. The pressure is maintained till the metal is solidified; then it is released enabling the excess liquid metal to drain down the connecting tube back into the bath. Since this system of upward filling requires no runners and risers, there is hardly any wastage of metal. As positive pressure is maintained to force the metal to fill recesses and cavities, casting with excellent surface quality, finish, and soundness are produced. Low pressure on the metal completely eliminates turbulence and air aspiration. Cores, if required, can be used in the dies: they may be of sand or shell.

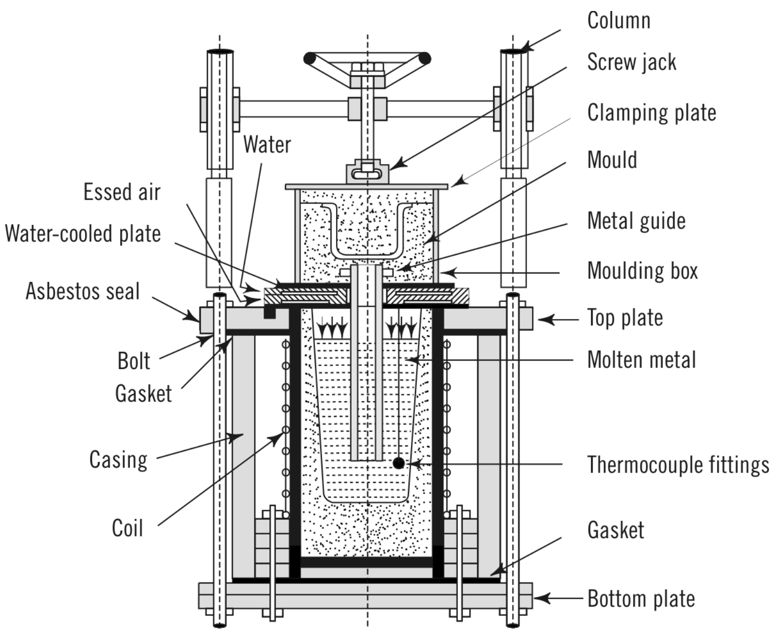


Fig. 4.9 *Low-pressure die-casting machine*

Low-pressure casting is applied in the manufacture of automobile and aircraft components, impellers for pumps, and rain-water fittings. For example, in a plant where aluminium alloy pump impellers of about 250-mm diameter are produced, a pressure of 0.75 kg/mm^2 is maintained for a period of 30–45 seconds. The dies and cores are pre-heated to about 250°C before use. The holding down pressure on the dies, about 30 kg/mm^2, is applied pneumatically. The cores are made in plaster. This results in castings with vanes of 1-mm thickness, a high degree of quality, accuracy, and finish, and hardly 2% rejection rate.

Low-Pressure Die-Casting Machine In case of the standard machines manufactured these days, the working of the machines is fully automated and simplified, giving accurate and reliable results. In the machine, a strong vacuum instantaneously evacuates all air from the cavities and feed channels. In about two seconds, the desired amount of molten alloy is drawn from the centre of the melt, through the transfer tube, and into the injection cylinder. The first movement of the plunger shuts off the metal flow from the feed tube to control the amount of metal ladled. The molten alloy is then smoothly injected into the air-free die cavities and high pressure is brought to bear on the freezing metal, while the vacuum remains active. After a dwell time, the die opens and the part is automatically ejected onto a shuttle tray for transfer out of the die area.

SQUEEZE CASTING 4.4

The squeeze casting process incorporates the advantage of forging or mechanical deformation into the casting process. Molten metal is poured into a die whose half parts are initially separated and then brought together to squeeze the casting while it solidifies. Simultaneously, pressure is applied from a punch in a direction lateral to the movement of the dies, thereby triggering squeeze action from all directions. The pressure is applied on to the molten metal at the precise time when the metal temperature at the interface of metal and die has reached solidus. Delay may necessitate the use of higher pressures, and premature application of pressure may produce coarse and uneven surfaces and ragged edges. Compression time should be such that complete solidification takes place without any air gap. After withdrawal from the die, the casting is cooled in hot sand.

Squeeze casting requires extremely accurate control of a number of variables, such as pressures applied, compression temperature of metal, compression time, die and punch temperature, and type of lubricant used. For any given casting and its composition, the correct values of these variables must first be decided. The process has therefore been put to restricted commercial use and laboratory investigations and research on ways to refine it are still in progress. In one case, it has been used to form forging die inserts in low alloy steel. The properties achieved have been found comparable to those in a forging. Fibre reinforced castings with

SiC or Al_2O_3 fibres interspersed in metal matrix have been successfully squeeze cast and commercially used to produce automobile pistons.

CENTRIFUGAL CASTING 4.5

In the centrifugal casting process, molten metal is poured into moulds while the latter are revolving. The metal falling into the centre of the mould at the axis of its rotation is whirled out by the power of centrifugal force towards the periphery, and the impurities, being lighter in weight, are left behind at the centre. Due to the application of centrifugal force, the castings are completely free from any porosity defect, denseness and strength are high and these castings have been proved as strong as similar forgings. The need for large gates, feeders, and cores is also eliminated, making the method less expensive.

4.5.1 Method of Centrifugal Casting

Three methods of centrifugal casting are generally employed:

1. centrifuging:
2. centrifugal casting; and
3. true centrifugal casting.

1. Centrifuging In this process, molten metal is poured into rotating moulds of which several identical or nearly similar mould cavities are symmetrically arranged off the axis of rotation around a central sprue. This central sprue feeds the metal into the cavities through a number of radial gates. The castings produced are not spun about their own axes and the pouring pressure used is not the same for all the castings. Thus, it is not a purely centrifugal process. Sometimes, when a large number of small-sized castings are required, stack moulding is advantageous. The arrangement of casting in such a case is referred as *Christmas tree formation*, the multiple gating being known as *umbrella gate*. By following the centrifuging process for stack moulding, as many as 150 small castings may be contained in a single mould.

2. Semi-centrifugal Casting This method is employed for making large-sized castings which are symmetrical about their own axis, for example, pulleys, spoked or disked wheels, gears, and propellers. While the mould rotates about a vertical axis in a properly balanced state, the metal is poured into a central sprue from where it first enters the hub and then is forced outwards to the rim by centrifugal force. If a central bore is required in the casting, a dry sand or CO_2 core is best suited. The central sprue also acts as a riser for the hub portion.

Owing to the bulk of the moulds and the tendency of molten metal to spurt out of the mould joint, the spinning speeds used are lower than in the case of true centrifugal casting. Since the speeds are low, high pouring pressures are not produced and the impurities are not effectively separated from the metal. The surface speed generally applied at the outer edge of the casting is about 180 metres per minute.

3. True Centrifugal Casting In this process, while the mould rotates about its axis, which may be horizontal, vertical or inclined at any suitable angle, the metal is poured in, so that the internal shape is formed by centrifugal action. The metal solidifies, forming a hollow casting without the use of a central core. To prevent the metal from escaping at the ends, end cores are used. The method is ideal for hollow cylindrical castings, such as bushings, gun barrels, cast-iron pipes, and hollow propeller shafts.

The positioning of the axis of rotation of the mould is affected by the radial force and the length of the job. Generally, for long jobs where the length is more than four times the bore, the axis of rotation is kept horizontal. In this case, the central cavity formed is a true cylinder, regardless of the outside shape of the casting. The inside diameter and thickness formed will depend on the volume of the metal poured. Tubular castings measuring up to 1200 mm in diameter and 4800 mm in length and with sectional thickness as low as 6 mm may be produced by this method. Figure 4.10 shows typical centrifugal castings.

Fig. 4.10 *Typical centrifugal castings*

When the length of the casting is less than four times the bore but more than the bore diameter, an inclined axis is preferred. When the length is less than the bore, as in very short jobs, the axis is kept vertical. With the axis of rotation inclined or vertical, the resulting cavity is not a true cylinder but a paraboloid. However, if the spinning speeds are fairly high, the paraboloid approaches a cylindrical shape and the slight taper obtained in the interior can be removed by machining. The vertical and inclined axis is generally more convenient to use since the metal can be poured more easily and the castings can also be removed with less difficulty.

The maintenance of proper spinning speed is very important, particularly in the case of a horizontal axis. A speed lower than the required one will cause slipping and raining of the metal, which will not adhere to the mould surface. If the speed is higher than necessary, the casting produced may have hot tears on its walls. The speed of the machine is generally calculated to obtain a radial force of the molten metal which equals about 75–100 times the force of gravity in the case of sand moulds and about 60 times the force of gravity in the case of metal moulds.

4.5.2 Moulding Materials for Centrifugal Casting

Both sand and metal moulds are used for centrifugal casting. Sand moulds may be of green sand, dry sand, CO_2 or other air-hardening or no-bake type. Green sands need special bonding materials to impart strength. When the cast metal tends to wet the mould surfaces, moulds are sometimes also made of graphite. Sand moulds are recommended when the chilling tendency is to be prevented; for instance, when the number of castings is small or when the casting is long, its typical shape requiring destruction of the mould for extracting the casting undamaged.

Metal moulds are ideal when large quantities of identical castings are required, as they facilitate withdrawal of casting from the mould. Their faster rate of cooling also makes them the best choice when the requirements include a fine grain structure. The composition of the metal may vary from grey cast iron to alloy steel, depending on factors such as size and composition of cast metal, temperature, and number of castings.

CONTINUOUS CASTING 4.6

Continuous casting, a major technical phenomenon in the steel industry, is a process used for casting metal direct into billets or other such shapes. The process involves continuously pouring molten metal into a rapidly cooled copper mould and passing it through a system of water and air cooling. This is carried out either wholly along a vertical axis or partly along a vertical and partly along a horizontal axis. The molten metal is poured from the crucible first into a heated basin, called a *tundish*, and then into a vertical copper mould, which is water-cooled and open at both upper and lower ends. The mould is usually 300–350 mm long and the internal shape of the mould corresponds to that of the cross section of the casting required. By the time the metal leaves the bottom of the mould, a solid crust is formed, while the interior remains liquid. It then passes vertically downwards through a set of water-cooled rollers and is further cooled by jets of compressed air. It is finally cut to size either by gas cutters or a circular saw, which is movable with the metal.

In some cases, reciprocating moulds can take the place of the stationary ones. Although the continuous casting process has been used for several years for casting non-ferrous metals, it has recently been adopted also for steel, in the manufacture of rounds, squares, pipes, tubes, and plates. It is claimed to have many advantages over the older method of rolling. Heavy equipment, such as ingot moulds and blooming mills, are completely dispensed with, and due to lower production costs, the steels produced are cheaper.

ELECTRO-SLAG CASTING 4.7

This process, developed originally in the erstwhile USSR, is based on the principle of the electro-slag welding process. It dispenses completely with the risering and gating system and also with the need for a separate melting unit, pouring ladle and transportation arrangements.

The process consists of a water-cooled iron or steel mould (*C*) which itself acts as a melting unit, and one or more consumable steel electrodes (*E*) to produced molten metal under a protective slag. Heat is produced by the passage of electric current between the electrodes and mould, through the conductive slag (*D*). As the temperature rises above the melting point of the electrode, it melts at the tip and flows through the basic slag into the molten metal pool (*B*) in the mould cavity. As the electrode gets consumed, it is continuously lowered at a controlled rate (*G*). Solidification takes place without any contact with the atmosphere. Besides refining action, the slag absorbs non-metallic impurities from the molten metal and protects it from atmospheric contamination. The electrode maintains a continuous pool of metal on top of the solidifying layer and therefore, feed metal is always available to guarantee a sound structure (Fig. 4.11).

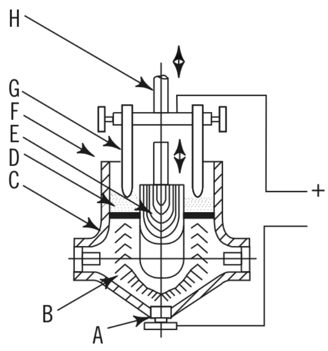


Fig. 4.11 *Electro-slag casting process*

Graphite and ceramic moulds have also been used in place of metallic ones. The transfer technique has also been adopted, in which metal is melted under cover of a protective slag in a separate chamber on the side of the mould, and molten metal flows continuously from the chamber into the mould cavity. This technique makes it possible to produce castings of complex shapes and composite forms. The typical items cast by this process are crankshafts, connecting rods, nozzles, valve bodies, high-pressure vessels, etc. There is no limit to the size and weight of castings that can be produced. The casting yield is almost 100%. However, the process is expensive owing to the high initial cost and high cost of electrodes which have first to be formed in suitable sizes and compositions.

Review Questions

1. What are the advantages and limitations of permanent mould-casting process? What metals can be cast by this process?
2. Explain with sketches the operation and control of hot-chamber die-casting process.
3. State the design considerations of die-casting process as against sand-casting processes. Name a few industrial components which are commonly produced by this process and give reasons for the same.
4. What factors affect the metal loss during the die-casting process? How can these losses be controlled?
5. What is low-pressure die casting? What are its process characteristics? For what components is it better suited than die casting and why?
6. Explain briefly the process of continuous casting. In what way is it superior to the rolling process?
7. Illustrate the principle and working of electro-slag casting process. What are its possible applications?
8. Explain the use of different types of dies for die-casting. On what factors does the choice of material of dies for die casting depend?
9. What factors govern the choice of selection of the following casting processes?
   (a) Low-pressure die casting
   (b) Hot-chamber die casting
   (c) Cold-chamber die casting
   (d) Centrifugal casting
10. What machining methods are commonly used for machining die cavities? What metals or alloys are suitable for die-making? Give their characteristics.

Chapter 5

Gating and Risering of Castings

GATING SYSTEM 5.1

The term 'gating' or 'gating system' refers to all the passageways through which metal enters a mould cavity. It thus mainly includes parts such as a pouring basin, sprue, runner, and gates.

The chief requisites of a gating system are the following:

(i) Metal should be able to flow through the gating system with a minimum of turbulence and aspiration of mould gases so as to prevent sand erosion and gas pick-up. Turbulence is the most important single factor affecting the design of the gating. Excessive turbulence results in the aspiration of air and the formation of dross.

(ii) The metal should be so introduced in the mould cavity that the temperature gradients established on the mould surfaces and within the metal facilitate directional solidification towards the riser.

(iii) The mould cavity should be completely filled with molten metal in the shortest possible time; the gating system should therefore be so designed that the rate of entry of metal into the mould cavity is well regulated.

(iv) The casting should be produced with a minimum of excess metal in gates and risers.

(v) Loose sand, oxides, and slag should be prevented from entering the mould cavity by providing a proper skimming action on the metal as it flows through the gating system.

(vi) Erosion of the mould walls should be avoided.

These requisites can be achieved by controlled pouring, use of proper pouring equipment, pouring metal at a specific temperature, and by correct design of sprue, runner, and gates. Table 5.1 gives typical pouring temperatures.

Foundries should follow the practice of designing and testing their gating systems on one or more pilot castings and the gates and runners directly on the pattern equipment before a production run is started. The gating system should be carefully designed so that the casting produced conforms to the prescribed specifications. Improving the design of a gating system can augment the casting yield and reduce rejections.

Table 5.1 *Typical pouring temperatures of ferrous castings*

Cast metal	Liquids temperature (°C)	Pouring temperature (°C)			
		Small castings		Large castings	
		Thin sections	Thick sections	Thin sections	Thick sections
Grade 20 CI	1150	1400	1370	1340	1310
Grade 25 CI	1180	1425	1400	1370	1340
Grade 30 CI	1220	1470	1440	1410	1380
0.8% carbon steel	1470	1550–1580	1535–1560	1500–1530	1480–1510

The parts that constitute a gating system (Fig. 5.1) are the pouring basin; sprue; runner; and gate.

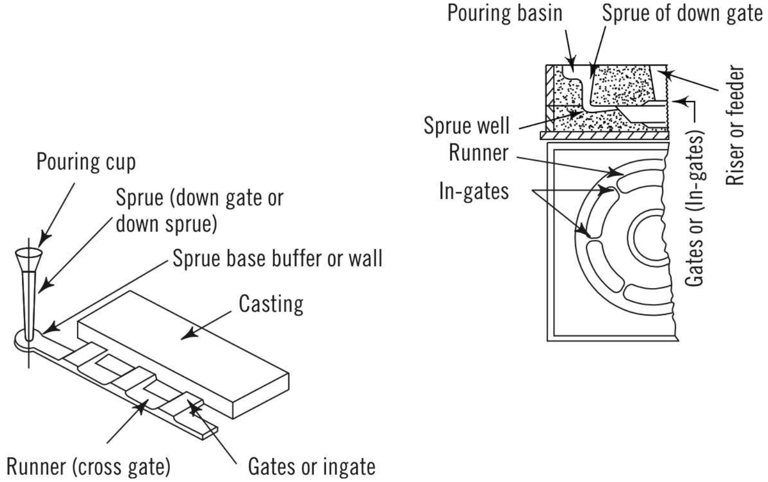


Fig. 5.1 *Parts of the gating system*

5.1.1 Pouring Basin

Molten metal is carried in a ladle from the furnace to some type of pouring basin on or in the top part of the mould. The main purpose of the pouring basin is to establish a proper flow system as rapidly as possible. For metals such as aluminium and magnesium, which react quickly when exposed to air, it is desirable to have a separate pouring basin made of dry sand core or cast iron on top of the mould. Sometimes, a funnel-shaped opening is made at the top of the sprue in the cope itself, which serves as a pouring basin.

Some typical designs of pouring basins are given in Fig. 5.2. The basin should be substantially large and should be placed near enough to the edge of the flask for the pourer to fill the mould quickly, keep it full during the entire pouring operation, and position the ladle lip at all times close to the pouring basin. If the pouring basin is designed to regulate the rate of metal entry, the metal flows smoothly into the sprue and turbulence is avoided. Good results are obtained by using a dam or a strainer core or both in the pouring basin. A sprue plug is also convenient for controlling the flow of metal into the mould cavity.

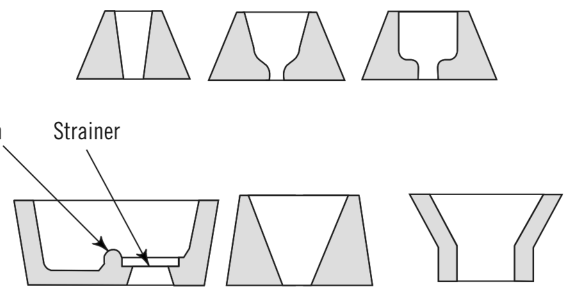


Fig. 5.2 *Typical shapes of pouring basins*

5.1.2 Sprue

The vertical passage through the cope and connecting the pouring basin to the runner or gate is called the sprue.

The sprue size should satisfy certain conditions, for instance, the sprue must be small enough for (i) the pourer to keep it full during the entire pouring operation, and (ii) the metal to enter the mould cavity at a velocity that avoids spluttering and turbulence. At the same time, the sprue must be large enough for (i) the mould cavity to fill completely without laps, seams, or misruns, and (ii) a metal head to build up quickly enough to prevent mould gases from being aspirated into the metal. Sprue sizes usually vary from 10 mm square for work below 12-kg poured weight to about 50 mm square for heavy castings. Sprues larger than 50 mm square are seldom used.

The cross section of a sprue may be square, rectangular, or circular. If a single sprue is not adequate to fill a large casting in the required time, two or more sprues and the same number of ladles may be employed for pouring. The sprues are generally tapered downwards to avoid aspiration of air and metal damage. If a sprue of uniform cross section is used, severe aspiration occurs because the metal velocity increases as it descends the vertical sprue. On the other hand, if the sprue is tapered to a degree so that the metal lies firmly against the mould, aspiration and turbulence are minimised. (Flow is said to be turbulent when the atoms of metal do not flow in a straight streamlined path but travel from side to side.)

Figures 5.3 and 5.4 illustrate the effect of sprue design on metal turbulence. It is observed that if the sprue is straight and has sharp corners, there is severe aspiration, thereby causing turbulence in the metal. If the sprue is tapered, corners are rounded, and a sprue well and dam type of pouring basin are used, aspiration is negligible and there is no turbulence.

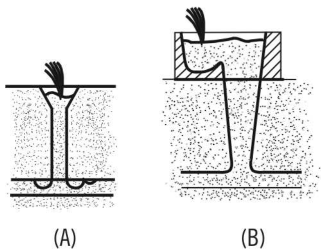


Fig. 5.3 *Effect of sprue design on metal turbulence (A) Severe aspiration (B) Negligible aspiration and turbulence*

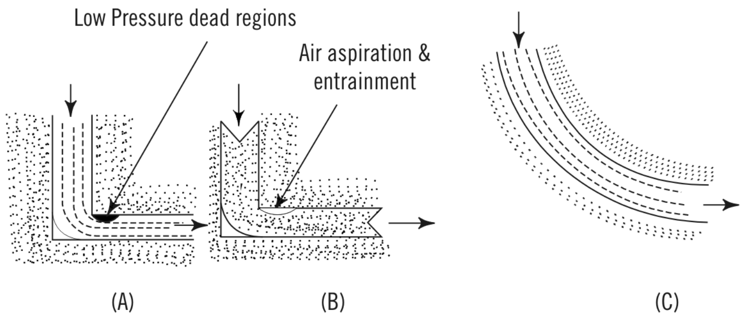


Fig. 5.4 *Metal flow in a gating system (A–B) Turbulence and metal damage due to sharp corner (C) Smooth flow of metal due to streamlining of corner*

The base of the sprue is usually enlarged and made deeper than the runner. This deeper and enlarged cavity beneath the sprue is called the sprue well. It serves as a cushion to the falling weight of metal and absorbs its kinetic energy. The width and depth of the sprue well are about 1½ times those of the runner.

5.1.3 Runner

In large castings, molten metal is usually carried from the sprue base to several gates around the cavity through a passageway called the runner (Fig. 5.5). When a mould has more than one cavity, the common gate supplying metal to a number of cavities is also called a runner, and the branches from the runner to the respective mould cavities are referred as in-gates. The runner may be positioned around the casting periphery so as to provide in-gates at a number of points. Although the runner is generally preferred in the drag, it may sometimes be located in the cope, depending on the shape of the casting. The runner should be streamlined to avoid aspiration and turbulence. In order to obtain a flow of approximately equal volume through each in-gate, the path of the runner is reduced in area after each successive in-gate by an amount equal to the in-gate area. Such *multiple in-gating* is often advised in the case of light metal castings.

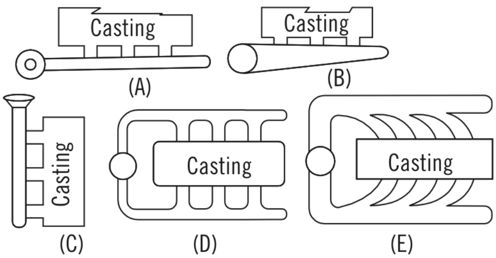


Fig. 5.5 *Types of runners (A) Sraight runner (B) Tapered runner (C) Step gate (may also act as feeder) (D) Uniform size runner (causes uneven metal distribution) (E) Runner for even distribution of metal (reduction in size of runner after each gate)*

5.1.4 Gates

The gate is the passage that finally leads molten metal from the runner into the mould cavity. The location and size of the gates are so arranged that the mould can be filled in quickly with a minimum amount of cutting of the mould surfaces by the flowing metal. The gates should be so placed that cracks do not develop when the metal cools. The gate connections should be located where they can be readily removed without damaging the castings. In-gates should not be placed too near the end of the runner. If necessary, a well may be provided at the runner end.

According to their position in the mould cavity, gates may be broadly classified as (1) top gates; (2) parting gates; and (3) bottom gates.

(1) Top Gates Molten metal is poured down the head or riser of the casting. Since the metal falls directly into the mould cavity, the mould should be hard and strong enough to resist erosion by the dropping metal. The advantage of top gating is that since all the metal enters the casting at the top, the hottest metal remains in this region. As such, proper temperature gradients are formed, and directional solidification towards the riser, located at the top of the casting, can be achieved. The gates themselves may be made to serve as risers (Fig. 5.6).

To prevent loose sand and drops from entering the mould cavity and to allow the metal to fall in a small stream, a large-sized pouring basin may be fixed on top of the sprue-cum-riser (Fig. 5.6A). A strainer core may also be fitted in the pouring basin for better results. In the case of light castings, wedge-shaped gates called wedge gates may be provided (Fig. 5.6B). Pencil gates, as shown in Fig. 5.6D, are used for massive iron castings where a minimum weight of head is desired and the slag is to be effectively checked from collecting in the mould cavity. In the finger gate (Fig. 5.6E), a modification of the wedge gate, the metal is allowed to reach the mould in a number of streams. The ring gate (Fig. 5.6F) also uses a core to break the stream of molten metal besides directing the metal into the desired position in the mould and, at the same time, retaining the slag.

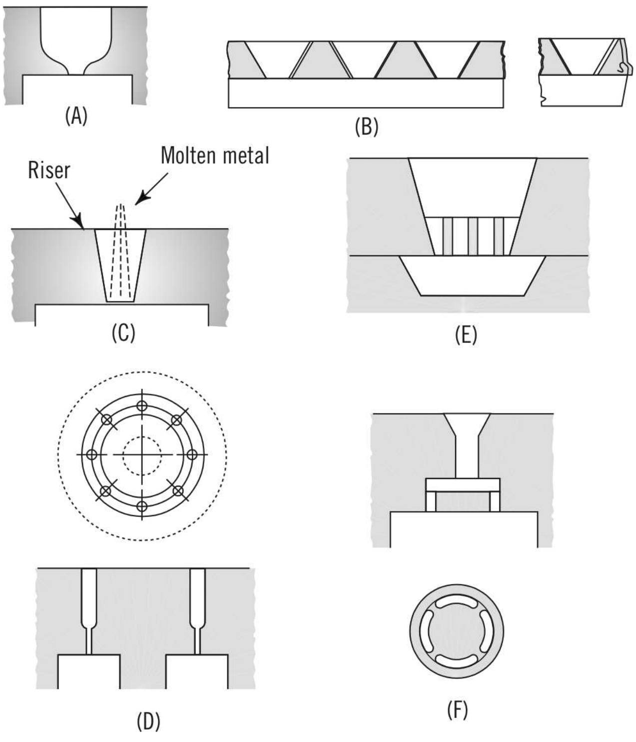


Fig. 5.6 *Types of top gates (A) Top gate with pouring basin (B) Wedge gate (C) Top run gate (D) Pencil gate (F) Ring gate*

(2) Parting Gates In the case of parting gates (Fig. 5.7), metal enters the mould cavity at the same level as the mould joint or parting line. Molten metal enters through the sprue and reaches the parting surface where the sprue is connected to the gate in a direction horizontal to the casting. The arrangement of providing a gate at the parting line allows the use of devices that can effectively trap any slag, dirt, or sand, which passes with the metal down the sprue.

Figure 5.7D shows the use of a skim-bob, which is a hollow or recess in the cope, to trap the slag and foreign matter in the metal. This figure also indicates the use of a choke, which serves as a restriction to control the rate of flow of the metal. The choke may be placed in the gate either close to the casting, or away

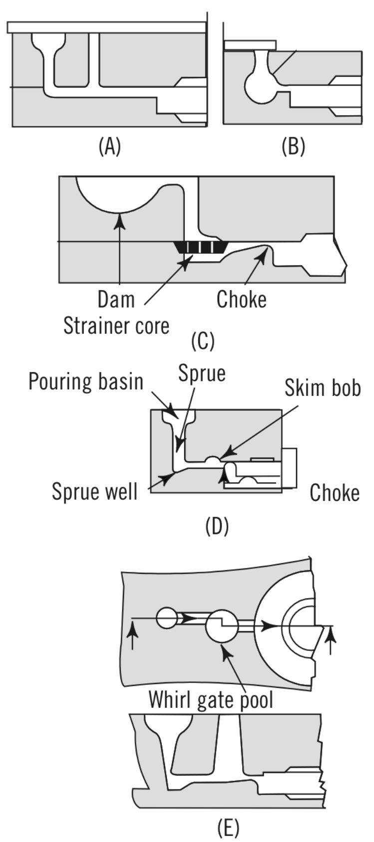


Fig. 5.7 *Types of parting gates (A) Skimming gate (B) Parting gate with shrink-bob (C) Parting gate with dam type pouring basin (D) Parting gate with skim-bob (E) Whirlpool gate*

from it so as to prevent squirting of metal in the mould cavity and erosion of sand. Figure 5.7A illustrates the use of a skimming gate, the purpose of which is similar to that of a skim-bob, viz., trapping the foreign matter which, here being lighter in weight than the metal, can rise up through the vertical passage. Figure 5.7C depicts the use of a dam-type pouring basin, formed in the upper part of the cope, and a strainer core. The purpose of both the dam and the strainer core is to separate the impurities and refine the metal. The metal, however, must be very fluid when a strainer core is used. If there is a tendency of shrinkage near the in-gate, a shrink-bob as shown in Fig. 5.7B may be required. At the bottom of the sprue, a dry sand core is sometimes fixed to prevent the sand from getting washed away. In the case of large castings, molten metal flows through a common runner, which is laid around the mould cavity, and the metal is uniformly distributed to the casting through a number of branch gates. To trap the slag, etc., another effective method is to use a skimming gate with a whirlpool (Fig. 5.7E).

The slag, due to whirlpool action, comes to the centre from where it rises up in the skimming gate.

(3) Bottom Gates In the case of bottom gates, usually favoured for large-sized casting, especially those of steel, molten metal flows down the bottom of the mould cavity in the drag and enters at the base of the casting. These are used to keep the turbulence of metal at a minimum while pouring and to prevent mould erosion. Metal is allowed to rise gently in the mould and around the cores.

The disadvantages of bottom gating are the following:

(i) The metal continues to lose its heat as it rises in the mould cavity, and, by the time it reaches the riser, it becomes much cooler. As such, directional solidification is difficult to achieve.

(ii) It is difficult to place the riser near the gate entrance where the metal is hottest.

Two types of bottom gates are shown in Fig. 5.8. The horn type (Fig. 5.8A) enables the mould to be made in two boxes only, thus eliminating the necessity of a 'cheek'. The pattern for this gate is rammed in the drag and later extracted by turning it out of the sand.

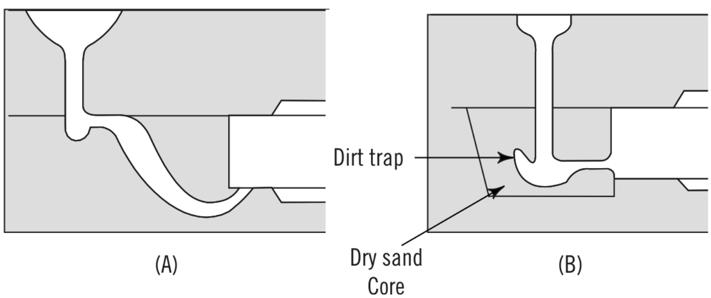


Fig. 5.8 *Types of bottom gates (A) Horn gate (B) Bottom gate with dry sand core*

Figure 5.8B shows a bottom gate using a dry sand core. The sprue is curved at the bottom end to form a dirt-trap for slag, dirt, etc. This type of gate also enables the mould to be made in two boxes. Bottom gating can be provided with ease in case of three-part moulds by keeping the in-gates on the parting face of drag and middle part. A draw-in type of runner gate can also be used for simplicity in moulding. The runner-gate pattern is tapered and can be pulled into the mould cavity after the main pattern for the casting has been withdrawn. The gate is generally placed tangentially on the casting so as to impart a spinning action to the incoming metal. The spinning and whirling action tends to move the slag and scum to the centre from where it can ascend into the riser.

Gating Ratio The term *gating ratio* is used to describe the relative cross-sectional areas of the components of a gating system. It is defined as the ratio of sprue area to the total runner area to the total gate area. A gating system having a sprue of

1 sq cm cross section, a runner of 3 sq cm cross section, and three gates, each of 1 sq cm cross section, will have a gating ratio of 1 : 3 : 3.

Gating ratios are grouped in two classes, viz., pressurised and unpressurised systems. In the pressurised system, the proportions of sprue, runner, and gate areas are so arranged that back pressure is maintained on the gating system by a fluid film restriction at the gates. This requires that the total gate area is not greater than the area of the sprue. Gating ratios such as 1 : 0.75 : 0.5, 1 : 2 : 1 and 2 : 1 : 1 will therefore produce a pressurised system. A pressurised system keeps itself full of metal. The danger of metal pulling away from the walls with consequent air aspiration is thus minimised. As this system is small in volume for a given metal flow rate, it results in a smaller loss of metal and greater yield. On the other hand, high metal velocities in a pressurised system may tend to cause severe turbulence at the junctions and corners and in the mould cavity. This system is generally suitable for ferrous metals and brass.

The unpressurised system of gating produces lower metal velocities and permits greater flow rates. It reduces turbulence in the gating system and spurting in the mould cavity. On the other hand, this system requires careful design to ensure complete filling, and large-sized runners and gates, which reduce the yield and increase the wastage of metal. Further, equal flow in the case of multiple gating is difficult to achieve.

The unpressurised system is generally adopted for metals such as aluminium and magnesium. The ratios used are 1 : 2 : 2, 1 : 3 : 3, etc.

Calculation of Gating-System Dimensions The dimensions of the gating system may be calculated as follows:

(1) Determine the casting weight.

(2) Estimate the critical thickness from the drawing. (The thinnest section through which metal has to flow is the critical thickness.)

(3) Determine the pouring rate of molten metal. (a) For ferrous metals and copper-base alloys, the pouring rate R in the kg per second is given by the empirical formula,

$$\mathrm{R} = \frac{(W)^p}{\left(1.34 + \dfrac{t}{13.77}\right)}$$

where W is the weight of the casting in kg, t the critical casting thickness in mm and p a quotient whose value depends on the weight of the casting.

The value of p for different castings is as follows:

Weight of casting	*Value of p*
Up to 500 kg	0.50
500–5000 kg	0.67
5000–15000 kg	0.70

(b) For light metal castings:

$$R = b\sqrt{W}$$

where the value of b depends on the wall thickness:

Wall thickness	*Value of b*
below 6 mm	0.99
6–12 mm	0.84
Above 12 mm	0.47

(4) In the case of cast iron, estimate metal fluidity k from the composition factor: Composition factor = ¼% total carbon + ½(% silicon) + (% phosphorus).

Composition factor	*Metal fluidity (k)*
3.2	0.5 to 0.7
3.6	0.6 to 0.9
4.0	0.75 to 10
4.2	0.90 to 1.2

In the case of other metals, k can be taken as unity.

(5) Calculate the adjusted pouring rate R_a for metal fluidity k and the effect of friction in the gating system (c factor). The c factor has a value of 0.85–0.90 for tapered sprues and 0.70–0.75 for straight sprues.

$$R_a = \frac{R}{k \cdot c}$$

(6) Determine the effective sprue height H according to the placement of the pattern in the mould:

$$H = h - \frac{a^2}{2c}$$

where h is the height of the sprue, c the total height of the mould cavity, and a the height of the mould cavity in the cope.

(7) Calculate the area of the sprue base A_s:

$$A_s = R_a(d\sqrt{2gH})$$

where d is the density of molten metal.

(8) Using the appropriate gating ratio, according to the type of metal cast and the type of sprue (tapered or straight), calculate the cross-sectional areas of runner and in-gates, and from there arrive at the corresponding sectional sizes. In the case of a runner, it is good practice to reduce its cross-sectional area after its path through each in-gate by the area of the in-gate so as to maintain uniform velocity of metal at each point of entry into the mould cavity.

Pouring cup height in relation to sprue height also affects the sprue diameter. It can be ensured that

$$\frac{\text{Sprue base area}}{\text{Runner/choke area}} \geq \frac{\text{Height of cope + height of pouring cup}}{\text{Height of pouring cup}}$$

According to practice in the USSR, the pouring time for steel castings is calculated by the empirical formula;

$$\tau = S\,[\delta\, G]^{1/3}$$

where,

τ is the pouring time, seconds.

δ is the mean thickness of the casting wall, mm.

G is the gross weight of the casting, kg.

S is a coefficient, whose value is taken as 1.3 for bottom gating, 1.4 for side gating, and 1.5–1.6 for top gating.

The pouring rate can be calculated by dividing the gross weight of the casting by pouring time.

The total cross-sectional area of the in-gates is then calculated as:

$$a = \frac{G}{\tau Y \mu \sqrt{gH}}\,\text{cm}^2$$

where,

τ is the density of molten steel, kg/cm3.

μ is the coefficient of friction between molten metal and channel walls.

g is the acceleration due to gravity.

H is the head of molten metal at the in-gate level, cm.

Table 5.2 gives the dimensions of the gating system for grey iron castings which can be used for guidance.

RISERING OF CASTINGS 5.2

A *riser* is a hole cut or moulded in the cope to permit the molten metal to rise above the highest point in the casting. The riser serves a number of useful purposes. It enables the pourer to see the metal as it falls into the mould cavity. If the metal does not appear in the riser, it signifies that either the metal is insufficient to fill the mould cavity or there is some obstruction to the metal flow between the sprue and riser. The riser facilitates ejection of the steam, gas, and air from the mould cavity as the mould is filled with the molten metal. Most important, the riser serves as a feeder to feed the molten metal into the main casting to compensate for its

Table 5.2 *Gating system dimensions for cast iron castings*

Rough casting weight (kg)	Sprue diameter		Runner cross-section (mm)		Total gate area (cm^2)	Triangular-in-gates, No. of in-gates						Rectangular in-gates, No. of in-gates			
	Single	Double	Single-ended	Double-ended		2	3	4	5	6	8	4	5	6	8
≤ 20	25	—	20/15 × 20	15/10 × 15	3	18	14	12	11	10	—	8.5	—	—	—
21–40	30	—	20/20 × 22	18/15 × 15	4	20	16	14	12.5	11	—	10	9	8	—
41–60	35	—	25/20 × 25	20/15 × 20	5	22.5	18	16	14	13	12	11	10	9	—
61–90	35	—	30/25 × 30	20/15 × 20	6	24.5	20	17.5	15.5	14	13	12	11	10	8.5
91–150	35	—	30/25 × 30	25/20 × 25	7	26.5	21.5	18.5	17	15.5	14	13	12	11	9
151–200	40	—	35/30 × 35	25/20 × 25	8	—	—	20	18	16	15	14	13	11.5	10
201–150	40	—	35/30 × 35	25/20 × 25	9	—	—	21	19	17.5	16	15	13.5	12.5	10.5
251–300	40	—	35/30 × 35	25/20 × 25	10	—	—	22.5	20	18.5	17	16	14	13	11
301–350	45	—	40/35 × 35	30/25 × 30	11	—	—	23.5	21	19	17.5	16.5	15	13.5	11.5
351–400	45	—	40/35 × 35	30/25 × 30	12	—	—	24.5	22	20	18.5	17.5	15.5	14	12
401–450	50	—	40/35 × 40	30/25 × 30	13	—	—	25.5	23	21	19	18	16	14.5	13
451–500	50	—	45/40 × 40	30/25 × 30	14	—	—	26.5	23.5	21.5	20	19	17	15	13.5
501–600	55	40	45/40 × 45	35/30 × 35	16	—	—	28.5	25.5	23	21.5	20	18	16	14
601–700	55	40	50/45 × 45	35/30 × 35	18	—	—	30	27	24.5	22.5	21	19	17.5	15
701–800	60	40	50/45 × 50	40/35 × 35	20	—	—	31.5	28.5	26	24	22.5	20	18	16
801–900	60	45	55/50 × 50	40/35 × 40	24	—	—	33.5	29.5	27	25	23.5	21	19	16.5
901–1000	65	50	55/50 × 55	40/35 × 40	24	—	—	35	31	28.5	26	24.5	22	20	17.5
1001–1200	65	50	60/55 × 55	40/35 × 40	26	—	—	36	32.5	29.5	27.5	25.5	23	20.5	18
1201–1400	70	50	60/55 × 60	45/40 × 40	28	—	—	38	34	30.5	28.5	26.5	23.5	21.5	18.5
1401–1600	70	50	60/55 × 60	45/40 × 45	30	—	—	39	35	31.5	29.5	27.5	24.5	22.5	19.5

shrinkage. The use of several risers may be necessary in the case of an intricate or large casting with thin sections.

The main requisites of an effective riser are the following:

(i) It must have sufficient volume as it should be the last part of the casting to freeze.
(ii) It must completely cover the sectional thickness that requires feeding.
(iii) The fluidity of the molten metal must be adequately maintained so that the metal can penetrate the portions of the mould cavity freezing towards the end.
(iv) It should be so designed that it establishes and effects temperature gradients within the castings so that the latter solidifies directionally towards the riser.

5.2.1 Directional Solidification

As the molten metal cools in the mould and solidifies, it contracts in volume. The contraction of the metal takes place in three stages:

(i) liquid contraction;
(ii) solidification contraction; and
(iii) solid contraction.

Liquid contraction occurs when the molten metal cools from the temperature at which it is poured to the temperature at which solidification commences. Solidification contraction takes place during the time the metal changes from the liquid state to the solid, e.g., when the metal loses its latent heat. Solid contraction spans the period when the solidified metal cools from freezing temperature to room temperature. Only the first two of these shrinkages are considered for risering purposes, since the third is accounted for by the patternmaker's contraction allowance. Of the first two types, liquid shrinkage is generally negiligible but solidification contraction is substantial and should therefore be considered.

Since all the parts of the casting do not cool at the same rate, owing to varying sections and differing rates of heat loss to adjoining mould walls, some parts tend to solidify more quickly than others. This contraction phenomenon causes voids and cavities in certain regions of the casting. These voids must be filled up with liquid metal from the portion of the casting that is still liquid and the solidification should continue progressively from the thinnest part, which solidifies, first, towards the risers, which should be the last to solidify. If the solidification takes place in this manner, the casting will be sound with neither voids nor internal shrinkage. This process is known as *directional solidification*, and ensuring its progress should be a constant endeavour for the production of sound castings. In actual practice, however, it may not always be easy to fully achieve directional solidification owing to the shape and design of the casting, the type of casting process used, and such other factors. In general, directional solidification can be controlled by

(i) proper design and positioning of the gating system and risers;
(ii) inserting insulating sleeves for risers;
(iii) the use of padding to increase the thickness of certain sections of the casting;
(iv) adding exothermic material in the risers or in the facing sand around certain portions of the castings;
(v) employing chills in the moulds; and
(vi) providing blind risers.

5.2.2 Design and Positioning of Risers

(1) Riser Shape and Size The most efficient shape a riser can assume is that which will lose a minimum of heat and thereby keep the metal in a molten state as long as possible. This condition can be met when the riser is spherical in shape so that its surface area is a minimum. For the same volume, the next best shape is a cylinder, and then a square. As it is difficult in practice, to mould a spherical riser, a cylinder is the best shape to employ for the general run of castings.

As regards the height of the riser, it must be tall enough to ensure that any pipe formed in it does not penetrate casting. The ratio of height to diameter usually varies from 1 : 1 to 1.5 : 1. The size of the riser, i.e., its diameter, is still largely a matter of experience. For general guidance, the empirical formulae derived by Chvorinov, Caine, etc., can also be used.

Chvorinov's rule is based on the assumption that freezing time is governed by its $(V/A)^2$ ratio, where V/A is the ratio of the volume of the casting to its surface area and is known as *modulus*. Chvorinov has stated that the freezing time of a casting,

$$t = (1/q^2)(V/A)^2,$$

where q is a solidification constant, depending on the composition of cast metal and the positioning of the mould cavity, i.e., along a horizontal or vertical axis. For steel, it may be assumed that $q = 2.09$. Values of $(V/A)^2$ and freezing time for different cylinder diameters and various metals and alloys have been ascertained in actual experiments and noted in handbooks on cast metals. To determine a suitable riser diameter, the $(V/A)^2$ ratio of the given casting is computed and a riser whose $(V/A)^2$ is slightly larger than that of the casting (say 10–15% larger) is chosen.

Caine's method of evaluating riser size is based on the relative freezing time of the casting and the riser. It defines the relative freezing time to complete solidification as

(surface area of casting) ÷ (volume of casting) : (surface area of riser) ÷ (volume of riser)

According to Caine, if the casting solidifies very rapidly, the feeder volume need be only equal to the solidification shrinkage of the casting. On the other hand, if the feeder and casting solidify at the same rate, the feeder must be infinitely large. This signifies that hyperbolic relationship exists between relative freezing time and relative volume. The relative freezing time, X is given by

$$X = \frac{L}{Y - B} + C$$

where Y is volume of riser/volume of casting, B is the relative contraction on freezing, and L and C are constants, depending on the metal to be cast.

The values of L, C and B for three common cast metals are as given in Table 5.3.

Table 5.3 *Values of L, C, B for three common cast metals*

Cast metal	L	C	B
Aluminium	0.10	1.08	0.06
Grey cast iron	0.33	1.0	0.03
Steel	0.12	1.0	0.05

Given the values of the constants L and C and the value of relative contraction B and by assuming a certain value of riser diameter, X can be found out. Then, with the help of a graph, as drawn in Fig. 5.9, the values of X and Y may be plotted. If they meet above the soundness curve, the value of the selected riser size will be satisfactory. If the meeting point is below the curve, the riser will be unsuitable and another value of riser diameter should be tried.

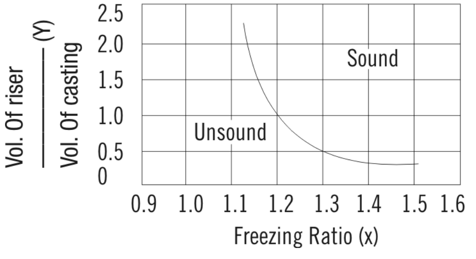


Fig. 5.9 *Caine's curve for risering*

The shape factor method is also used for rough estimation of riser size. The shape factor is given by the ratio of length + width : thickness of casting. From the factor curves which are available in handbooks for different cast metals, the value of V_r/V_c, where V_r is the volume of the riser and V_c the volume of the casting, is determined. From this ratio the casting volume being known, the riser volume can be found out. And from the riser volume, the riser diameter can be calculated once the height of the riser is decided.

(2) Riser Location The location of the riser should be chosen keeping in view the metal to be cast, the design of the casting, and the feasibility of directional solidification. The riser may be located either at the top of the casting or at the side. Top risering is extensively used for light metals as it enables the benefit of metallostatic pressure in the riser. Frequently, the number of users has to be more than one so as to derive its most effective use. In such cases, their spacing should be carefully arranged so as to minimise the shrinkage. The feeding range, which is the distance a riser can feed the metal in a casting, thus becomes an important consideration in riser design. It is found that the casting thickness is the main parameter affecting the feeding range. The riser diameter and the riser height have only a limited effect on it. It is usual practice to maintain a feeding range of about 4.5 times the thickness (T) for plate-type castings and 2–2.5T or $6\sqrt{T}$ for bar-type castings. Where an exothermic riser is used, the feeding distance can be 50 – 75% more. It is advisable to reduce the diameter of the riser at the neck by about 30 – 45%. This improves the feeding range and helps in easy knocking-off of the riser from the casting. The neck area can be further reduced by using wash-burn core or exothermic material around the neck.

(3) Types of Risers Risers may be classified as open risers and blind risers. In the open riser, the upper surface is open to the atmosphere and the riser is usually placed on the top of the casting or at the parting plane. The open riser seldom extends downwards into the drag, i.e., below the parting plane. This riser, therefore, derives feeding pressure from the atmosphere and from the force of gravity on the metal contained in the riser. In case a certain thickness of metal solidifies in the upper part of the riser, atmospheric pressure no longer remains effective, rendering metal flow from the riser to the casting difficult.

The blind riser, on the other hand, is surrounded by moulding sand on all sides and is in the form of a rounded cavity in the mould placed at the side or top of the casting. It may be located either in the cope or in the drag. Since this riser is closed from all sides, atmospheric pressure is completely shut out. The pressure due to the force of gravity is also reduced due to the formation of vacuum within its body. In some of the improved designs, a permeable dry sand core, fitted at the top of the blind riser, extends up through the cope to the atmosphere. Due to its permeable nature, air is able to enter the riser and exert some pressure. There is also less chilling effect, due to the use of dry sand core, and the solidification of the riser is slowed down, thus making it more effective. Sometimes, artificial pressure is created in blind risers by putting some explosive substance in the riser cavity. When the substance comes in contact with the molten metal, it explodes, creating high pressure within the riser.

(4) Riserless Design As the use of risers on castings decreases the yield, efforts should always be made to reduce the size of risers to the barest minimum. There are instances when risers are completely eliminated through proper mould design, right selection of moulding materials and following correct moulding and casting techniques. For example, in SG iron casting, a riserless design can be achieved if the modulus of the casting is greater than 25 mm, pouring temperature is between 1300 and 1360°C, moulds are highly compacted, rigid, and well vented, pouring is fast, thin in-gates of maximum 15-mm thickness are used, and the iron poured is of high metallurgical quality.

5.2.3 Use of Padding

When, despite the use of standard remedies, shrinkage is found to occur and directional solidification is not fully achieved, padding sometimes proves useful. The padding is simply extra metal added to the original uniform section of the casting. This extra metal, if not desired, can later be removed by machining.

5.2.4 Use of Exothermic Materials

Exothermic materials serve to produce directional solidification by the generation of heat. The exothermic material may be added either to the surface of the molten metal in the riser just after pouring or to the sand in the riser walls. Due to its contact with molten metal, chemical reaction takes place, producing substantial heat. The metal in the riser thus gets superheated and remains molten for a longer time. It also forms a refractory insulating top on the riser to conserve this heat.

The exothermic material is a mixture of the oxide of the metal to be cast and aluminium metal in powder form. Each cast metal requires exothermic material which contains its own oxides. A binder-like gelatinous starch is generally used to prepare a self-made mix.

The exothermic material also serves as an insert in the mould at the desired position to help in controlling directional solidification. The material may be moulded in the form of a core by mixing it with water and then baking it. The exothermic core is then inserted at a given location. The core retains its shape after the reaction and provides heat insulation to the metal. Another method of using exothermic material is to mix it with the facings and apply the mixture around those portions of the casting where greater heat is required. IS : 10504–1983 covers the use of exothermic feeding aids for foundry.

5.2.5 Use of Chills

When the casting consists of both thick and thin sections, the thinner sections tend to solidify earlier than the thicker ones. This differential cooling rate produces uneven contraction of parts and gives rise to internal strains in the metal. It may even produce cracks if the cooling of thinner parts is too severe. For rapid solidification of heavy sections and the achievement of directional solidification, which ensures controlled freezing towards the riser, chills are commonly used. Chills, which may be external or internal, also help in making the metal dense, thereby avoiding internal flaws.

External Chills These are placed in the mould wall facing the cavity and become part of the same. External chills may be direct or indirect. The *direct* type forms a section of the mould face that comes into direct contact with the molten metal. If it is embedded behind the mould wall, so as not to have any direct contact with the molten metal, it is called an *indirect chill*. These are made in numerous shapes so that they can merge into the mould contour. External chills are made of metals such as cast iron, steel, and copper. Owing to its extreme heat conductivity and high specific heat, copper makes the most effective chill.

Internal Chills These are placed within the mould cavity and go into the casting when the metal is poured. They may be in the form of a helical spring with a straight shank. The shank is pushed into the sand wall so that the chill, in the form of a spring, projects into the mould cavity. The chills may also be in the form of a nail with a large head. The head, in this type, protrudes into the mould cavity.

The metal for internal chills should obviously be the same as the one being cast.

The chill used must be of the correct size. If a chill is oversized, the excessive chilling will tend to prevent directional solidification. On the other hand, if it is undersized, it will fail to serve its purpose. Internal chills must be thoroughly clean and free of moisture and foreign matter when placed in the mould. They are often coated with tin, copper, or zinc.

The size of the chill is determined according to the thickness of the cast portion where it is used and the chilling capacity. The latter depends on the heat conductivity of the material of the chill. Also, the greater the chill thickness, the more the chilling effect. The effect of chill thickness is, however, limited to a certain value beyond which it does not have any marked influence on the chilling effect. Effective chill thickness is given as 0.7–1.0 times the casting thickness where chill is to be applied. While designing the shape of the chill and fixing its location, care should be taken to reduce the temperature gradient between the solidified and the solidifying metal sections so as to prevent hot tears at the edges of the chill.

CASTING DESIGN 5·3

For a proper and sound design of casting, it is imperative that the designer and metallurgist or foundryman understand and accept each other's difficulties. It is only with such mutual appreciation that a sound casting can be made. The general principles of casting design may be classified into three broad categories: (a) metallurgical considerations: (b) design considerations; and (c) considerations for reliable and economic moulding and casting.

5.3.1 Metallurgical Considerations

It is necessary to understand the fundamental principles of metallurgy which affect the process of casting. The quality of casting produced and the defects occurring in the casting depend largely on various metallurgical phenomena taking place during the process of casting—the solidification process, solidification, contraction, directional solidification and hot spots, the occurrence of hot tears, the process of crystallisation and grain formation have all to be studied in this context. The factors to be given due consideration in this regard are

(i) the thermal properties of the mould;
(ii) the freezing range of the metal;
(iii) the thermal conductivity of the metal;
(iv) the effect of solidification on the temperature of the metal;
(v) the prevention of shrinkage during the state of solidification and the effect of risering;
(vi) the formation of hot tears;
(vii) crystallisation; and
(viii) the control of directional solidification.

It is desirable that the casting section be so proportioned and disposed that the part most distant from the point where the casting is to be fed will solidify first, with subsequent solidification proceeding towards the head or risers where the hottest metal is located. Solidification should thus proceed from the thinnest sections toward the centres of large mass. Such centres, which have high heat capacity, are known as *hot spots*.

The heat capacity of a particular metal is determined by its total volume. Its ability to retain heat is regulated largely by its surface area through which the heat must pass. The combined effect of these two parameters is shown by the ratio of the surface area to the volume of the casting. It can also be shown that solidification time is proportional to this ratio. Thus, the higher the ratio, the more rapid the solidification, whereas the lower the ratio, the slower the rate of freezing. In the case of a plate casting of uniform thickness, it can be shown that the cooling at the end of the plate is about ten times as effective as at an *X*-junction.

Hot spots are usually indicated by the low values of surface area/volume ratio. These hot spots must be suitably risered or fed so that no shrinkage cavities are caused. The casting should preferably be designed so as to eliminate hot spots. The various methods used for preventing hot spots include adequate provision of gates and risers, and proper manipulation of metal temperatures and pouring speeds. During the solidification stage, all portions of the casting contract. If there is any resistance to solidification, hot tears may occur, the metal being quite weak at those temperatures. Often hot tears are formed close to hot spots, where metal is usually weak. Cast steel and non-ferrous alloys are more susceptible to hot tears than is grey iron.

In the case of alloys undergoing allotropic modifications, there are additional dimensional changes, because of both contraction and expansion. Further, in castings that have large variations in sectional thickness, contraction may take place in some members and expansion in others. The design of such member junctions requires very careful consideration.

Metals solidify by the formation of crystal structures called grains. The size of the grains depends on the rate of solidification and the alloy type. Thus heavier sections that cool slowly have coarse grains whereas lighter sections cooling quickly have fine grains. Metal moulds produce fine-grained structures.

Columnar grains develop when grains grow from the mould walls towards the centre. The presence of columnar grains may weaken corners during freezing. This can be avoided by providing generous fillets. Columnar grains may also give rise to centre-line shrinkage. The casting designer can prevent these defects by selecting proper sizes and shapes. Critical section sizes should be avoided. The best practice is to use minimum castable section thicknesses, which will ensure the necessary strength or weight. Often chilling can be of considerable help. Table 5.4 shows a summary of casting defects due to poor design.

Table 5.4 *Summary of casting defects attributable to poor design*

Defect	Cause	Foundry remedy	Design remedy
Shrinkage cavity	Insufficient feed metal	1. Feeder heads 2. Chills 3. Padding	1. Uniform thickness 2. Progressive and uniform variations of thickness 3. Modify junctions 4. Minimise local accumulation of metal
Hot tears	Hindered contraction, stress and strain concentration	1. Reducing hindrance 2. Using less hard mould (non-rigid) 3. Use of reinforcement (brackets, ribs)	1. Avoid design producing stress concentration 2. Avoid local heavy sections 3. Allow uniform and progressive variation in thicknesses 4. Avoid sharp corners, use adequate fillets
Blow holes	Collection of evolved gases in the mould	1. Proper venting 2. Improved sand mixes producing low gas	1. Avoid sharp corners and re-entrant angles
Misruns	Low metal fluidity	1. Fast pouring 2. High pouring temperature 3. Improved gating system	1. Avoid very thin sections which have a large surface area
Contraction cracks	Uneven cooling of high carbon and alloy steels	Heat treatment removes stress	Improved design of sections and junctions

5.3.2 Design Considerations

(i) Section thickness should be uniform as far as possible. Variations, if necessary, should be gradual. The aim should be to reduce hot spots. Specific design rules for different cast metals can be taken from casting design handbooks.

(ii) Concentration of metal may be avoided by making cored openings in webs and ribs.

(iii) Ribs or webs can be staggered, if design permits, to eliminate hot spots.

(iv) Thin ribs should not be joined to thick sections; they will freeze first and pull away from the heavier mass.

(v) Ribs should be used only in compression.

(vi) In the case of an L or V section, radii at junctions should be so provided as to make the section thinner than the principal width at the junction.

(vii) Cored holes in the ribs or webs should be rather oval than rectangular with longer dimension in the direction of the stress.

(viii) Extremely thin sections will present difficulties in pouring and filling. The minimum thickness will depend on the alloy to be cast and the casting method used. Thin sections, moreover, can be run only over a limited distance. The general recommendations for minimum casting thickness (mm) are listed in Table 5.5.

Table 5.5 *Recommendations for minimum casting thickness (mm)*

Metal	Sand castings	Die castings: Large areas	Die castings: Small areas	Permanent mould castings	Plaster mould castings
Al-alloys	3–4.5	2.0	1.2	3	1.0 – 2.5
Cu-alloys	2.5	2.5	1.5	3	1.5
Grey cast iron	3–6	—	—	4.5	—
Lead alloys	—	2.0	1.0	—	—
Mg-alloys	3.5	2.0	1.25	3.5 – 4.5	—
Malleable iron	3	—	—	—	—
Steel	4.5	—	—	—	—
Tin alloys	—	1.5	0.75	—	—
White cast iron	3	—	—	—	—
Zn-alloys	—	1.2	0.40	—	—

(ix) Proper dimensional tolerances should be provided on castings so that the correct method of production can be selected, machining allowances be kept to minimum values, correct matching between components while assembling be ensured, and right size of chucking tools, jigs, and fixtures be used. Figure 5.10 shows schematically the common design considerations.

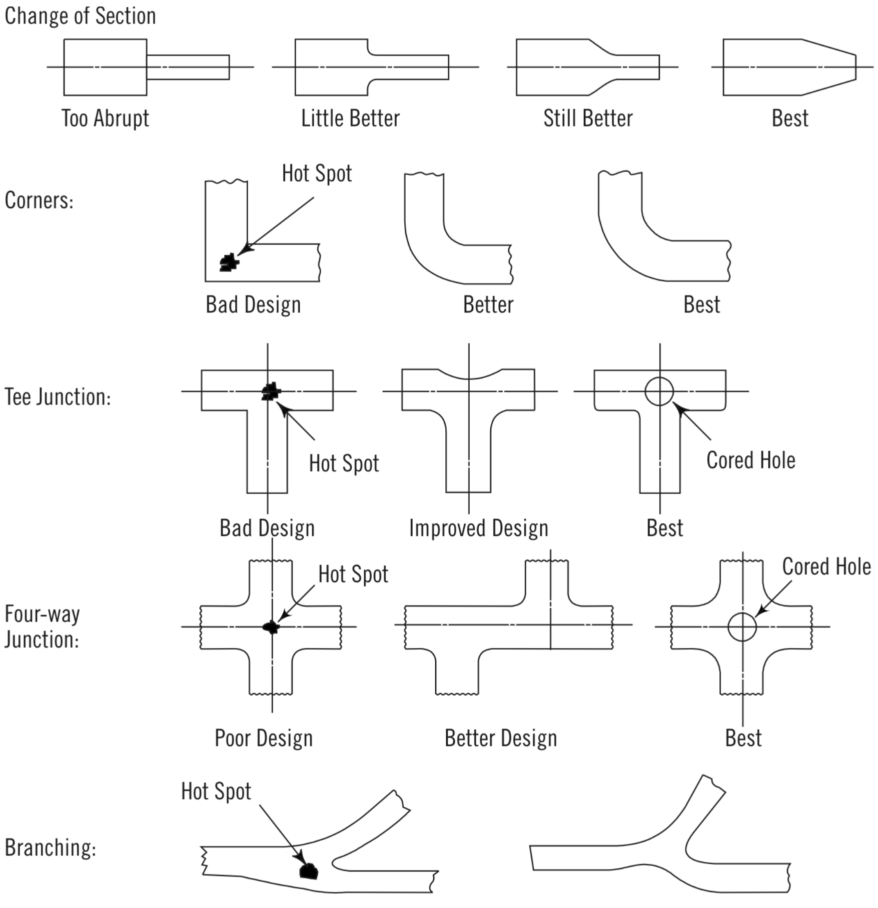


Fig. 5.10 *Common design considerations*

Tolerances on a casting dimension depend on several factors:

(a) design of casting;
(b) material and condition of patterns and core boxes;
(c) clearance on bushes and pins on moulding boxes and pattern plates;
(d) moulding materials and moulding characteristics;
(e) rapping or stripping of pattern;
(f) deformation in mould cavity due to mould enlargement;
(g) fettling process; and
(h) heat treatment.

The variations likely to occur due to these reasons should therefore be accounted for in the specified tolerance. Tolerances that can normally be achieved by investment casting, shell moulding, and by sand moulding in the case of grey iron and steel castings in as-cast form, are given in Table 5.6. These values are not based on any standard specifications but are indicative of what can be achieved economically. Before accepting the customer's order, it is advisable to study the requirements and negotiate with customer such tolerance values, which are realistic and which can be conveniently achieved.

Table 5.6 *Tolerance values achieved by different methods of moulding for grey iron and steel castings*

Basic size (mm)	Tolerance values for			
	Investment casting	Shell moulding or HP moulding	Machine moulding	Hand moulding
≤ 10	0.2	0.8	1.5	2.5
(10)–30	0.25	1	2	3
(30)–50	0.3	1.2	2.5	3.5
(50)–80	0.35	1.4	3	4.5
(80)–120	0.4	1.6	3.6	5.5
(120)–180	0.5	1.9	4.2	6.5
(180)–250	0.6	2.2	5	7.5
(250)–400	0.7	2.5	5.8	9
(400)–600	0.8	2.9	6.8	10.5
(600)–900	1	3.4	8	12
(900)–1500	—	4	9.5	14
(1500)–2500	—	—	11.5	17

Note: (i) Tolerance value should be positioned symmetrically in equal amounts on either side of the basic size.

(ii) Tolerance should be suitable increased for mould joints, cored holes, and wall thicknesses.

5.3.3 Economic Considerations

The casting should be so designed that it can be most economically produced. For a given casting job, there is usually one casting process that will produce the best results and be least expensive. The designer must select this 'optimum process' from among the host of methods available.

The optimum process may be defined as the one that will give the lowest total cost of the part produced (not the lowest cost of casting alone). The total cost of a part includes

(1) tooling costs;
(2) rough casting costs; and
(3) machining and finishing costs.

(1) Tooling Costs This cost is prorated over the number of pieces to be cast.

Proper types of tooling (patterns, core boxes, dies, and other equipment) must be designed and used according to the requirements of quality, quantity, and delivery period; multiple cavity tooling can be applied wherever possible to reduce the costs.

The casting design must be such that the tooling required is simple and can be made at a nominal cost and the coring is kept at a minimum.

(2) Rough Casting Costs

(a) Metal Costs This is the most important of the cost factors. It can be reduced by using

(i) the lowest sectional thickness;
(ii) close tolerance;
(iii) efficient design with maximum weight saving (experimental stress analysis techniques are used to locate areas where metal does not serve any useful purpose); and by
(iv) restricting metal losses and wastage during melting and casting.

(b) Direct Foundry Costs These can be reduced by simplifying the procedures of moulding, core making, cleaning, etc., as far as possible. Any changes in the casting design that would make moulding, core making, and fettling easier and less costly without affecting the design and functional requirements of the casting should be considered.

(3) Machining and Finishing Costs Very often, machining costs may account for a sizeable part of the total cost of casting. Machining and finishing time spent on a casting can be saved in many cases if appropriate tolerances are specified and unduly high machining allowances are not provided on the pattern. Clear rapport between the designer and foundryman can help in reducing unnecessary machining work.

Design considerations in Investment casting

Investment castings are poured in hot moulds having thin and highly permeable shells. There is less loss of temperature during pouring and mould filling. The process therefore allows casting of thin-walled castings in almost any alloy. as also castings with sharp edges and un-radiusized junctions without much difficulty. The wall thicknesses that can be conveniently cast in ceramic shell investment casting process are given in Table 5.7 below:

Table 5.7 *Wall thicknesses produced by ceramic shell investment casting for some cast alloys*

Alloy	Min. wall thickness (mm)
Aluminium alloys	1.25
Bronze	1.05
Stainless steel 400 series	1.62
Stainless steel 300 series	1.25
Carbon steels	1.50
Cobalt alloys	1.25

However, alloys with low fluidity require moulds with higher permeability. A suitable stuccoing sequence designed for open mould structure as also higher mould preheat temperature would be useful in overcoming defects associated with low melt fluidity. Use of flow enhancement techniques, such as pouring under vacuum may help in overcoming the problem.

Investment castings are cast as a cluster built around a single sprue, each casting partially shadowing the other. Since the preheated thin shells lose heat mainly by radiative heat transfer mode, shadowing of the mould surface restricts the radiative heat transfer to the surroundings. After pouring of the molten metal into the mould, the melt superheat as well as the latent heat released during the initial skin formation quickly raises the shell temperature close to the solidification temperature of the metal and saturates the heat absorption capacity of the shell material. The initial and the boundary conditions are therefore very different from those in sand casting operation. The process of investment casting is specified over other manufacturing methods, due to its unlimited flexibility of design. This flexibility allows deriving full advantage of the functional choices without making any concessions necessary to fabricate the items by other means. The following situations particularly call for the use of investment casting:The process of investment casting is specified over other manufacturing methods, due to its unlimited flexibility of design. This flexibility allows deriving full advantage of the functional choices without making any concessions necessary to fabricate the items by other means. The following situations particularly call for the use of investment casting:

(i) When the design is so complicated that a one-piece casting could replace a part comprised of several components fabricated by other methods or assembled together

(ii) When the mechanical properties required are attainable from alloys that are difficult to machine

(iii) When expensive machining is to be avoided

(iv) When tolerance of 60.1 mm is satisfactory on most of the dimensions

(v) When fine surface finishes are desired on the cast surfaces

The selection of investment casting process would not be suitable or economical if the part can be manufactured by die casting, stamping, forging with secondary operations or by machining on automats. During design of an investment casting, attention is to be paid to the ease of production and to keep the production costs low. Investment casting offers design freedom not met by any other manufacturing process. Few of the basic design rules, which can be used as thumb rules, are the following:

(i) Keep section thickness in the casting as uniform as possible.

(ii) Make use of adequate fillets and chamfers to avoid sharp corners and sharp edges.

(iii) Do not cause a number of sections to meet at one point. Try to stagger them, if the design permits.

(iv) Most investment castings can be economically cast with 0.05 mm/cm. Closer tolerances than this can be achieved, if required. Dimensional accuracy obtainable depends on the casting geometry. Close cooperation between designer and the foundryman is desired to produce high quality castings at an economical level.

(v) Close surface finish can be obtained by investment casting process, on the average, 5 to 15 times smoother than sand castings. Surface roughness close to 0.8 to 3.2 can be achieved.

(vi) The casting dimensions significantly affect flatness of surfaces. Proper use of ribs and reinforcements can minimize bowing and distortion defects. It can be controlled within 0.05 mm/cm. Similarly, straightness can be controlled within a tolerance of 0.1 mm/cm of cast length.

General tolerances on radii may be around 60.075 mm/cm.

(vii) In case of cast holes, the maximum length should not exceed 5 times the diameter in through holes, whereas, the maximum length should not exceed 2.5 times the diameter in blind holes.

Screw threads can be produced in as-cast form on castings that are difficult to machine.

5.3.4 Computer-aided Design and Drafting in Foundries

Engineering design is a highly complicated procedure, which calls for a considerable level of ingenuity, supplemented by a large amount of information or knowledge. The advent of computers has given rise to several possibilities. They offer designers the scope to do all routine and unimaginative work efficiently and that too in a very short time.

The essence of the computer-aided design (CAD) philosophy is effectively expressed in the definition. "It is a technique in which man and machine are blended into a problem-solving team, intimately coupling the best characteristics of each, so that the team works better than either, alone." Thus the most important part of a CAD system is the designer–computer interface. The degree of interaction the designer can have with the computer, trying to exploit fully its capabilities, is the essential feature of CAD. An important requirement of this interactive system is the graphics capability. Drafting is an indispensable part of any design process. The interactive graphics terminal is used by the designer to design the component, machine or tooling, such as a pattern or die taking into consideration the stress, strain, elongation, deflection, temperature distribution, fluid flow, or any other relevant characteristic. The designer then drafts the design and produces drawings in the form of one or more views, in orthographic or isometric projection, stores them in an disk for future use and also to take a hard copy, if and when required.

Systems concept and simulation are fundamental to all design processes. Simulation is defined as 'the duplication of the system or activity without actually attaining the reality itself.' Thus the systems approach is to develop a manipulative model which will appear to have the same behavioural characteristics as the real system. This is the essence of computer-aided design which mainly involves developing a mathematical description of parts or shapes in 3D space, within a computer data base. This mathematical description is used to simulate the mechanical system and to check the various material properties and design criteria of the component. Techniques like mesh generation are used in geometrical modelling.

CAD has now gained significance and generated considerable interest in the field of metal casting. The areas amenable to the use of CAD in this field can be identified as

(a) Casting design for optimum strength and other requirements of design, and for lowest weight
(b) Selection of alloy composition for lowest cost
(c) Design of dies or moulds
(d) Methoding of castings, involving design of gating and risering systems, chilling practices, etc.
(e) Study of physical processes, which can be simulated to evaluate the soundness of a casting, such as heat transfer, fluid flow, thermal stresses and strains, solidification and cooling characteristics and microstructural development

The soundness of the casting can be evaluated by computer simulation. The simulation can even allow a visual display of the liquid metal entering and flowing through a die, solidifying and finally cooling to room temperature. This can be helpful in predicting the occurrence of shrinkage, blowholes, hot spots, hot tears, surface cracks, internal cracks and microstructural segregation.

Based on these predictions, suitable modifications can be made at the design stage to produce a design that will lead to production of a sound casting very first time.

Design Software Various software packages are now available which consist of general purpose finite element programs for computer-aided design. These packages usually incorporate 3D finite element analysis and finite element modelling with interactive colour graphics and post-processing capabilities. For use on personal computers, these packages are generally subsets of more powerful mainframe or graphics workstation-based finite element analysis packages. The functions or capabilities of the design packages consist broadly of the following:

1. Solving structural problems, including 2D and 3D automatic mesh generation, load and boundary conditions, such as those applicable to pattern and dies.
2. Supporting isotropic and orthotropic material properties which may be temperature dependent and enabling temperature distribution in a casting or a pattern from the output of the heat transfer analysis; further offering linear and non-linear steady state and transient heat transfer finite element analysis using the wavefront method.
3. Allowing a large variety of loading conditions such as point force, distributed force, pressure load, gravitational load, thermal load, specified displacement or angular acceleration. Making available a 3D and axi-symmetric program capable of analysing a wide range of incompressible, viscous, laminar and turbulent fluid flow problems.
4. Containing libraries of elements commonly used to facilitate part design.
5. Offering a number of output options such as displacements, deflections, strain energy, nodal stresses, principal stresses, shear stress, temperature gradients, contraction, expansion, etc.
6. Generating finite element models from geometry data base or drawing, modelling any 3D geometry, using lines, arcs, curves, surfaces and solids.
7. Pri-processing allowing geometrical transformations of shape, including translation, rotation, scaling and mirror imaging, automatic mesh generation and mesh refinement by dragging a curve along an arbitrary 3D path.
8. Offering complete load definition so that the load and boundary condition data may be defined interactively and then viewed graphically.
9. Post-processing providing extensive capabilities for graphical interpretation of finite element results, allowing the user to plot stresses, displacements, temperature distribution, fatigue life and other outputs.
10. Providing command as well as menu-driven facilities with online help for the user.

It can be seen from the above features of design software packages that these can be utilised to a large extent in metal casting, particularly for solidification studies, methoding of castings, design of patterns, dies and tools and in the design of castings, specially those required for critical applications.

Computer-aided Drafting Personal computers are now increasingly being used for generation, storage, retrieval and reproduction of drawings. Several software packages, which are compatible with DOS and Windows operating systems are available, thus facilitating the work of drafting on the computer. The drafting packages can be used for preparation of all types of drawings, civil, architectural, electrical or mechanical, and can generate the views in orthographic or isometric projection. Graphics workstations are now also becoming popular for carrying out computer-aided design and drafting work with greater speed and efficiency in foundries and other manufacturing areas.

The important features of these packages which make them so versatile are as follows:

1. The drawings can be produced to high accuracy exactly according to the instructions and data supplied. The drawings so produced are clean and free from any erasure marks or corrections. Once produced, they can be enlarged or reduced without the need for redoing them. Further, drawings of any size and complexity can be produced and printed on paper and different entities made in separate layers can be obtained in different colours.
2. Text of the drawings can be obtained with great flexibility in size, angle and style. Operations like dimensioning and hatching can be carried out easily by giving appropriate commands.
3. The drawings can be safely stored with a minimum requirement of storage space. A single floppy can store a large number of drawings.
4. Simple shapes, used repeatedly in drawings, can be produced and stored. These can then be called and inserted in the main drawing just by giving a command. Simple shapes may include bolts, nuts, washers, studs, split pins, keys, cotters, certain commonly required texts, etc. Drawings prepared earlier can be integrated with new drawings thus, saving time spent on redrawing. By the use of pointing devices, the speed of drawing can be greatly enhanced. Various entities of a drawing, drawn on separate layers can be superimposed on one another or concealed as desired.
5. Drafting softwares such as AUTOCAD, VERSACAD, DRAFTPACK, etc., are powerful drawing aids which follow instructions given by the user through the keyboard or pointing devices and quickly produce exact drawing. The features available also allow correction of errors and the making of revisions without redoing the entire drawing.
6. The facilities available on the software package allow erasure or moving of any of the entities, copying them as desired to produce repeated patterns, rotating the drawing about a given axis, so as to view it from different angles, enlarging or reducing the entire drawing or a part of the drawing as selected by a process of zooming in or out, panning a drawing, so as to be able to view various parts of a large drawing which are otherwise off the screen, without changing the magnification.
7. Menus, sub-menu and help menu are provided on all drafting software so that the desired commands can be easily selected and there is no need to write the command through the keyboard.

Review Questions

1. What are the main requisites of a gating system? Name the parts of a gating system and show them in a figure.
2. What different types of gating systems are used and where? What factors affect their selection?
3. What is gating ratio? What considerations affect its selection? What are the typical gating ratios for the following applications?
   (i) Grey iron bed castings for lathes
   (ii) Valve body castings made in cast steel
   (iii) Aluminium pistons for automobiles
   (iv) Large gun metal bushes for bearings.
4. Explain the procedure for calculation of dimensions of a gating system. Illustrate with an example.
5. What functions are served by a riser? Explain the theoretical considerations behind the design of risers. How are its shape and size determined?
6. Explain the terms:
   (a) Directional solidification
   (b) Use of internal and external chills
   (c) Blind risers
   (d) Use of exothermic and insulating meterials for risering
7. Outline the general principles of casting design
8. What factors are to be considered as part of metallurgical considerations?
9. Discuss the casting defects caused due to poor design of castings. What remedies are suggested for these defects?
10. What design considerations are to be kept in mind during casting design? On what factors does tolerances on casting dimensions depend?
11. What is meant by systems approach to casting design? How can it be useful?
12. Discuss the use of few design softwares useful in computer-aided design of castings.
13. What considerations govern the selection of sprue size in the moulds? Explain the phenomenon of turbulence during the flow of metal in the gating system.
14. Explain the use of different types of runners and show their relative merits and demerits.
15. Calculate the pouring rate of molten metal required for producing steel castings weighing about 4 tonnes in the rough state, assuming the critical casting thickness to be 20 mm.

16. Discuss the reasons for formation of hot tears in steel castings. Explain how this defect can be prevented keeping in view the principles of casting design.
17. During the design stage of investment castings, explain the considerations to be kept in mind in order to produce defect-free castings.

Chapter 6

Technology of Melting and Casting

In foundry practice, melting and casting ranks second in importance only to mould-making. Melting practice is an extensive subject in itself. The melter should not only understand the operation of the equipment he is required to use, but he must also have a thorough knowledge of the nature and metallurgy of various cast metals and alloys, their behaviour during solidification and cooling, and their physical and mechanical properties. Further, he must be acquainted with the specification and requirement of different raw materials used during melting so that sound castings of consistently good quality can be produced.

6.1 MELTING EQUIPMENT FOR FOUNDRIES

Generally, the metals obtained from the blast furnace, steel-making furnaces, or from other smelting furnaces in cases of non-ferrous metals are not cast directly into the desired shapes of components or articles mainly for two reasons: first, the metal so obtained is not always in a sufficiently refined state to be directly cast; secondly, it is difficult from a practical viewpoint to pour a huge quantity of molten metal in moulds of different sizes and shapes. The iron obtained from the smelting furnaces is first cast into some regular forms, such as ‘pigs’ and ingots, and these forms are re-melted in foundries for casting the required objects. For re-melting purposes, there is a wide range of equipment; crucible furnace; open-hearth furnace; air or reverberatory furnace; cupola furnace; and electric furnace.

6.1.1 Crucible Furnace

A crucible furnace is very convenient for small foundries where the operation is intermittent and a variety of alloys are handled in small quantities. The metal to be melted is put in a heated crucible, which acts as a melting pot. The crucible is made of clay and graphite by moulding these materials into a standard shape, and it is produced in sizes from number 1 to 400. The crucible number represents its approximate melting capacity in kilograms of copper. The capacity of a crucible for other metals may be determined by multiplying with the ratio of densities. The fuel used for heating the metal may be coke, oil, or gas.

Coke-fired Furnace The coke-fired furnace is commonly used for melting non-ferrous metals, such as brass, bronze, and aluminium, owing to its low cost of installation, low fuel cost, and ease in operation. Generally, this furnace is installed in a pit and so is referred to as the *pit type* (Fig. 6.1). The furnace has a cylindrical steel shell, lined on the inner side with refractory bricks, closed at the bottom with a grate, and covered at the top with a removable lid. The metal to be melted is contained in the crucible, which is embedded in burning coke.

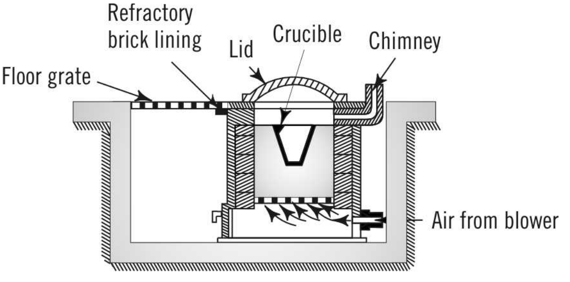


Fig. 6.1 *Pit type coke-fired crucible furnace*

Preparation of the furnace involves kindling a deep bed of coke and allowing it to burn until a state of maximum combustion is attained. Some coke from the top is removed and the crucible is lowered into the furnace. The coke is again added on all sides of the crucible. The metal is then charged in the crucible and the lid is replaced to facilitate the chimney draft. If forced draft is available from a blower, it is used to help in rapid combustion of the coke. When the metal reaches the desired temperature, the crucible is drawn out with special long-handled tongs and carried away for pouring.

Oil- and Gas-fired Furnace

Some furnaces (Fig. 6.2) make use of oil or gas as fuel for heating the crucible. The furnace is cylindrical in shape and the flame produced by the combustion of oil or gas with air is allowed to sweep around the crucible and uniformly heat it.

Gas or atomised fuel oil is fed through a manifold. It enters the furnace tangentially where it ignites and swirls upwards between the crucible and the refractory lining. The metal is charged through the opening in the centre of the head. Modem oil- and gas-fired furnaces are equipped for automatic proportioning—they produce a neutral flame by regulating the fuel and air ratio. The temperature is also controlled thermostatically.

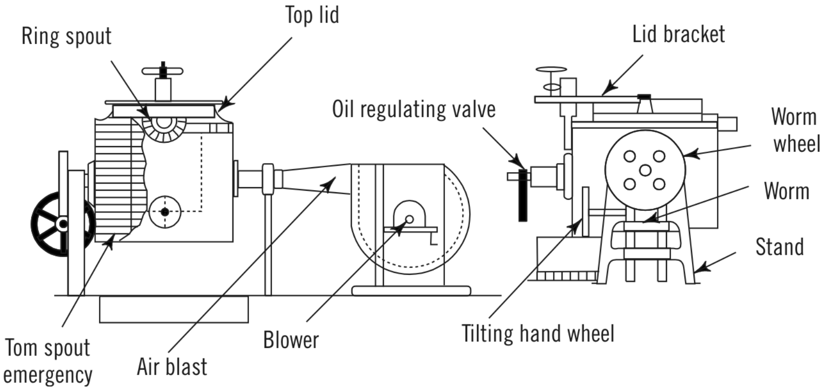


Fig. 6.2 *Oil-fired tilting type crucible furnace*

The oil- and gas-fired furnaces are generally the tilting or the bale-out type. The tilting type of furnace is raised above floor level, mounted on two pedestals, and rotated by means of a geared handwheel. The tilting gear is customarily so designed that the furnace tilts on a central axis. The bale-out or lift-out furnace is fixed, but, unlike the pit type, is installed on the floor. For extracting the molten metal, the crucible has to be lifted out of the furnace with the help of tongs.

Advantages of Oil- and Gas-fired Furnace

(i) There is no wastage of fuel; no sooner is the metal ready than the supply of oil or gas can be stopped. The fuel supply can also be regulated while working to suit the requirements.

(ii) The output in a given time is greater due to higher efficiency.

(iii) Better temperature control can be maintained.

(iv) Less contamination of metal takes place.

(v) Saving in floor space is achieved.

(vi) As stoking is not required, labour cost is reduced.

6.1.2 Open-hearth Furnace

Open-hearth furnaces, in small sizes in the neighbourhood of 25 tonnes, have been used in the casting industry for melting steel or producing steel from pig iron direct for casting. Lately, however, these have been superseded by electric arc furnaces. The furnace may have basic or acid lining, depending on the type of pig iron used. The charge consists of pig iron in varying amounts along with steel scrap and limestone.

The open-hearth process is based on the regenerative principle of heating and involves obtaining very high temperatures, as required for steel, by pre-heating the gaseous fuel and air by the outgoing products of combustion. The hearth of the furnace (Fig. 6.3) is shallow—about 13 m long, 5 m wide and 0.5 m deep—and made of suitable refractory material. It has gas and air ports at each end, and two pairs of regenerators, one for gas and the other for air, with the necessary flues and the chimney.

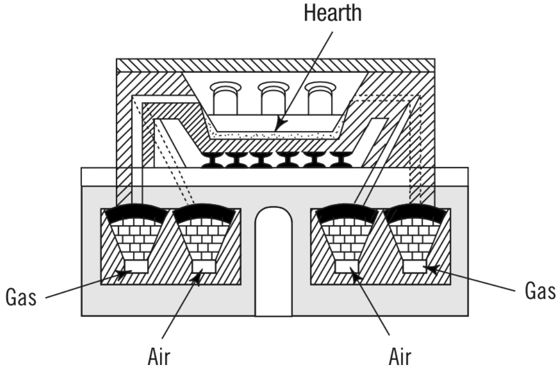


Fig. 6.3 *Open-hearth furnace*

Heating Action The gas and air flow through one of the pairs of regenerators and absorb heat from them. They are then led through the uptake flues into the hearth where they get ignited. The products of combustion so formed sweep over the bath, containing the metal charge and provide effective heating. The combustion products then leave the furnace through the ports on the other side, pass through the other pair of regenerators, transferring most of their heat to the checker bricks, and finally escape to the atmosphere through the chimney.

When sufficient heat has been stored in the checkers, the furnace is reversed, i.e., the gas and air now enter the pair of regenerators on the other side and get pre-heated and the products of combustion after heating the metal charge, leave the hearth from regenerators through which gas and air were passing previously. This reversal of the furnace generally occurs every 20–30 minutes.

The gaseous fuel used may be producer gas, natural gas, coke oven gas, or a mixture of coke oven gas and blast furnace gas.

Advantages of Open-hearth Process

(i) As the ore acts as an oxidising agent, and external application of heat is used, the temperature and the composition of the bath are under proper control.

(ii) A variety of raw materials can be employed to produce many types of products and, as such, the method has considerable flexibility.

(iii) Its output of finished steel is higher than that of other methods due to the addition of ore and scrap to the pig iron.

(iv) Basic open hearth process permits the use of any pig iron and can eliminate phosphorus completely. In the acid open-hearth process, however, low phosphorus and low sulphur pig iron are required in the charge.

6.1.3 Air Furnace

An air furnace (Fig. 6.4) is sometimes used in the production of cast iron, particularly malleable iron, as also for non-ferrous metals, such as brass and bronze. The furnace works on the principle of a reverberatory furnace and has a long, low roof, which deflects the flame towards the metal lying in the shallow hearth. The hearth is formed of refractory bricks on which moulding sand is fused to form a hard surface. The bottom of the hearth slopes from both ends towards the centre where there is a tapping hole on each side of the long furnace. The size of the hearth for a 20-tonne capacity furnace may be about 8 m long and 2 m wide. The roof is made of arched sections called *bungs*. The charging and repairing involves removing these bungs from the roof. For stirring, skimming, etc., suitable openings are provided in the side walls.

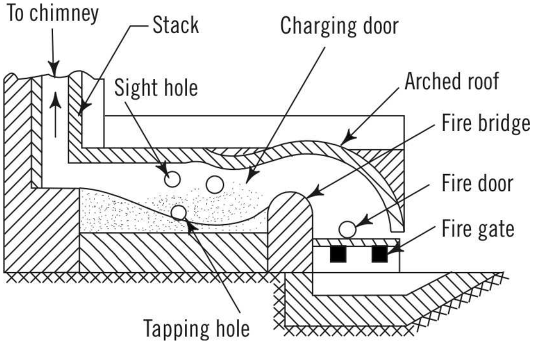


Fig. 6.4 *Air furnace*

The fuel generally used is pulverised coal. Since the air furnace has a low ratio—about 2½ kg of metal per kg of coal, the metal is often melted in a cupola and transferred to the furnace for refining and adjusting the composition.

6.1.4 Rotary Furnace

Reverberatory furnaces with rotating furnace shells are called rotary furnaces. These are extensively employed by small- and medium-sized foundries for the production of grey and malleable iron castings. The capital investment required is low and, as a batch-type furnace, it facilitates easy adjustment and control of metal composition with a constant cycle of operation. Consistent pouring schedules can be achieved, resulting in optimum utilisation of available resources. Equipped with a low-pressure oil-air or gas-air burner and pre-heated air supply, rotary furnace operation can enable efficient combustion and emission-free exhaust gases. They can be operated round the clock for a week at a time. Large outputs at a high rate of productivity can be obtained. There are few operational problems with this furnace. Lining maintenance is required only once in about 50 melts. In order to meet the stringent pollution-control regulations, rotary furnaces are known to have even replaced cupolas in many countries.

The furnace consists of a monolithic refractory-lined steel shell, straight in the middle and tapering inwards at both ends. The shell is provided with a segmental gear and pinion arrangement for its rotation at a speed of 1 to 2 rpm. The furnace is either oil or-gas-fired and the burner is located at one end of the shell. The metallic charge is placed in the shell through a charging door in the middle of the shell, and the door is closed. As the shell slowly rotates, the charge tumbles about and comes in contact with the intense flame emitted by the burner. Heat transfer initially takes place by radiation and then by conduction and convection under the slag cover. Exhaust gases escape from the other end of the shell. In order to utilise the waste heat of the exhaust gases, a recuperator system is invariably provided to preheat the air for combustion. With the convector-type heat exchanger used, the heat transfer is about 50%, taken as a temperature value, i.e., combustion air temperature is 420°C for a waste gas temperature of about 900°C. The slag is removed through the exhaust end before tapping. Figure 6.5 shows a schematic of a hydraulic end tilt rotary furnace.

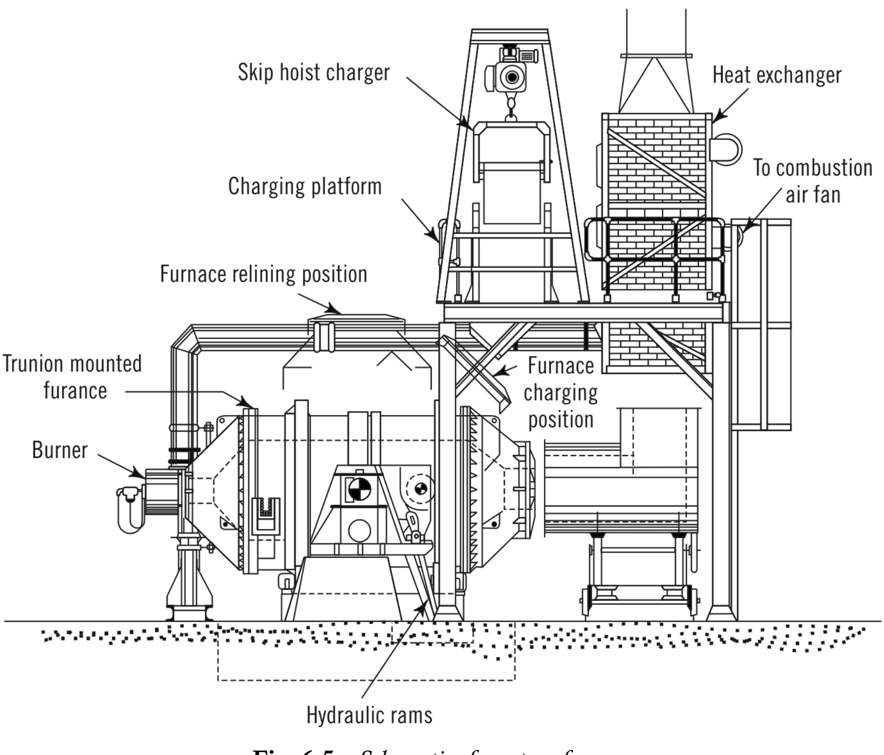


Fig. 6.5 *Schematic of a rotary furnace*

The charge consists of a suitable proportion of pig iron, iron scrap, steel scrap, ferro-alloys and limestone as flux, all adjusted to achieve the desired composition of the metal. Limestone should be limited to 2% of the charge weight so that excessive lining erosion does not occur. The loss of elements during melting in the rotary furnace varies according to the nature of the flame. The carbon and silicon loss is negligible. Manganese loss is about 15% and phosphorus about 12%, which can be made up by adding FeMn and FeP after slag removal. Sulphur loss depends on the type of oil used. Use of furnace oil with high sulphur content could result in a gain in sulphur content of the metal.

The furnace is specified by its capacity, indicating the quantity of metal that can undergo melting during each heat. The capacity of the rotary furnace is influenced by combustion volume, available surface area of the heated refractory, heat input from the flame and furnace rotation speed. Rotary furnaces of capacities varying from 500 kg to 5 tonnes are in common use by small and medium-scale foundries.

Fuel consumption in rotary furnaces varies with the type and grade of oil. Using furnace oil, fuel consumption is about 160 litres per tonne of metal melted, if the oil is preheated to 90°C. Using light diesel oil, consumption gets increased to 200 litres per tonne of metal melted. The average melting time for each heat of grey CI is about 2 hours for a 2 tonne rotary furnace.

6.1.5 Cupola Furnace

A cupola furnace is most commonly employed for melting and refining pig iron along with scrap in the production of iron castings. This furnace has many distinct advantages over other types, e.g., simplicity of operation, continuity of production, economy of working and increased output coupled with a relatively high degree of efficiency.

The cupola furnace (Fig. 6.6) is made up of a vertical steel shell, 6–12 mm thick, lined with refractory material down the whole length. The lining is generally thicker in the lower region, i.e., beneath the charging door, where the temperatures encountered are higher than in the upper region. A constant volume of air for combustion is obtained from a motorised blower of the positive displacement type. The air is carried from the blower through a pipe called the windpipe, first to a circular jacket around the shell and then into the furnace through a number of openings called *tuyeres*. These tuyeres are generally 4, 6, or 8 in number, depending on the size of the cupola. The combined area of air inlets or tuyeres should be about one-fourth of the cupola plan area. The height of the tuyeres from the bed of the cupola is about 450–500 mm. Opposite each tuyeres, a small window with mica covers makes the inspection of fire conditions possible. At the bottom of the bed, a spout, called the *tapping spout*, is provided for the molten metal. Opposite this tap hole, and somewhat above it, is another hole, called the *slag hole*, which enables the slag to be taken out.

The base of the cupola is made by thoroughly ramming moulding sand. It is prepared on drop-bottom plates, which are hinged on two sides and supported by a vertical rod called the prop. When the melting work is over, the furnace is

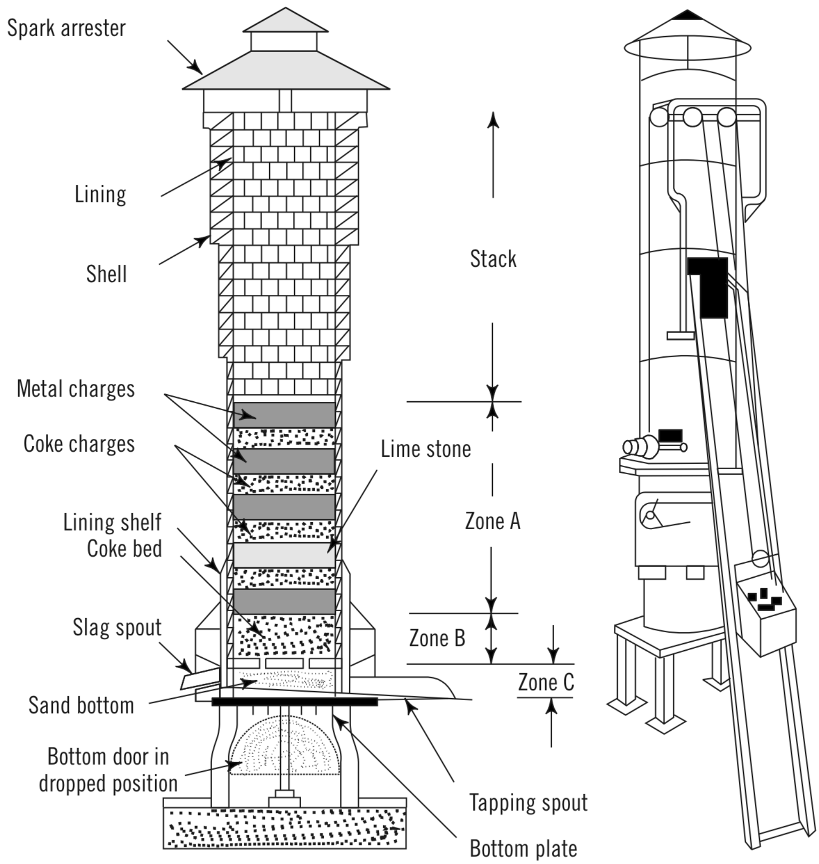


Fig. 6.6 *Cupola furnace*

emptied of the remaining contents by removing the prop; this causes the bottom plates to open out.

The entire furnace is supported by four cast-iron pillars on the floor. Since the charging door is at a higher level from the floor, a charging platform is provided at a suitable height. At the top of the furnace, a conical cap, called the *spark arrester*, prevents hot sparks from emerging into the vicinity. The spark arrester cools down the sparks and allows only smoke to escape from the opening. Figure 6.6 also shows the outside view of a cupola, complete with the mechanical charging device. IS : 5032–1983 gives the recommended sizes and performance characteristics of a cold blast cupola.

Cupola Operation

Preparation of Cupola The slag and refuse on the lining from the previous run is removed and, if necessary, the lining itself is repaired or remade. The bottom plates are swung to closing position and the prop inserted beneath them. The sand bottom is then prepared with moulding sand such that it slopes towards the tap hole.

Firing the Cupola The cupola is fired by kindling wood at the bottom. This should be done 2.5 to 3 hours before the molten metal is required. On top of the kindled wood, a bed of coke is built. The height of this coke bed may vary from 50 cm to 125 cm according to the size of the cupola.

Charging the Cupola When the coke bed has thoroughly ignited, alternate layers of pig iron, coke, and flux (limestone) are charged from the charging door. Suitable scrap is also added with the pig iron to control the chemical composition of the iron produced. The thickness of the layers is kept about 150–200 mm. The purpose of adding flux is to eliminate the impurities and thereby refine the metal, to protect the metal from oxidation, and to render the slag more fluid for easy disposal. Besides limestone, fluorspar and soda ash are also sometimes used as fluxing materials. The quantity of limestone required may be 30–40 kg per tonne of iron melted or 25% by weight of the coke charged. As per IS: 4140–1978, limestone shall be of three grades. The CaO content required is 52, 50 and 45 per cent in grades 1, 2 and 3 respectively.

Soaking of Iron After the furnace has been fully charged, it is so maintained for about 45 minutes. The charge gets slowly heated since the air blast is kept shut during this time. This causes the iron to get soaked.

Opening of Air Blast At the end of the soaking period, the air blast is opened. The tapping hole is kept closed by a plug, called the bot, till the time the metal gets molten and sufficient metal has accumulated. As the melting proceeds, the contents of the charge move gradually downwards. The charge should therefore be replenished and the furnace be kept filled up to the charging door during the entire operation.

Pouring the Molten Iron When sufficient metal has collected in the hearth above the sand bed, first the slag hole is opened to allow the slag to get ejected and then the bot from the tapping hole is removed. The molten metal that flows out of the spout is carried in ladles to the moulds for pouring. The same procedure is repeated until all the metal is melted and the operation is over. Sometimes, a fore-hearth is used to collect molten metal from the cupola in a large quantity before it is transferred to the ladles.

Closing the Cupola When the operation is over, the blast is shut off and the prop knocked down so that the bottom plates swing open. This enables the dregs inside the furnace to drop to the floor. They are then, quenched and removed from underneath the cupola.

Air Requirements for Cupola

For complete combustion of the fuel in the furnace, about 8.4 cu m of air is required per kg of coke at normal atmospheric pressure and temperature. The relationship between the amount of metal melted and the coke burnt is termed the metal : fuel ratio. This ratio varies from 6 : 1 to 12 : 1. If this ratio is 8 : 1, which is considered a satisfactory figure, the coke required per tonne of iron will be 100/8 kg, i.e., 125 kg. Thus, the volume of air required per tonne of melted iron is

$$8.4 \times 125 = 1050 \text{ cu m}$$

To allow for leakage, etc., the air supplied is generally a little in excess, i.e., about 1100 cu m per tonne of iron.

Depending on the size of the cupola, the type of iron melted, and the compactness of the charge, the pressure of air may vary from 250 mm to 400 mm of water for small and medium-sized furnaces and from 400 mm to 750 mm for large-sized furnaces.

The inside diameter of the cupola determines the amount of coke that can be burnt and the amount of iron that can be melted per unit of time. It has been observed that 14 sq cm of cupola plan area burns about 1 kg of coke per hour. Thus, a cupola having a capacity of 5 tonnes per hour will require (5 × 125) = 625 kg of coke per hour, assuming a metal–fuel ratio of 8 : 1. The plan area required will therefore be equal to (14 × 625) = 8750 sq cm. The internal diameter will then be

$$\sqrt{\frac{8750 \times 4}{\pi}} = 106 \text{ cm}$$

Problem A fan supplies 90 cu m of air per minute to a cupola. If the air required to melt one tonne of metal is 860 cu m per hour, calculate the capacity of the cupola.

Solution The amount of air reaching the cupola per hour (allowing 5% as leakage in the pipe line) is

$$\frac{90 \times 60 \times 95}{100} = 5130 \text{ cm}$$

If the capacity of the cupola is M tonnes per hour, the amount of air required will be 860 × M. Therefore,

$$860 \times M = 5130$$

or

$$M = \frac{5130}{860}$$

$$= 6 \text{ tonnes per hour}$$

Table 6.1 gives recommendations for dimensions and operating parameters of cold blast cupolas.

Calculation of Cupola Charges

In order to control the specifications of the cast iron produced by the cupola furnace, it is necessary to estimate the proportion of the contents of the charge, particularly that of pig iron and scrap. Usually, several grades of pig iron and scrap are available to the foundryman.

Grading of Pig Iron Pig iron is graded according to the chemical composition. Various types of general-purpose pig iron recommended for foundry use, have been classified (IS: 224–1973) according to the manganese and phosphorus content as shown in Table 6.2.

Table 6.2 *Types of pig iron recommended for foundry use*

Grade	Manganese %	Phosphorus %
A	1.5–2.0	up to 0.40
B	1.0–1.5	up to 0.40
C	0.5–1.0	up to 0.40
D	0.5–1.0	0.40–1.0
E	0.5–1.0	1.0–1.3

The sulphur content allowed in all the five grades listed in Table 6.2 is up to 0.05%. Further, each of these five grades is subdivided into four subgrades 1, 2, 3, and 4 according to the variations in silicon content (Table 6.3). A decreasing amount of silicon indicates a lesser amount of graphite and a large amount of chemically combined carbon in pig iron.

Table 6.3 *Grades of pig iron*

Subgrade	Silicon %
1	2.75 to 3.75
2	2.25 to 2.75
3	1.75 to 2.25
4	1.25 to 1.75

The prescribed weight of pig iron pieces is 45 kg and 22.5 kg, the former having two notches and the latter, one notch. To differentiate between various grades and subgrades, a suitable colour scheme of painting is also suggested.

To achieve a desired composition of the cast metal, these grades have to be suitably combined in a most economical manner. Since the various impurities in metal undergo chemical change during the re-melting operation, allowances have to be made for their loss or gain while making up the charge. The important constituents for which loss or gain allowance is provided in the computation are as follows:

Carbon During the passage of molten metal through the incandescent coke, carbon from the latter is absorbed by the metal. The factors that affect the absorption of carbon are: (i) initial carbon content; (ii) size of the coke; (iii) temperature; and (iv) time allowed for the molten metal to remain in the cupola. With properly controlled melting conditions, a gain of 0.15% carbon may be expected.

Silicon Silicon has a tendency to get oxidised and lost during the melting operation. Even under well-controlled and normal working conditions, the loss may be 10% of the silicon present in the charge. Under abnormal conditions, the loss may be as high as 30%. Thus, to achieve a certain silicon content in casting, either the original charge taken must be richer in silicon by the amount that is expected to be lost or, to compensate for the loss, silicon in the form of ferro-silicon may have to be added externally to the ladle containing molten metal. For homogeneity and uniform distribution all over the metal, granulated charge of ferro-silicon is added to the stream of molten metal as it is tapped from the cupola into the ladle.

Sulphur Like carbon, the sulphur content also tends to increase due to its absorption by the metal from the coke. The gain in sulphur may depend on the sulphur content of coke, the iron-coke ratio, the manganese content in the charge, and the flux used during melting. Generally, the gain in sulphur content is assumed to be about 0.03–0.05%.

Manganese Manganese also has a tendency to get lost along with silicon during melting. The loss may be about 15–20% of the manganese present in the charge. Here again, to get a certain manganese content, either the initial charge taken must be richer in manganese or external additions may have to be made in the form of ferro-manganese.

Phosphorus It is observed that this constituent is not found to change appreciably and its percentage remains nearly the same throughout the re-melting operation.

Iron During the melting operation, iron itself also tends to get oxidised and lost, but the loss which is generally quite small, may be assumed to be about 3-4%.

The method adopted for computing the charging mixture is based mostly on trial and error. From experience, a certain mixture is arbitrarily chosen and, considering the loss and gain of various constituents, the analysis of the cast metal is estimated. If it does not conform to the desired specifications, the necessary changes are made in the mixture and the analysis is again checked up. This is repeated till the desired composition of the cast metal is achieved. The procedure becomes clear when applied in an actual problem.

Problem Estimate the probable analysis of the.charging mixture so that the cast metal will have 3.20–3.50% total carbon; 2.30–2.60% silicon; 0.40–0.60% manganese; 0.40–0.50% phosphorus; and 0.08% (maximum) sulphur.

The raw materials available in the foundry have the percentage composition as given in Table 6.4.

Table 6.4 *Percentage composition of melting raw materials*

	CARBON	SILICON	MANGANESE	SULPHUR	PHOSPHORUS
Pig Iron No. 1	3.50	2.50	0.40	0.01	0.40
Pig Iron No. 2	3.20	1.50	1.00	0.02	0.60
Home Scrap	3.50	1.80	0.60	0.09	0.50
Outside Scrap	3.20	1.20	0.50	0.10	0.40
Ferro-silicon		50%			

Solution In the first trial mixture, it is decided to use 50% scrap consisting of 10% home scrap and 40% outside scrap. Since the sulphur content of both scraps is high and the silicon content is low, a larger proportion of Pig Iron No. 1 is chosen, e.g., 30% of No. 1 and 20% of No. 2.

The analysis of the cast metal obtainable with the foregoing charge may be computed as shown in Table 6.5A. From this computation, it is seen that in the cast metal, the silicon percentage will be lower and the sulphur percentage higher than desired. To achieve the required result, the charge is re-adjusted by increasing Pig Iron No. 1 and decreasing outside scrap by a corresponding amount.

The excess sulphur per tonne of mixture in the trial mixture is

$$\frac{0.106 \times 1000}{100} - \frac{0.08 \times 1000}{100} = 1.06 - 0.80 = 0.26 \text{ kg}$$

The reduction in sulphur obtained by substituting 1 kg of Pig Iron No. 1 for 1 kg of outside scrap is

$$\frac{0.10}{100} - \frac{0.01}{100} = 0.0010 - 0.0001 = 0.0009 \text{ kg}$$

When the reduction in sulphur is 0.0009 kg, the amount of Pig Iron No. 1 used is 1 kg; or when the reduction in sulphur is 0.26 kg, the amount of Pig Iron No. 1 used is

$$0.26/0.0009,$$

$$= 290 \text{ kg, or say, } 300 \text{ kg.}$$

Thus, the new mixture should have (300 + 300) = 600 kg of Pig Iron No. 1. The amount of outside scrap will be reduced by a corresponding amount, i.e., (400 – 300) = 100 kg.

The silicon content obtained with this changed mixture may be calculated in the same way (see Table 6.5B).

Table 6.5A *Analysis of cast metal obtained from a given change*

Constituents of the charge			Carbon		Silicon		Manganese		Phosphorus		Sulphur	
			%	KG	%	KG	%	KG	%	KG	%	KG
Pig Iron No. 1	30	300	3.50	10.5	2.50	7.5	0.40	1.2	0.40	1.2	0.01	0.03
Pig Iron No. 2	20	200	3.20	6.4	2.50	3.0	1.00	2.0	0.60	1.2	0.02	0.04
Home Scrap	10	100	3.50	3.5	1.8	1.8	0.6	0.60	0.50	0.5	0.09	0.09
Outside Scrap	40	400	3.20	12.8	1.2	4.8	0.50	2.0	0.40	1.6	0.10	0.40
Total	100	1000		33.2		17.1		5.8		4.5		0.56
Analysis of aggregate charge (%)			3.32		1.71 (10% loss)		0.58 (25% loss)		0.45		0.056	
Loss or grain during melting (%)			+0.15		–0.17		+0.14				+0.050	
Estimated analysis of cast metal (%)			3.47		1.54		0.44		0.45		0.106	
Desired analysis (%)			3.2~3.5		2.3~2.6		0.4~0.6		0.4~0.5		0.08 max.	

Table 6.5B *Computation of silicon content obtained in cast metal*

Constituents			Silicon	
	%	kg	%	kg
Pig Iron No. 1	60	600	2.5	15.0
Pig Iron No. 2	20	200	1.5	3.0
Home Scrap	10	100	1.8	1.8
Outside Scrap	10	100	1.2	1.2
Total	100	1000	—	21.0

Analysis of aggregate charge (%)	2.10
Estimated loss (%)	– 0.21
Estimated analysis of cast metal (%)	1.89
Desired percentage	2.3–2.6

The deficiency in silicon cannot therefore be met by increasing Pig Iron No. 1. Hence, to get about 2.4% silicon, ferro-silicon has to be separately added to the molten metal. The amount of ferro-silicon required may be calculated as follows:

The deficiency of silicon per m tonne of cast metal is

$$\frac{2.40 - 1.89}{100} \times 1000 = 5.1\text{kg}$$

The increase in silicon by adding 1 kg of ferro-silicon for 1 kg of Pig Iron No. 1 is

$$\frac{50.0 - 2.5}{100} = 0.475 \text{ kg}$$

When 0.475 kg is the increase in silicon, the ferro-silicon required is 1 kg. Therefore, for 5.1 kg increase in silicon, the ferro-silicon required

$$= 5.1/0.475 = 10.8 \text{ kg or } 11 \text{ kg}$$

The quantity of Pig Iron No. 1 required per m tonne of the charge will be

$$(600 - 11) = 589 \text{ kg.}$$

The correct analysis of the mixture will therefore be as given in Table 6.5C

For the purpose of a final check, the estimated analysis of cast metal for the second charging mixture can again be computed. The results obtained should lie within the specified limits. The final computation is shown in Table 6.6.

Table 6.5C *Analysis of the charge mixture*

	KG	%
Pig Iron No. 1	589	58.9
Pig Iron No. 2	200	20.0
Home Scrap	100	10.0
Outside Scrap	100	10.0
Ferro-silicon	11	1.1
Total	1000	100

Instead of using the foregoing procedure of trial and error, a quicker and modern method of linear programming can be adopted to arrive at the exact cupola charges. A numerical method using the simplex technique can be used for the purpose. A computer program made in Fortran or Basic langauge can also be used to compute the optimum charge.

Factors Affecting Efficiency of a Cupola

(i) Coke Rate The coke rate or coke ratio is the inverse of the metal fuel ratio, expressed as a percentage.

(ii) Blast Rate It may vary from 70–125 cu m per sq m of cupola plan area per minute at 0°C and 760 mm pressure of mercury.

A net diagram (Fig. 6.7) shows the relationship between the melting rate, the coke ratio, the blast rate, and the metal temperature. The maximum temperature is achieved when the cupola is operated at the melting rate and the blast rate shown by the optimum line for any given coke ratio. It is thus seen that the blast rate and the coke ratio play a vital part in controlling the performance of the cupola. The thermal efficiency of the cupola is also found to reach a maximum at a particular value of the blast

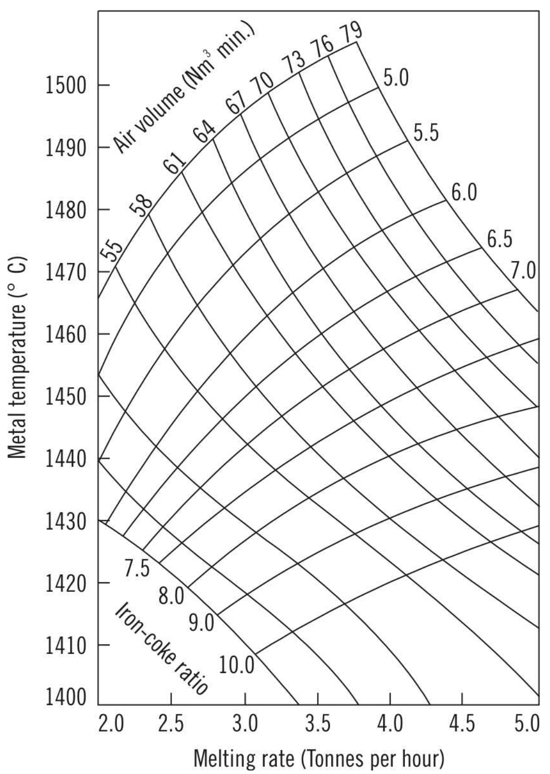


Fig. 6.7 *Operating conditions for a cupola (Inner diameter after lining: 900mm)*

Table 6.6 *Final computation of cast metal analysis*

Constituents of the charge			Carbon		Silicon		Manganese		Phosphorus		Sulphur	
	%	kg	%	kg	%	kg	%	kg	%	kg	%	kg
Pig Iron No. 1	58.9	589	3.5	17.5	2.5	14.7	0.4	2.36	0.4	2.36	0.01	0.59
Pig Iron No. 2	20.0	200	3.2	6.4	1.5	3.0	1.0	2.0	0.6	12.0	0.02	0.04
Home scrap	10.0	100	3.5	3.5	1.8	1.8	0.60	0.60	0.5	0.50	0.09	0.09
Outside scrap	10.0	100	3.2	3.2	1.2	1.2	0.50	0.50	0.4	0.40	0.10	0.10
Ferro-silicon	1.1	11			50	5.5						
Total	100	1000		30.6		26.2		5.46		4.46		0.289
Analysis of aggregate charge (%)				3.06		2.62	0	.546		0.446		0.029
Loss or gain during melting (%)			+0.15			–0.26		–0.13			+0.05	
Estimated analysis of cast metal (%)				3.21		2.36		.416		.446		0.079
Desired analysis (%)			3.2~3.5		2.3~2.6		0.4~0.6		0.4~0.5		0.08 max.	

rate, which gives the highest metal temperature. Figure 6.8 further shows the relationship between the cupola diameter, the melting rate and the blast rate.

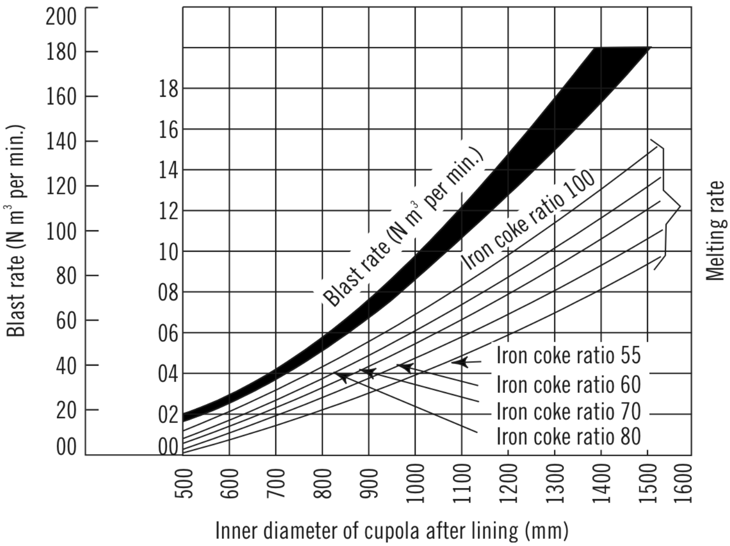


Fig. 6.8 *Relationship between cupola diameter, melting rate and blast rate*

(iii) Coke Size and Coke Quality The coke size and quality are also important considerations in achieving high thermal efficiency. It has been established that the smaller the coke size, the lower is the thermal efficiency (e.g., percentage of total heat input absorbed by metal and slag), the lower the temperature of metal, and the less complete the combustion of carbon into carbon dioxide. The quality of coke has an appreciable effect on the melting rate, metal temperature and quality of cast metal produced. IS: 4836–1968 gives the specifications of coke. The ash content should be as low as possible, and volatile matter high. The broad requirements are given below:

Porosity	35–45%			Sulphur	0.5–1%
Volatile matter	0.5–2%			Phosphorus	0.1–0.3%
Ash content (max.)	28%				
Shatter index	over	75 mm	28–35%	by weight	
	over	50 mm	70–80%	by weight	

The size of coke used in the cupola may be as follows:

(i) For cupola under 900 mm dia. : 50 mm for charge and 120 mm for bed coke.

(ii) For cupola of 900 mm and above: 75 mm for charge and 150 mm for bed coke.

From the above, it can be noted that the performance of a cupola may be judged in terms of four factors:

(a) Maximum temperature of metal It may vary from 1300°C to 1550°C.

(b) Melting rate It may vary from 5.0 tonnes to 12.0 tonnes per sq m plan area of cupola per hour.

(c) Combustion ratio It is given as

$$\frac{CO_2}{CO_2 + CO} \times 100$$

quantities of CO_2 and CO being expressed volumetrically. The ratio may vary from 45% to 90%.

(d) Percentage of total heat input absorbed by metal and slag or thermal efficiency, which may be between 28% and 45%.

Development in Cupola Melting

(i) Hot Blast Operation The use of a hot blast of air instead of a cold blast carries several advantages:

(a) Molten metal attains high temperature. Heating the blast to 500°C can cause increase of metal temperature by 100°C. Therefore, pig iron or iron scrap can be partly replaced by steel scrap to obtain an improved quality of metal required to produce high grade cast iron.

(b) Reduced loss of alloying elements in the iron—for instance, manganese and silicon—along with improved reduction of sulphur. The loss of iron is also reduced.

(c) For a given temperature requirement, less coke is required. A higher metal–fuel ratio is possible and the melting rate can be enhanced. Similarly, it is possible to use inferior quality coke to arrive at the same temperature and melting conditions.

The hot-blast cupola also has certain shortcomings, such as higher installation cost, larger maintenance and operative cost, higher rate of lining erosion, and greater control of equipment, which renders its operation economical only when the work entails long runs on cupolas of 10– tonne capacity and above.

Two systems of producing hot blast are prevalent: (1) The recuperator type in which the waste heat of exhaust gases is utilised to heat the blast of air before it is introduced into the cupola (Fig. 6.9).

(2) The external combustion type where the cold blast of air is heated in a heat exchanger by hot gases produced by the combustion of oil or gas in separate unit; the exhaust gases are not utilised for heating the blast in this system.

The recuperator system is more expensive and effects combustion inside the cupola. The availability of hot blast and its temperature are dependent on the physical characteristics of exhaust gases and the system therefore lacks flexibility. It is, however, economical for continuously running a large-sized cupola, which melts more than 150–200 tonnes of metal per week. For smaller cupolas, the external combustion type, which requires lower capital cost, is more economical.

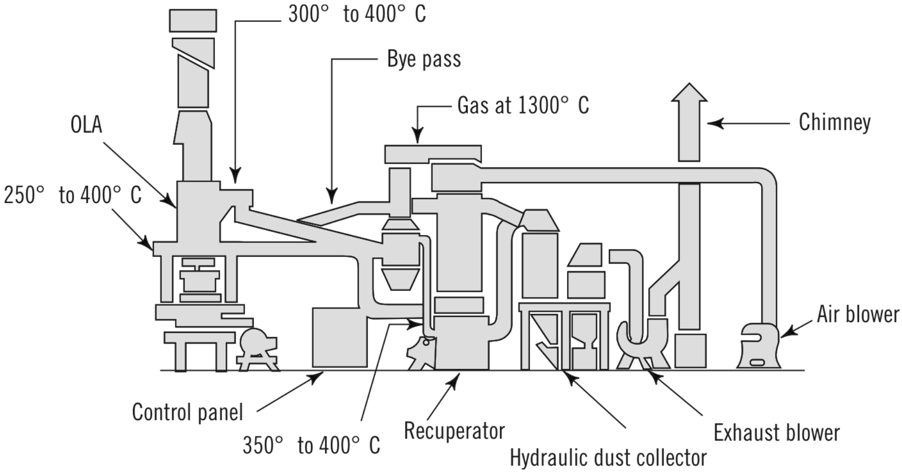


Fig. 6.9 *Complete hot blast cupola installation*

(ii) Water-cooled Cupolas Many large-sized cupolas are water-cooled to minimise the consumption of refractory lining, to enable long melting durations, and to reduce the expense and time required in repairing the lining. Water-cooling is employed generally above the tuyere level for a height of about twice the internal diameter of the cupola (in the melting and superheating zone). Basic lining is provided only in the well portion. No lining is necessary in the area where water-cooling is arranged.

Cooling is achieved either by providing a jacket around the shell and circulating cold water through the jacket, or by arranging showers to drop continuously on the outside of the shell and collecting the water in a trough around the cupola. In both modes, the water is re-circulated after cooling. Since lining is dispensed with, the internal diameter of the cupola gets enlarged and a greater quantity of metal can be melted.

Water-cooling is usually adopted in combination with a hot blast operation so that a high temperature of metal can be maintained and the furnace can be operated under uniform conditions of combustion despite the cooling effected by the furnace walls. The system is again economical only in large cupolas which run on a continuous basis or for long runs.

(iii) Cupolas with Basic Slag Operation In an acid-lined cupola, the sulphur content of the charge cannot be reduced while melting. On the contrary, the metal absorbs a certain amount of sulphur from the fuel. Thus, where iron with a low sulphur content is required, as in the production of spheroidal graphite iron (SG iron) or when melting iron for production of steel in electric furnaces, a basic-lined cupola may be used. As basic lining is expensive, its life should be prolonged as much as possible by water-cooling around the lining.

With basic slag, as the basicity $\left\{\frac{CaO\% + MgO\%}{SiO_{2\%}}\right\}$ ratio increases, the carbon content also goes up and both silicon and sulphur are reduced. The loss of silicon can be made up by additions of ferrosilicon.

Figure 6.10 shows the relationship between carbon and sulphur content, slag basicity, and metal temperature. It is seen that at a high sulphur level, i.e., when slag basicity is 1.0 or less, the carbon content can be varied over a wide range and a low value of carbon is possible. However, when sulphur is very low (i.e., 0.01~0.02%), carbon cannot be limited to a low value. Thus, low carbon and low sulphur iron, as required for SG iron, cannot be obtained in a cupola that has basic slag too. But high carbon, low sulphur irons, as required for ingot moulds, premelts for steel-making, etc., can be conveniently produced.

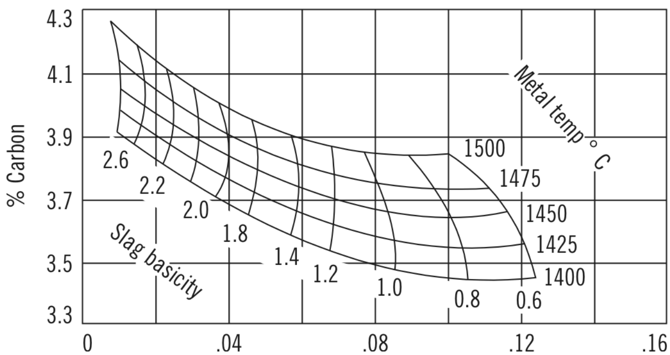


Fig. 6.10 *Relationship between % carbon, % sulphur, metal temperature and slag bascity*

(iv) Oxygen-enriched Blast in Cupola Oxygen has been advantageously used in cupolas for enriching the blast and achieving higher temperature by injecting it into the well. It has been noticed that 2% enrichment of blast with oxygen increases metal temperature by 10°C with 0.4% carbon pick up, whereas 2% injection into the well increases temperature by 70°C and carbon pick-up by 0.12%. Fuel consumption can be reduced by maintaining the same temperature.

(v) Use of Calcium Carbide It has been observed that the addition of calcium carbide is helpful in effectively reducing the sulphur content of the metal and raising its temperature. It is found more effective with basic slags. However, the high cost of carbide greatly restricts its use.

(vi) Use of Supplementary Fuels in Cupola Supplementary fuels such as oil and natural gas have been tried and found useful in improving combustion conditions and thermal efficiency. Injection of oil or gas above the tuyeres helps in increasing the melting rate and metal temperature. The higher cost of supplementary fuel is the main limiting factor. In areas where low cost gas is available, for instance Gujarat, its use can be promoted to obtain the advantages.

(vii) Cokeless Cupola Though natural gas, producer gas and fuel oil have been tried and used as supplementary fuels in cupolas, their popularity has been arrested in view of poor carbon pick-up, large silicon loss and inability to produce high melting temperatures. A lot of controversy exists, in spite of extensive investigations, as regards the technical and economic advantages of partial substitution of coke by gas or oil.

It has been observed through elaborate trials that a completely cokeless operation can be much more advantageous in that it is free of smoke and emissions, cost of melting is lower, and a better quality of metal with extremely low sulphur pick-up and consistent composition is produced. The molten metal can be tapped at about 1450°C, or even higher depending on the requirements, holding the carbon equivalent at any desired value. Considerable saving in space is also achieved in cokeless operation. Besides graded cast irons, SG iron can also be produced as there is practically no sulphur pick-up and the desired temperature can be obtained.

The shaft of the cupola is partitioned by a water-cooled grate consisting of several refractory-coated steel tubes. This grate supports a refractory bed on which charge materials are placed. Below the grate, a number of high-intensity burners are arranged, inclined 10° downwards, through which the air–gas mixture is introduced. Partially reducing conditions are maintained in the cupola by operating on excess gas. As the hot gases move upwards after combustion, the refractory bed gets heated up and the charge above is preheated. As the metallic charge near the refractory bed gets melted, the molten iron trickles down through the bed and the grate and collects in the well. The carbon required in the iron has to be added separately. This is done by injecting graphite into the cupola well through tubes inclined downwards at 45°.

The fuels suitable for cokeless operation are propane, natural gas and light fuel oil. The operating cost of the cokeless cupola will depend on the cost of fuel. In regions where natural gas is available, it can be an economical substitute for the conventional coke-fired cupola. Figure 6.11 shows the arrangement of a cokeless cupola.

(viii) Balanced and Divided Blast Cupola A system of introducing air blast into the cupola through two levels of tuyeres, one above the other, in order to achieve more efficient combustion of coke is known as a balanced-blast arrangement. The results, however, are not consistent since the flow of air to each row of tuyeres is not controlled. An improvement of the balanced blast system, in which each row of tuyeres is provided with its own wind boxes, air-flow meters and blast mains with individual blast control, is known as divided-blast cupola. The distance between the two rows of tuyeres ranges from 800 to 1050 mm. The ratio of blast volume in the lower row of tuyeres to that in the upper row varies from 70 : 30 to 50 : 50. The divided blast cupola is now commonly used in many foundries. It helps achieve higher metal temperature, reduced coke consumption and improved melting rate. As an example, a charge coke consumption of 15% was required to produce a tapping temperature of 1500°C when operating with a single row of tuyeres, whereas, with divided blast, the same temperature was attained with a charge coke of 10.8%. Likewise, at a blast rate of 44.8 m^3 per minute, the melting rate obtained with 15% charge coke was 3.41 tonnes per hour, using a single row of tuyeres. When using divided blast, a melting rate of 4.07 tonnes per hour was achieved with only 10.8% charge coke. IS: 12272–1987 gives specifications of a divided blast cupola.

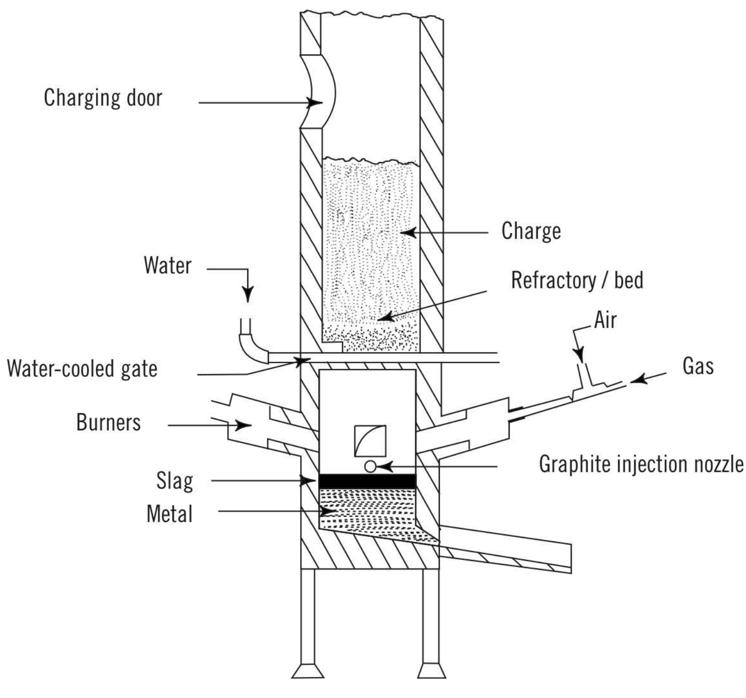


Fig. 6.11 *Cokeless cupola*

The divided blast arrangement can be advantageously used in all sizes of cupolas and the gains accrued in terms of higher temperature of metal, increased melting rate or reduced fuel consumption can be utilised to reduce the cost of melting and to produce castings of graded cast iron, malleable iron and SG iron as required for automobiles, machine tools, ingot moulds and general purposes. Figure 6.12 shows the details of a divided blast cupola.

(ix) Use of Sponge Iron in Metallic Charge Sponge iron has been widely used as a substitute for steel scrap in electric arc furnaces. Its use has been successful in some Indian foundries in cold blast cupolas also, but its extent is limited to about 30% without affecting the melting rate. Its average specifications are given below:

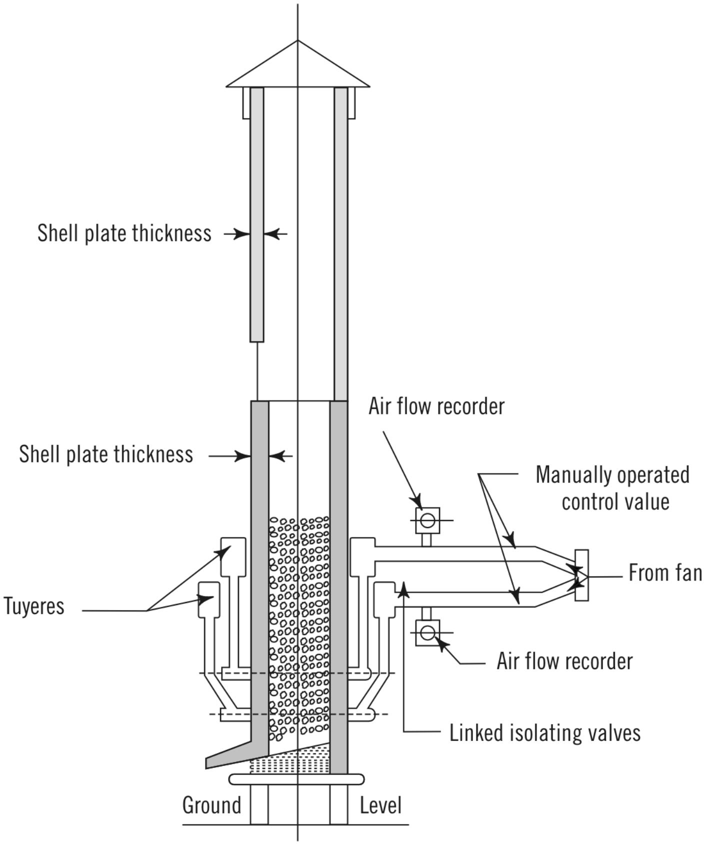


Fig. 6.12 *Constructional detail for divided blast cupola furnace*

Iron (total)	85–92%
Iron (metallic)	75–82%
Phosphorus (max.)	0.05–0.15%
Sulphur (max.)	0.02–0.05%
Al_2O_3, SiO_2 (max.)	5–10%

During melting, the silicon in the metal gets oxidised at a higher rate than in the usual run. It is therefore essential to add 10 –15% FeSi to maintain the carbon equivalent of the metal. To take care of the extra gangue material to the tune of 5–6% in sponge iron, and to keep the slag in a free-flowing condition, it is essential to use about 10–15% extra coke and a proportionate quantity of limestone. Arrangements should be available to take care of the 50–60% extra slag caused by the additional gangue, coke and limestone.

During melting there is a slight lowering of manganese, which may be beneficial in SG iron manufacture. Thus, sponge iron can be advantageously substituted for steel scrap or pig iron in cupolas. Its use is, however, governed by prevailing market prices and the techno-economic feasibility must be considered before it is used.

Cupola fluxes

The fluxes used in cupola may be classified into two categories:

1. Primary fluxes, and 2. Secondary fluxes.

Primary Fluxes used are limestone ($CaCO_3$), calcite, oyster and other seashells and dolomite ($MgCO_3 + CaCO_3$). These fluxes are added in the proportion of 2 to 7% of metal charge depending on (i) cupola diameter; (ii) ash content in coke; and (iii) impurities present in the charge. Larger cupolas need less quantity of flux than the smaller ones. In case of limestone or dolomite, the reactions taking place are

$$CaCO_3 \rightarrow CaO + CO_2$$

CaO combines with the silica in the charge, forming silicates:

$$CaO + SiO_2 \rightarrow CaO\ .\ SiO_2$$

Size of stone is an important factor affecting the calcination process. Generally, the recommended size is between 20 and 50 mm. For smaller sizes of cupola, a size up to 25 mm is enough.

Secondary Fluxes are used in small quantities, usually from 0.2 to 2.0% of metal charge, according to the composition and nature of charge materials. Sodium carbonate, fluorspar and calcium carbide are generally used as secondary fluxes. Sodium carbonate is a very effective basic flux and it liquefies slag efficiently. However, slag has basicity, and so it attacks the cupola lining of fire bricks and causes its rapid damage. This material should be used only in very small quantities. Fluorspar is also a strong basic flux. It accelerates the fluxing reaction and keeps the slag very fluid. However, its attack on linings is very severe and further, the generation of fluorine gas during chemical reaction gives rise to an irritating smell and is also harmful if inhaled continuously.

Calcium carbide is also a powerful fluxing agent. When brought in contact with water, acetylene gas is evolved, which is inflammable and explosive in nature. It should therefore be stored at a safe place where there is no contact with moisture. During chemical reaction, heat is generated, helping in raising the temperature of molten metal, increasing carbon pick up and desulphurisation of metal. The proportion of calcium carbide may be kept between 1 and 5% of metal charge, depending on the requirements of metal and cupola diameter. The reactions taking place are

$$2\ CaC_2 + 3\ O_2 \rightarrow 2\ CaO + 4\ CO\ (+382\ \text{kcal})$$

Also,

$$2\ CaC_2 + 5\ O_2 \rightarrow 2\ CaO + 4\ CO_2\ (+650\ \text{kcal})$$

The molten CaO produced by reactions quickly and effectively fluxes the slag besides raising the metal temperature and increasing its carbon content.

6.1.6 Electric Furnaces

Electric melting is one of the major methods of melting in iron and steel foundries. Electric furnaces have proved a big asset in the production of good-quality metal as they attain high melting efficiency with minimum loss. Unlike cupola or air furnaces, electric furnaces possess greater adaptability and flexibility and provide precise control over the temperature of molten metal. The high cost of electric power is a limitation, but this is outweighed by several overwhelming advantages.

Electric furnaces are now being used for melting and refining all kinds of steel, including stainless steel, tool steel, and other alloy steels. At times, they are also used for melting plain and alloy cast irons.

Electric furnaces are of three types:

(i) direct arc furnace;
(ii) indirect arc furnace; and
(iii) electric induction furnace.

(i) Direct Arc Furnace

This furnace is used for melting, refining, both melting and refining or merely for holding molten metal at a constant temperature.

The most popular type of direct arc furnace is the Heroult furnace. It is built in sizes ranging in diameter from 2 m to 8 m and in capacity from 1 tonne to 125 tonnes. In foundries, the furnaces usually have capacities ranging from 5 to 25 tonnes. The power input of the transformers used to supply the current may vary from 850 KVA to 30,000 KVA. A 10-tonne arc furnace may have an outside diameter of about 3 m, a height of 2¼ m and be encased in a 25-mm steel shell; the diameter inside the refractory lining may be 2.4 m.

An arc furnace (Fig. 6.13) consists mainly of a steel cylindrical shell with a spherical or flat base, which is mounted on rollers to enable tilting the furnace when operating a handwheel. The charge is contained in a bowl-shaped hearth, lined with suitable basic material, such as magnesite bricks. There are two spouts opposite each other, one for pouring the molten metal and the other for taking out the slag. The roof is dome-shaped and is detachable to facilitate easy charging from top. Figure 6.14 shows three different mechanisms for roof mounting.

In order to provide the arc with the means of carrying the current, three large vertical electrodes are arranged in a triangular pattern. These electrodes can be raised or lowered automatically by suitable electric or electronically controlled devices or by hydraulic control with the help of servomotors. At the point of entry through the roof, the electrodes are surrounded by a cooling box and sealing device for reducing and cooling the gas escaping up the sides of the electrode.

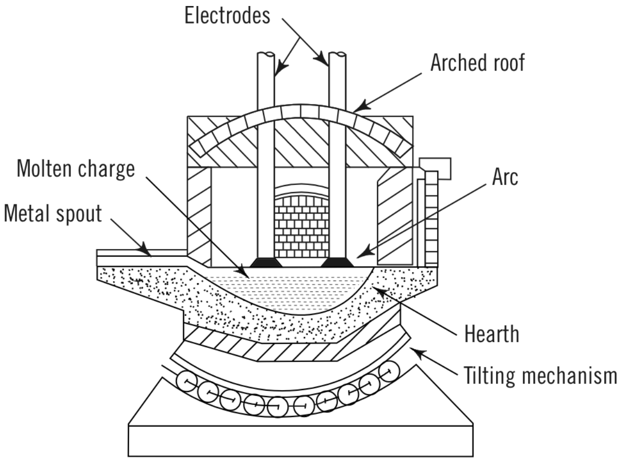


Fig. 6.13 *Direct arc electric furnace*

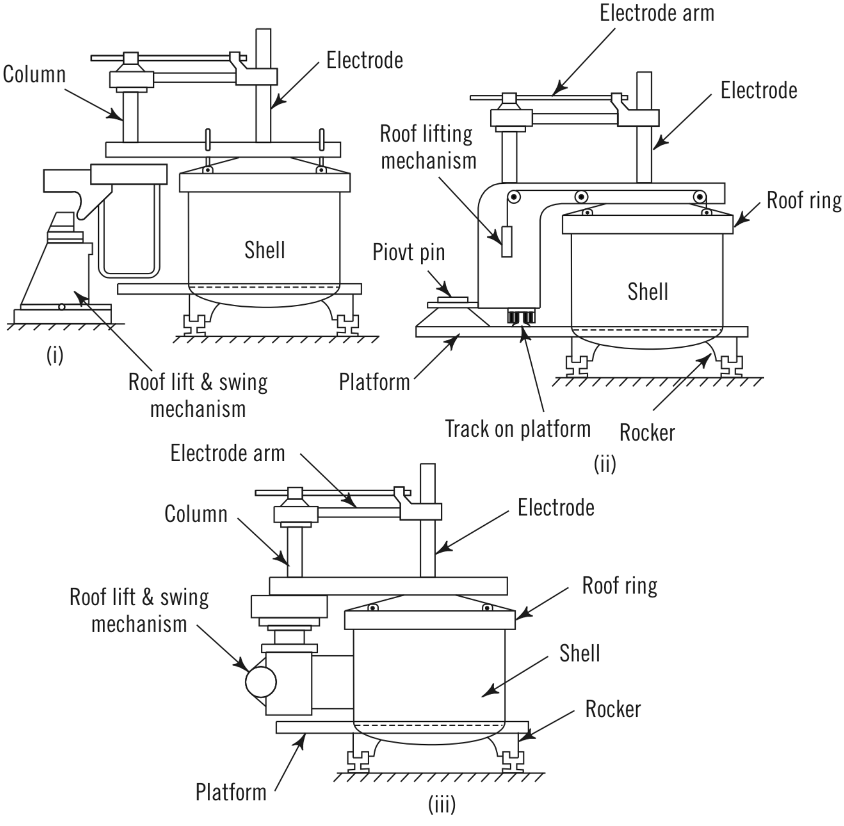


Fig. 6.14 *Three types of roof mounting mechanism: (i) Roof lift and swing arm separately mounted (ii) King pin arrangement for rotating furnace roof (iii) Roof lift and swing mechanism attached to furnace*

The furnace works on the principle that heat is produced when resistance is offered to the flow of electricity. In this case, it is the metal in the charge that provides the resistance to the flow of current. When the metal is molten, the slag offers resistance to the current flow. Thus, to maintain proper heating even when the metal is molten, the current input required, the energy consumed, and the melting time for steel melting are detailed in Table 6.7.

Table 6.7 *Current input and energy consumptions for different furnace capacities*

Liquid metal capacity (tonnes)	Shell diameter (metres)	Melting period (minutes)	KVA input	Energy kWh per tonne melted (~1550°C)
20	4.0	120	8000	450
15	3.5	100	7000	465
10	3.0	90	5500	480
5	2.5	90	3000	510
2.5	2.1	85	1500	545

The electrodes are raised and the furnace roof is swung open for charging the metal. The roof is then replaced, the electrodes lowered, and the current turned on. The electrodes are lowered to the base until the molten metal starts collecting and begins to rise. The electrodes are then raised gradually as the level of the molten metal rises.

The electrodes should have high electrical and low thermal conductivity, good refractoriness, and resistance to oxidation or chemical reaction. They should also possess good mechanical strength at elevated temperatures. Two types of materials that satisfy most of these conditions are graphite and amorphous carbon. The former is considered the superior of the two as it has higher electric conductivity and is lighter. As the electrode is consumed inside the furnace, a new one is joined at the top by means of a nipple with taper screws.

Advantages of Direct Arc Electric Furnace

(i) The electric arc is the greatest commercial source of heat without any risk of contamination. Thus, the method ensures high purity in the metal.

(ii) The rate of heat application can be closely controlled.

(iii) The thermal efficiency is considerable: about 70%. However, the high cost of electricity may tend to offset this advantage.

(iv) The furnace atmosphere above the molten metal can be easily controlled.

(v) Most alloying elements, such as chromium, nickel, and tungsten, can be recovered from the scrap at negligible loss.

(vi) Steel may be made direct from pig iron and steel scrap, using the same method as for open-hearth furnaces.

Charging To obtain optimum results from an electric arc furnace, close attention has to be paid to the selection and arrangement of charge material, which is usually steel scrap. The charge generally consists of 40% heavy scrap, such as heads, risers and bloom ends, 40% medium scrap, and 20% light scrap. An overweighted proportion of heavy scrap will increase melting time whereas too much light scrap may not allow all the charge to be utilised at one time. The charge should be so distributed as to facilitate the formation of a pool under the electrodes; it should not be too dense as this would interfere with the localisation of the arc; and it should be so arranged that the arc is spread throughout the hearth. It is sound practice to place on the furnace base a small amount of light scrap topped by heavier scrap. Light scrap or turnings form another layer to reduce electrode breakage and allow faster melting. The heaviest pieces of scrap are then placed directly below the electrodes, where the heat is the greatest.

Steel Melting Practice in Direct Arc Furnace Broadly, there are two processes of steel making, viz., acid slag process and basic slag process. Both the processes depend on the formation of slag and its nature and composition. Acid slag is essentially a silica-saturated iron manganese silicate. It is always an oxidising slag. The refining of the metal is concerned with controlled elimination of elements such as carbon, manganese, and silicon by oxidation. Elimination of phosphorus and sulphur is not possible since they are not stable in acid slag. The control of these two elements can only be had by proper selection of charge materials, which must initially have low phosphorus and sulphur.

Basic Slag Process In this process, overdue attention to the sulphur and phosphorus contents of the scrap is not necessary since these can be effectively eliminated, even when present in the scrap in quantities above 0.10%. The carbon content is so adjusted that the charge will melt out; a sufficiently high content of carbon ensures a good boil. Most operators opt for a boil of at least 2.2% carbon. In the production of alloy steels, it is possible to begin with a pure carbon steel charge and to make up the final composition with ferro-alloys. Economy, however, usually demands that the maximum of the alloying elements should be obtained from alloy scrap itself, and it is often possible to obtain practically all the alloys from scrap. Certain readily oxidisable elements, such as vanadium and titanium, cannot be recovered from scrap. Others, such as chromium can be partially recovered, but too high a percentage of chromium in scrap leads to difficulties in operation, since a high chromium content in the slag makes it viscous and difficult to work. Molybdenum and nickel are examples of metals that give almost 100% recovery.

There are considerable differences of opinion amongst melters as to whether ore and lime should be added with the charge or only after the charge is molten. Additions of ore and lime with the charge induce the elimination of phosphorus in the early stages of melting when the temperature conditions are most favourable. Lime also prevents damage to the banks by impurities oxidised during melting. The additions do, however, retard melting and they must be carefully made so that they do not get under the arc and break the electrode. The amount of ore used depends on the condition, and in particular on the cleanness, of the scrap. The quantity of lime to be added also varies according to the amount of impurities, such as sulphur and phosphorus, which have to be removed. An average value is about 2% of the charge weight, although quantities up to 5% may be utilised in high phosphorus charges. No more lime than that required to reduce the sulphur and phosphorus should be used since it causes a greater resistance to the arc and so reduces furnace output.

When the furnace has been properly charged, the doors are closed, the electrodes lowered on to the charge, and the arc struck. The electrodes then bore their way into the charge. In order to preserve the refractories, many operators choose to start on a moderate voltage tapping and wait until the electrodes have bored some distance before switching on to full power. The electrodes bore a hole through the charge to the furnace base and form a pool of molten liquid on the hearth. The correct formation of this pool is vital, since it protects the base from the effect of the arc. After the pool has been formed, the melting of the charge should proceed from the base upwards. Care should also be taken to use proper voltage and current settings to suit individual conditions in the light of past experience.

When the bath is completely molten and all the scrap has been pushed off the bank, the first test sample is drawn and sent to the laboratory for analysis. At this stage, the remainder of the lime or limestone is added, and 5 kg ore per tonne of metal may also be added. The power is maintained to raise the temperature high enough for the boil to commence. By the time the boil begins, a good slag of the correct composition and fluidity should have been formed. The actual composition of the slag at the commencement of the boil depends on the carbon content of the metal, and also on the amount of dephosphorisation and desulphurisation required. It is not possible, therefore, to give exact compositions, but a fairly average slag contains

42% CaO;
25% SiC_2;
17% FeO;
8% MnO;
2% Al_2C_3; and
5% MgO

During the oxidation period; which begins as soon as the metal is melted and continues until the reducing slag is formed, the elements S, P, Mn, Si, Cr, and C are actively removed. The chemical reactions involved may be written as follows, although the actual reactions are not as simple as the equations indicate.

$$2P + 2FeO + 3CaO \rightarrow Ca_3P_2O_5\sim + 2Fe$$

$$Si + 2FeO \rightarrow SiO_2 + 2Fe$$

$$Mn + FeO \rightarrow MnO + Fe$$

$$FeS + CaO \rightarrow CaS + FeO$$

$$FeS + MnO \rightarrow MnS + FeO$$

$$C + FeO \rightarrow CO + Fe$$

The equilibrium for silicon and manganese is favourable for the removal of these elements, and they are generally reduced to a low value by the time the boil has commenced. Considerable quantities of sulphur (about 20% of the content) are also removed during the oxidation period. The exact mechanism of this removal has not yet been established, but it is known that it is facilitated by high temperature, a high manganese content in the metal and a high lime content in the slag.

The main reaction occurring during the oxidation period is the removal of carbon according to the reaction:

$$C + FeO \rightarrow CO + Fe$$

It is the evolution of the carbon monoxide produced throughout the metal that is responsible for the boil. To initiate the boil, oxygen, usually in the form of iron ore, needs to be added to the bath. Since the amount of oxygen (as well as carbon) has been depleted by the reaction, further additions have to be made to maintain it. The amount of oxygen in the metal required to initiate a boil depends on the carbon content of the metal, the relationship being such that the product of the carbon and oxygen contents is constant at any given temperature. Care should, however, be exercised not to add too much oxygen, otherwise the metal will be over-oxidised. The addition should be such that the boil has largely subsided by the time the carbon content has dropped to the required value. In this way, it is ensured that the carbon and oxygen are in near equilibrium, and that the metal contains the minimum quantity of oxygen, thus facilitating the subsequent de-oxidation process.

In addition to reducing the carbon content of the bath to the desired level, the boil has several other functions. It serves to agitate the bath, ensuring thorough mixing. It also facilitates distribution of the heat throughout the metal and so helps to melt any scrap at the base. Further, the thorough agitation helps to bring non-metallics into contact with the slag in which they are held and in the process cleans the metal. Lastly, a vigorous boil greatly reduces the hydrogen and nitrogen content of the metal. These gases diffuse into the bubbles of carbon monoxide and are eliminated along with it. This is particularly valuable in metal to be used for casting, since gas porosity can be a source of considerable trouble.

A development, which has attained wide popularity, is the use of gaseous oxygen for the removal of carbon. In this process, oxygen is piped into the furnace. From the gas main, it is connected by means of a rubber hose to a length of steel tubing of about 18 mm inside diameter. Gas at a pressure of approximately 8–12 kg/cm^2 is passed through the steel pipe, which is inserted in the bath until its end is at the slag–metal interface. A vigorous reaction then takes place. For the first few seconds, copious red fumes are evolved, and as the carbon begins to separate, white fumes are emitted, and the bath boils vigorously. When the carbon content has fallen to below 0.1% the flames subside and the oxygen is turned off. As the blow proceeds, the steel tube is consumed and has to be continually pushed into the furnace. The consumption of the tube can, however, be substantially reduced by covering it with refractory sleeves or refractory cement. To ensure the best results, an oxygen supply capable of delivering 1.5–3 cu m/tonne/min is necessary.

By means of the oxygen technique, decarburisation can be achieved within a few minutes, as compared to the 20–30 minutes required with arc practice. Time and power too are saved also because a considerable rise in temperature occurs during the blow. Against these advantages must be offset the increased wear on the furnace bottom, side walls, and roof when oxygen blow is used.

The oxygen technique is particularly valuable in the production of stainless steels, where, due to the very high temperatures produced (over 1900°C, carbon can be readily removed without excessive loss of chromium. This is because the relative affinities of carbon and chromium for oxygen change with temperature. At temperatures of 1600°C, the relation is such that carbon is oxidised in preference to chromium and this works out very economical since much greater quantities of scrap can be recovered.

Reverting to the melting practice for carbon and low alloy steels, irrespective of whether the carbon content is reduced by ore or oxygen, oxidation is continued until the carbon content is reduced to the required figure (generally some 0.1% below the final specification). By this time, silicon will have been reduced to a trace, manganese and chromium to a value of 0.2–0.3%, and, if proper slag conditions have been maintained, the phosphorus content should be less than 0.02%. The oxidation period can then be considered complete and deoxidation ready to commence.

By the time the carbon content has been reduced to the required level, the boil should have largely subsided if the ore addition has been properly controlled. Next, the oxidising slag should be removed before beginning to deoxidise. To slag off, the furnace is tilted backwards and the slag raked off with rabbles. To facilitate this operation, the slag may first be thickened by adding lime, the power is kept shut off and the electrodes raised during this operation. The slag should be removed as thoroughly as possible to prevent reversion of phosphorus from any slag left on the metal and also because of its highly oxidising nature.

The necessary additions of silico-manganese, and, in some cases, ferro-silicon, are made at this stage to kill the bath. The result of the sample drawn before slagging should now be available, and additions of carbon, if required, are made to the bare metal. The bath may be stirred by rabbling, and high power should be applied to help absorption of the carbon.

When recarburisation is completed, the second or refining slag is formed by the addition of lime, sand, fluorspar, and coke or coal. These may be pre-mixed or the coke or coal may be added separately later. Typical proportions are: 6 parts lime, 1 part sand, 1 part fluorspar, and 1–2 parts coke or coal. The quantities added are sufficient to give a slag bulk of about 2%.

The second slag should be well-fluxed some 10–15 minutes after the additions. A reducing atmosphere is maintained in the furnace by additions of fine coal or coke, and by sealing the doors of the furnace to prevent access of air. Due to the presence of CaC_2 or fine ferro-silicon, the slag has a high affinity for oxygen, and it soon reduces the oxide content of the metal to a negligible value. At the same time, due to the high basicity and low oxygen content, sulphur is also readily removed. The elimination of sulphur is one of the main objectives of the reducing period, and occupies the greater portion of the time. Where very low sulphur contents are required, it may be necessary to remove the first refining slag before forming a new one.

The reactions taking place in the refining period may be represented by the equations:

$$CaC_2 + 3MnO \rightarrow CaO + 2CO + 3Mn$$

$$CaC_2 + 3FeO \rightarrow CaO + 2CO + 3Fe$$

$$2MnO + Si \rightarrow SiO_2 + 2Mn$$

$$2FeO + Si \rightarrow SiO_2 + 2Fe$$

$$CaO + FeS \rightarrow CaS + FeO$$

$$CaO + MnS \rightarrow CaS + MnO$$

$$2CaO + CaC_2 + 3FeS \rightarrow 3CaS + 2CO + 3Fe$$

$$2CaO + CaC_2 + 3MnS \rightarrow 3CaS + 2CO + 3Mn$$

Desulphurisation is aided by high lime content, high manganese content, low oxide content in the slag, and high slag fluidity.

When the refining slag is of the correct composition and fluidity, the final chemical test is conducted. As soon as the analysis is available, the last additions are made to bring the heat within specification, and ferro-silicon is added for the final deoxidation. When the additions have melted and the temperature raised to the correct value, the heat is ready for tapping. This will generally be 15–20 minutes after final deoxidation, thus allowing time for the removal of insoluble deoxidation products as slag. Finally, aluminium can be added either to the furnace before tapping or to the ladle.

Just prior to the tapping, the temperature is checked to as certain its suitability for the foundry. This may be done by using a quick immersion type of thermocouple with a recorder and indicating instruments, or by one of the following methods which are based on the experience of the operator:

(i) A well-slagged sampling spoon is filled with metal from the furnace and laid on the furnace bench. The time required for a skin to form over the bare metal surface is observed. It is a measure of the degree of superheat of the metal.

(ii) A well-slagged sampling spoon is filled with metal and the metal poured slowly out of the spoon. If the steel is hot enough to tap, it should pour out cleanly, without leaving a skull in the spoon.

(iii) A standard chill mould is filled with metal and the sample broken. The metal temperature can be estimated by the depth of the columnar crystals in the fracture.

(iv) A steel rod is moved slowly in the metal bath. By observing the rate at which the rod is dissolved, the temperature can be estimated.

When the melter is satisfied that the heat is ready for tapping, the tap hole is cleared, the power shut off, the electrodes raised, and the furnace tilted forward to tap the metal into the ladle. Care must be taken to ensure that the furnace is completely drained. The furnace is then tilted back to the original position and the bottom surface examined carefully. Any holes in the bottom surface are fettled with dolomite and the furnace is then considered ready for charging with the next quota of heat.

The chemical reactions occurring in the arc furnace are generally between constituents in the slag and metal, and so depend on intimate contact between these phases. Stirring and mixing are important in speeding up these reactions. In the oxidising stage, mixing is enhanced by the boil, but in the refining stage, when the bath is quiet, it is difficult to obtain adequate agitation. A recent development has been to make use of the stirring effect of high-frequency-induced currents in the molten steel. The furnace shell is made of non-magnetic steel, and a coil is placed directly under the bath. High-frequency currents from a suitable generator are made to flow in the coil and in turn induce secondary eddy currents in the bath of molten steel. Due to the interaction of these induced currents, the metal is caused to circulate, resulting in a stirring action. It is claimed that by this method, the refining reactions are speeded up and that closer control over the chemical composition can also be obtained.

A complete melting schedule for 18 : 8 stainless steel in now given as a case study in Table 6.8.

Composition required

0.06–0.08% carbon;
1.0–1.5% silicon;
0.6–0.9% manganese;
8.2–8.7% nickel; and
18.5–19.5% chromium.

Charge Composition

50% 18 : 8 scrap;
10% steel turnings;
16.2% plate scrap;
15% ferro-nickel (low carbon);
8% ferro-nickel (high carbon); and
8% ferro-manganese (high carbon).

(ii) Indirect Arc Electric Furnace

The indirect arc furnace may be used to melt all types of metals, but it is specially designed for non-ferrous metals. The furnace is made up of a barrel-shaped drum, mounted horizontally and so geared that it can be rotated back and forth through an angle of 180°. The shell is lined with insulating and refractory material.

Table 6.8 *Melting schedule for 18:8 stainless steel in direct arc elctric furnace*

	Limestone (30 kg/tonne) FeSi (7kg/tonne)	Oxygen blow (8–12kg/m² water)	Low carbon FeCr (Temp. reducer)	Limestone (45 kg/tonne) FeSi (15 ~ 20 kg/tonne) Low carbon FeCr FeSi	Limestone	CaSi Low carbon FeCr Metallic NiFerro-	MnFerro-SiAl ingot (99.9%) (0.5 ~ 1kg/tonne)
	Melting Slag-off	Oxygen Blow		Alloy Recovery		Reduction	Tapping
Time (min)	90~120	5	25~35	25~35	5–10		30~60
%C	0.5~1.0		.04~.06	.04~.06			.06~.07
%Si	0.4~0.6		<.05	0.4~0.6			1.0~1.2
%Mn	1.0~1.2		0.4~0.6	0.5~0.7			0.7~0.8
%Cr	16~19		12~15	18~19			18.5~19.5
Temp (°C)	1620		1900	1600~1650			> 1570

Two electrodes are used, each one entering the furnace from either end and coinciding with the horizontal axis of the cylinder. As the electrodes are brought near each other, an arc is struck between the two ends and tremendous heat is generated. The electrodes are then automatically separated from each other to maintain proper arc length. The heat of the arc is radiated and reflected in all directions. Thus, a part of the heat is directly absorbed by the metal and the remainder by the lining. As the shell rotates back and forth, metal flows over the heated surface and absorbs the heat energy from the walls by conduction.

Generally, the furnace is designed as the tilting type and is mounted on trunnions. The capacity of the furnace varies from 100 kg to 5 tonnes and the average electric consumption is 700–1000 kWh per tonne of steel. These furnaces are excellent for melting and refining plain carbon and low alloy and high alloy steels in addition to non-ferrous metals.

(iii) Electric Induction Furnace

Melting of metal in an electric induction furnace differs from that in the arc furnace in that, instead of the bulk of the heat being generated in an arc and radiated to the charge, all the heat is generated in the charge itself. The furnace (Fig. 6.15) contains a crucible or a monolithic lining surrounded by a water-cooled copper coil. The coil represents the primary to which a high frequency current of 1000 cycles per second or higher is supplied by a motor generator set, a spark-gap converter or an electronic solid state converter. By induction, secondary currents, called eddy currents, are produced in the crucible charge. The flow of these currents is motivated by potential difference between the various parts of the charge. Resistivity of metal causes current losses, which are dissipated into heat energy, thereby melting the metal. In the case of ferrous metals, which show magnetic property, the loss due to hysteresis produces extra heat.

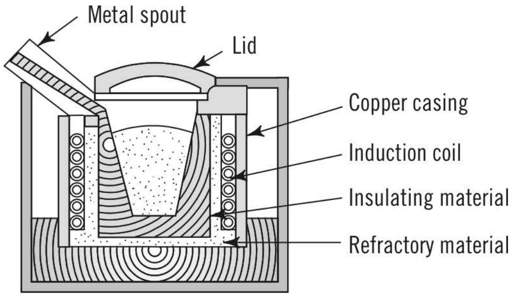


Fig. 6.15 *High frequency induction furnace*

Very high temperatures can be obtained by this method of melting, the only limitation being the ability of the furnace lining to withstand the temperature developed. Induction furnaces are of two types, viz., cored and coreless. The *cored furnace* carries an induction coil, which is immersed within the metal bath and acts as a core for the eddy currents to flow. The electromagnetic induction effect causes the liquid metal to move through the channels around the coil and, simultaneously, secondary currents, which cause heating, are induced in the liquid metal around the core. This type of furnace, though most efficient, requires a liquid metal charge while starting and therefore, cannot be used for intermittent operation. The cored furnace is largely used for melting non-ferrous metals on a relatively long run basis. Modern channel furnaces are the forerunners of conventional cored-type induction furnaces, which are now being extensively used for mixing, superheating, melting and storing of molten metals for grey, malleable and SG iron castings. During periods of power shortage, when the availability of power is limited in daytime and demand for metal is high, use of channel furnaces enables melting during the night, and pouring during daytime. The arrangement enhances the efficiency of the casting process and increases productivity. The special characteristics of channel melting include moderate power input, low bath movement, good holding properties and low melting losses, large holding capacity and suitability for adoption of the automatic pouring system. *Coreless induction furnaces*, on the other hand, do not have any induction coil or core and the secondary currents or eddy currents are induced in the charge itself by electromagnetic induction. Such furnaces are designed particularly for ferrous metals.

Induction furnaces are built in capacities varying from 100 kg to 30 tonnes, though, for foundry use, a capacity in the range of 1 tonne to 5 tonnes is found most suitable. The present trend in cast iron and alloy cast-iron melting is more and more towards the use of induction melting and, in many large automotive foundries, the cupolas are being or have already been replaced by induction furnaces of large capacities. The approximate power consumption of these furnaces is about 650–750 kWh per tonne of metal.

Induction furnaces have largely been of the high frequency type, the frequency of current ranging as high as 100,000 cycles per second. However, medium frequency or main frequency induction furnaces, which have proved ideal for melting cast irons, have also come into use. They work efficiently and melt rapidly if a small quantity of molten metal (heel) is left in the furnace after tapping. Stirring action is also better in these furnaces. When a liquid heel is present, even finely divided scrap can be quickly melted due to the fast stirring action of eddy currents. When the furnace is to be started from cold, the initial metal charge must consist of a large piece of metal such as an ingot. This difficulty does not occur in high frequency furnaces, which can easily melt small pieces of metal from cold.

Advantages of Induction Furnaces

(i) Induction furnaces have high flexibility in that even a small quantity of metal of any composition can be melted. The melting process is also quite simple.

(ii) The induction furnaces have an extremely high rate of melting. Though the actual time depends on power input and size, the melting time is generally about one hour. The unit can therefore deliver metal at regular intervals.

(iii) The control of temperature is very easily and quickly obtained within a wide range, the upper limit being higher than that in any other established commercial method.

(iv) Highly alloyed steels can be melted without appreciable loss of alloying elements, and can therefore effect large economies. The actual metallic yield of liquid steel from scrap is also exceptionally good.

(v) High quality metal and alloys free of hydrogen and nitrogen can be produced by this method.

(vi) The initial cost of installation is generally higher than that of an arc furnace of the same capacity, but operating costs are lower because of low refractory consumption, low power consumption, absence of electrodes, better heat utilisation, and shorter melting times. The induction furnace also has the advantages over other types of melting units in the saving of floor space and freedom from pollution.

Disadvantages of Induction Furnaces

(i) The initial cost is high.

(ii) There can be no refining process due to difficulties in maintaining hot fluid, and reactive slag on the metal surface.

(iii) Both sampling cannot be carried out owing to high speed of melting.

Melting Procedure for High Frequency Induction Furnace The charge for melting is made up from a specially selected scrap and suitable alloy additions so as to give the required composition. The high melting speed and small surface area results in small loss of alloys during melting limited to maximum 10%. Only a small amount of deoxidising alloys are added just before tapping. As no refining action can occur, the sulphur and phosphorus content of the charge must initially be within the specification limits.

The scrap is charged into the furnace with turnings or plate scrap at the bottom and the power is switched on. As the steel melts, a pool of molten metal forms at the bottom of the furnace, and the remaining charge in the upper portion slips down into it until all of it is melted. As the melting proceeds, extra scrap may be added, till the required metal temperature is reached. The power is then switched off, and alloys are added to adjust the composition of the metal. The final deoxidisers—ferro-silicon or aluminium—are then added. Aluminium may also be put in the ladle.

When the alloy additions have been absorbed by the metal and the reactions are complete, a small amount of the slag produced is removed. The metal is then tapped into a ladle by tilting the furnace.

Electric melting is compared with other melting practices in Table 6.9.

Table 6.9 *Comparison of electric melting with other melting practices*

Item	Electric melting	Other melting practice
Initial investment	High	Low
Operating costs	High	Low
Flexibility of operation and versatility for small and large castings	Very good	Little
Quality of metal and control of composition, etc.	Easily possible	Difficult
Temperature control	Easy	Difficult
Floor space required	Less	More
Loss of metal and alloys	Less	More
Alloy recovery	High	Low
Power consumption	High	Low
Rejection of castings	Low	High
Environmental pollution	Very low	High
Availability	Good	Good
Thermal efficiency	High	Low

6.2 REFRACTORIES FOR MELTING UNITS

Refractories are materials that can withstand high temperatures and resist the action of slags. These materials should not show any sign of fusion below 1580°C because they are used to serve as receptacles for molten metal. Refractories form a vital part of all melting furnaces in foundries.

Good refractory materials

(i) do not fuse and soften at the temperature at which they are used;
(ii) are able to withstand thermal shock due to sudden change in temperature;
(iii) resist abrasion;
(iv) do not get crushed under the heavy pressure of the charge when used at high temperature;
(v) have a low thermal coefficient;
(vi) are chemically inert and resist corrosion;
(vii) do not allow gases to permeate through them; and
(viii) have high electrical resistance if used for electric furnaces.

In actual practice, no refractories fulfil all these requisites, but there are some materials that satisfy many of the conditions.

Refractory materials are classified as acid, basic, or neutral, according to their reactivity with acidic or basic slags formed in the furnaces.

6.2.1 Acid Refractories

Acid refractories are those that are not attacked by acid slags. The common acid refractory materials are silica and fire clay. Silica, in the pure state, fuses at a temperature of 1710°C; when heated in contact with some basic material, it forms a silicate. Silica bricks are hard and refractory and can withstand 3 kg/cm^2 load at 1600°C. The thermal shock resistance is low and a tendency to spall is shown during rapid fluctuations of temperature. Fire clays are composed of hydrated aluminium silicate ($A1_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). The properties of fire clay bricks differ markedly due to variations in chemical composition.

The thermal expansion of these bricks is low, but the resistance to spalling is high. The fusion temperature is well over 1700°C, but, under load conditions, it gets lowered (1380°C under about 1.5 kg/cm^2). The general requirements of fire bricks, classified into two types as per IS: 1871–1958, are as shown in Table 6.10.

6.2.2 Basic Refractories

Basic refractories are those that do not react with basic slags. They are suitable for lining furnaces operating on the basic slag practice. Common basic refractories are magnesite, chrome-magnesite and dolomite. Magnesite has a high fusion point

Table 6.10 *General requirements of fire bricks*

PROPERTY	TYPE I	TYPE II
Pyrometric cone equivalent, minutes (ASTM Cone No.)	30 minutes	31 minutes
Apparent porosity (% max.)	25	22
Cold crushing strength (kg/cm^2, min.)	200	200
Permanent linear change after reheating (% max.)	For 5 hours at 1350°C ± 1.0	For 2 hours at 1400°C ± 0.5

of 2800°C and good resistance to the corrosive action of basic slags. Magnesite bricks have poor thermal shock resistance and low resistance to abrasion whereas chrome-magnesite bricks have superior refractoriness under load and better thermal shock resistance. These consist of 20–30% MgO and 70–80% chromite. Both magnesite and chrome-magnesite bricks are expensive and are used only where slags are highly basic in nature. Dolomite, a double carbonate of calcium and magnesium ($CaCO_3 \cdot MgCO_3$), serves as a cheaper substitute for magnesite. Stabilised dolomite, which consists of $3CaO \cdot SiO_2$ and MgO, is a better refractory than ordinary dolomite as it is not overprone to expansion and cracking. Bauxite ($Al_2O_3 \cdot 3H_2O$) is also highly refractory when pure and is basic in nature. Its utility is, however, limited owing to the presence of many impurities which lower its refractory value.

6.2.3 Neutral Refractories

Neutral refractories neither react with acid nor with basic slags and they permit the use of both acid and basic processes on the same lining. Common neutral refractory materials are carbon, graphite, chromite, and sillimanite. Carbon bricks do not form a liquid phase on heating and thus retain strength at high temperatures. Their resistance to thermal shock is high and the coefficient of thermal expansion low. They are not melted by molten metal and slag. The oxidation in air as well as in other oxidising gases is rather high at temperatures above 1400°C.

Chromite bricks are manufactured from chromite ore, which is composed of 32% FeO and 68% Cr_2O_3. The fusion temperature of chromite bricks is about 2180°C.

Sillimanite contains 63% Al_2O_3 and 37% SiO_2. Its fusion temperature is 1900°C. It has a low coefficient of thermal expansion, and good resistance to abrasion, spalling and corrosive action of slags. The strength retained at high temperature is also fairly high.

Zircon, composed of 100% zirconium oxide, is also suitable as neutral refractory.

Neutral refractories, though ideal in properties, are very expensive and their use is therefore limited to special applications.

Selection of Refractory Materials for Different Furnaces

1. Cupola In the hearth area of the cupola, refractory lining is in contact with molten metal, slag, and relatively static coke. The effect of abrasion is therefore not serious, but the lining is prone to the chemical attack of slag. In the melting zone, the lining encounters high temperature and chemical reactions, and thermal shock too, as cold air rushes through the opening when the base is dropped. The choice of refractories in the hearth and melting areas depends on slag practice. Acid slag practice requires a lining of fire bricks, silica, or alumina. Basic slag practice needs magnesite, chrome-magnesite, or burnt dolomite lining; carbon lining is also used occasionally. Lining in the charging zone is not subject to high temperature or attack by the action of slag, but it withstands severe abrasion when the charge moves downwards. Hard-burnt fire clay of low porosity is quite suitable for this region. Cast iron blocks are also used in the upper part near the charging door. The area above the charging door serves only to protect the shell from the heat of stack gases. It is also lined with fire bricks.

2. Electric Arc Furnace The type of refractory used in this furnace depends on the type of operating practice, viz., acid or basic. If the lining is acid, the roof and side walls are built of silica bricks. The hearth has first a layer of fire bricks next to the shell, followed by two courses of silica bricks. The brickwork is rammed finally with a hearth mixture comprising silica sand mulled with about 4% ball clay. In the case of basic practice, the roof is constructed of silica bricks or sillimanite. Sometimes, the outer circle is made of chrome-magnesite bricks and the side walls are lined with silica bricks. However, it is more advisable to use magnesite bricks. Chrome-magnesite bricks are also used for side walls. The hearth shell is lined with magnesite bricks. Stabilised dolomite bricks are also suitable for the hearth. The brickwork is thoroughly dried before the working hearth is rammed with magnesite or dolomite powder.

Maintenance A good refractory maintenance aimed at balanced wear is important to get optimum performance of an electric arc furnace. The slag line including the hot spots and the banks are the areas where most of the repair is necessary. Hot repairs to the furnace lining, in contrast to those made after shutdown, have potential advantages such as increasing the operating efficiency and preventing loss of heat. Eroded spots on the banks or hearth of the furnace are filled up immediately after tapping each heat by throwing furnace bottom sand or crushed ganister in the case of acid lining.

For basic lining the refractory maintenance materials are usually basic products but they differ substantially from the basic materials used for manufacturing of basic bricks. A maintenance material must have adequate refractoriness, but at the same time it must contain a percentage of low melting phases which promote sintering in the temperature of 925 to 1425°C. In addition, a chemical binder must be included to impart sufficient strength after drying and prior to sintering. However, this binder lowers the refractoriness of the maintenance material. Regarding grain size of the maintenance material, it may be noted that although a compact layer may give maximum wear resistance, the grade suitable for maximum compactness will not flow satisfactorily through the spray machine and will give rise to segregation. Moreover, if a wet maintenance material is used excessively, the compact layer hinders escape of water vapour during drying. The large-sized grain fraction contributes to the rebound loss whereas the fine fractions lead to down flow. For this reason, fairly even grain size distributions are generally selected. The maintenance materials are usually magnesia, doloma, doloma magnesia or magnesia chrome products. The range of minor constituents added as binding, sintering and plasticising agents include silicates, alkaline phosphates, sulphates, chromates and clays.

The machines used for application of the maintenance material include pressure chamber spray guns, rotary valve guns or centrifugal spinners.

3. Induction Furnace A high-frequency current is carried by a water-cooled coil in the induction furnace. The inside of the coil is rammed with a thin layer of sillimanite refractory to form a melting chamber. The thin layer is rammed by hand around a core which is made in the form of a steel or asbestos cylinder. The core can be either withdrawn or melted with the first charge. When the lining is acid, a rammed ganister bonded with clay or sodium silicate is used. For basic lining, sintered magnesite, fused alumina, and zircon give best results.

The refractories for lining must have the following characteristics:

Compatibility with Alloys and Oxides The life of the furnace lining depends upon its compatibility with the metals and alloys being melted and the oxides formed during melting.

Retention of Strength at Steelmaking Temperature This is a desirable characteristic, because at this temperature, the lining is subject to mechanical abuse when putting scrap into the furnace and when using crowbars to prevent scrap from bridging over.

Low Thermal Conductivity The refractory should have low thermal conductivity for prolonged life of the induction coils and less heat loss.

Low Electrical Conductivity Electrical conductivity of the refractory material should be low for efficient induction heating.

Resistance to Slag Corrosion and Erosion The refractory lining should be resistant to slag corrosion and erosion to minimise the chance of metal breakthrough and repair between relinings.

Low Reheat Shrinkage The lining should undergo small volume changes during heating up and cooling down of the furnace such that chances of development of cracks and subsequent metal breakthrough to the coil is minimum.

Resistance to Thermal Shock Induction furnaces, because of their small size, are subject to rapid temperature changes. Consequently, the refractory material should have good thermal shock resistance to prevent cracking and metal penetration.

Table 6.11 *Principal refractory raw materials and familiar refractory products*

Raw material	Occurrence	Products	Essential components
Dolomite ($CaCO_3$)	Natural	Raw dolomite, burned dolomite and brick	$CaCO_3$, CaO-MgO
Magnesite ($MgCO_3$)	Natural	Gunning and ramming mixes, magnesite cements, mortars	Magnesia (Periclase) MgO
Brucite ($Mg(OH)_2$)	Natural and synthetic		
Chrome	Natural	Chrome ore as plastic mortar or ramming material, chrome brick	Chromite spinel
Chromite spinel (Mg. Fe) O. (Cr, Al, Fe)$_2$O$_3$			
Sillimanite (Al_2O_3-SiO_2)	Natural		Mullite SiO_2
Kyanite (Al_2O_3)	Natural	Sillimanite-mullite mortars, ramming mixes, and brick	Mullite & SiO_2
Mullite ($3Al_2O_3$-$2SiO_2$)	Synthetic		Mullite
Fireclay (X Al_2O_3; Y SiO_2; Z H_2O)	Natural	Raw fireclay, wide range of cements, mortars, plastics, castables, ramming and gunning mixes, and brick	Mullite SiO_2
Quartzite (SO_2) Ganister	Natural	Sand, acid ramming	SiO_2

Good Maintainability The refractory material should be easy to repair and renew.

Proper Hardening Characteristic The unfused portion of the lining should not harden. As a result, when a crack develops on the lining surface, the soft backing refractory flows into the crack and seals it, thereby preventing metal breakthrough and enhancing lining life.

Economy Above all, the refractory lining material should have optimum characteristics for overall economy.

The thickness of refractory lining of a coreless induction furnace must be such as to ensure good electrical efficiency and thick enough to counter the risk of unexpected failure and major damage to the coil. A thumb rule generally used is a thickness of about 8″ of the crucible diameter.

Maintenance After each heat, it is important that the furnace be thoroughly cleaned of all slag and metal using suitable tools and the lining patched if necessary when it is cold. The bottom of acid lined furnaces are generally repaired by fettling with a mixture of quartzite and boric acid. After pouring the mixture of the damaged area, it is tightly rammed and covered by a sheet of boiler plate and then the furnace charge is put in. For patching the walls when their thickness falls by one-third, a template of 2-mm thick steel (with bottom) is inserted and filled with the furnace charge. Quartzite is poured into the space between the walls of the crucible and the template and packed down with a 5–10 mm dia steel rod. After patching the melting period is extended 1½ hours to sinter the new layer.

In case of small cracks or pits formed on the inner surface of the magnesite lining, the damaged area is smeared with a mixture of fine magnesite and chrome magnesite powder (1 : 1) with 10% clay and moistened with sodium silicate solution.

4. Air Furnaces These furnaces, which are commonly used for the production of malleable iron, require silica for the hearth and fire bricks for the side walls, crown, bungs, and stack.

The common tests applied for refractories are

(i) specific gravity;
(ii) bulk density;
(iii) porosity;
(iv) permeability;
(v) refractoriness;
(vi) slag attack;
(vii) resistance to spalling; and
(viii) cold crushing strength.

IS: 1528–1962 gives the methods of sampling and the physical tests for refractory materials.

METALLURGICAL CHARACTERISTICS OF CAST METALS 6.3

6.3.1 Nature of Cast Metals and Solidification

All metals, whether in pure or alloyed form, are crystalline in nature. When the metal starts solidifying, metal crystallites, called *nuclei*, first form. The growth of nuclei takes the shape of a pine tree often described as *dendritic*. The growth of dendrites takes place as shown in Fig. 6.16 and the growing arms keep impinging on each other and increasing in size until the metal becomes completely solid. Dendrites are called *crystals* or *grains.* Within each grain, atoms of the metal are aligned in certain definite form, called *lattices.* Lattices of austenitic iron, copper, and aluminium are the face-centred cubic type; those of ferritic iron and chromium are the body-centred type, and those of magnesium and zinc, the hexagonal close-packed type. These different arrangements of atoms impart varying peculiar properties to the metal (Fig. 6.17).

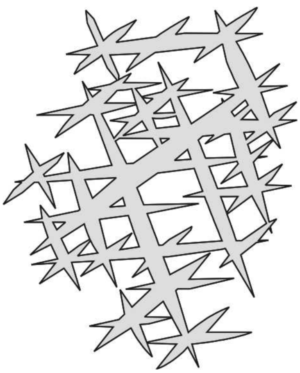


Fig. 6.16 *Dendritic structure*

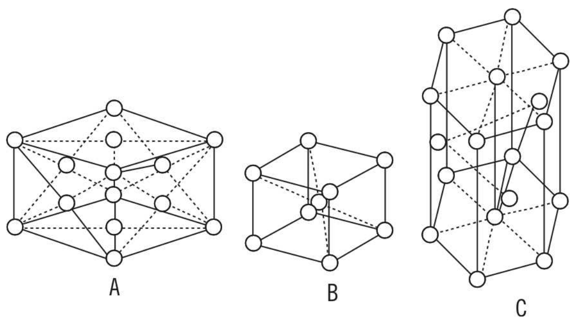


Fig. 6.17 *Types of Lattice Formation: (A) Face-centred, (B) Body-centred, (C) Hexagonal close-packed*

Pure metals possess certain typical characteristics, such as high thermal or electrical conductivity, good resistance to corrosion, and high melting points. However, from the foundry point of view, pure metals present difficulty in casting as they freeze at one definite temperature and solidify quickly (Fig. 6.18). Though pure metals are required to be cast in a foundry for certain specialised applications, their scope is rather limited. More commonly, pure metals are alloyed with other elements to modify or improve the existing properties. In alloyed form, they are stronger, melt at lower temperatures, solidify slowly (melting range is increased), and hence have better fluidity and

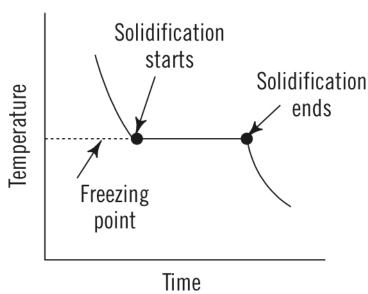


Fig. 6.18 *Single temperature freezing of a pure metal*

castability (Fig. 6.19). For a given alloy, there is a particular temperature (*liquidus temperature*) above which all is liquid, and there is another (*solidus temperature*) below which all is solid. The portion lying between solidus and liquidus is called the *mushy zone* (Fig. 6.20).

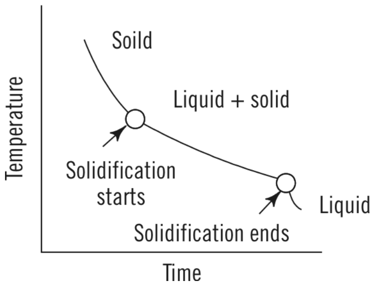


Fig. 6.19 *Freezing of an alloy over a temperature*

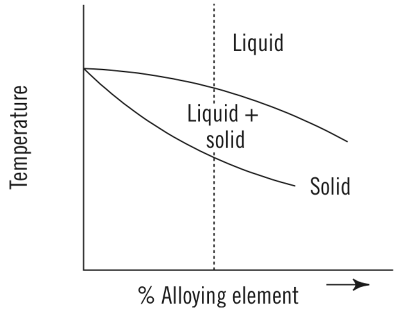


Fig. 6.20 *Effect of alloying on solidification of an alloy*

Alloying elements may get completely dissolved in the crystal structure of the base metal and the combination is called a *solid solution*. On the other hand, if the alloying element is not completely soluble, the final alloy may be a mechanical mixture of two or more types of grains of varying composition. Such a mixture is called an eutectic mixture. The eutectic mixture is formed at a definite temperature, known as *eutectic temperature*. The peculiarity of the *eutectic mixture* is that it freezes, as does a pure metal, at a constant temperature (Fig. 6.21).]

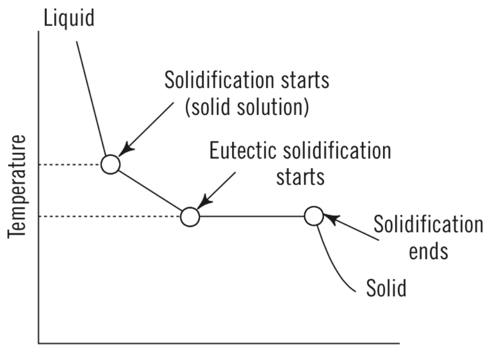


Fig. 6.21 *Freezing of an eutectic alloy*

If the solidification is not arranged to occur at a slow rate thereby causing full diffusion and solid solution, non-equilibrium conditions prevail and give rise to a 'cored' structure. In such a case, the composition of the alloy formed by solid solutions as cored dendrites in the centre differs from those in the outer surface. In cast alloys, the ;coring' phenomenon is extremely common as the solidification rates are relatively fast and seldom so slow as to allow complete diffusion under equilibrium conditions.

When a metal or alloy cools from liquid state to solid state, it contracts in three distinct stages: (i) liquid contraction, which takes place when the alloy cools from the pouring temperature to the solidification temperature; (ii) solidification contraction, which occurs when the metal passes through the stage of solidification; and (iii) solid contraction, which spans the period when it cools from solidification temperature to room temperature. Figure 6.22 shows the relation between temperature and the specific volume of steel.

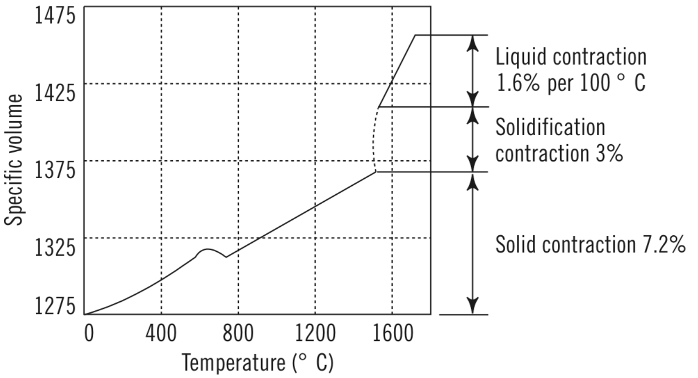


Fig. 6.22 *Change in specific volume of steel with temperature*

Of these three contractions, the first two, i.e., liquid and solidification contraction, are taken care of by a proper risering system. The void created by these two shrinkages in the casting is filled up by the molten metal supplied by the riser. The solid contraction of the casting is accounted for by making the pattern dimensions larger than those of the casting by the amount of contraction. Solid contraction, if not properly controlled, may cause warping or hot tearing of castings besides producing dimensional errors.

Pure metals or nearly pure metals solidify by first forming a thin solid skin at the metal mould interface where cooling is maximum (Fig. 6.23). This skin then grows progressively in size inwards into the casting. It is found that when the mould wall is plain and flat, the thickness of the skin formed is proportional to the square root of time. Thus, $t \propto \sqrt{T}$ where t is the skin thickness and T the time after pouring the metal into the mould,

or $\quad t = k\sqrt{T}$

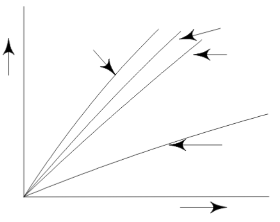


Fig. 6.23 *Relationship between skin thickness and time for different mould materials*

where k is a constant whose value depends on the mould material and its thermal conductivity.

The time taken for the complete solidification of the casting can be approximately expressed, as per Chvorinov's rule, as proportional to the square of the ratio of volume by the surface area.

$$\text{Thus, solidification time} = K_s \left(\frac{\text{volume}}{\text{surface area}} \right)^2 .$$

It is also seen that solidification in the casting depends on its shape and configuration. For example, heat is more easily dissipated and solidification is more rapid at external angles than at internal angles.

Unlike pure metals, alloys freeze over a range of temperature. Even metals having a small amount of impurities tend to so react, causing the melting point of the alloy to be lowered. During the solidification of alloys, a mushy area, comprising solid dendrites protrudes into the unaffected liquid–solid interface and it is found to be in jagged form, as shown in Fig. 6.24.

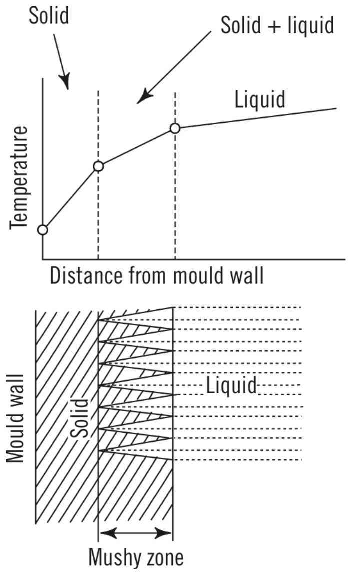


Fig. 6.24 *Formation of mushy zone in case of an alloy*

The width of the mushy zone for a given alloy is again a variable factor, depending on the mould material, the cooling rate, and the temperature gradient. In the case of steels, the mushy area of low carbon steel is very narrow, the carbon content being small and the metal freezes more in the manner of a pure metal. As the carbon content is increased, the width of the mushy zone also increases. Thus, in the case of high carbon steels, the mushy region can be so wide that the protruding dendrites can reach far into the centre of casting before a solid skin of considerable thickness is formed. The temperature gradient between the pouring temperature of metal and that of the mould also affects the solidification and the width of the mushy zone. The more steep the thermal gradient, as in the case of steel, the narrower will be the mushy zone and vice versa. From the foundry point of view, the wider the mushy zone, the more fluid the molten alloy can remain and flow, thus facilitating its casting. Most foundry alloys, except steels such as cast iron, brass, bronze, aluminium, and magnesium alloys, have a very wide mushy zone. In fact, brass freezes without forming any solid skin.

The grain structure created in the solidified metal depends largely on the rate at which the heat is extracted from it by the mould. Initially, when the metal is poured into a cold mould, the liquid at the mould face cools very rapidly, and its temperature often drops even below its freezing point (the metal is said to be super-cooled). This region is called the *chill zone* and fine equiaxed grains are produced here. In the area adjoining the chill zone, the cooling slows down and dendrites tend to grow perpendicular to the mould wall to form an elongated type of dendrite, called *columnar grains*. Pure or near-pure metals generally have a structure comprising chill grains and columnar grains. During latter stages of solidification, if the mushy zone is large, as in the case of alloys, a third type of grain, called *coarse equiaxed* grain, is formed. In alloys such as cast iron or non-ferrous metals, which have very wide mushy zones, the coarse equiaxed grains predominate over the columnar grains. Sometimes, special grain-refining substances are also added to hinder the formation of columnar grains and promote a fine type of equiaxed grain throughout the structure.

Gases such as hydrogen, oxygen, and nitrogen and elements such as carbon and sulphur tend to get dissolved in metals. The solubility of these gases is high enough in liquid metals, but decreases considerably when the temperature is lowered below 600°C. However, even these leftover gases can produce defects in castings in the form of blowholes, pinholes, or micro-porosity. Hydrogen is one of the gases that is soluble in all metals and can cause maximum trouble in many metals and alloys.

The molten metal may absorb gases from various sources, such as the atmosphere (during melting in the furnace or during pouring), or lining material if it is not fully dried, or wet or oily charge materials, or mould materials. Certain precautions can be taken to keep the gas absorption from these sources at a minimum, although it cannot be fully prevented. These precautionary measures include (i) use of dry and clean charge, dry lining, dry and clean tools, and moulding materials free of volatile matter; (ii) melting in a protective atmosphere, e.g., a slag, under vacuum, or in an inert gas atmosphere; (iii) melting and pouring at as low a temperature as is practically possible; and (iv) handling the molten metal for stirring, re-ladling, etc., as little as possible.

As the metal must, as far as possible, be free of dissolved gases when it enters the mould, the gases present can be eliminated by an operation called degassing. The three common methods of degassing include (i) flushing the molten metal by passing inert gas such as argon, nitrogen, or chlorine through it (done in the case of light alloys); (ii) using solid degassers, which produce an inert gas by chemical reaction with the dissolved gas; for example, calcium carbide, which forms acetylene by reacting with dissolved hydrogen, is used in cast iron, the calcium forming a slag; similarly, C_2C_{16} produces chlorine as an inert gas; in steel-making, CO produced during the carbon boil period, itself acts as an inert gas to flush hydrogen from the metal; and (iii) vacuum degassing, which is concerned with melting metal in a furnace and then placing it in a chamber from which the air is evacuated.

The foundryman needs to consider the nature of the cast metal, its solidification process, the shrinkage caused during solidification, and other characteristics. Accordingly, he must design the patterns and moulds, melt and cast the metal so as to produce castings that are faultless and conform to the desired quality specifications.

Measurement of Molten Metal Temperature

Efficiency of operation of the cupola is reflected by the temperature of the metal tapped. If the design of the cupola, charge proportions, volume and pressure of air blown are all correct, the tapped metal will have high temperature, which means high fluidity of metal, resulting in castings produced being free from misrun, cold shut or blow holes. For purposes of quality control and corrective measures, measurement and recording of temperature of metal tapped and poured is an important procedure to be adopted during the operation of the cupola.

Experience in operating the cupola for long periods enables the operators to gauge the temperature of the metal tapped by looking at the colour and fluidity of the metal. Thus a dull red colour would indicate a low temperature, and a brilliant white colour would indicate a high temperature. As composition and reaction inside the melting zone will have an effect on the physical character of tapped metal, such visual perceptions may become erroneous.

Fluidity Spiral Test was another method utilised to gauge the temperature. This test measures the length of metal traversed in the green sand mould. The length of the spiral will give a comparative idea of temperature. But composition and melting conditions have an effect on the fluidity and thus this test cannot be used as a reliable test for measurement of temperature. (More details about the Fluidity Spiral Test can be read on page 18 of the March/April 1994 issue of Foundry.) This test was widely used in all foundries prior to the development of good temperature measuring instruments.

Temperature measurement has to be done not only during the tapping of metal but also during the pouring of metal. The pouring temperature, particularly the last mould poured from the tap has to be sufficiently high to prevent defects in castings. Measurement of pouring temperature is usually possible by taking the temperature inside the ladle, as the duration of the time of pouring the mould is limited.

In the production of SG Irons, the measurement of temperature during processing and pouring is of great importance.

Temperature Measuring Instruments

These are also called pyrometers. There are three types of *pyrometers.*

1. Optical Pyrometer
2. Radiation Pyrometer
3. Immersion Pyrometer

Optical Pyrometer It is used in many foundries. It is convenient to use, can be held in the hand and sighted as a telescope, temperature can be taken without dipping any part in the molten metal, and thus needs no replacement of any part. Hence the cost of measurement is nil. It has become popular for its economy in use.

The operation of the optical pyrometer depends on the photometric comparison of the intensity of light emitted from the body under observation with that emitted by the filament of the incandescent wire within the instrument. The intensity of the light filament is proportional to the electric current passing through the wire which is varied using a rheostat operated by a knob. The brightness of the filament is varied to match the brightness of the light emitted by the stream of metal coming out of the spout of the cupola. The current passing in the wire is directly read on the meter as temperature in °F or °C. In the Disappearing Filament Instrument, when the filament is at a higher temperature than the stream, the filament looks like a bright line. When the filament is at a lower temperature, it looks like a black line. When the temperature is the same as that of the stream of metal, the filament disappears. At this point the meter is read directly in °C or °F.

The instrument is capable of measuring temperatures from 1000 to 1750°C to an accuracy of plus or minus 2°C. Certain precautions have to be taken during measurement. The telescope should not be sighted through smoke and fumes or sighted on slag or scum surfaces. The best way is to take the temperature reading when the metal is coming out in a stream. If the ladle temperature is measured, the slag or dross should be pushed aside.

Radiation Pyrometer This type of instrument is not commonly used in the foundry. This works on the principle of measuring the heating effect of the energy emitted by the surface of the hot metal. This heat energy is concentrated on the hot junction of the thermocouple measuring the temperature. As there is a time factor involved in measuring the heat energy effect, this type is not used to measure the temperature of cupola-tapped metal.

Immersion Pyrometer This is a very popular instrument used in the foundries, especially to measure temperature in the ladle. Thermocouples of various alloys, the most common being platinum–platinum rhodium, are used in this measurement. When two alloys of different compositions are joined together and the joint is heated, an electric current is generated which is proportional to the temperature to which the joint is heated. This current is read by the instrument calibrated in °C or °F. The wire is embedded in a ceramic tube, which is again enclosed in a graphite or clay tube. This is immersed inside the molten metal in the ladle and the temperature read in the instrument. After a few dippings the clay or graphite tube has to be replaced.

This method is more expensive than the use of an optical pyrometer as tubes and elements have to be replaced regularly. But this is a more accurate method and is very popular in Steel and SG iron foundries. Care has to be taken to frequently calibrate the instrument with standard instruments to avoid inaccurate measurements.

6.3.2 Characteristics of Cast Metals

Iron Casting

Cast iron, the most commonly cast ferrous metal, is made up of iron, along with carbon, silicon, phosphorus, manganese, and sulphur. Carbon has a powerful effect on the structure and properties of iron. As is evident from the iron–carbon equilibrium diagram (Fig. 6.25), the solubility limit of carbon in iron at the eutectic temperature of 1130°C is 2.0%. If the carbon content is less than this limit, the material is graded as steel, whereas anything above this limit is considered cast iron. In addition to carbon, the amount of silicon present in cast iron is also of consequence in controlling most of its characteristics. Smaller amounts of manganese, phosphorus, and sulphur also affect the properties of iron.

When alloying elements, such as carbon in iron, are present, they tend to be rejected by the solidifying metal at the liquid interface. These rejected particles of alloying elements act as nuclei for the solidification process, e.g., the atoms of the parent metal begin getting deposited on these nuclei. The latter thus grow in size, forming the so-called dendritic (tree-like) structure. The cooling characteristics and the entire transformation phenomenon can be readily understood from the iron–carbon equilibrium diagram.

Fracture and Structure A study of a fractured section of a wedge-shaped test piece cast from molten cast iron shows a grey fracture in a slow-cooling area, i.e., the area with a thick wall; a white fracture in a fast-cooling area, i.e., the area with a thin wall, and a combination of grey and white in the intermediate area. The grey area is called *grey cast iron*, the white area is called *white cast iron*, and the intermediate area is called *mottled iron*. A microstructure of grey cast iron may show graphite flakes existing in pearlite and ferrite matrix or only in pearlite. A microstructure of white cast iron, on the other hand, consists of cementite and pearlite. A mottled structure contains a mixture of graphite interspersed in pearlite along with cementite. The phenomenon is conveniently explained by a double equilibrium diagram, according to which the formation of white iron structure is illustrated by Fe–Fe_3C system (solid line) and the formation of grey iron by Fe–Graphite system (dotted lines) (Fig. 6.25).

It is seen that even with the same composition of iron, the sectional size of the casting and its cooling rate have a remarkable effect on the structure. The amounts of carbon and silicon present exert a further influence. When carbon and silicon are low, iron easily turns into white iron and, with increase in carbon and silicon, mottled and grey irons are produced. Even in grey iron, the fracture may be light grey with very tiny particle sizes of graphite, and near black with coarse particle sizes of graphite.

The cooling rate has an appreciable effect on the size and distribution of graphite flakes. A rapid rate of cooling produces fine graphite, frequently in an unwanted dendritic distribution. A very slow cooling, on the other hand, gives rise to coarse distribution of graphite.

Grey irons have lower melting point than white irons in the hypoeutectic range but are more fluid in molten state, and are easier to cast. They also expand during solidification and take a very good impression of the mould. Solid contraction after solidification is also less in the grey variety. Flaky graphite present in grey iron makes it weak and brittle, but, at the same time, it imparts softness, easy machinability, and vibration damping capacity. Most cast-iron castings are made in grey cast iron because of its easy castability and low cost. On the other hand, white cast irons, being extremely hard and unmachinable, have a very limited application, mainly for subsequent manufacture of malleable iron. Figure 6.26 shows typical grey iron castings.

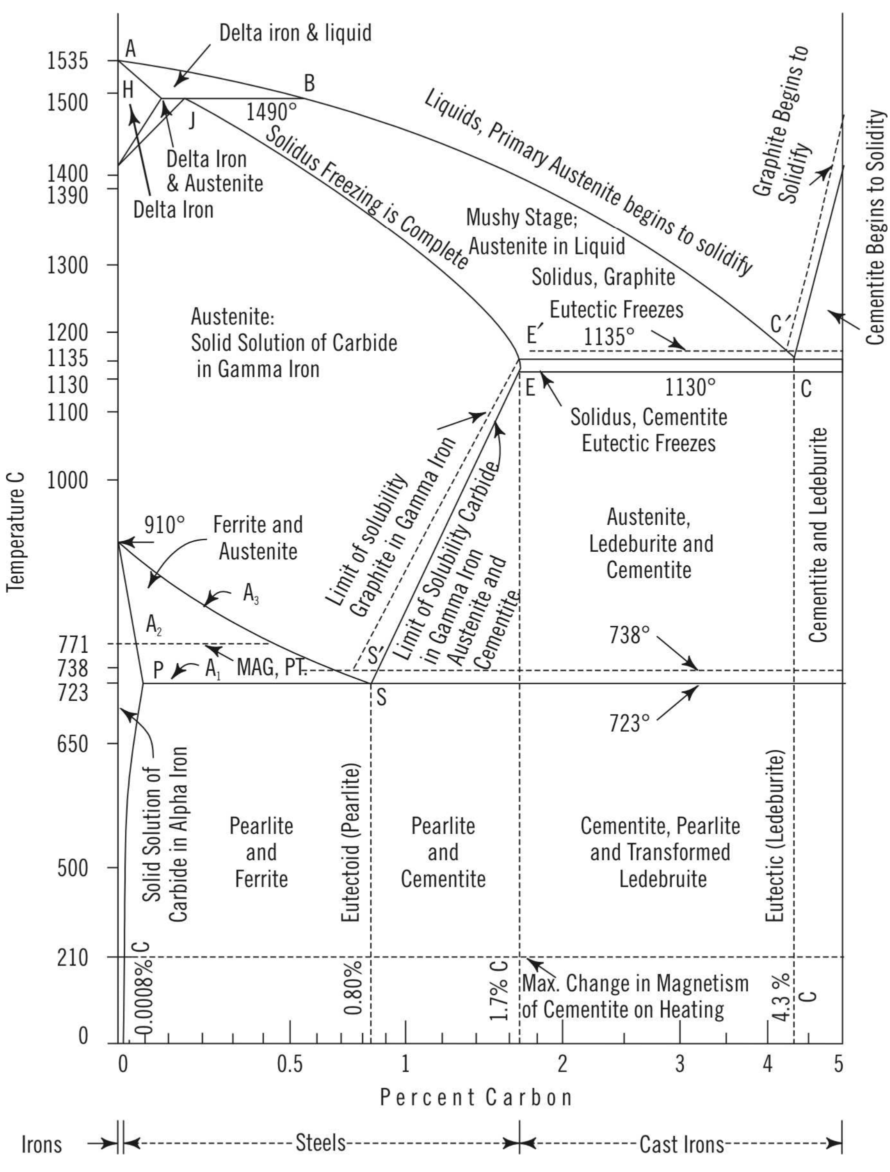


Fig. 6.25 *Iron, Iron-carbon equilibrium diagram*

Effect of Other Alloying Elements

Silicon is always contained unexceptionally in all cast irons in the range of 1–3%. Given the same cooling rate, the higher the silicon content, the greater likelihood that iron will become grey iron; and the higher the carbon content, the more likely again it is that iron will become grey iron. The actual structure of iron is thus

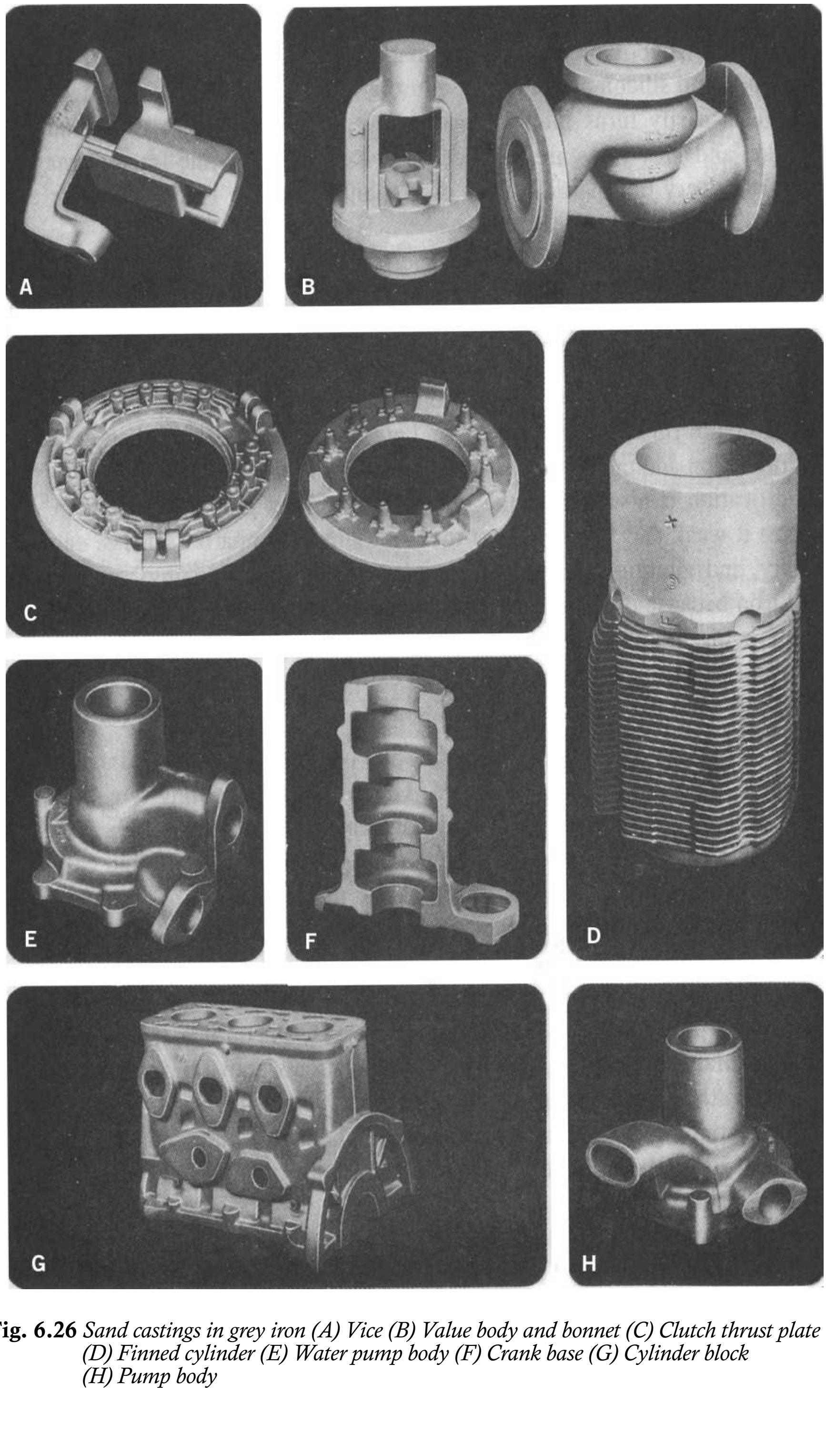


Fig. 6.26 *Sand castings in grey iron (A) Vice (B) Value body and bonnet (C) Clutch thrust plate (D) Finned cylinder (E) Water pump body (F) Crank base (G) Cylinder block (H) Pump body*

controlled by the correlation of carbon and silicon. Silicon acts as a graphitising agent and tends to decompose the iron carbide into ferrite and graphite.

Manganese is ordinarily contained in cast iron in the range of 0.4%–1.0%. The primary purpose for the addition of manganese is to neutralise the harmful effect of sulphur. Manganese forms MnS, which either floats above molten iron or remains inside molten iron, turning into greenish grey inclusions after solidification and hardly disturbing the properties of the iron. The manganese content in iron is usually three times the sulphur content to enable the formation of MnS, plus an excess of 0.2–0.3%. In pearlitic cast iron, an increase in the manganese content even beyond 1% cuts the pearlite size and resists the appearance of ferrite.

Phosphorus is found in iron in small amounts, i.e., not exceeding 1%. It is present partly in solid solution with ferrite and partly as one phase of an iron–iron phosphide cementite ($Fe–Fe_3P–Fe_3C$) eutectic, called *steadite*. The presence of phosphorus lowers the melting point and improves the fluidity of the metal. It is thus helpful in producing thin-walled and intricate castings. However, a morethan 0.3% increase in phosphorus brings about increase in steadite, making the cast iron hard and brittle.

Sulphur is present in iron as iron sulphide. This sulphide has a lower freezing point than that of iron and so destroys the cohesion between the grains by forming a thick grain boundary. It also accelerates the formation of white iron and the occurrence of hard spots in the metal. Normally, the presence of sulphur is regarded as undesirable and its content is kept below 0.05%. In exceptional cases, its carbon-stabilising property is utilised in the production of white cast iron.

IS: 210–1970 gives a classification based on tensile strength, deflection, and hardness, and covers the requirement of six grades of grey cast iron: Nos. 15, 20, 25, 30, 35, and 40. Each grade number pertains to the minimum tensile strength required on a 30–mm test bar. For example, grade 30 iron refers to iron having a minimum tensile strength of 30 kg/mm^2, obtained on a test piece of 30 mm diameter.

Selection of Metal Composition The foundryman must know the composition of metal required for achieving the desired tensile strength and metallurgical structure. Based on this composition, he can choose the charge materials, as described in Section 6.1.4.

Figure 6.27 shows the method for finding out the carbon equivalent of a melt for a given section size and tensile strength. Tensile strength and Brinell hardness are both shown on the ordinate, and section size/diameter on the abscissa. The carbon equivalent value is read on a radial scale by extending a radial line passing through the intersection of section size and tensile strength values and the centre of the arc. It is given as % total carbon + 1/3 (% silicon).

Figure 6.27 can be further used to determine the total carbon and silicon content in iron, knowing the tensile strength and section thickness of the casting, and the

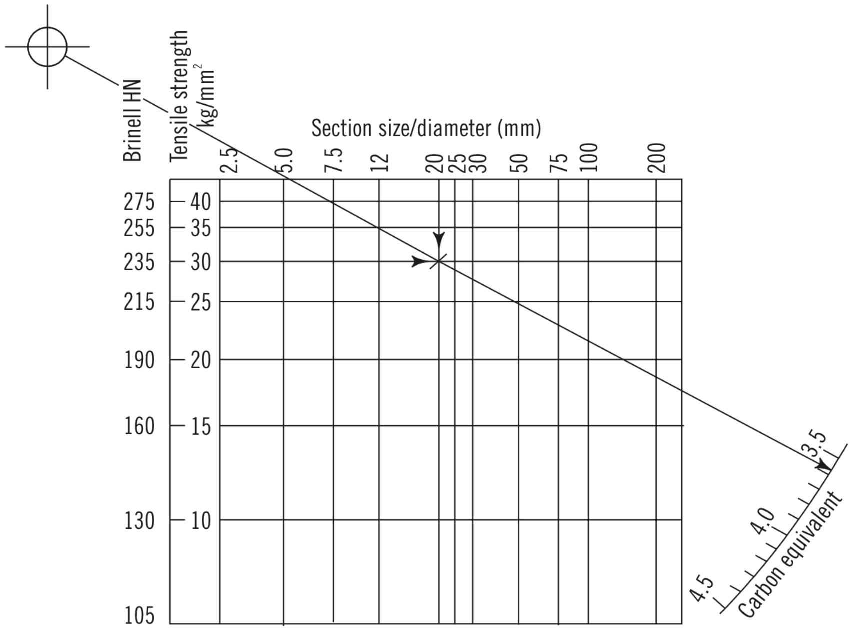


Fig. 6.27 *Determination of carbon equivalent of a melt for varying section sizes*

type of iron to be produced. The diagram on the upper right shows the total carbon for different tensile strength values. From the lower diagram, various types of iron, ranging from white iron to ferrite-pearlitic-grey iron can be produced according to the combined carbon present. The diagram on the upper left shows the proportion of pearlite and ferrite in case of irons having combined carbon varying from 0.1 to 0.8%.

The results obtained from Figs 6.27 and 6.28 can be used as a guideline to establish the exact chemical composition of the iron of the desired grade. Suitable adjustments may have to be made thereafter, based on actual trials.

High-Duty Iron

In order to improve the mechanical and other properties of cast iron, various types of improvements are made in the structure of ordinary grey cast iron. Such improved iron is broadly termed *high duty cast iron*. In grey iron, the cavities occupied by the graphite flakes are long and narrow and their pointed ends tend to act as stress raisers from which cracks can emanate. This tendency is minimised by obtaining the graphite in a finely dispersed form and in fine flaky, nodular, or spherical shape in high duty irons.

A common type of high duty iron is *inoculated cast iron*. This high duty iron has a finely dispersed graphite structure. An iron whose composition would give a white fracture on cooling is used, but just before pouring the molten metal, a

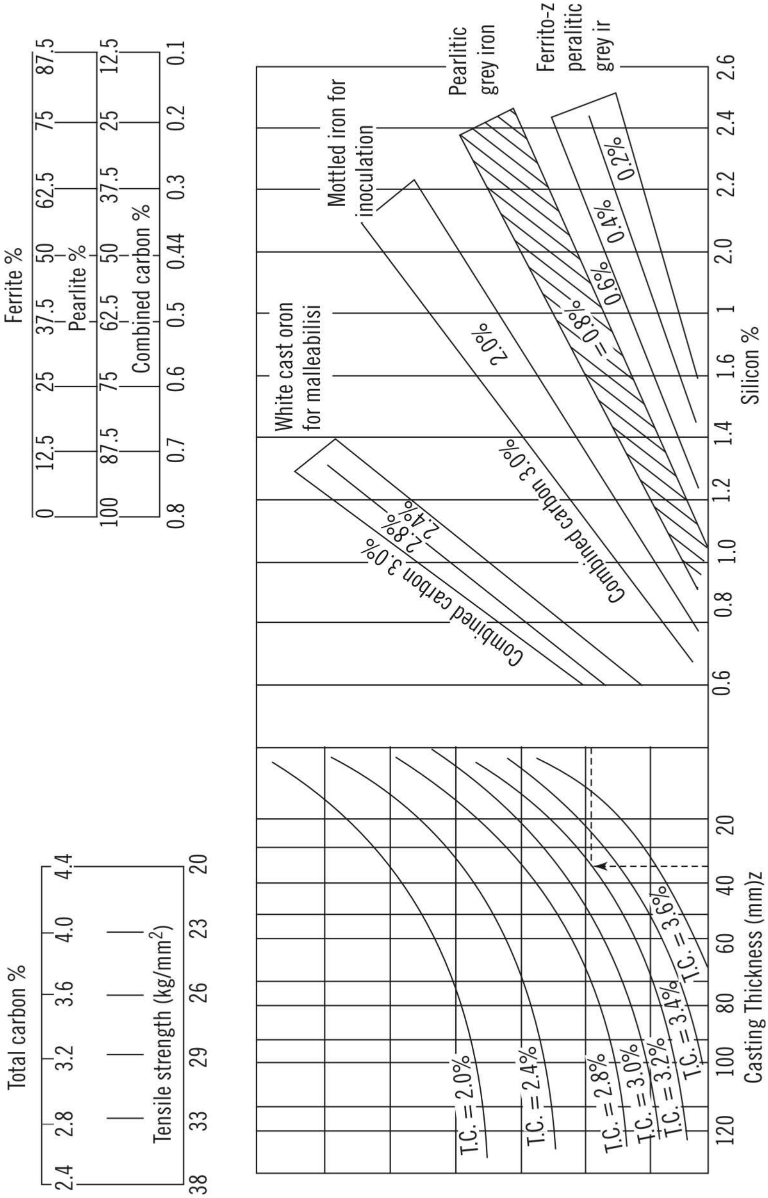


Fig. 6.28 *Determination of total carbon and silicon content in iron*

suitable inoculant, such as calcium silicide, is added to cause precipitation of the finely dispersed graphite.

Inoculated cast iron can be produced with varying mechanical properties, according to the requirements of the designer. The metal in general, may have exceptionally high physical properties and in certain cases replaces steel forgings and castings, high tensile bronzes and other non-ferrous metals. It may be oil-hardened with little or no distortion. It has been extensively used for cast crank shafts in compressors, petrol and diesel engines stamping, forging, blanking, drawing and heading dies, engine heads and covers, high-pressure valve bodies, cylinder liners high-speed gearing and flywheels, rolls, machine tool tables, head stocks, saddles, beds, pistons, piston rings, pulleys, propellers, brake drums, etc.

High duty inoculated iron can be produced to meet specific service conditions, such as high fluid pressure, vibratory stresses and impact, dimensional stability, endurance, damping capacity, machinability, heat resistance, resistance to wear and corrosion.

Typical properties which can be achieved by proper technology and control are:

Tensile strength 35 to 40 kg/mm^2 on (30 mm test bar)

Modulus of Elasticity 12 to 15 × 103 kg/mm^2

Transverse modulus of rupture 50 to 65 kg/mm^2

Compression strength 100–140 kg/mm^2

Brinell Hardness 190–230 and higher

Specific gravity 7.3–7.5

In order to achieve the desired properties, the selection of metal and the treatment to be given are extremely important. A very familiar proprietary name in the field of inoculated iron is 'Meehanite iron', produced under licence from the International Meehanite Co. Ltd., UK There are a large number of foundries in the country, which are licensed producers of Meehanite cast iron. Under the licence, a foundry can get the proprietary inoculants required for production, along with complete know-how and technology.

Inoculation

Inoculation treatment is used to establish nucleation centres for the precipitation of graphite into small type A flakes, uniformly distributed in matrix. Under controlled conditions, as solidification progresses, inoculation helps to create an equilibrium condition between time and temperature. Thus, by inoculation, the following gains are achieved:

1. Improved mechanical properties of gray or SG iron.
2. Control of graphite structure
3. Elimination or reduction of iron carbide
4. Reduction of casting section sensitivity
5. Prevention or minimising of under-cooling

Mould Inoculation Though inoculation in the ladle is a common practice, in which the inoculant in the form of a powder or tablets is placed in the ladle and the molten metal poured over it, a problem of uniformity in the dispersion of the inoculating material is often experienced, and the castings produced lack in consistency as regards hardness and machinability.

Mould inoculation has been successfully used in many foundries to overcome the problems with ladle inoculation. The inoculant in this process, in the form of tablets, is placed at a suitable position in the gating system, such as in the pouring basin by the side of the sprue hole or at the base of the runner bar. Though mould inoculation is an easier process, proper positioning of the inoculant needs to be done for effective and consistent properties. Tablets are made by bonding powdered inoculant with wax or stearic acid.

If no inoculant is used, severe under-cooling may occur, resulting in poor mechanical properties. A typical graphitising inoculant may consist of 72% Si, 1% Mn, 1% Ca, 2% Al, and 4% Fe. In-mould inoculation compensates for the fading of the primary inoculant, which may have occurred prior to pouring. Several new complex inoculants have been developed to improve nucleating and fading characteristics, both for grey iron and SG iron.

Malleable Iron Malleable iron was developed in an effort to make grey cast iron which is, characterised by brittleness when it is bent much, like steel. It is obtained by a heat treatment process carried out on a low silicon, low phosphorus white iron. The structure of the white iron in as-cast form should consist of pearlite and cementite and there should be no free graphite present. The heat treatment which follows, allows the carbon to separate from the iron carbide and form globules of graphite finely dispersed throughout the casting. Further details of malleable iron will be discussed in Chapter 8. IS: 2107–1962 and IS: 2108–1962 cover different types and grades of malleable iron castings.

Spheroidal Graphite (SG) Cast Iron

It is a type of cast iron in which free graphite is present in the form of spheroids or nodules. This makes the iron stronger and more ductile, the strength and ductility values approaching that of cast or forged steel. It thus combines the process advantages of cast iron, and product advantages of casting iron and steel. The typical nodular structure is produced by the incorporation of elements such as cerium and magnesium in the molten metal just before casting. This process of making high-strength iron eliminates the prolonged heat treatment necessary in the malleabilising process. Moreover, the form of graphite particles depends on the additions and is little affected by the rate of cooling. Large castings required in small quantities can therefore be easily produced. SG iron possesses much higher tensile strength (varying from 40–70 kg/mm^2) and ductility (elongation 1–12%) than grey cast iron. Its toughness rates between that of ordinary cast iron and steel and its shock resistance is comparable to that of mild steel. It exhibits excellent pressure tightness and can be welded or brazed. It can be softened by annealing or hardened by quenching. IS: 1865–1992 covers six grades of SG iron castings for common use. IS: 5787–1970, IS: 5788–1970 and IS: 5789–1970 also cover SG iron castings for specific applications. SG iron is also known as *ductile iron* or *nodular cast iron*.

Production of SG Iron

It involves melting of base iron of the correct chemical composition, followed by nodularising treatment with either pure magnesium or an alloy containing magnesium, with or without cerium, so as to leave a residual magnesium content of 0.03 to 0.05% in the treated iron. It is desirable to desulphurise the molten iron by suitable chemical treatment before nodularising. The magnesium treatment is usually followed by a post-inoculation treatment of addition of ferro-silicon, in order to ensure good ductility of the product.

A close control of the chemical composition is essential for the production of good quality SG iron. The total carbon in the base iron should be 3.5 to 4% so that the carbon equivalent of the treated iron is around 4.3. The silicon content of base iron should be 1.5 to 2% so as to achieve 2.2 to 2.5% in the treated iron. As a thumb rule, it may be ensured that total carbon % + silicon % ÷ 7 is not less than 3.9, in order to produce good quality sound castings. The manganese content is limited to 0.5% as it tends to rise hardness and lowers impact strength. Phosphorus content should be kept as low as possible and preferably below 0.05%. In case the phosphrous percentage is initially high in the charge, dephosphorisation treatment is further required after desulphurisation, which may considerably increase the cost of production. It decreases impact strength and lowers the elongation value. Indian pig irons, in general, contain 0.3 to 0.4% phosphorus (Table 6.2), besides some tramp elements which have a harmful effect on the properties of the metal. Use of pig iron, therefore, is best avoided in the charge. Instead, steel scrap of consistent quality is favoured. The presence of sulphur affects the efficiency of nodularisation. Magnesium and cerium are both strong desulphurisers. High sulphur would cause excessive consumption of these metals and would hinder effective nodularisation. Thus, sulphur content in the base iron must be kept as low as possible.

For melting base iron, a coreless, mains or medium-frequency induction furnace is ideal since both chemical composition and temperature can be precisely controlled. A basic-lined or a liningless hot blast cupola used in conjunction with basic slag practice is suitable for production of large quantities of heavy castings. In this furnace, it is possible to reduce the sulphur content to a very low level and obtain sufficiently high carbon in the melt. Cold blast cupolas are not suitable because of low carbon pick-up and low tapping temperatures. Air furnaces of the rotary or reverberatory type are also unsuitable because of high carbon loss due to the oxidising flame and high sulphur pick-up from oil.

Desulphurisation of molten iron is required where the sulphur content in molten iron is more than 0.03%. Several methods are available for desulphurisation. In one case, molten iron is brought in contact with soda ash, calcium carbide or quicklime. High efficiency of desulpurisation is achieved when the area of interface contact between the desulphurising agent and molten metal is large. To achieve this, powder injection using an inert gas like argon or nitrogen as a carrier is practised, through a porous plug or graphite lance. The gas disperses the powder and agitates the iron. Another method is to introduce the inert gas through a porous plug at the bottom of the ladle and to throw desulphuriser powder on the top of the molten iron. Yet another method sometimes practised is to use a shaking ladle which allows mechanical stirring of the molten iron. The amount of sulphur removed depends on the type and amount of desulphuriser, contract time, and method of creating dispersions. Proprietary agents are also available.

The nodularising treatment is effected by using either nickel or silicon-base magnesium alloys. IS: 9630–1980, *Recommended Practices for Production of SG* Iron, gives the chemical compositions of commonly used magnesium master alloys. Pure magnesium is also used but to a lesser extent because of the difficulties of introducing it in the melt. Magnesium impregnated coke has also been used in many foundries. It has been found more economical than other materials.

A large number of techniques are available for graphite speroidization. However, the *ladle transfer process* is most commonly used due to its simplicity. The master alloy is either placed at the bottom of the ladle and molten iron poured over it, or it is introduced while the metal is being poured into the treatment ladle. The ladle may have a recess in its bottom for keeping the master alloy covered with mild steel punchings.

Various other methods are also in use, such as the plunging process, porous plug method, in-mould process and T-knock process, which claim higher recovery of magnesium than the ladle transfer process. These methods are not suitable if pure magnesium is used. In case of treatment with pure magnesium, special arrangements are necessary. Pressure chamber, injection of magnesium powder in a stream of inert gas, and a detachable bottom type of ladle have been used. A GF converter, a device developed by M/s George Fisher, is being increasingly adopted for high recovery of magnesium.

Post-inoculation with ferro-silicon is necessary when good ductility with a higher nodule count is required in the metal. Usually, the metal is transferred to another ladle for post-inoculation. The mould must be poured within 10 minutes of the inoculation to ensure a good quality of SG iron.

It should be ensured that nodularising and post-inoculation treatments are carried out at a temperature not lower than 1450°C so that the temperature at the time of pouring the metal into the moulds does not fall below 1360–1380°C.

SG iron possesses some unique properties which have made it very popular for use in diverse industrial applications. These properties are

1. High strength, even greater than that for steel in certain cases
2. Adequate ductility
3. Superior castability

4. Excellent machinability
5. Lower density than that for steel
6. Superior surface lubrication like that of cast iron
7. Better vibration-damping characteristics, like that of case iron
8. Better reliability in service
9. Lower cost of products than that of forged or cast steel products

Important Applications of SG Iron in Industry

1. Engine crankshafts
2. Machine tool beds and other components
3. Steering knuckle and rack and pinion for knuckle assembly
4. Rolling mill rolls
5. Brake shoes for heavy duty brakes, brake caliper, brake anchor, etc.
6. Piston rings
7. Moulds for glass industry
8. Pistons for impact drills
9. Electric insulator post and cap
10. Moulding boxes and mould box clamps for foundries
11. Railway wagon and coach components

Table 6.12 *Summary of SG iron specifications (ISO: 1086–1976 and IS: 1865–1992)*

Grade	Ultimate tensile strength (min.) N/mm^2	0.2% Proof stress (min.) N/mm^2	Elongation (min.) %	Hardness Brinell	Matrix structure
800–2	800	480	2.0	248–352	Pearlite or tempered martensite
700–2	700	420	2.0	229–302	Pearlite
600–3	600	370	3.0	192–269	Pearlite-ferrite
500–7	500	320	7.0	170–241	Ferrite-pearlite
400–12	400	250	12	< 241	Ferrite
370–17	370	230	17	< 179	Ferrite

Factors Affecting Quality of SG Iron Castings

1. Nodularity and Matrix Control The following points should be observed to achieve a good degree of nodularity in the metal and proper control of matrix:

(i) Quality of raw materials used
(ii) Selection of charge composition
(iii) Selection of correct chemistry, particularly, % of C, Si and Mn (Figs 6.29 and 6.30)
(v) Standardisation of melting practice
(vi) Close control of magnesium treatment and inoculation.

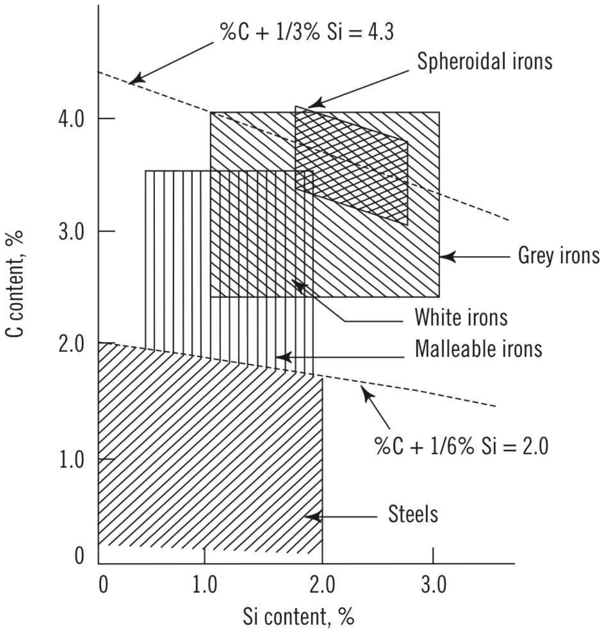


Fig. 6.29 *Carbon and silicon compostion ranges of various cast irons and steels*

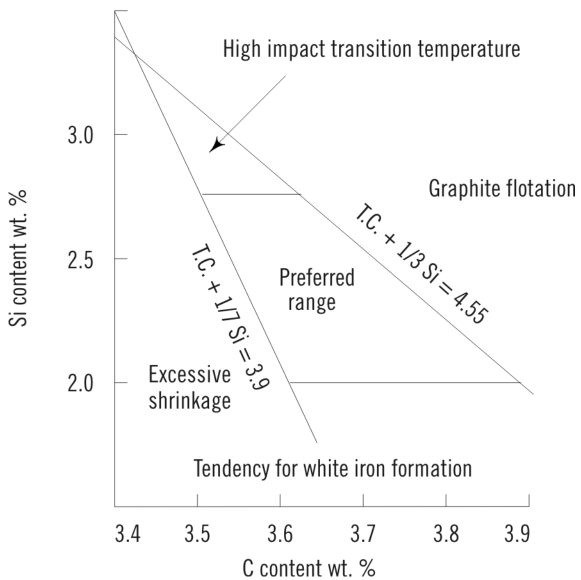


Fig. 6.30 *Typical C and Si concentration range for spheroidal graphite irons and factors that limit these ranges*

Tramp elements can often cause problems of quality and strict control is necessary for producing high quality of SG iron. For instance, nitrogen if present above 0.02% may cause pin holes in the metal. Lead severely affects nodule structure, even if present above 0.0015%. Phosphorus causes drop in machinability and fracture toughness and segregates at eutectic grain boundaries. Al, As, Sb and Bi are deleterious elements.

2. Control of Microporosity Microporosity, or shrinkage, is caused by mould-wall movement occurring in the metal. Pressure exerted on the walls of the mould be the solidifying molten metal during the precipitation of free graphite nodules and metallurgical phase changes causes the phenomenon called mould wall-movement. This tendency can be avoided by proper selection of the moulding and core-making process, and use of rigid mould and cores. In case of green sand moulds, hardness should be same, both in moulds and cores.

3. Control of Inclusions Both metallic and non-metallic inclusions are equally harmful and should be avoided. Inclusions, if present, may cause hard spots, excessive tool wear or tool breakage, poor machinability, poor dimensional control during machining and stress concentration zones, all of which may lead to fracture and fatigue failure. Inclusions may originate from various sources such as charge, alloy additions in the melt, inoculation, furnace lining, ladle lining and mould or core erosion. Remedial measures to eliminate inclusions include proper selection of charge composition, taking care of the causes mentioned above and filtration of molten metal.

The following tests are recommended for quality evaluation of SG iron:

(i) Fracture toughness test
(ii) Fatigue strength
(iii) Microstructure evaluation
(iv) Graphite morphology study by electron microscopy
(v) Checking of carbide segregation, micro-inclusions and microporosity
(vi) Eddy current testing for matrix control
(vii) Magnaflux test for surface and sub-surface cracks
(viii) Ultra-sound velocity test or sonic test for nodularity
(ix) Read time radiography for internal soundness

SG iron has helped to replace many expensive die forgings. Some of the common applications are crankshafts for passenger vehicles, cam shafts, driving gears for power presses, hydraulic pistons and cylinders, high pressure gas mains, water pipes in earthquake-prone areas, steel mill rolls, paper mill rolls, and parts for mining and construction machinery. Alloyed varieties of SG iron are also produced to get further widely varying properties. Alloying elements used in such cases are molybdenum, chromium, nickel, etc. Typical SG iron castings are shown in Fig. 6.31.

Austempered Ductile Iron (ADI) Austempered ductile iron is a new and improved variety of SG iron which has higher tensile strength, yield point, toughness, wear resistance and improved fatigue properties as well as fracture toughness. The cast-

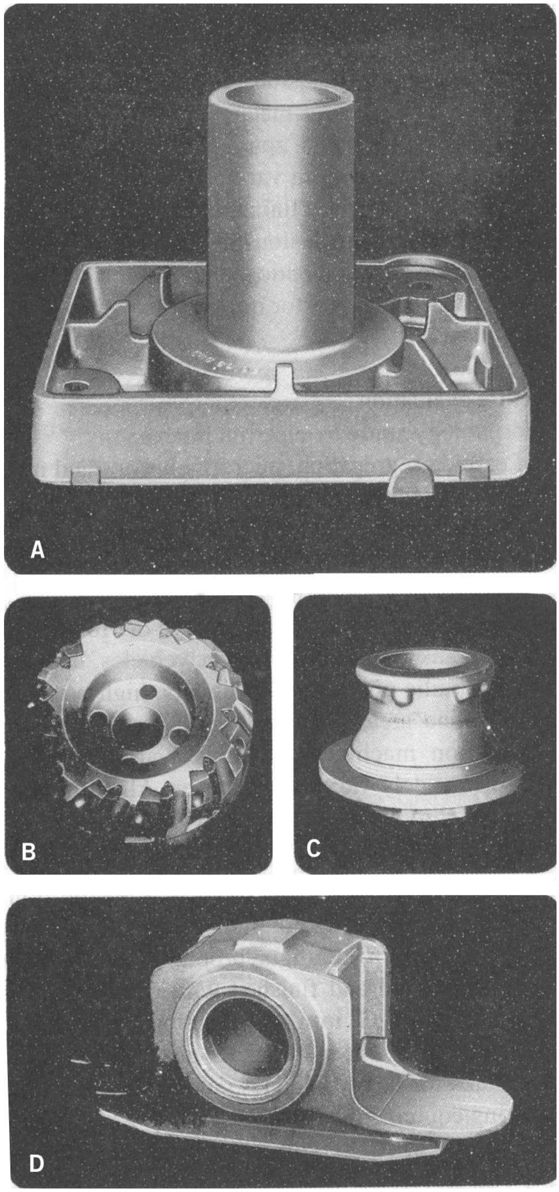


Fig. 6.31 *Spheroidal graphite cast iron castings (A) Jolting table, 613.0 kg (B) Cutter head, 6.5 kg (C) Reer-wheel hub, 23.0 kg (D) Rollar axle box, 92.0 kg*

ings can be machined and finished with ease. The metal thus possesses superior characteristics than SG iron and therefore, it is now being increasingly used for items like crankshafts, chain sprockets, gear wheels, connecting rods, steering knuckles wheel hubs for heavy vehicles, and for a variety of railway parts and components for mining equipment.

The production process of ADI consists of first producing normal ductile iron but of high quality and closely controlled composition and then subjecting it to the following heat treatments:

(a) 'Austenitising' in an austenitising or salt bath furnace by heating the castings to a temperature between 850 and 925°C and maintaining for 1 to 3 hours according to the tensile strength, yield point and other properties required in the castings.

(b) Cooling the casting to a temperature between 230–380°C for austempering treatment and holding for a period of ½–3 hours both the temperature and holding time, adjusted and controlled closely depending on the mechanical properties required. For maximum tensile strength, an austempering temperature of 275–325°C is recommended. The castings are then cooled in air to room temperature.

In order to prevent any scale formation, it is desirable that the austempering treatment is carried out in an inert atmosphere of nitrogen or argon gas. It is very important to keep the time of transferring the castings from austenitising furnace to austempering furnace as small as possible, and not greater than 10–12 seconds. Machining of castings can be carried out prior to heat treatment or after heat treatment.

Compacted Graphite (CG) Iron CG iron is another improved variety of grey cast iron in which the base iron is either hypo- or hyper-eutectic iron though, generally an eutectic or hyper-eutectic composition is preferred. The graphite flake structure of grey CI is modified as rounding of ends followed by thickening and shortening of the flakes. The graphite remains interconnected within the eutectic cell. Shortening, rounding and thickening of the flakes give this metal higher strength and better ductility in contrast to cast iron. The interconnected graphite form further imparts CG iron the excellent machinability and also high heat conductivity. The metal is therefore used where increased strength and ductility are required over flake graphite cast iron, and where castability, yield, thermal conductivity and machinability are to be improved. The iron produced has good tensile strength, some amount of ductility, good impact and fatigue properties, higher thermal conductivity, good damping capacity and good machinability.

The process is more economical as compared to SG iron production since the gating system is similar to that for grey iron, risering is less, the dross produced is less and on the whole the yield of metal is higher.

The common production methodology for obtaining CG iron is to inoculate the base metal with a smaller amount of nodulariser, than required to produce SG iron, so as to achieve incomplete modification, concomitantly using a denodulariser. Magnesium (Mg) alone as nodulariser can produce CG iron over a narrow range of Mg content, making production control so difficult as to be impracticable. Too large an addition leads to nodular graphite and if it is too low, the structure will contain only normal flake graphite.

Though, CG iron was developed many years ago, it has been commercially exploited only in recent years and its popularity is fast increasing. The process is suitable for items, such as diesel engine blocks, exhaust manifolds, cylinder-heads, heavy duty brake drums, wheel hubs, valve castings, gears, ingot moulds and hydraulic cylinders.

Acicular Cast Iron This is obtained by adding nickel (1.5–5%) and molybdenum (0.8–1.0%) to molten iron. These additions cause the transformation from austenite to pearlite to be sluggish enough to slow the rate of cooling in the mould. A fairly good strength coupled with high resistance to shock and fatigue is obtained without any need for further heat treatment.

Alloy Cast Irons

To achieve specific properties in cast iron, such as high resistance to heat, corrosion, and wear, and non-magnetic properties, suitable alloying elements such as chromium, nickel, copper, and manganese are added in requisite quantity. Chromium is added when high resistance to heat and corrosion are required. Chromium enters iron carbide and forms a complex iron carbide, which is very stable even at elevated temperatures. It also serves as a means of neutralising the effect of silicon and is often used along with smaller amounts of nickel. Nickel is a chill-restraining or graphitising element unlike chromium which is chill-inducing. Nickel increases the fluidity and castability of metal, improves strength and other mechanical properties, machinability and resistance to heat and oxidation.

Nihard Castings are used for applications demanding very high hardness (500–700 BHN), combined with high tensile strength, wear and abrasion resistance and impact resistance. The composition of iron usually is C: 2.8~3.5%, Si: 0.3~0.5%; Mn: 0.3–0.7%, P: 0.3% max.; S: 0.15% max; Ni: 3.5~4.5%, and Cr: 1.5~2.5%. It is desirable that the ratio of Ni to Cr is kept in the range of 2.5~3.0 : 1. Ni additions may be made up to 0.5%, in order to further improve the impact properties.

The metal is melted in a cupola, rotary furnace or electric induction or arc furnace, keeping a close control on its composition and temperature while tapping. The pouring temperature required is a minimum of 1300°C. Chilling of the casting is essential to avoid graphite precipitation. Chill coating is often carried out, either using graphite suspended in linseed oil and turpentine mixture, or a slurry of iron oxide in fuel oil. After pouring the metal, the castings have to be cooled down to room temperature before knocking off from the moulds.

It is necessary to subject castings to heat treatment, in order to convert any amount of residual austenite into martensite or bainite. Nihard castings are often not free of cracks and welding is normally adopted to fill the cracks. The castings have to be preheated to about 350°C prior to welding. The filler rod used for welding must be of the same composition as the cast metal. Thorough gouging of the crack cavity is also necessary before welding.

As the metal is very hard, machining of the casting is difficult. Alternatively, machinable inserts prepared separately in grey CI or mild steel are inserted in holes, cavities or projections made in the casting where machining is otherwise required. The inserts sunk into the casting are machined in situ.

Copper is a mild chill-restraining element and its addition assists in improving corrosion resistance. As nickel is very expensive, copper is being increasingly used where good resistance to corrosion, wear, and abrasion are required. Manganese is used to impart non-magnetic properties in electrical casting. No-mag alloy, which contains 10–15% Ni and 5–10% Mn, is practically non-magnetic, has low permeability and high electrical resistance.

Steel Casting

As is evident from the iron–carbon diagram (Fig. 6.25), iron that contains no carbon is ferrite at room temperature and has a body-centred cubic form. Ferrite has little solubility for carbon, it being able to dissolve a maximum of only about 0.025%. Between 910° and 1400°C, pure iron attains a face-centred cubic lattice form in which it can dissolve up to 2% carbon. The face-centred cubic form is termed austenite. Cast plain carbon steel having carbon up to 0.5% solidifies by a peritectic reaction to form a single phase solid solution 'austenite'. The rate of diffusion of carbon being high; negligible coring occurs during the solidification. When carbon is more than 0.5%, however, the steel solidifies directly to austenite over a temperature range. The microstructure of steels in the austenitic region appears to have uniform polygonal grains.

Steel having carbon between 0.025 and 0.8% cools through a two-phase region where both austenite and ferrite co-exist. The ferrite tends to get precipitated at the austenite grain boundaries and austenite also appears to get consumed. At 723°C, an eutectoid transformation takes place whereby the austenite remaining in the steel inside the ferrite boundaries transforms directly into a final lamellar aggregate made up of ferrite and cementite, known as pearlite. At 0.8% carbon, steel transforms entirely into pearlite and the microstructure is said to be pearlitic.

Steels containing 0.8% carbon are known as eutectoid steels. Those containing less than 0.8% carbon are termed hypo-eutectoid steels and those containing more than 0.8% carbon, hyper-eutectoid steels. The eutectoid reaction is similar to a eutectic reaction, the only difference being that all the reaction products are solid in the case of the former. Steels containing more than 0.8% carbon, e.g. the hyper-eutectoid steels, when cooling from the austenite region transform with the formation of cementite at the grain boundaries. At the eutectoid temperature, the remaining austenite transforms into pearlite.

Casting of Alloy Steels Castings made of carbon steel find extensive applications in industry. Low carbon steel having 0.15–0.25% C is employed for castings required to withstand impact loads. Castings, such as gears, pinions, etc., required to be case-hardened have a lower carbon content, 0.10–0.16%. The percentage of phosphorus and sulphur has to be kept sufficiently low, up to 0.08% and 0.03%

respectively. The fluidity of low carbon steels is low, creating difficulty in casting. The moulds must be filled as fast as possible and special measures like the use of insulating or exothermic materials may be necessary. Medium carbon steels with 0.30% to 0.40% C are easiest to cast due to their high fluidity and hence they are used for a large variety of steel castings in any size and shape. For higher strength and wear resistance, the carbon percentage can be increased to 0.55%, with a corresponding increase in manganese and decrease in sulphur content. High carbon steels can also be cast but they tend to decompose into cementite and free carbon in the form of graphite. Though sufficiently hard, and abrasion-resistant, they have a lower impact strength and elongation. They are used for manufacture of plates of ball mills, parts of stone crushers, and rolls.

Casting of Steels Although the basic processes of moulding and casting are similar for all cast metals, certain special considerations apply in the case of each metal, depending on its physical and metallurgical characteristics and its castability. The main points of difference between the moulding and the casting of steel and iron are as follows:

(i) Since the melting point of steel is higher than of iron, higher pouring temperatures are involved, necessitating sands of greater refractoriness. Usually, high silica sands bonded with refractory clays are used for steel castings. Zircon sand, chromite sand, etc., are often used for alloy steel castings.

(ii) In order to eliminate solidification shrinkage in the metal, all castings must be fed in the heaviest section. This factor is not so important in the case of iron because the value of its solidification shrinkage is relatively low.

(iii) Since molten steel has a tendency to dissolve carbon, no carbonaceous material or washes can be used on the mould faces.

(iv) In order to reduce cost, new facing sand having high refractoriness is generally used on the contact faces, and backing-up sand of inferior grade is used in other parts of the mould.

(v) To produce sound castings, the metal must be thoroughly deoxidised (killed) before it is poured into the moulds. The unkilled metal spits and boils in the ladle due to dissolved oxygen and will produce defects such as gas holes, gas porosity, and sponginess. Alloy steels are invariably killed whereas low carbon steels may be killed or unkilled.

Steels may be killed in one of several ways:

(a) by adding small amounts of grain size control elements or deoxidisers, such as Al, Mn, and Si, to the molten metal in the ladle;

(b) by allowing the metal to remain in the crucible for a longer time so that the silicon of the crucible will combine with the oxygen and form slag on the surface of the molten metal; or

(c) by normalising treatment.

(vi) Directional solidification helps in ensuring sound castings. By this means, the metal starts solidifying from the point farthest from the riser and the solidification proceeds progressively towards the riser, the latter being the last to solidify.

Directional Solidification can be achieved in one of the following ways:

(i) Proper design of casting

(ii) By using risers of optimum size and shape and locating them at the most appropriate place; in steel casting, heavy risering is essential owing to a high rate of solidification shrinkage so that the riser remains molten for a longer time than the section it is going to feed

(iii) By the use of chills, either of the external or the internal type

(iv) By gating methods, which are capable of setting up favourable temperature gradients in the metal during pouring and subsequent to it

(v) By the use of exothermic compounds in the moulds to have differential cooling

(vi) By using mould materials having varying thermal properties in different portions of the mould which will cause the desired change in the rate of heat loss

The design of the whole gating system should be given proper consideration since it plays an important part in producing a sound casting

Effect of Gases on Cast Steel Liquid iron and its alloys possess a high degree of chemical activity and they interact with furnace gases, slag and furnace lining material and the moulding and core-making materials. The gases produced by the chemical reactions taking place in the furnace bath as well as during the pouring operation either tend to escape from the metal as bubbles or get trapped in it. Three gases, oxygen, hydrogen and nitrogen, produce maximum effect on the characteristics and quality of cast steel.

Oxygen gets dissolved in steel and its concentration at constant temperature is a function of pressure. Its solubility increases rapidly with a rise in temperature for example, in pure iron, solubility amounts to 0.11% at 715°C, 0.21% at 1535°C and 2.0% at 1700°C. In oxidised steel, the ferrous oxide (FeO) formed evolves in a free state on the grain boundaries and discontinuities appear in the casting when it cools down. The oxygen present in metal increases the susceptibility of metal to temper brittleness and decreases its resistance to corrosion. De-oxidation of steel, using suitable deoxidisers, is therefore necessary before pouring it into moulds. In case of steels alloyed with chromium or titanium, the problem is more acute and it is preferred to have a neutral or reducing atmosphere during pouring.

If the steel solidifies when the FeO produced exceeds the equiibrium amount, it begins to boil due to the evolution of carbon monoxide (CO). In order to prevent the evolution of CO, the steel should contain a minimum of five times more silicon than the FeO produced. Medium-carbon steels, which are commonly cast, should contain at least 0.35% silicon to prevent boiling in the mould. Aluminium is a powerful deoxidiser and is commonly used.

Pin holes occur often in small steel castings and are caused by the evolution of hydrogen from the advancing layer of freezing steel. Hydrogen dissolves in iron at a high temperature (above 1400°C) but its solubility drops sharply during solidification and later, the solubility of nitrogen also decreases sharply with a decrease in temperature, from about 0.013% at 1530°C to 0.001% at 800°C and lower. This gas forms iron nitrides (Fe_2N and Fe_4N) when it comes in contact with hot steel, which again decomposes into pure nitrogen and iron at about 550°C. Presence of nitrogen in steel has been observed to bring about stone-like fractures and is considered to be harmful.

Warpage in Steel Castings Warpage is undesirable or unintentional deformation that occurs during or after solidification of some castings. It can also occur during heat treatment in general and quenching in particular.

The root cause of warpage is the setting up of differential stresses during cooling. As casting cools it contracts. If it is restrained from contracting in certain areas, because of their geometry or mould/core condition, it may develop tension. If this tensile stress is higher than the strength of solidifying/cooling casting, it cannot resist this stress. Ultimately, the casting would either warp or crack.

Grey iron and ductile iron castings are more prone to warpage. But some steel castings are severely attacked by warpage defetc,

Probable cause behind Warpage A particular casting defect may find its root cause in pattern design, methoding, moulding, pouring, fettling or in any other production stage. Warpage is caused by various process parameters related to production. They are listed below.

1. Casting and Pattern Design Large, flat sections are particularly prone to warpage. An example is shown in Figs 6.32(a) and (b). Judicious use of ribs in the casting can correct this tendency, but an incorrect rib design can worsen or even create a warp. It is important that the rib sections are equal to the adjoining sections and designed to promote uniform cooling and contraction.

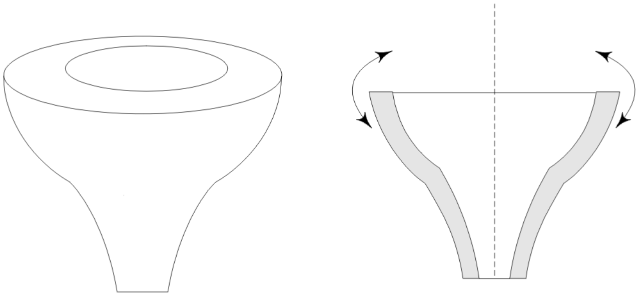


Fig. 6.32

Flat sections tend to solidify and cool most rapidly at the edges causing warpage. So any ribs involved should help to offset this effetc, In other words, rapid cooling should not be used where ribs act as cooling fins in those areas already.

2. Pattern Equipment The most common technique to prevent warpage or distortion in castings is to warp the pattern or to provide 'camber' to the pattern in the opposite direction to compensate for warpage. The orientation of warpage is shown In Fig. 6.33. Chamfer angle is given in the opposite orientation as shown in Fig. 6.34. Casting will be of desired dimension after warpage. This is a trial-and-error method. It is up to the foundry to operate under conditions that create a uniform degree of warp in such a design. The Methods Engineer can then compensate for such uniform warpage.

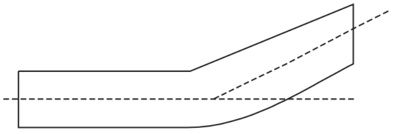


Fig. 6.33

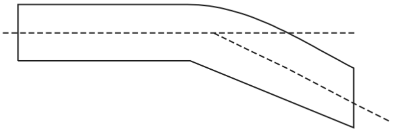


Fig. 6.34

Pattern equipment may also be responsible for warpage when there is a lack of tie bars or presence of too many tie bars. (Figs 6.35 and 6.36.)

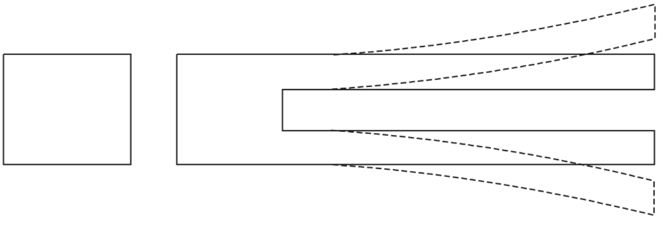


Fig. 6.35 *Tendency for warpage in a 'yoke' casting. The reason is absence of tie bar*

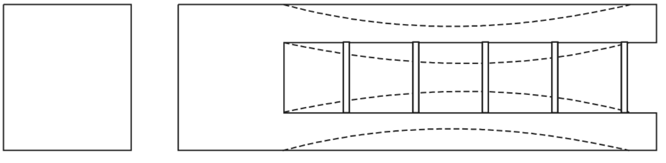


Fig. 6.36 *Tendency for warpage due to the presence of too many tie bars*

3. Conditions which Prevent Desired Contraction These include moulding box bars too close to the pattern (Fig. 6.37), flask bars too close to risers and down sprue (Fig. 6.38) etc. These factors separately or collectively prevent or hinder the normal contraction while cooling, and thus the stresses developed remain unrelieved. This can result in warpage.

The same phenomenon can occur in case the moulding box is not large enough to accommodate the natural contraction.

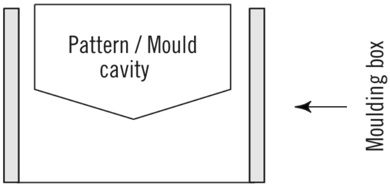


Fig. 6.37

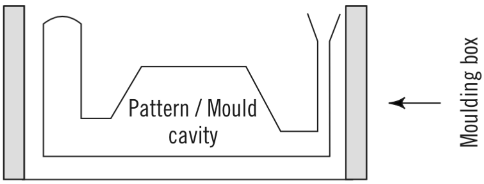


Fig. 6.38

4. Gating and Risering A gating system which prevents desired contraction because of continuous or multiple runner system tied to casting by gates could be responsible for warpage defects (Figs 6.39 and 6.40).

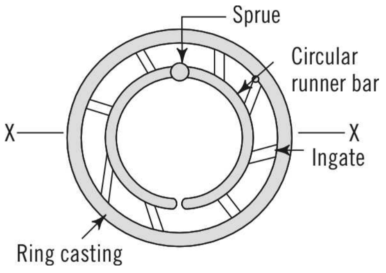


Fig. 6.39 *For ring castings having large Diameter and also if OD/HT ratio is large, the above runner system may hinder normal contraction, leading to warpage*

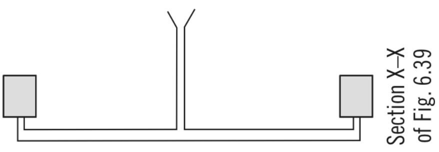


Fig. 6.40 *In the casting of Fig. 6.39 if horn gates are provided, the tendency for warpage can be minimised. Also runner system acts as a tie bar*

Inadequate in-gates for sufficient rapid pouring may cause warping. In this case, one part of the casting might have started solidifying very fast while in some other part of the same casting, the molten metal might still be filling up. The remedy is to provide sufficiently large runner and in-gates with proper locations so that there will be equal distribution of molten metal throughout the mould cavity while pouring.

Having an optimum size of the risers is very important to tackle warpage defetc, If the size is insufficient, it will result in shrinkage. But an oversize riser can cause warping if it is kept on a thin section. Molten metal will remain in the riser for quite a long time while the casting section gets solidified very fast. This causes heavy thermal gradient resulting in warpage. Hence the size of the riser should be optimum and location should ensure directional solidification.

Risers kept on ring castings will have a tendency to distort the casting outwards as shown in Fig. 6.41.

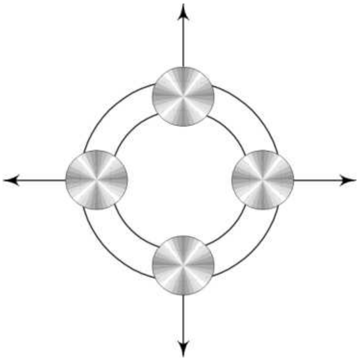


Fig. 6.41 *Top view of a ring casting with risers. Here, distortion will be radially outwards making dimensional changes in top portion of the casting*

5. Moulding Sand If green strength is not adequate, the mould walls will not be able to accommodate the thrust of contraction while the metal is solidifying. The result will be warpage. The same effect can be expected for low mouldability or low hot strength of sand. In case the hot strength of moulding sand is too high, it will be too rigid. Because of the lack of cushioning effect, the casting may warp.

6. Core Practice Excess pitch, moisture, fines, clay or binders, etc., would cause increased hot strength of cores resulting in reduced cushioning effect, localised tension in casting and finally in warpage.

Hence, it is desirable to

(i) avoid excess amount of moisture, fines, clay, binder, etc., in core sand,
(ii) avoid prolonged storage of cores,
(iii) add sufficient amount of collapsibility agents in core sand, and
(iv) make cores hollow to the maximum extent.

7. Moulding Practice There are chances of improper relationship of mould hardness between cope and drag. A standard method of controlling design prone to warpage is to control the relative hardness of cope and drag surfaces. If the casting warps up, the cope should be hardened; if the casting warps down, the drag should be hardened. Balanced distribution of weights on the top of the mould will decrease the tendency for warping. Also, it is advisable to keep weights for a prolonged period in vertical plane after pouring for castings having warpage tendency.

8. Pouring Practice If molten metal is poured cold (i.e., with insufficient superheat) it may result in uneven contraction and finally the casting may warp.

9. Heat Treatment When castings are subjected to heat treatment they may undergo asymmetrical changes in their shape. When steel components are heated or cooled at a fast rate, internal stresses develop in them because of differential expansion/contraction. Some layers/portions of the component expand while other layers/portions contract.

Shape distortion is a change of shape, form or geometry of a component without noticeable volume change. It can be caused by the presence of residual stresses, sagging, formation of thermal and transformational stresses during heating and quenching and sharp variation in casting section.

The chance of warpage due to heat treatment can be minimised by the following methods:

(i) Avoiding abrupt changes, sharp corners and thin walls in the component
(ii) Maintaining uniform microstructure in the component and uniform temperature in the furnace
(iii) Subjecting the casting to stress-relieving heat treatment before risers are cut
(iv) Keeping heating rate slow (as low as 50°C per hour) depending on the section thickness; preheating is advisable to a temperature just below lower transformation temperature of steel

(v) Selecting appropriate quenching media and ensuring uniform cooling rate as far as possible

(vi) Distortion can be minimised during pressure quenching by physical restraint of a part during its rapid cooling from austenitic condition; Quenching jigs can be used for this purpose

Vacuum Degassing

The vacuum degassing treatment effectively reduces the gas content and the non-metallic inclusions in steel. The molten steel to be degassed is first poured from the furnace ladle to a 'pony' ladle and from there it is poured into another ladle placed inside a sealed chamber, maintained under vacuum so that the gases are removed from the pouring stream. When degassing is complete, the chamber is brought to the atmospheric pressure and the molten metal duly degassed is poured into moulds in the usual manner.

Plain carbon steel castings, though suitable for a large variety of engineering components, do not possess all the characteristics required for several stringent applications, calling for special properties, such as rusting and corrosion, high heat resistance, high wear, abrasion or impact resistance or even electromagnetic properties. To meet such requirements, steels have to be suitably alloyed with elements like Ni, Cr, Mn, Mo, Si, Cu, etc., according to the properties desired. Alloy steels are classified broadly as low-alloy steels, medium-alloy steels and high-alloy steels.

However, most of the commonly used alloy steels fall into either the low-alloy or high-alloy range.

Low Alloy Steels

(i) Manganese Steel Manganese, when present up to 1.6%, increases wear resistance of the working surfaces of castings, making these steels suitable for heavy structural applications. Tensile strength increases with an Mn content of up to 4% and elongation is highest at 2% Mn. These steels can be easily welded. Mn steels are widely used for railway rolling stock, such as couplers, gear wheels of cranes and parts of road-making machinery, excavators and earthmovers. Appropriate heat treatment is necessary to get optimum properties.

(ii) Copper Steel Copper, when used in steel in the range of 1–2%, increases strength, ductility, impact resistance, hardness, and corrosion resistance. In its action, it resembles nickel though it is much cheaper and hence finds application in heavy engineering components for cranes, excavators, structural parts, large gears, etc.

(iii) Silico-Manganese Steel Manganese alone increases strength and ductility of steels but thick-walled castings with a thickness beyond 100 mm are not easy to produce due to reduced hardenability. Silico-manganese steels, on the other hand, overcome this problem and are extensively used for components of agricultural and printing machinery, railway coaches, couplers, cranes and blades of hydraulic

turbines. Its low cost with high strength and ductility makes it attractive for reducing weights of castings. Under the same load conditions, casting made in this alloy may be 1.6 times lighter.

(iv) Nickel–Chromium Steel Steels with a small addition of nickel and chromium help in improving the tensile strength, toughness, wear and corrosion resistance, and hardenability. Ni additions may vary from 0.5–2.0% and Cr from 0.5–1.0%. A small addition of molybdenum (up to 1.0%) further helps in enhancing tensile strength and hardenability. Close control is necessary during melting and casting. Heat treatment such as homogenizing, hardening and tempering may be necessary according to the properties required.

High-Alloy Steels

(i) Nickel-Chromium Alloy Steels or Stainless Steels These steels have a high resistance to rusting and corrosion and they resist oxidation. There are three classes of these steels: (a) martensitic steels, containing 0.1–0.4% C and 12–16% Cr, possessing high strength and hardness, (b) ferritic steels, containing 16–30% Cr, having high resistance to oxidation, high toughness and good ductility, and (c) austenitic steels, containing 18% Cr and 8% Ni, and having excellent strength, low heat conductivity, high heat resistance, and resistance to wear as well as atmospheric corrosion. Austenitic stainless steels are most commonly cast and are used for steam and hydraulic turbine blades, propellers and shafts of ships, pump impellers and other pump parts, valves, bearings, journals, surgical instruments, measuring tools, springs, kitchenware and many other applications.

(ii) Austenitic Manganese Steels Manganese steels, containing 1.00–1.40% carbon, 10.0–12.5% Mn and up to 1.0% Si are known as *Hadfield steels*. These steels possess exceptional toughness and ductility in the water-quenched condition, combined with high tensile strength, wear resistance and impact resistance. They also have a low magnetic permeability, low thermal conductivity and a high coefficient of themal expansion. These exceptional mechanical properties render these steels extremely suitable for mining machinery parts, like hammers, end mill, grate shell liners, wedge bars, jaws and mantle of crushers, railway couplers, rail bends for railways, bullet-proof plates for tanks and other defence machinery, bulldozer track links, bullet-proof helmets, etc. An electric arc furnace is normally used for melting using the basic lining and single slag practice. The charge may consist of steel scrap, silico-manganese, high carbon ferro-manganese, limestone, coke breeze and iron ore. Aluminium in ingot form is added as a deoxidiser to prevent pin holes and improve soundness. Heat treatment of the alloy is essential to dissolve the carbides that produce a marked brittleness. It consists of heating slowly to 1100–1150°C, holding for at least 5 hours and quenching it in cold water.

Non-ferrous Castings

Non-ferrous alloys include all metallic materials except iron and steel. These alloys have many properties that do not characterise ferrous metals and they find extensive use in every walk of life in spite of their limitations by way of resources, production, and cost. Like iron and steel, most non-ferrous alloys are not simple binary metals; they often contain small amounts of two or three other elements, which must be controlled to obtain the desired physical and mechanical properties.

Most of the common non-ferrous metals can be readily cast to shape by the usual casting process. Besides being sand cast, they can also be easily cast by permanent mould and pressure die casting. They can also be heat-treated to homogenise their composition and structure or, if necessary, to develop any special properties. Two of the most common types of cast non-ferrous alloys are copper-base alloys and aluminium alloys. Details of individual alloys are available in specialised books, some of which are listed in the appendix.

Copper and Copper-Base Alloys

Copper One of the most important non-ferrous metals for engineering purposes, copper has high electrical and thermal conductivity and very good resistance to corrosion. Pure copper is difficult to cast due to its tendency to get oxidised during melting and casting and to absorb hydrogen. In cast form, therefore, its use is limited.

Copper Alloys

(i) Brasses Brasses contain mainly Cu and Zn, the latter varying from 5% to 43%. They have high resistance to corrosion and are easily worked, cast, machined, joined, and fabricated.

Common types of brasses are the following:

(a) **Muntz metal or beta brass** It contains 60% Cu and 40% Zn. It is easily cast into kitchenware, household articles, weights, water fittings, etc.

(b) **Naval brass** It is made up of 62% Cu, 37% Zn, and 1% tin. Its high resistance to corrosion renders it ideal for marine purposes and chemical plants.

(c) **High tensile brass** It is composed of 36% Zn, 3% Al, 2% Mn, 2% Fe, and the rest Cu. This alloy has high tensile strength (viz., up to 60 kg per sq mm) and also excellent resistance to corrosion, wear, and fatigue. It is used for ship propellers, turbine blades and runners, gears, pump parts, etc.

(ii) Bronzes These alloys are the straight copper–tin or copper–tin–phosphorus type. The tin varies from 5% to 14%, the phosphorus content is up to 1%, zinc up to 5%, and the remaining content is copper. Common varieties, all easily castable, include the following:

(a) **Gun** metal contains 8–10% Sn, 2–4% Zn, and up to 0.1% P. This alloy which has excellent bearing and wearing qualities, is most favoured as it can be easily cast and machined.

(b) **Phosphor bronze** is composed of 10–14% Sn and 0.1–1% P. The alloy has very good toughness and resilience besides ductility, strength, and corrosion resistance. It is used largely for small springs in measuring instruments, and for knife edges and bearings.

(c) **Aluminium bronze** is made up of about 10% Al, besides Sn and Cu. This alloy is the strongest and most resistant to corrosion. It has very good high temperature properties, and is therefore ideal for marine equipment, chemical plants, electrical parts, etc.

Aluminium and Aluminium Alloys

Aluminium Aluminium has various typical characteristics which make it one of the most important engineering metals. Some of its outstanding features are

(i) lightness;
(ii) high electrical conductivity;
(iii) high thermal conductivity;
(iv) high resistances to corrosion;
(v) affinity for oxygen; and
(vi) easy castability and ability to take good finish.

In pure form, aluminium is a weak material, greatly prone to oxidation, and not readily castable. Its strength and other mechanical properties, as well as castability, can be considerably improved by suitable alloying treatment.

Aluminium Alloys These alloys are of both the cast type and the wrought type. Table 6.13 gives the important aluminium alloys with their common composition and applications. IS: 617–1975 gives the specifications for aluminium alloy ingots and castings for general engineering purposes. Figure 6.42 shows typical aluminium alloy castings.

Casting of Non-ferrous Metals

In general, the moulding and casting practice for the production of non-ferrous castings is almost similar to that used for iron castings. However, non-ferrous metals have some common characteristics which are ordinarily taken into account while moulding. The main requisites for non-ferrous founding are as follows:

(i) Generally, a large proportion of small-sized work in a non-ferrous foundry is executed by bench moulding, or floor moulding.
(ii) The wide variety of metals and compositions dealt with requires familiarity with the metallurgical characteristics and properties of different metals and their alloys. Since numerous alloys are available for each of these metals, the metallurgical side of non-ferrous foundry practice is extremely complex.
(iii) As the non-ferrous alloys chill and solidify at a relatively faster rate than ferrous metals, the area of entry has to be increased.
(iv) Precautions have to be taken while pouring since these metals get quickly oxidised and tend to develop air aspiration and turbulence.

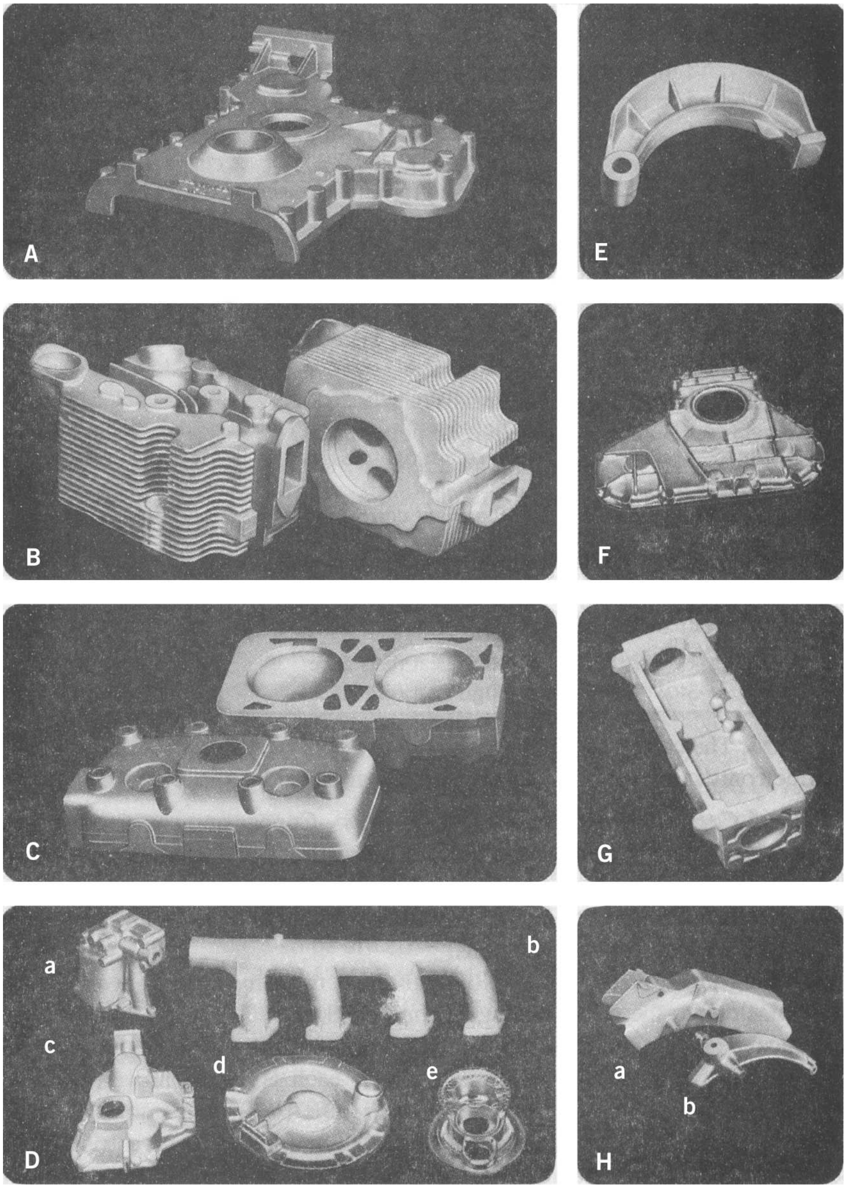


Fig. 6.42 *Aluminium alloy castings (A) Gear cover, 5.8 kg (B) Cylinder head, 4.95 kg (C) Cylinder head, 3.3 kg (D) (a) Oilpan screen case, 2.47 kg (b) Induction pipe, 3.87 kg (c) Gearbox case, 1.83 kg (d) Cover for oil sump, 2.58 kg (e) Gear part, 2.87 kg (E) Brake block, 3.6 kg (F) Case cover, 4.0 kg (G) Injection case (lower part), 1.8 kg (H) (a) Saddle support, 3.65 kg (b) Front-wheel rocker, 2.9 kg*

(v) The sands used for moulding non-ferrous work have relatively smaller grain size due to the high fluidity and seeping tendency of these metals at the pouring temperatures.

(vi) As most non-ferrous metals contract to a large extent when cooled from the molten state, special care has to be taken to avoid shrinkage cavities and cracks. The cores used in these moulds are prepared from materials that allow free contraction of the metal when it solidifies and cools around them.

Table 6.13 *Aluminium alloys with composition and applications*

Type of alloy	Composition				Properties	Uses
	Cu	Si	Mg	Ni		
Al-Cu	4 to 8				Good strength, hardness, castability	Crank case, flywheel housing
Al-Cu-Si	4	5			Good strength, hardness, castability	Manifold, crank case clutch housing etc.
Al-Si		13			High corrosion resistance, low shrinkage, high fluidity	Marine castings, housing, cover, general use
Al-Si-Mg		9	0.5		High corrosion resistance, low shrinkage, high fluidity	Brake drum, crankcase, general use
Al-Si-Cu	3	9			Good strength, corrosion-resistance	Engine parts, general use
Al-Si-Cu-Mg	1.3	5	0.3		Good strength, pressure tightness	Water-cooled cylinder head, cylinder block
Al-Cu-Ni-Mg	4		1.5	2	Pressure tightness, heat resistance	Air-cooled cylinder head, position, bearings
Al-Mg			5		Excellent corrosion resistance, long life	Food processing, chemicals, marine, architectural
Al-Mg			10		Anti-shock, good strength, hardness	Parts for aircrafts, coaches, etc.
Al-Si-Cu-Ni-Mg	1	12	1	2	High heat resistance	Pistons
	3	9	1	1	High heat resistance	Pistons

Casting of Copper and Copper-Base Alloys

Copper and copper-base alloys form the most important section of the non-ferrous foundry. The factors regulating work with copper and its alloys, apart from the ones just listed, are the following:

(i) The sand used must be finer and should be suitably bonded with strengtheners such as molasses, oils, and resins.

(ii) Chilling practice is often employed in brass founding work to avoid internal strains due to the difference in sectional thickness.

(iii) Since the melting temperature varies for different alloys, the pouring temperatures must be carefully controlled to suit each alloy. Moreover, fluidity is found to be most only at a certain temperature. If the temperature of pouring is too high, the metal tends to get oxidised and lost; this gives rise to extra shrinkage and tends to absorb gases, causing gas porosity defetc, The molten metal should be held for the shortest possible time.

(iv) The oxidised metal, which starts floating on the surface of the molten metal, should be prevented from entering the mould cavity. There should be a minimum amount of agitation and the metal should be poured at a steady rate.

(v) A gating ratio that is best suited for the given alloy should be selected.

Copper-base alloys are usually cast in the alloy form. The alloys are first prepared from virgin metals by melting and casting in ingot moulds. The metals should be melted in the order of their melting temperatures, those with the highest melting points being given top priority. To avoid chilling action, the additions should be made gradually. The mixture should be thoroughly stirred before pouring into the ingot mould and allowances should be made for the volatilisation and oxidation.

The furnaces used for subsequent melting for casting purposes may be coke, oil, or gas-fired crucible or air furnaces. Elective induction furnaces and electric resistance furnaces are also used for high-quality applications.

Special Precautions in Case of Pressure-Tight and Intricate Bronze Castings

1. The crucible should be cleaned of all slag or splash and emptyied before charging. A separate crucible must be used for each type of alloy to avoid contamination of one alloy with the other.

   The crucible should be placed in position inside the furnace and preheated to a red-hot condition. All charge materials should be preheated before charging, care being taken to avoid oxidation.

   The entire quantity of charge materials required for a single heat should not be preheated at a time. Only the required quantity should be preheated before charging. Preheating of the charge can be done by placing it (if convenient) around the top of the furnace a few minutes before charging so that oxidation of the charge can also be avoided.
2. To prevent zinc volatilisation, melting should be done under oxidising conditions.
3. Every effort should be made to prevent contamination of the melt with sulphur by using fuel that is (as nearly as possible) sulphur-free.
4. The flux used in case of bronze castings, particularly for Al bronze, may consist of a mixture of 3 kg of anhydrous borax with 1 kg of silica per 100 kg of charge metal. If this does not work, the proprietary fluxes may be used.
5. Before pouring the molten metal, hydrogen gas, if present, should be removed from the melt. Otherwise, the castings will be unsound (porous).

Effective degassing can be done by the 'purging' technique in which an inert gas like nitrogen is bubbled through the melt. For 100 kg of melt, 6 litres of gas per minute is bubbled for 4 minutes. Altenatively, for degassing the melt, proprietary degassers may also be effective.

6. The molten metal should be thoroughly deoxidised in the crucible before pouring. The common method is to add phosphor–copper containing 15% phosphorus to the melt (100–150 g per 100 kg of melt). A more effective method, though expensive, is to add lithium, carefully. It also helps remove hydrogen. Proprietary deoxidisers available in the form of tubes may also be used.

   Real proof of effective deoxidation and degassing is only when the casting is found free of porosity and is leakproof under pressure. However, as a rough test, a high gas level in the melt will be shown by a puffed surface (rather than well-defined shrinkage) on a standard-sized test sample.

7. The tapping temperature should be high enough to enable the pouring ladle to arrive in the pouring area at or above the desired pouring-temperature range.

   The metal must be poured in the correct temperature range into the mould. Approximate pouring temperatures are given below which must be adhered to prevent leaky castings or mis-runs. The actual pouring temperature may have to be established for a given composition and intricacy of castings.

Table 6.14 *Approximate pouring temperatures*

METAL	LIGHT OR THIN CASTINGS °C	ORDINARY OR THICK CASTINGS °C
Brass	1100–1150	1020–1070
Tin. Bronze. Leaded red brass	1200–1220	1100–1120
Mn bronze	1040–1080	980–1020
Silicon bronze	1180–1200	1100–1120
Aluminium bronze	1200–1250	1130–1150

   Too high a pouring temperature produces leaky castings and too low a temperature gives rise to mis-run defects.

8. A proper method of measuring the temperature of molten metal must be installed where leakproof and pressure-tight castings are required consistently (optical or radiation pyrometers are not suitable for any alloy containing zinc). Temperature should be measured with open end chromel–alumel or platinum–Pt–rhodium calibrated thermocouples (ends of thermocouples must be uncontaminated, when used).

9. The speed of operation during melting and pouring is extremely important to minimise contamination and reduce cost. Proper melting technique

and trained melting personnel can help a lot. Dross formation can be kept low by reducing melting time and minimising excessive holding at high temperature, excessive agitation or overheating of the metal. Metal surface exposed to the atmosphere should be minimum.

10. Special precautions are required for Al–Bronze and Mn–Bronze. These alloys have a narrow freezing range and form tight, adherent, non-fluid slags. These alloys, therefore, require much greater care in pouring than other Cu-base alloys. The main points to be paid attention to are the following:
    - (i) Never stir molten alloy. The metal should be carefully skimmed off before pouring, but not agitated.
    - (ii) While transferring metal from crucible to ladles, the distance through which the metal must drop should be minimum (such as by holding the ladle close to the furnace lip).
    - (iii) Pouring in the mould must be smooth, even and uninterrupted to avoid splashing and separated streams.
11. A well-designed gating system is a pre-requisite for getting sound casting. Points to observe:
    - (i) Provide a pouring basin with a dam or skim-core (made in dry sand).
    - (ii) Provide a generously sized sprue well (its diameter being double the runner width and extending below the runner).
    - (iii) Use gating ratio of 1 : 2 : 2 to 1 : 4 : 4 (latter for thin castings).
    - (iv) Place runner in drag and in-gates in cope.
    - (v) Cross sectional area of the runner should be reduced after each gate by the area of cross section of the gate.
    - (vi) Do not keep the sprue too close to gates.
    - (vii) Use standard practice for gating dimensions.
12. A proper risering system should be worked out and used to prevent shrinkage in the casting. Riser size, location and spacing should be carefully established.
13. Chills may be used where thermal gradients are found unsatisfactory. Bronze chills, though costly, are more effective. The normal practice is to use grey CI chills. Chills are to be shot blasted after every use and well-coated before use. Lampblack with spirit base can be used as a chill coat.
14. Sand used for mould and cores needs very careful control. Coarse sand helps prevent porosity and leaky castings, whereas fine sand produces good surfaces. If a unit-sand system does not work, a two-sand system should be used for easier control.

15. For all copper-base castings required to withstand high pressure, such as valves, diesel engine parts, gas fittings, etc., it is desirable to subject the castings to impregnation treatment in order to overcome the problem of pinhole porosity and consequent leakage during service.

Review Questions

1. Name the various melting equipment used on foundries and compare their suitability and performance.
2. What is a rotary furnace? How is it operated? For what applications is it well-suited?
3. Explain the construction and working of a cold-blast cupola. What factors affect its performance?
4. Explain how the charge for a cupola is calculated for optimum working. How can computer programmes help in optimising the charge?
5. What are primary and secondary fluxes used in melting operations? Give applications of some of the commonly used fluxes and show the chemistry behind their use as a fluxing material.
6. What is the role of fluxes in the operation of cupola? What fluxes are used in case of acid and basic-lined cupolas?
7. What is a cokeless cupola? How is it operated?
8. Explain the construction and working of a direct-arc electric furnace. For what applications is it most suitable?
9. Describe the operation of an electric induction furnace. How does frequency of electric supply affect its operation? Explain its process characteristics. Give its advantages and limitations.
10. Write a short note on the use of refractories for melting units.
11. What steps should be observed in the maintenance of (i) cupola, (ii) electric arc furnace, and (iii) electric induction furnace? What materials are used in the process of maintenance and repairs?
12. Explain briefly the metallurgical characteristics of cast metals, with particular reference to (i) iron, and (ii) steel.
13. What factors affect the selection of carbon and silicon content in cast iron? What is meant by carbon equivalent value and what is its significance?
14. What are the common types of high-duty irons? What are their characteristics? Explain the process of 'inoculation'.
15. What are the unique properties of SG iron. What are their important applications?

16. What are the factors that affect the quality demands of SG iron? Explain.
17. What factors are to be controlled in the production of SG iron? What methods are used for (i) desulphurisation, and (ii) nodularising treatment.
18. What are the special features of steel casting in comparison to iron casting? What is meant by 'killing of steel'? How is it carried out?
19. What special precautions are to be observed in case of pressure-tight castings subjected to high pressures made of (i) steel (ii) tin bronze?
20. What special precautions are to be taken in the casting of aluminium alloys? Name some of the cast aluminium alloys used for (i) foundry patterns, and (ii) automobile cylinder blocks.
21. What are the advantages of oil/gas-fired rotary furnaces over other types of melting units? Discuss their suitability for producing malleable iron castings.
22. How is the capacity of a cupola furnace evaluated? How is the desired composition of cast metal determined, keeping in view the losses and gains of various constituents in a cupola furnace?
23. How are the different grades of pig iron specified according to the Bureau of Indian Standards? Discuss the suitability of different grades for producing varying grades of cast iron?
24. Discuss briefly the recent developments in cupola melting for achieving higher efficiency and performance.
25. Discuss the use of sponge iron in metallic charge of a cupola furnace. What are its merits and demerits?
26. Show by a diagram the construction of a divided blast cupola. How is it superior to conventional cupola?
27. What different types of measuring devices are used in a foundry to measure the temperature of molten metal? What are their relative advantages and limitations?
28. How would you determine the composition of charge metal required in order to achieve the desired tensile strength and metallographic structure in the cast metal? Discuss.
29. What are the problems associated with mould inoculation? What Indian standards are available for classifying different types of SG Iron?
30. What are the causes of warpage defect in steel castings? Explain how these can be prevented.

Chapter 7

Defects in Castings and Quality Control

7.1 DEFECTS IN CASTINGS

Several types of defects may occur during casting, considerably reducing the total output of castings besides increasing the cost of their production. It is therefore essential to understand the causes behind these defects so that they may be suitably eliminated. Casting defects may be defined as those characteristics that create a deficiency or imperfection contrary to the quality specifications imposed by the design and the service requirements. Defects in castings may be of three basic types:

(i) major defects, which cannot be rectified, resulting in rejection of the casting and total loss;

(ii) defects that can be remedied but whose cost of repair may not justify the salvage attempt; and

(iii) minor defects, which clearly allow the castings to be economically salvaged and thereby leave a reasonable margin for profit.

Broadly, the defects may be attributed to

(i) unsuitable or unsatisfactory raw materials used in moulding, core making or casting;

(ii) the application of unsatisfactory moulding or casting practice by the individual worker or incorrect advice by the supervisor;

(iii) the use of improper tools, equipment, appliances, or patterns; and

(iv) unprofessional management policies relating to the fixing of incentive plans and setting up of production procedures, faulty organisation and poor work discipline, or lack of training.

Castings are born on a designer's drawing board where sections of a casting are assumed to be of metal, uniformly sound, homogeneous and having certain mechanical and other characteristics. The relation between these assumptions and the castings actually produced depends largely on the casting design, materials used, foundry practice, and the nature of the alloys. The common types of defects encountered in castings, their causes and remedies are discussed as follows.

1. Shift A shift results in a mismatch of the sections of a casting usually at a parting line. This defect is usually easy to identify. Unless the error caused due to mismatching is within the allowable variation on the casting, it cannot be rectified and the casting has to be scrapped.

Mis-alignment of flasks is a common cause of shift. The defect can be prevented by ensuring proper alignment of the pattern or die parts, moulding boxes, correct mounting of patterns on pattern plates, and checking of pattern flasks, locating pins, etc., before use.

Like the shift of the two or more parts of the moulds, core shift may also occur due to mis-alignment of cores or core halves during assembly. It may also be the result of undersized or oversized core prints or the failure to use core sets, or if the chaplets used are of the incorrect size. Core shift can be prevented by using prints and chaplets of the proper dimension and design.

2. Warped Casting Warpage is an undesirable deformation in a casting which occurs during or after solidification. Large and flat sections or intersecting sections are particularly prone to warpage. A proper casting design can go a long way in reducing the warpage of the casting. A judicious use of ribs can prevent the warping tendency, but an incorrectly placed rib may worsen the defect. Warpage may also be due to

(i) too small flasks, which may cause rapid cooling of the edges or ends of the casting;
(ii) weak flasks, which may allow movement of the sand mould walls;
(iii) insufficient gating system, which may not allow rapid pouring of metal;
(iv) sand with too low green strength, which may cause it to move; and
(v) non-provision of camber allowance on the pattern, wherever necessary.

A warped casting can be straightened wherever the shape permits and where the metal of the casting is not brittle. If warping cannot be altogether eliminated, extra warpage allowance may have to be provided along with the machining allowance so that it can be subsequently machined.

3. Swell A swell is an enlargement of the mould cavity by metal pressure, resulting in localised or overall enlargement of the casting. It may be caused by insufficient ramming of the sand. If molten metal is poured too rapidly, a swell may occur. Insufficient weighing of the moulds during pouring may also cause the cope to lift, giving a swell.

4. Fin A thin projection of metal, not intended as part of the casting, is called a fin. Fins usually occur at the parting of the mould or core sections. A 'run-out' of molten metal may be considered an extreme type of fin. Moulds and cores incorrectly assembled will cause fins. 'Kiss cores' of shorter length than necessary may also give rise to a fin. High metal pressures due to too long sprue, insufficient weighing of the moulds, or improper clamping of flasks may again produce the fin defect or, if the trouble is more critical, run-out may result. A pattern that is too large for a given flask or placed too close to the flask edge may result in a weak spot and give rise to run-out. Improper sealing of moulding joints may also produce run-outs.

5. Blowhole Blowholes are smooth and round holes clearly perceptible on the surface of the casting. They may be either in the form of a cluster of a large number of small holes having a diameter of about 3 mm or less or in the form of one large and smooth depression. Blowholes are caused in a casting by the generation and/or accumulation of gas or entrapped air in the mould cavity. Gas may accumulate when permeability of sand is low, such as when sand contains high moisture, sand grains are too fine, sand is rammed too hard, or when venting is insufficient. To prevent blowholes, the moisture content in sand must be well adjusted, sand of the proper grain size should be used, ramming should not be too hard, and venting should be adequate.

6. Pinholes Pinholes are numerous holes of small diameter, usually less than 2 mm, visible on the surface of the casting. They are caused by the absorption of hydrogen or carbon monoxide when the moisture content of sand is high or when steel is poured from wet ladles or is not sufficiently degassified. The defect can be minimised by using good melting and fluxing practices, by reducing the moisture content of moulding sand and increasing its permeability, and by promoting a faster rate of solidification.

7. Gas Holes Gas holes are those holes that appear when the surface of the casting is machined or when the casting is cut into sections. If the core prints are of inadequate size, gas cannot escape from the mould as fast as it is generated in the cores. The accumulation of gas from the core may give rise to gas holes in the casting. Faulty and poor quality of metal, the lack of controlled solidification, and excessively moist sand may also create gas holes.

8. Shrinkage Cavity Shrinkage cavity is a void or depression in the casting caused mainly by uncontrolled and haphazard solidification of the metal. It may be due to wrong location or an improperly sized gating system, inadequate risers, or poor design of casting involving abrupt changes of sectional thicknesses. Shrinkage may also be produced if the pouring temperature is too high. The defect can be eliminated by applying the principles of directional solidification in mould design and by judicious use of chills, denseners and padding.

9. Porosity Porosity is also due to gas formation and gas absorption by the metal while it is poured. Metal may dissolve some gas or air from the mould or core faces. These gases are liberated later when the metal cools, leaving behind porosity in the casting. Obviously, the porosity defect may lead to leaking castings and reduce pressure tightness. Adequate fluxing of metal and controlling the amount of gas-producing materials in the moulding and core-making sand mixes can help in minimising this defect.

10. Drops When the upper surface of the mould cracks and pieces of sand fall into the molten metal, 'drop' occurs. Sand having too low green strength, soft ramming or insufficient reinforcement of the mould may cause this defect.

11. Dirt Dirt generally appears in the form of foreign particles and sand embedded on the surface of the casting. The causes for this defect may be crushing of the mould due to mishandling, sand wash when the metal is poured because of low strength and soft ramming, insufficient fluxing of molten metal, and the presence of slag in the mould due to its incomplete separation from molten metal.

12. Metal Peneteration and Rough Surfaces This defect appears as an uneven and rough external surface of the casting. It may be caused when the sand has too high permeability, large grain size, and low strength. Soft ramming may also cause metal penetration.

13. Slag Holes These are smooth depressions or cavities on the upper surface of the casting or near it, usually near the in-gates, and are produced when the slag tends to find its way into the mould cavity along with the molten metal. Incorrect gating system and poor fluxing of metal are mainly responsible for this defect.

14. Scabs Scabs are a sort of projection on the casting which occur when a portion of the mould face or core lifts and the metal flows beneath in a thin layer. Scabs can be recognised as rough, irregular projections on the surface containing embeddec sand.

Scab are of two types: (i) expansion scabs, and (ii) erosion scabs.

An *expansion scab* is caused by the expansion of the surface layers of the sand mould. It may occur on any part of the mould, but more often it is found where the sand gets strongly heated, such as the top face of the mould which gets heated first by the radiation of heat from the molten metal rising upwards and then by actual contact with the molten metal. Heating by radiation causes a thin outer layer of sand to dry up and expand, leaving the interior green. This local expansion subjects the layer to severe stress and it eventually cracks. Molten metal enters through the crack and flows behind the layer of sand. It thus appears as a shallow, flat-topped projection on the casting. Olivine or zircon sands, due to their low thermal expansion, are much less prone to scabbing than silica sand.

An *erosion scab* may occur where metal has been agitated or has partly eroded the sand, leaving behind a solid mass of sand and metal at the spot where erosion took place. The sand that is eroded may find its way to the top part of the mould as dirt inclusion. Erosion scabs may thus be caused by hard and uneven ramming, improper selection of gates such that metal impinges on the mould or core and its flow is not streamlined, too high a moisture content in sand, too low permeability of sand, intermittent pouring of metal, or insufficiently baked cores or moulds.

15. Hot Tears (Pulls) Hot tears are internal or external ragged discontinuities or cracks on the casting surface, caused by hindered contraction occurring immediately after the metal has solidified. They may be produced when the casting is poorly designed and abrupt sectional changes take place; no proper fillets and corner radii are provided, and chills are inappropriately placed. Hot tears may also be caused when the mould and core have poor collapsibility or when the ramming is too hard and the casting is thereby under severe strain during cooling. Incorrect pouring temperatures and improper placement of gates and risers can also create hot tears. Methods to prevent hot tears may entail improving the casting design, achieving directional solidification and even rate of cooling all over, selecting proper mould and core materials to suit the cast metal, and controlling the mould hardness in relation to other ingredients of sand.

16. Cold Cracks Cold cracks are similar in appearance and formation to hot tears except that the breaks are less ragged and the cracks occur at a temperature below 430°C.

17. Cold Shut and Mis-run A cold shut is a defect in which a discontinuity is formed due to the imperfect fusion of two streams of metal in the mould cavity. The defect may appear like a crack or seam with smooth rounded edges. A mis-run casting is one that remains incomplete due to the failure of metal to fill the entire mould cavity. The reasons for cold shut or mis-run may be too thin sections and wall thicknesses, improper gating system, damaged patterns, slow and intermittent pouring, poor fluidity of metal caused by low pouring temperature, improper alloy composition, etc., When the metal cavity is not completely filled because of insufficient metal, the defect is called *Pour short*.

Figure 7.1 shows some of the common casting defects. Table 7.1 provides a guide to select non-destructive tests for iron castings and gives complete scrap diagnosis for castings.

Defect Analysis When a defective casting is produced, it is necessary to analyse the defect or defects observed and determine the causes for their occurrence, so as to arrive at appropriate remedial measures.

Often, there are a large number of inter-related factors affecting the occurrence of any defect and it becomes difficult to determine the exact causes. In order to

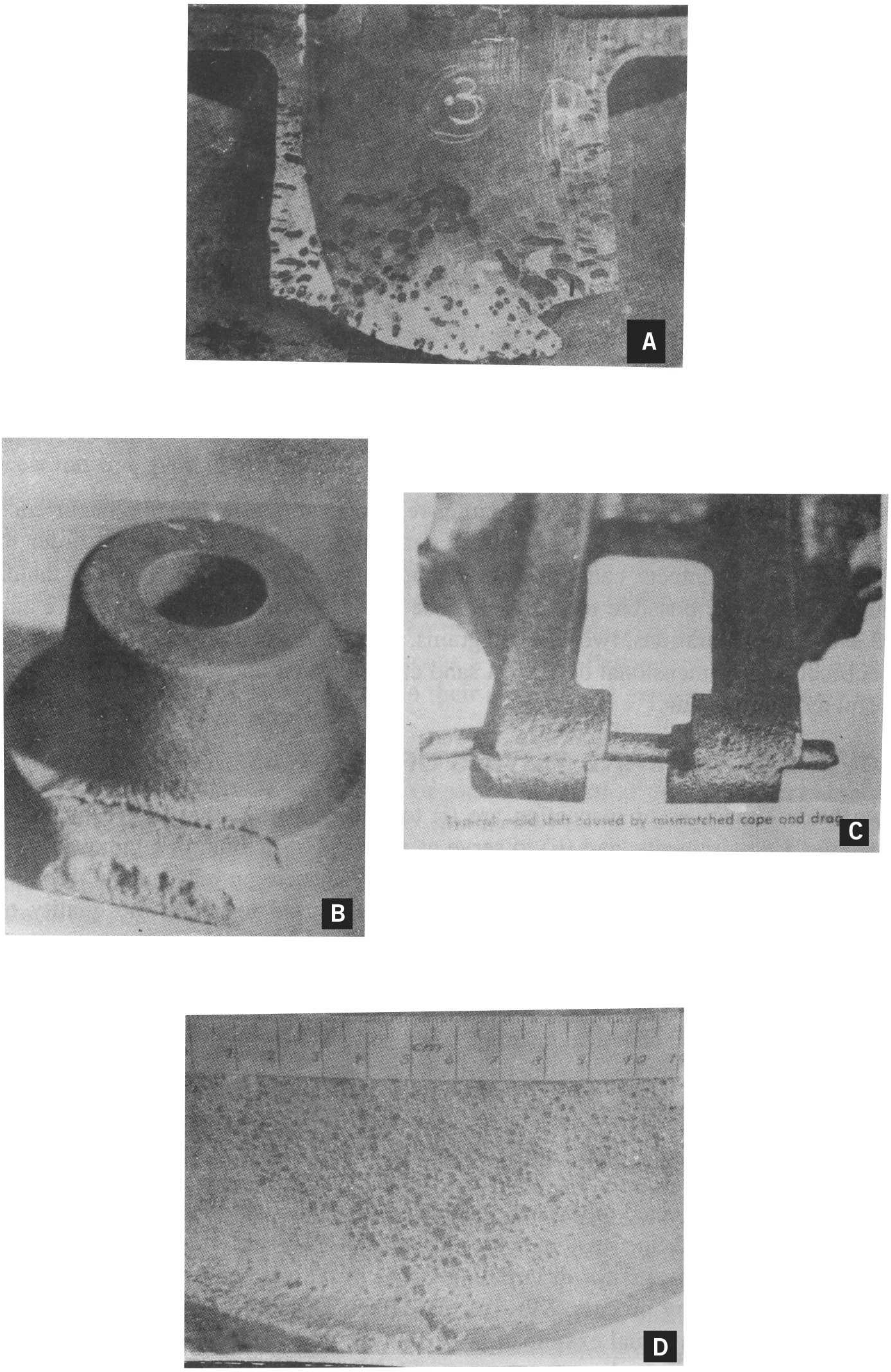
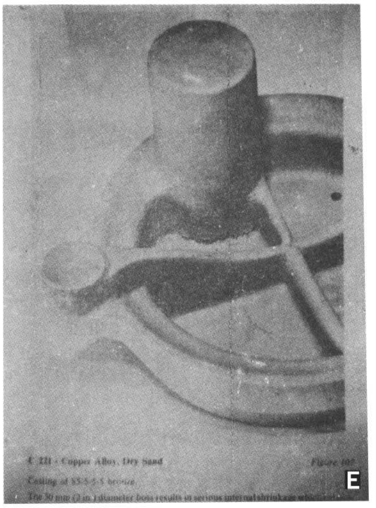
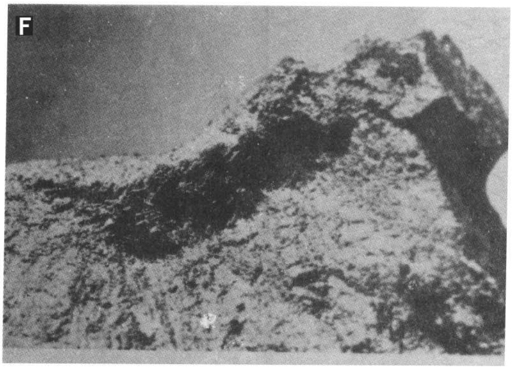


Fig. 7.1 *Different types of casting defect: (A) Blow holes (B) Cracked casting (C) Mismatch or shift (D) Pin holes*





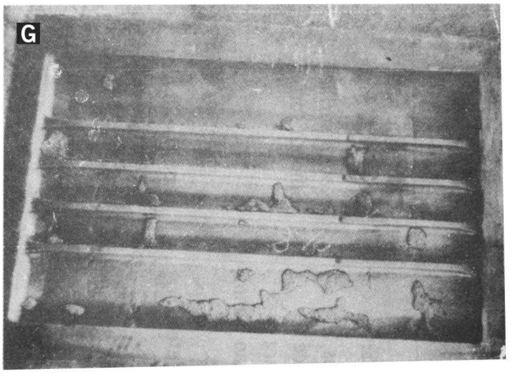


Fig. 7.1 *(E) Hot tears (F) Shrinkage (G) Expansion scabs*

assist analysis of defects, cause-and-effect diagrams can be prepared showing major causes and all the possible reasons for those causes (sub-causes). Figures 7.2 and 7.3 show, as illustrations, two such diagrams, one for casting defects and the other specifically for dimensional defects in sand casting. Such diagrams are particularly useful as training aids.

INSPECTION AND TESTING OF CASTINGS 7.2

Two basic objectives of inspection are (i) to reject castings that fail to meet the customer's requirements, and (ii) to serve as a means of maintaining the quality of workmanship and materials used in the foundry. *Inspection of castings* broadly covers a large number of methods and techniques used to check the quality of castings. These methods may be classified into five categories:

1. visual inspection;
2. dimensional inspection;
3. mechanical and chemical testing;
4. flaw detection by non-destructive methods; and
5. metallurgical inspection.

7.2.1 Visual Inspection

All castings are subjected to a visual inspection to ensure that the surfaces fulfil the requirements of both the customer and the producer. Visible defects that can be detected provide a means for discovering errors in the pattern equipment or in the moulding and casting process. Most of the defects covered in Section 7.1 can be discerned by careful visual examination. Visual examination may prove inadequate only in the detection of sub-surface or internal defects in which case more sophisticated methods may be necessary.

7.2.2 Dimensional Inspection

Dimensional control is usually required for all types of castings. Sometimes it is not so critical but at other times it may be vital. When precision castings are produced by processes such as investment casting, shell moulding and die casting, dimensions need to be closely checked. Initially, when the castings are made from a new pattern, a few sample castings are first made which are carefully checked with the drawings to ensure that the sizes obtained conform to those specified and will be maintained within the prescribed tolerances in the lot under production. On testing of the sample lot, deviations from the blueprint are rectified on the pattern equipment. When the castings are found to be consistently within the tolerances, spot checks, together with a regular check of the patterns and dies being used, may be sufficient. In the case of the jobbing type of foundry, each casting produced

Table 7.1 *Guide to selection of non-destructive tests for iron castings*

Nature of Defect	Nature of Application	Radiography		Ultrasonic	Dye Penterant	Eddy Current	Magnetic Crack Detection
		X-Ray	Y-Ray				
Surface	magnetic and				√ √		√ √ √
cracks, tears:	non-mag. irons				√ √ √		
Blowholes,	Rough surface	√		√			√
sub-surface	Smooth surface	√		√ √			
defects, not							
deeper than 3 mm;							
inclusions.							
Internal defects:	Sections 20 mm	√ √ √		√			
blow holes,	Section 20–150 mm	√ √ √	√ √	√ √			
shrink cavities,	Sections above 150		√ √	√ √			
inclusions.							
Incorrect hardness:						√ √ √	
Chilled edge:						√	
Wrong heat treatment:						√ √ √	
Dimensional errors:	Wall thickness			√ √ √			

√ √ √ Best suitable
√ √ Suitable
√ Possible

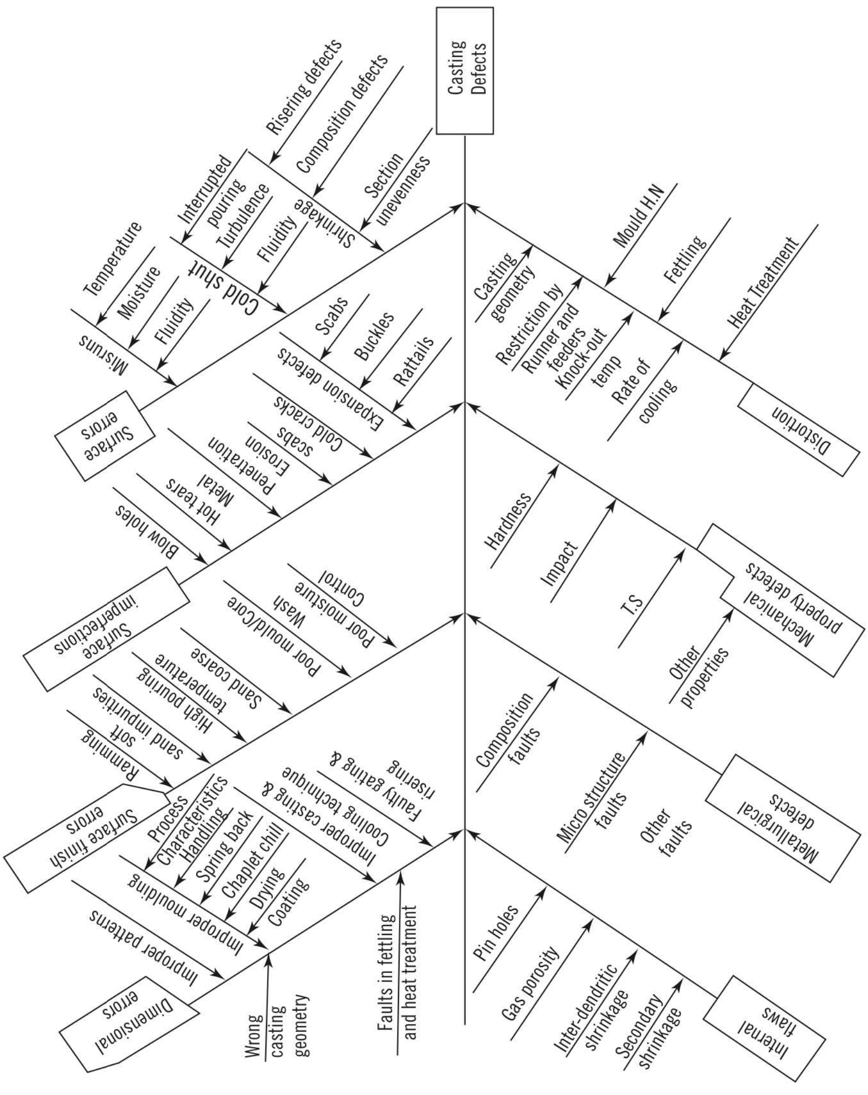


Fig. 7.2 *Cause and effect diagram for casting defects*

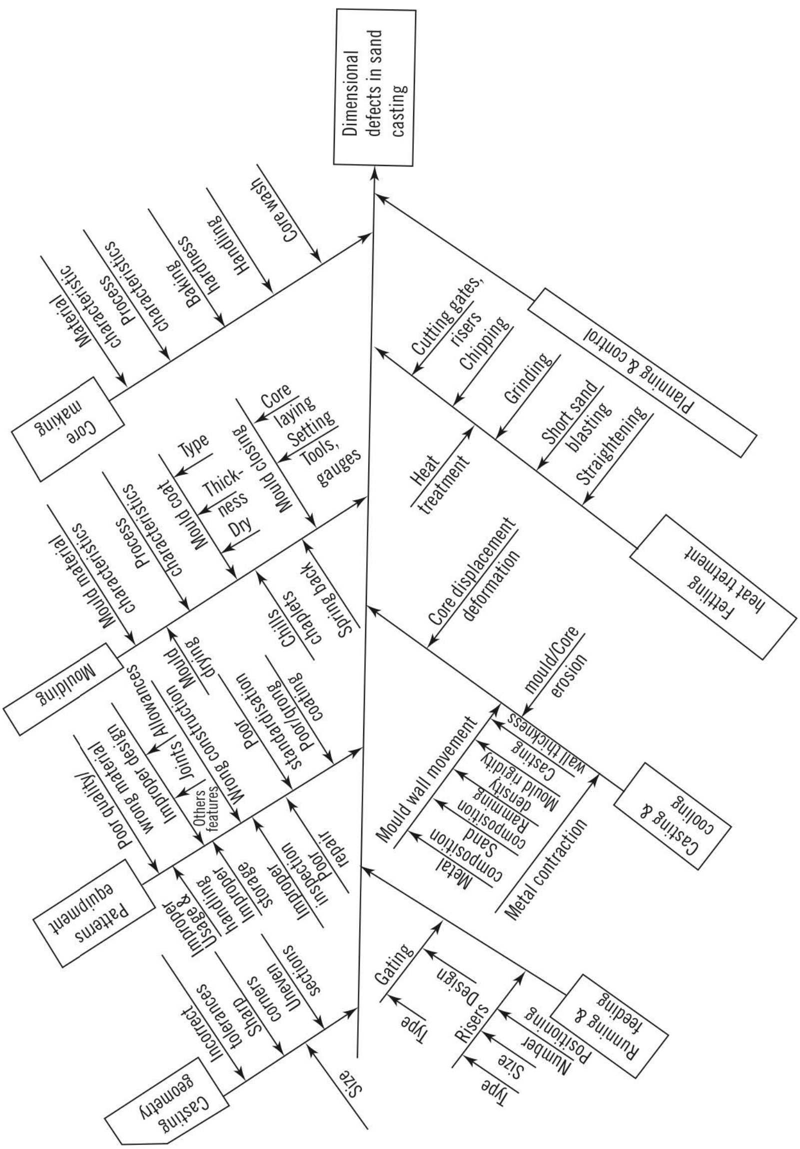


Fig. 7.3 *Cause and effect diagram for dimensional defects in sand casting*

may be different and, therefore, according to the customer's requirements, each one may have to be thoroughly inspected for dimensional variations.

Dimensional inspection of castings may be conducted by various methods:

(i) Standard Measuring Instruments to Check the Sizes Instruments such as rule, vernier calipers, vernier height gauge, vernier depth gauge, micrometers, scribing block, combination set, straight edge, squares, spirit level, and dial indicator are commonly used. For high precision castings or after machining, more advanced measuring instruments, such as auto-collimator, comparator, ultrasonic instruments for measuring wall thickness and projection instruments are also required.

(ii) Templates and Contour Gauges for the Checking of Profiles, Curves, and Intricate Shapes Templates act as time-saving aids in measurement and facilitate the entire job. These can be easily prepared in mild steel or brass sheet by marking out, and cutting and finishing the profile that is required to be checked on the castings.

(iii) Limit Gauges For toleranced dimensions on casting produced on a repetitive basis, limit gauges are usually used. The type of limit gauges—plug, ring, snap, plate—depends on the shape of the parameter to be checked. Periodical checking and maintenance of limit gauges is very important.

(iv) Special Fixtures Special fixtures are required to be designed and used where dimensions cannot be conveniently checked by using instruments, for instance, during the checking of locations, relative dimensions, centre-to-centre distance, angularity of surfaces, and so on.

(v) Coordinate Measuring and Marking Machine (CMM) This machine is very useful for measurement and inspection of uneven, undulated, irregular, or curved surfaces which cannot be conveniently or accurately checked by other measuring tools or instruments. The accuracy of measurement of these machine ranges from 0.001 mm to 0.05 mm. Besides measuring, it can be used for marking purposes also in all three dimensions on metallic or non-metallic surfaces. Measurement and marking are accomplished easily without errors in reading in all three dimensions. Once the machine is set, all measurements can be carried out in a programmed sequence automatically. The machine in reality is a multi-axial device providing measurement of output of position and displacement sequentially without a need for changing tools.

The machine essentially consists of a touch probe, usually having a ruby tip, which is mounted on a horizontally sliding arm, movable vertically along a column. The column is fixed to a base which in turn is held on a large accurately machined granite surface plate and is movable in a direction perpendicular to the direction of the movement of arm. Thus, the probe is capable of being moved along all three axes for carrying out measurement of different surfaces of a workpiece. The sliding movements of the arm and column are performed with great precision and are read on an electronic digital read-out unit, attached to the machine. When marking is to be done on surfaces, a scriber is used in place of a probe. A larger variety of probes, scribers and other accessories are available to enable the machine to be highly flexible and accurate in operation. The movements along the three axes may be manual or motorised. The machine can be further equipped with a small computer system for processing the data obtained from measurement and for storing and retrieving the same.

A special software is also available with the computer so that measurement and inspection of different types of surfaces can be carried out automatically without the need for manual control. The drawing data from CAD station can be also transmitted to this machine by interlinking the two systems with the actual value of dimensions. A printer can also be provided with the computer for producing a hard copy of the inspection report.

The CMM machines are now getting increasingly popular in inspection departments attached to tool rooms, pattern and die shops, foundry and forging shops, press shops, welding and structural shops and plastic and glass-part manufacturing units.

Surfaces finish of casting

The appraisal of surface roughness or finish is required in addition to the dimensional measurement. Surface roughness is expressed as a number (in microns), which is an arithmetical average of the heights of the peaks and depths of the valleys on a casting surface above and below a mean line within a specified sampling length. IS: 3073–1967 provides a method for assessing the surface roughness by this system. The approximate values for different types of castings are specified in Table 7.2.

Table 7.2 *Roughness values for different type of castings*

Costing process	Roughness value
Sand castings (ordinary)	25–50
Sand castings (good quality)	5–25
Permanent mould casting	0.8–6.3
Die casting	0.8–3.2
Shell moulding	1.6–6.3
Investment casting	0.8–3.2
Ceramic moulding	0.2–1.6

Surface roughness is evaluated approximately, as is usually sufficient for castings, by surface roughness comparison standards, where the given cast surface is compared visually or with the aid of a magnifying lens with a set of standards duly marked with varying surface roughness values. For finished surfaces and more precise measurements, electrical type of direct-reading, surface-measuring instruments or profilometers, such as Talysurf, are used. These machines use a tracer method, in which a styles is dragged across the given surface.

The main factors affecting surface finish of castings are:

- Cast metal characteristics
- Pattern material and equipment
- Moulding materials, moulding method and equipment
- Core production
- Mould and core coatings
- Fettling process

7.2.3 Mechanical and Chemical Testing

All foundries should have facilities for determining the mechanical properties of a cast metal and its chemical composition. Mechanical testing methods include certain procedures which require a standard type of equipment. These are

(i) tensile test to determine the tensile strength, yield strength, percentage elongation, and percentage reduction in area,

(ii) bend, notch bend, and impact transverse tests to evaluate the ductility and resistance to shock of the cast metal;

(iii) hardness test, which can indicate the strength and ductility of the metal (often, only hardness testing is conducted with visual inspection. Other tests are used only when so required);

(iv) fatigue test, applied in cases where an appraisal of the life of the casting in service is to be known; and

(v) tests for damping capacity and wear resistance.

Chemical testing is required to determine allowable limits. In the case of ferrous castings, it is necessary to know the percentage of carbon, silicon, sulphur, manganese, and phosphorus contents. The presence of alloying elements or metallic inclusions, such as Cr, Ni, Cu, Mg, W, V, Mo and Co, may also have to be determined. Chemical analysis can be used in all such cases to accurately ascertain the composition, though certain tests may be too cumbersome and time-consuming.

In many instances, it is necessary to quickly determine the content of carbon, silicon, and sulphur. This may also have to be regularly checked where a close control of the composition of metal is consistently required. Certain quick tests have been developed for such cases. One such test, commonly used in the case of grey iron, malleable iron, and ductile iron, is called *Carbon Equivalent Measurement.*

Carbon equivalent (CE) is given by

$$\text{Total carbon \%} + \frac{1}{3}\text{Si \%}$$

Since silicon has a predominant effect on the graphitising tendency of iron, the cumulative effect of carbon and silicon can indicate the strength characteristics of the iron produced. For shop floor use, a measuring instrument, known as 'instant carbon sensor' that quickly assesses CE. is available. It works on the principle that CE is directly related to the liquidus arrest temperature of the metal. The instrument is equipped to hold molten metal in a small reservoir over a chromel-alumel thermocouple and the temperature of the metal, as it solidifies in the reservoir, is registered on the chart of the temperature recorder. From this chart the liquidus arrest temperature can be easily determined. A conversion table (Table 7.3) is available for arriving at CE corresponding to the determined value of liquidus temperature.

Similarly, for rapid determination of silicon in cast iron, a special apparatus called the *Strohlein thermoelectrometer* is available. It is equipped to measure the thermal emf produced when a junction between the metal whose silicon is to be determined and another metal, such as copper, is heated. The thermal effect depends on the actual metals involved and on the temperature difference between the junction and the cold ends. Silicon possesses a special position in the thermoelectric series and it is possible to determine its content by means of empirical calibration curves. The equipment is so designed that constant operating conditions are maintained at all times. Calibration curves are first prepared by using samples of known silicon content. The metal under test is then taken in the form of shavings and kept between two anvils on the apparatus. One of the anvils is heated by circulating a thermostatic liquid through it and the thermal emf generated due to the heating of a dissimilar junction is measured on a transistorised micro-voltmeter. From the calibration curves, the percentage of silicon is determined from the emf value.

Table 7.3 *Conversion table for liquids temperature to carbon equivalent*

Liquidus temperature	Carbon equivalent
2250	3.60
2230	3.70
2210	3.80
2190	3.90
2170	4.00
2150	4.10
2130	4.20
2110	4.30

Chemical analysis, though the most accurate and reliable method, takes a long time. When metal is melted and refined in an electric furnace, the composition needs to be quickly determined, so that alloys can be added to adjust the constituents to the desired proportions. In such cases, chemical analysis is not suitable.

More rapid methods are available not only for CE or silicon, as mentioned earlier, but also for most of the other elements, which may be present in the metal even in traces. These methods are based on the principles of spectroscopy. Spectroscopic analysis is gaining popularity in foundries for quick determination of the constituent elements including the trace elements. Various types of spectroscopic analysers are available, the selection depending on the nature of requirements in terms of the elements to be checked, the accuracy desired, the frequency at which tests are to be conducted, and the type of cast metal.

A microprocessor-based system operating on the principle of thermal analysis is also available for quick determination of carbon equivalent, total carbon, silicon and temperature of molten metal. It can be used for various cast metals like grey iron, malleable iron, SG iron, steel and copper-base alloys. The instrument is equipped with a digital display. A print-out is also obtained for permanent record. It has a high degree of accuracy, e.g., within ± 0.05% for carbon equivalent and total carbon and within ± 0.15% for silicon.

7.2.4 Flaw Detection by Non-destructive Methods

Non-destructive tests are also required to be conducted in foundries to examine the castings for any sub-surface or internal defects, surface defects, which cannot be detected by visual examination and for overall soundness or pressure tightness, which may be required in service. These tests are valuable not only in detecting but even in locating the casting defects present in the interior of the casting, which could impair the performance of the machine member when placed in service. Parts may also be examined in service, permitting their replacement before the actual failure or breakdown occurs.

The important non-destructive test for castings include:

1. sound or percussion test (stethoscope test);
2. impact test;
3. pressure test;
4. radiographic examination;
5. magnetic particle inspection;
6. electrical conductivity test;
7. fluorescent dye-penetrant inspection;
8. ultrasonic test; and
9. eddy current test.

1. Sound or Percussion Test (Stethoscope Test) This is an old method, which has been refined over the years. Basically, it entails suitably supporting the suspension of the part by chains or other equipment, permitting the part to swing free of the floor and other obstructions, and then tapping it with a hammer. The weight of the hammer blows is so adjusted that vibrations will be set up in the casting producing a certain characteristic tone which may or may not change the wavelength of sound produced by the blows.

The stethoscope test serves to detect relatively large discontinuities in an otherwise homogeneous metal and may be successful when applied to simple shapes and uniform cross sections. The drawback of the method is that it is difficult to judge the extent of the defect and to locate the fault.

2. Impact Test This test may be destructive or non-destructive in nature, depending on the quality of casting. Moreover, it cannot be used in all cases as it can damage the casting.

A hammer of appropriate size is used to strike or fall on certain members of the casting where the defect is suspected. It is expected that the casting containing harmful defects will break and will thus be automatically rejected whereas those that are faultless will stand the test.

A variation of this method involves dropping the casting from a specified height onto a steel base. Obviously, the method of testing is not very reliable and sometimes even the defect-free castings may break. This method is therefore sparingly used these days.

3. Pressure Test This method is employed to locate leaks and to test overall strength of certain parts, such as cylinders, valves, pipes, and fittings, which are required to hold or carry fluids in service under various amounts of pressure. The fluid used in testing may be water, air, or steam. Water being incompressible is generally preferred since danger is minimised even if the casting should shatter due to pressure. The pressure may vary from one and a half times to two times the working pressure. For safety reasons, the pressure is generally applied by means of a small hand pump. A leak, even if it is not located immediately, may be detected on the pressure gauge. Steam tests have the advantage that steam can press through smaller holes or openings through which water may not readily pass. Besides, the heat of the steam also causes minute cracks to widen due to expansion. While testing pneumatically, the casting is immersed in a tank carrying water and then the air pressure is applied. If there is a leak, air bubbles are formed.

4. Radiographic Examination Radiography is a non-destructive test for detection of internal voids in castings. Electromagnetic waves having low wavelengths (varying between 10^{-6} and 10^{-10} cm) are used as a means of inspection. These waves, generally called X-rays, have properties similar to those of light waves, but they have much shorter wavelengths, which lie outside the range of human sensitivity. These X-rays can, however, be detected by a sensitive photographic film. Owing to their shorter wavelengths, these waves can penetrate materials that are normally opaque to light. The denser the material, the shorter the wavelength required to penetrate it. The test can be applied to all grades of iron and steel castings, though it is an expensive method of inspection.

The X-rays are produced by an X-ray tube which carries two sealed copper elements, the cathode and the anode. The cathode bears an electrically heated filament which generates electrons; when these electrons strike the tungsten target fixed to the anode they are driven towards the positively charged anode. The striking of the electrons causes their kinetic energy to be partly converted into heat, which is conducted away through the cooling fins provided on the anode and the remainder of the energy is converted into electromagnetic waves, termed X-rays. The X-rays pass out of the tube through a window in the form of a beam. The intensity of these X-rays is controlled by regulating the current passing through the filament. Similarly, the wavelength of the ray is inversely proportional to the voltage applied between the two poles. The shorter the wavelength, the greater the depth of penetration.

If there is a cavity or a hole in the casting under inspection, and, when such a casting is kept against the X-rays, the rays finding less obstruction penetrate more freely than at the place where the metal is more dense and solid. The rays that penetrate and emerge from the casting are absorbed by a photographic plate. Thus the part of the photographic plate opposite the defect will receive more rays and will be more exposed than the rest of the plate. This will produce a contrasting image on the negative. For more accurate results, special films with an emulsion coating are found suitable. Sometimes, in place of a photographic plate, fluoroscopic screens are used; these screens are made of materials that fluoresce when exposed to X-rays in a dark room. To protect the viewer from continuous exposure to the rays, the image of the screen is observed in a mirror, which is so placed that observer is located out of the path of the X-rays. The voltages required for the X-ray machines depend on the density of the metal and its section thickness.

Like X-rays, gamma rays which are emitted during the decomposition of radium, are also suitable for the inspection of castings. The wavelengths of these rays range between $10^{-7.5}$ and $10^{-10.5}$ cm and since these are shorter than X-rays they can penetrate metals more easily. Due to their high penetrating power, the radiation absorbed by the photographic film is negligible and the remainder passes through the film. Further, the difficulty experienced during the observation of thick and thin sections simultaneously is also less than when using X-rays. But due to the high cost of radium and the need for expensive protective equipment, the technique is used to a limited extent.

Radiography does not enable detection of cracks. The position of defects in the section also cannot be easily defined unless special techniques are employed. Interpretation of radiographs depends on a subjective assessment and hence requires proficiency in the work along with experience. Castings which have passed the radiography test may still not be entirely leakproof. Recommended radiations and their sources are given in Table 7.4.

Table 7.4 *Recommended radiations and their sources*

Radiation		Iron thickness (mm)	Exposure time
X-rays	100 kV	< 12	
	200 kV	12– 40	1–10 min
	400 kV	40– 90	
	1000 kV	50–150	
	20,000 kV	60–250	
Y-rays	Cobalt 60	40–100	
	Iridium 192	12–100	3–6 h
	Cesium 137	20–200	

5. Magnetic Particle Inspection This test is used to reveal the location of cracks that extend to the surface of iron or steel castings, which are magnetic in nature. The casting is first magnetised and then iron particles are sprinkled all over the path of the magnetic field. The particles align themselves in the direction of the lines of force. Their distribution is also in proportion to the strength of the magnetic field. In the case of a faultless casting, particles will be distributed uniformly all over the surface, whereas if a defect exists, the iron particles will jumble round the defect. The reason is that a discontinuity in the casting causes the lines of force to bypass the discontinuity and to concentrate around the extremities of the defect. By studying the concentration of the particles, the depth at which the defect occurs can also be judged. However, considerable experience is necessary for an accurate estimation of the defects. With correct test procedure, cracks longer than 1 mm and a fraction of a millimetre deep can be detected.

Generally, a casting can be magnetised by passing an electric current through it. The current may be either alternating or direct. An alternating current is used when high surface sensitivity is desired, and the direct current is preferred where defects are to be located beneath the surface. Other methods for magnetising castings include positioning the casting between two magnetic poles or placing the casting in a coil carrying a direct current.

Iron particles may be applied either dry with a handshaker or bulb blower or in wet form by spraying or pouring over the surface. When wet, the particles are carried in suspension form in liquid, for instance, kerosene, gasoline, or carbon tetrachloride. After testing, casting remains magnetised unless subjected to demagnetisation.

6. Electrical Conductivity Method In this method, current is passed through the casting and read on an ammeter. If the casting has imperfections, there is a resistance to the flow of current and this is evident by a drop in the reading. The method is difficult to apply in practice owing to variations in sectional thickness, size and metallurgical structure; also it cannot be used directly unless a suitable standard is developed for a given lot of castings.

7. Fluorescent Dye-Penetrant Inspection Penetrant testing helps to direct small surface cracks in castings, which cannot be observed with the naked eye. Although this method shows up the finest surface defects in a magnified form, interior defects, where the penetrant does not reach, cannot be revealed.

The method is very simple and can be applied to all cast metals. It entails applying a thin penetrating oil-base dye to the surface of the casting and allowing it to stand for some time so that the oil passes into the cracks by means of capillary action. The oil is then thoroughly wiped and cleaned from the surface. If the casting under inspection has any surface cracks, the oil will remain in these cracks and will tend to seep out. To detect the defects, the casting is painted with a coat of whitewash or powdered with talc and then viewed under ultraviolet light. The oil, being fluorescent in nature, can be easily detected under this light, and thus the defects are clearly revealed. By close observation of the amount of penetrant coming to the surface, the form and size of the crack can also be estimated with a fair degree of accuracy. The oils used are water-emulsifiable penetrants and are of proprietary nature.

Fluorescent dye inspection can also disclose those surface defects that are not revealed by radiographic inspection. For this reason, the penetrant test is often used to supplement the radiographic test.

8. Ultrasonic Testing Ultrasonic testing used for detecting internal voids in castings, is based on the principle of reflection of high-frequency sound waves. If the surface under test contains some defect, the high-frequency sound wave, when emitted through the section of the casting, will be reflected from the surface of the defect and return in a shorter period of time. On the other hand, if the section is homogeneous and faultless, the wave will be reflected back after it travels through the whole of the section. In this case, it will take longer to return to its source. For detecting the lengths of time, an oscillograph is used. The path of travel of sound wave is plotted on the CRT screen of the oscillograph where it can also be measured. The advantage this method of testing has over other methods is that the defect, even if in the interior, is not only detected and located accurately, but its dimension can also be quickly measured without in any way damaging or destroying the casting. With a clean metal of small grain size, holes as small as 0.025 mm in diameter can be detected.

Ultrasonic testing can be applied to spheroidal graphite, compacted graphite, malleable and high-grade iron castings. The ease of application depends on casting shape. Proper test procedure can detect almost any hole, cavity or discontinuity. The method can be adopted for measuring wall thicknesses when only one side is accessible. Defects closer than 2 mm to a surface need special techniques to be detected.

The test frequencies used for detection vary from 0.5 to 5.0 MHz, according to the nature of iron and section thickness. For example, for SG iron having 20–50 mm section thickness, 5 MHz frequency is required, whereas for Grade 20 grey iron, 1 to 1.5 MHz is adequate. The equipment is light and portable; weighing 5 to 6 kg and can be taken anywhere at the work sites.

9. Eddy Current Test This test is used for rapidly checking the hardness of iron castings. In this method of non-destructive testing, a coil carrying alternating current induces an eddy current of the same frequency in the test part under investigation. The eddy currents produced are affected by changes in the electrical conductivity, magnetic permeability and physical and metallurgical properties of the test part.

The instrument consists of (i) a main unit, with a cathode ray tube (CRT) video display complete with frequency selector, oscilloscope controls, coil balance and sensitivity controls, and phase-shifting controls, and (ii) a matched pair of coils. The physical or metallurgical characteristics of any two parts kept in these coils are electromagnetically compared by observing their signals on the CRT screen. Before actual testing, the instrument has to be balanced. For this purpose, two similar parts are kept in the two coils and the test frequency is adjusted to the optimum value suiting the parameters of the test. The instrument is then balanced to obtain a horizontal straight line on the screen, showing that both parts are identical. Calibration curves are prepared and used for regular inspection.

One of the two parts kept originally for balancing is replaced by the part under test. The dissimilarity in shape of the signals, as observed on the CRT screen, indicates the variance in the concerned property of the two parts.

The eddy current intensity is greatest at the surface of the specimen and decreases as the depth increases. At high frequencies, eddy currents are produced only in the skin region, enabling the study of case depth, case hardness, and surface flaws or imperfections. Use of lower frequencies can be made to study sub-surface flaws, segregation, grain structure and chemical composition. The depth of penetration also depends on the conductivity and relative permeability of the specimen. Thus, the optimum frequency suiting the conductivity, magnetic permeability and depth of penetration desired must be selected such that the signals are clear and easily interpretable.

The eddy current method is suitable for testing hardness of rolled, forged, extruded, sintered or cast components in ferrous and nonferrous alloys, particularly, heat treated castings, such as malleable iron, nodular iron and CG iron. Hardness can be predicted to ±10 points Brinell. The test is normally limited to castings which will fit inside a 300-mm dia. coil. It is particularly well-suited for inspection of components produced by mass production machines on the shop floor, where the components produced have to be simultaneously inspected and segregated into good or bad lots or into different categories according to the quality.

Table 7.1 shows a guide to selection of non-destructive tests for iron castings.

7.2.5 Metallurgical Inspection

Metallurgical inspection is very useful for checking grain size, non-metallic inclusions, sub-microscopic pin holes, the type and distribution of phases present in the cast structure, and the response to heat treatment. These features can be appraised by certain methods:

1. chill test;
2. fracture test;
3. macro-etching test;
4. sulphur print test; and
5. microscopic examination.

1. Chill Test Wedge test is a common method for chill testing of grey iron. It offers a convenient means for an approximate evaluation of the graphitising tendency of the iron produced and forms an important and quick shop floor test for ascertaining whether this iron will be of the class desired. The depth of chill obtained on a test piece is affected by the carbon and silicon present and can therefore be related to the carbon equivalent, whose value, in turn, determines the grade of iron.

In practice, a wedge-test specimen (Fig. 7.4) of standard dimensions (IS: 5699–1970) is cast in a resin or oil-bonded sand mould. The test specimen is removed from the mould as soon as it is completely solid, quenched in water and then fractured in the middle by striking with a hammer. The chilled iron at the apex of the wedge usually consists of two zones; the portion nearest the apex entirely free of graphite is 'clear chill' followed by the portion in which spots of cementite or white iron are visible, called 'mottled zone'. The width of the chilled zone, measured parallel to the base and across the wedge is designated as 'total chill'. The value should not exceed more than half the value of the base. Chill width is largely affected by

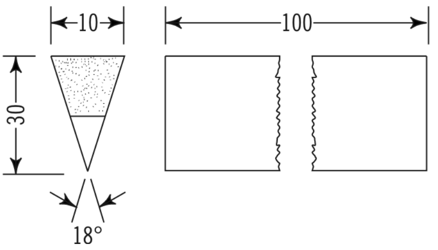


Fig. 7.4 *Standard wedge No.2*

Table 7.5 *Recommended wedge-test specimen dimensions*

WEDGE NO.	BREADTH MM	HEIGHT MM	INCLUDED ANGLE DEG.	LENGTH MM
1	5	25	11.5	100
2	10	30	18	100
3	20	40	28	100
4	25	45	32	125
5	30	50	34.5	150

the use of alloy additions or inoculants and therefore the same value should not be expected in all cases.

2. Fracture Test By examining a fractured surface of the casting, it is possible to observe coarse graphite, mottled graphite or chilled portion and also shrinkage cavity, pin hole, etc., The apparent soundness of the casting can thus be judged by seeing the fracture.

In case of steel casting, fracture test is also used in some foundries to quickly judge the amount of carbon present. A test rod of 25-mm diameter and 75-mm length is cast in a sand mould and quenched in water. The rod is then broken into two pieces and the fracture examined visually. Due to quenching, martensite is formed which is seen in the fractured section in the form of white spots or lines according to the amount of carbon present. Figure 7.5 shows three types of fractures for varying amounts of carbon.

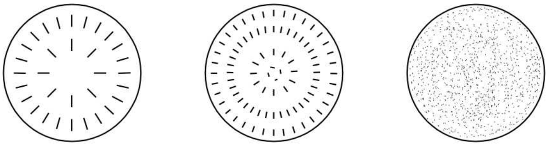


Fig. 7.5 *Fractured sections of steel having varying carbon content*

3. Macro-etching Test (Macroscopic Examination) The macroscopic inspection is widely used as a routine control test in steel production because it affords a convenient and effective means of determining internal defects in the metal. Macro-etching may reveal one of the following conditions:

(a) crystalline heterogeneity, depending on solidification;
(b) chemical heterogeneity, depending on the impurities present or localised segregation; and
(c) mechanical heterogeneity, depending on strain introduced on the metal, if any.

The test entails etching the sample piece of casting in a suitable reagent at a particular temperature for a prescribed length of time. The heterogeneity in the metal is revealed by the difference in chemical relations between the structural components of the metal and the selected etching reagent. Surface defects, inclusions, segregated area, etc., are selectively attacked by the reagent, and are therefore easily detected. Macro-etching reagents found suitable for steel and cast iron include hydrochloric acid, nitric acid, and Stead's reagent.

4. Sulphur Print Test Sulphur may exist in iron or steel in one of two forms: either as iron sulphide or manganese sulphide. The distribution of sulphur inclusions can be easily examined by this test. The component to be examined for sulphur segregation is sectioned, ground, and polished. A sheet of photographic bromide paper is soaked in 2% solution of sulphuric acid for about five minutes. It is then removed from this acid solution and allowed to drain free from excess solution or is lightly pressed between two pieces of blotting paper. The emulsion side of the paper is then placed on the polished surface of the sample under moderate pressure for about two minutes. Care should be taken to ensure that no air bubbles are trapped. The paper is then removed and found to have brown stains where it was in contact with any sulphides. The reaction of sulphuric acid with the sulphide region of the steel produces H2S gas, which reacts with the silver bromide in the paper emulsion, forming a characteristic brownish deposit of silver sulphide. The darker and the more numerous the markings, the more the sulphur indicated. The paper is finally placed in a fixing solution for ten minutes, washed in running water, and dried. The entire operation can be carried out in daylight.

5. Microscopic Examination Microscopic examination can enable the study of the microstructure of the metal or alloy, elucidating its composition, the type and nature of any treatment given to it, and its mechanical properties. In the case of all cast metals, particularly steels, cast iron, malleable iron, and SG iron, microstructure examination is essential for assessing metallurgical structure and composition.

The sample for examination is first cut to about 12-mm diameter and 9-mm thickness, and filed and ground to erase any deep grooves or marks. The piece should not get overheated at any time as this may alter its structure. The specimen is then polished on a series of emery papers of various grit sizes, the last one being of the finest variety. Sample polishing machines are available for the purpose. It may sometimes be desired to mount the sample in Bakelite, epoxy resin, or some plastic material before it is polished so as to keep edges from getting rounded off. For final polishing, the specimen is rubbed on a special cloth, which has already been impregnated with a polishing medium. It is then thoroughly cleaned and degreased, by washing in hot water, and sprayed with acetone or spirit.

The next step is to etch the specimen so that the etching reagent will first dissolve the thin bright layer produced during polishing and then attack metal at the grain boundaries and make them prominent on the surface. Owing to the nature of the grain boundaries, the rate of chemical solution along the boundaries will be greater than within the grains. Therefore, etching will produce the true underlying microstructure. The specimen is treated with the etching reagent for a few seconds until it acquires a dull matt appearance. It is then washed in hot water and dried in hot-air blast.

Etching Reagents

For steel and cast irons

(i) nital. (2% solution of nitric acid in alcohol);

(ii) picral. (4% solution of picric acid in alcohol); and

(iii) alkaline sodium picrate (2 g of picric acid and 25 g of caustic soda added to 100 ml of water).

For copper and its alloys

(i) ferric chloride solution in water or alcohol; and

(ii) ammonium hydroxide–hydrogen peroxide.

For aluminium and its alloys

(i) hydrofluoric acid solution in water (0.5%);

(ii) sodium hydroxide solution in water (1.0%); and

(iii) sulphuric acid.

After the specimen is etched and washed, it is ready for examination under the metallurgical microscope.

Scanning Electron Microscope The use of a scanning electron microscope (SEM) has brought new insights in the field of metallurgical analysis, particularly in the study of fractures (fractography), grain size and grain growth, phase transformations, impurities and trace elements, characteristics of powders and their compaction. No specimen preparation is usually necessary. Even non-conducting materials can be examined by applying a mild conductive coating on the surface. The resolution of SEM being as high as and the depth of field being nearly 300 times that of an optical microscope, this instrument can be extremely valuable in quality control of castings, as also other products.

A fine beam of electrons is allowed to interract with the sample. The low-energy secondary electrons are made to strike a scintillator. The photon image is then fed to a photo multiplier through a light guide. The signal from the photomultiplier is used to influence the scanning in a cathode ray tube in synchronism with the scanning of the specimen by the original electron beam. The image on the tube is a magnified view of the specimen surface with excellent fidelity to topographic details.

QUALITY CONTROL IN FOUNDRIES 7.3

The main purpose of quality control is to 'prevent rather than merely detect' defective parts. Inspection, on the other hand, is generally accepted as just separating the good parts from the bad. The quality of production cannot be improved simply by inspection. Quality control in its true sense, deals with the whole system of production and the methods employed to establish and achieve the desired standards. Quality control should therefore be aimed at the appraisal of the causes of scrap and re-work, and at the elimination of these causes.

In a total quality control system, the responsibility for quality has to be shared by the entire organisation, not just one or two groups of people or departments. Everyone involved with the product, from the designer to the sales executive, is delegated his task. The designer must design for simplicity, easy castability, and lowest cost. The customer's requirement must be within the normal capabilities of the plant. The management must be able to provide satisfactory materials and the tools required at all stages of production, and offer sound working conditions, train operators, plan methods, and provide adequate checks to maintain the required quality. The employees must endeavour to produce accurately the first time, whether it is a pattern, mould, core or casting, communicate difficulties or problems, make sure they understand what is expected of them, and act as a team. Lastly, the sales personnel must not promise deliveries that cannot be met, prices that are low and therefore unrealislic and quality that cannot be produced.

Quality control is concerned with the manufacture of the product into which quality is designed, built and maintained at a level that is the most economical and yet allows for full customer satisfaction. It can be appreciated that designing and building a given component to a prescribed quality standard once, is not as difficult as consistently maintaining that quality in all the components subsequently resulting from the production line.

Statistical analysis has developed as an invaluable aid in quality control. With the help of statistical techniques, it is possible to use the data available for present and past production to predict the quality of items or lots to be produced in future. Similarly, without a detailed inspection of parts, it is possible to confidently predict the quality of a whole lot just by examining a few sample pieces.

Quality control using statistical techniques, known as statistical quality control (SQC) and statistical process control (SPC) has several applications in the foundry:

1. Sand Control It is essential to limit variations in sands within allowable values. Control chart techniques can be of great use in regulating various sand and mould characteristics, such as moisture content, green permeability, green compressive strength, dry permeability and compression, hot tensile strength, deformation, collapsibility, dry shear (for facing sand), and clay content. Control may be exercised on shift averages of each of these parameters and individual values on a batch basis. Statistical control limits can be determined for average and range charts from the data available from previous experiments.

2. Control of Cores The quality of cores can be controlled with regard to their critical dimensions, spacing, etc., A dimensional check may be kept either by using a limit gauge and preparing control chart based on attributes or by using actual measuring instruments and making control charts based on variables.

3. Melting Control A number of variables, such as electrode consumption, slag control, carbon and silicon content in melts, pouring temperature, and weight of raw materials, can be controlled by using control charts based on variables.

4. Control of Casting Defects By setting a quality level for castings, a number of likely defects can be controlled and corrective measures taken before the actual scrap is produced.

5. Casting Weight Control Control limits can be established for the minimum and the maximum allowable casting weights and the variations can be controlled.

6. Control of Scrap and Re-work By studying the process to be adopted, it is possible to determine the range of scrap that can be reasonably expected. Control limits can then be expressed as percentage or as a number of items.

7. Product Appraisal Records of various mechanical tests, such as hardness, tensile strength, chemical and non-destructive tests and dimensional inspection, can be maintained through control charts which can be of utmost help in predicting performance and laying down the future policies of the company. Sampling inspection methods can also be adopted with advantage where castings are produced on a repetitive basis under controlled production conditions, such as in automotive foundries, malleable iron foundries, consumer goods foundries and railways.

8. Other applications, such as cost control, check on absenteeism, accident prevention, and safety evaluation are possible where SQC techniques can be usefully applied.

Bureau of Indian Standards has rendered valuable service by bringing out three standards on SQC, which are useful in the understanding and application of the principles in any practical situation. These standards are

(i) IS: 397–1952—The method for SQC during production by use of control charts;

(ii) IS: 1548–1960—The manual for basic principles of lot sampling; and

(iii) IS: 2500–1963, 1966—Sampling Inspection Tables, Parts I and II.

EXPERT SYSTEM FOR CASTING DEFECT ANALYSIS 7.4

Expert systems are computer programs in which the knowledge and experience of one or more experts is captured and stored so as to make it widely available. These systems can be of great assistance in the decision-making process as the computer can be made to think, reason, make inferences and give judgement, conclusions or solutions to problems. Expert systems have wide engineering applications in manufacturing, quality control, defect analysis, fault diagnosis and plant maintenance. In foundries, casting-defect analysis is one of the common application of this system. The entire system consists of an input device like keyboard, a knowledge base, database, inferencing capability and output device. The knowledge base written in the form of a series of rules contains facts, concepts and procedures in a form suitable for storage, interpretation and for matching with the information obtained for a specific problem in the database. During inferencing, the data for the current problem is matched with the knowledge using search and pattern-matching technique and decision or solution, as the case may be is indicated as output. Foundries can buy an expert system shell, so that any desired knowledge can be collected, developed and written into it, and the software is then ready for use.

Expert systems are a part of computer technology in which computers can be made to think like people. In a foundry, where many decisions are based on rules of thumb, the expert system can mimic such decision-making and give suitable solutions. Initially, the availability of an expert who is thoroughly familiar with the concerned field of technology is essential to gather knowledge required to develop the expert system. This system once developed can be used as and when required without any further need of human experts or advisers. The expert system discussed in this topic is related to analysis of defects in cylinder block casting. The work consists of three parts:

(i) the identification of defect from casting,
(ii) the analysis of various possible causes for each defect, and
(iii) the remedial solutions for each cause.

The expertise is tapped from the expert, who is also an author, by regular discussions and structured in the form of a knowledge tree during the knowledge acquisition stage. Then this knowledge is codified into the computer in the form of rules. It gives quick solutions to the problems and is helpful to a person who is new to the foundry field. It can be modified at any stage during the usage. A knowledge base contains rules and facts. The expert knowledge is represented in the form of rules of thumb (heuristics) in the knowledge base. Facts consist of information supplied by the user or from sensors. Facts are stored in the database as and when supplied by the user or deduced by the inference mechanism. Inference engine or rule interpreter is a control strategy employed to solve the problem. It basically determines in which order to carry out inferences to achieve the desired goal. Two popular strategies are forward chaining and backward chaining. In forward chaining, the program asks for all facts, compares them and determines what conclusions can be drawn from the data. In backward chaining, the program assumes a conclusion and starts asking questions either to accept or reject the conclusion.

A human interface is the dialogue handler between the user and the system. It asks the user for information and displays the action to be taken. It also explains why the system has asked a specific question or how it has come to a particular conclusion. Engineering fields, such as foundries, derive much benefit from expert systems. Some of the potential areas for the development of expert systems in foundries are the following:

(i) *Diagnosis Expert Systems* can be developed to analyse the defects in castings. Expert systems can also be developed in finding faults in any foundry machinery.
(ii) *Monitoring Expert Systems* can be developed to monitor, e.g., the sand mixture properties and give corrective measures for the proper maintenance of a sand system.

7.4.1 Requirements for the Development of an Expert System

(i) Problem Identification Primary factors that are to be considered are:

Losing expertise When experienced people are leaving an organization.

Criticality of the problem

Frequency of use The higher the frequency of occurrence of a defect, the greater is the suitability of the expert system.

If any one of the above 'factors are satisfied then the following factors are to be considered:

Stability of technology for which the expert system is being developed.

Size of the problem If the size of the problem is big then it has to be divided into different modules.

Acceptability to the end user

(ii) Identification of Expert After selecting the problem for development, an expert is identified who can give his knowledge explicitly. The expert should be able to express his knowledge in the form of heuristics. He should be knowledgeable with a reputation for providing good results. A knowledge engineer is a person who interviews the expert, organizes the knowledge and decides how it should be implemented in an expert system.

7.4.2 Development of Knowledge Base for Casting Defect Analysis

Knowledge Acquisition Extracting the knowledge or expertise from a domain expert is an important stage. The knowledge in an expert system may originate from many sources such as textbooks, reports, databases, case studies, empirical data and personal experience. Our expert system contains knowledge gathered from experts, and some knowledge from standard data and textbooks. In the first phase of knowledge acquisition, the defect is identified from the physical observation of the casting, like size, shape, location, etc., and also from metallurgical observation like presence of dendrites. Any range of defects can be identified, viz., a gas-hole., shrinkage, dimensional inaccuracies, cold shuts/cold laps, core broken, mould broken, rough surfaces, micro-porosity and chilled edges. In the second phase of knowledge acquisition, each defect is discussed in detail considering all factors from melting, moulding, core-making, equipment, design, etc., The knowledge is structured in the form of a tree which is shown in Fig. 7.6.

7.4.3 Codification

The knowledge which is structured in the form of a tree is now codified into the computer using a *shell* (software for developing expert systems). For our expert system, the Shell VP-Expert which is a rule based system was used. The rule format used is

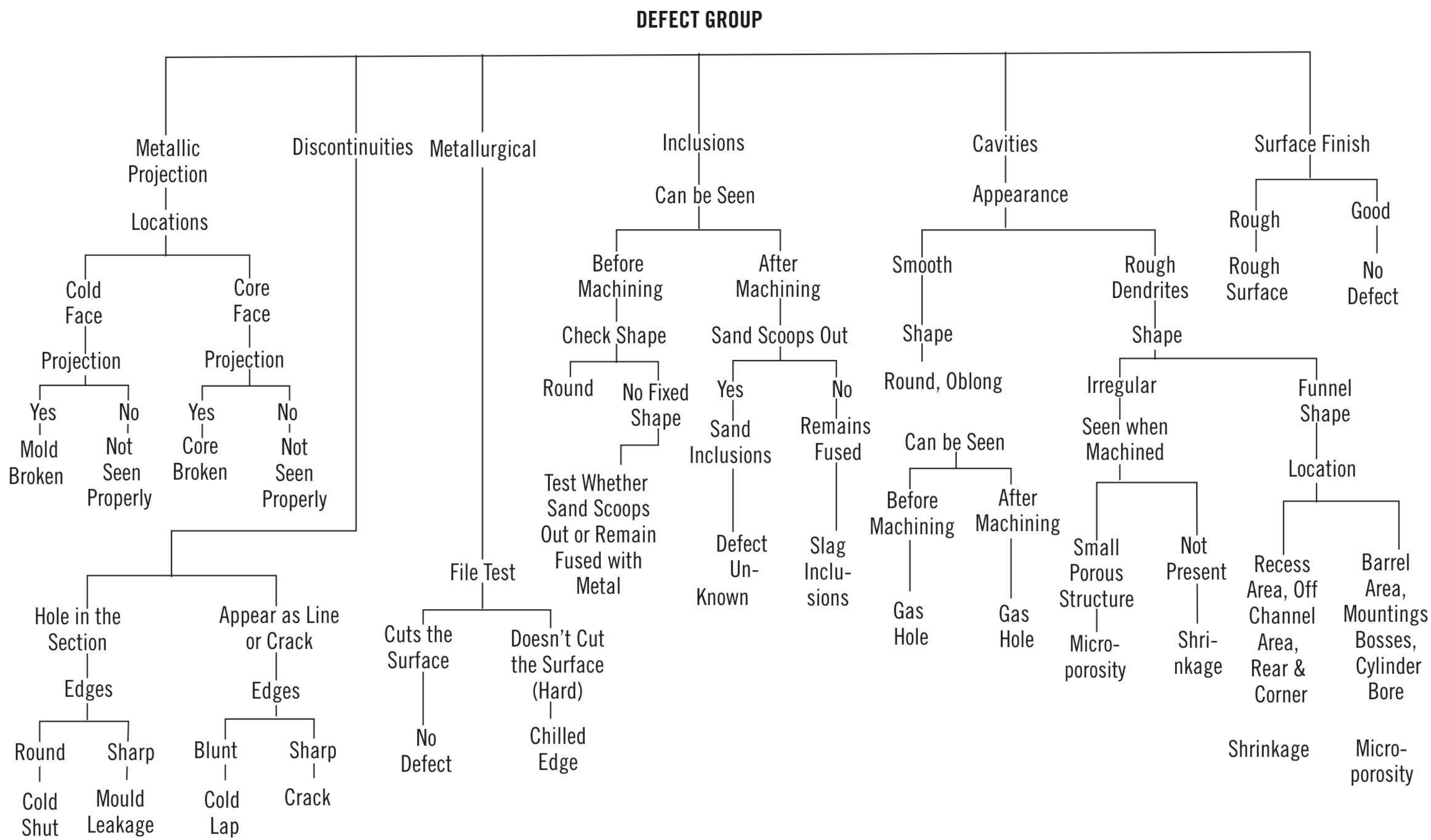


Fig. 7.6 *Knowledge tree for casting defects*

```
Rule <No>
IF <condition>
THEN <action>
```

Example

```
RULE 10
IF defect=dimensional inaccuracies AND
dimensional problem = Water jacket High AND
transverse strength=less than 14 p.s.i.
THEN the core strength = low RULE 15
IF the core strength=low AND
resin content=3.6 percentage AND
curing temperature=229 to 231 C AND
curing time=120 sec and
properties=non uniform
THEN the coating is improper.
```

A sample run is shown below indicating what questions are to be answered by the user which form the database. This database is checked by the computer with the knowledge base already stored there and inferencing takes place so as to declare the reason(s) for the problem and the possible solution.

7.4.3 Sample Run

1. Select the defect group among the following.

Cavities/Discontinuities/ Surface finish/ Inclusions/ Metallic projection/ Incorrect dimension/

How does the surface look/either visually or under the microscope?

Smooth walled//Rough and dendritic.

What is the shape of the defect? Round /Oblong

Can they be seen before machining or after machining?

Before machining/ machining

The defect is GAS HOLE.

2. Which one of the following dimensional problems are you facing?

Water jacket high /Foot core high/ Water jacket out.

Foot core out/ Oversized (head side and sump side)

What is the mould strength? Less than 14 psi /14 to 17 psi

Check the compressed air pressure of moulding machine. Less than 100 psi/ 100 psi

Check whether ribs of moulding box are broken. Yes/No

See whether moulder has stickled the mould uniformly. Yes/No

What is the time of jolting?

22 to 26 seconds/Less than 22 seconds

Is the machine giving proper squeezing? Yes/No

The problem may be with sand.

Check the sand properties, i.e., moisture and GCS. Moisture should be in the range of 3.9. to 4.3%. GCS should be in the range of 14.5 to 16.5 psi.

STATISTICAL PROCESS CONTROL (SPC) IN FOUNDRIES 7.5

Quality control involving statistical analysis may broadly be applied in two ways. One is for controlling the quality of materials as they are received and processed through various stages of production till the finished or final product is ready for dispatch to the customer. The control of quality in this case is mainly confined to various materials going into production; these may be raw materials, in-process materials, supplies or finished product. The type and nature of controls exercised and the quality of these controls are not concerned with the processes, methods, operations or techniques being used to carry out production.

The other type of application of statistical control in production is where the quality or consistency of the processes used during all the stages of production is to be controlled and maintained. This control is specifically termed as 'statistical process control.' For example, while pouring molten iron from a ladle into a mould in a foundry, process parameters which need careful control are composition of metal, particularly, carbon and silicon content, pouring temperature, pouring time or pouring rate. During the machining operation, the process parameters to be controlled may be cutting speed, feed rate, depth of cut, tool geometry, work material hardness, tool material hardness, metal removal rate or tool wear.

It is possible to maintain statistical control on some of these parameters which show a tendency to vary so that their values can be maintained throughout and undesirable deviations are highlighted. Similarly, during the welding process, process controls may be usefully employed for variable parameters, such as welding current, arc voltage, preheating temperature, and welding rate. Statistical controls can be applied to any of these parameters which will control the process quality in order to finally produce the right product. All such controls are grouped for convenience as statistical process controls and these are employed at every stage of production.

Statistical process control uses statistical analysis of data collected from a process in order to monitor and control each stage of that process. The aim of SPC is to improve the performance of processes by emphasising on the prevention of defects rather than on the detection of defects after they have already been produced. Correct application of SPC techniques, therefore, not only serves to improve and ensure product quality but also helps in minimising process costs due to wasteful production. At the outset, it must be understood that SPC will not rectify any inadequate product design, inefficient processes or outdated or poorly maintained machines and equipment. However, when applied in conjunction with other analytical procedures, such as failure modes and effects analysis and design of experiments, SPC can assist in the recognition of the problem areas and in the implementation of corrective actions.

SPC methods recognise variations in processes such that no process or machine will produce consecutive items which are identical in every respect. SPC methods quantify variation in processes and divide the sources of such variations in two types, common and special. Common causes occur randomly and are always present during the operation of a process for reasons, such as compositional variations, machine vibrations, temperature difference, etc., These variations are characteristic of a given process and their occurrence is natural and unavoidable. In contrast to these, special causes are not inherent of a process and they give rise to variation which is not predictable. When SPC is applied, the special cause variations are identified and eliminated such that only common cause variations remain. Common cause variations are then examined and the process is gradually refined to render it more consistent. The level of such variations must be compared with component tolerance to assess both the machine and the process capabilities.

Process Variations Variations from a machine or a process usually follow a definite pattern as seen from the frequency in Table 7.6 and histogram shown in Fig. 7.7. These observations are few but if a large number of measurements were taken and if accuracy of measurement were very high, a smooth curve could be drawn to model the distribution following a normal curve or Gaussian curve (Fig. 7.8).

Table 7.6 *Frequency variations in hardness values from a given process*

Hardness HB	Frequency
96	1
97	2
98	5
99	8
100	14
101	18
102	16
103	11
104	6
105	3
106	1

A normal distribution is described by taking the mean of X values ($\bar{X}$) and by its standard deviation (σ). Mean is the central value of the normal distribution and describes the setting or location of a process or product characteristic. The standard deviation (σ) is a measure of the variation or spread in a process or product characteristic. It can be calculated from a standard formula:

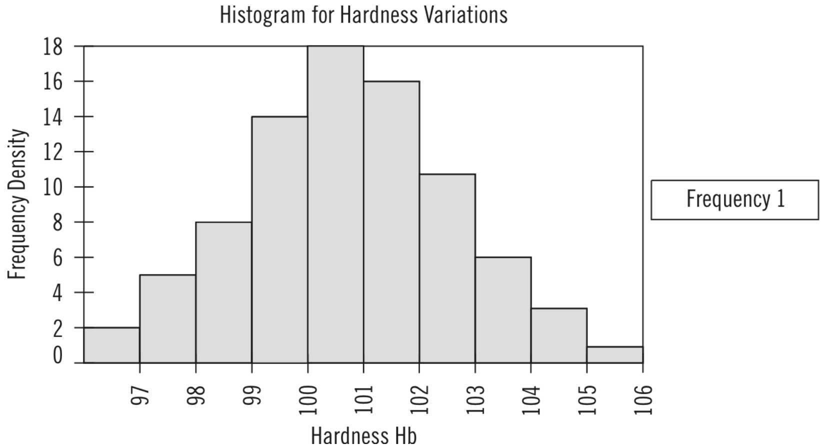


Fig. 7.7 *Histogram*

$$\sigma = X\sqrt{\Sigma(X_i - \bar{X}^2)} \div n$$

where, X_i is the individual value of the parameter, $\bar{X}$ is the mean value of the observations and n is the total number of observations.

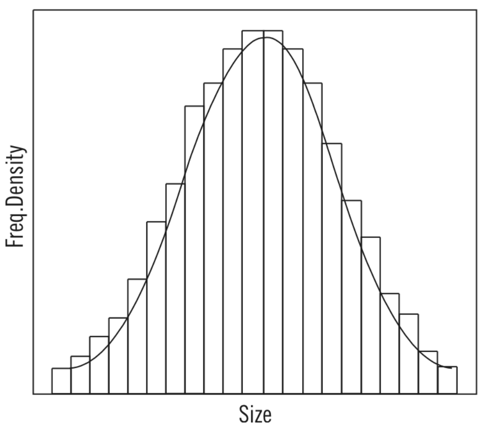


Fig. 7.8 *Frequency distribution curve*

The mean value for hardness is 101.0 and standard deviation is 2.25. Hence, we can predict that 99.73% of the results will be between 94.25 (i.e., 101.0–2.25) and 107.75 (i.e., 101.0 + 2.25). Now, if the process characteristics do not alter, these predictions should remain true for all subsequent runs of production and hence, these values can be used to assess the capability of a process against the customer's requirements. This forms the basis of machine capability study, which is carried out to establish the capability of a machine or process to satisfy the required specifications.

Statistical quality control and statistical process control therefore are two branches of total quality control. The quality of a product ordered by the customer can be assured and produced, only when both these controls are given due attention and are properly introduced in the production system. The statistical techniques used in statistical process control are mostly same as those for statistical quality control. Control charts for attributes and variables are applied in the same manner for each of the process control parameters under control.

Statistical process control, backed by a progressive organisation and management commitment to quality, provide objective means of controlling quality in any transformation process. SPC is not just a tool kit but it is a strategy for reducing variability of a process, which constitutes the major cause for all quality problems. Variations could be in product quantities at the time of delivery, in material specification, equipment operating parameters, maintenance practices and even in people's attitudes. Total Quality Management demands that the process in use should be improved continually by reducing its variability. Therefore, statistical process control when correctly applied can directly lead to the successful implementation of total quality management in a company.

The basic tools used in SPC are

(i) Process flow chart to understand, what is being done
(ii) Check sheets and tally charts to observe the frequency of occurrence of the process
(iii) Histograms to appreciate as to how the variations in frequency of occurrence appear
(iv) Graphs to see the pictorial representation of the numbers
(v) Pareto analysis to segregate serious and minor problems
(vi) Cause and effect analysis to study the causes of the problems
(vii) Scatter diagrams to study the relationship between various interacting factors
(viii) Control charts to interpret and decide which variations to control and how to go about them
(ix) Failure modes and effects analysis

The process flow chart is an industrial engineering tool used to study an existing process and evaluate it for finding out what improvements can be carried out. Process control also requires a similar approach and hence this chart becomes the starting point for further study. Check sheets and histograms are used to study the frequency of occurrence of any of the parameters under study, such as different values of hardness or variations on dimensions. A histogram gives a fair idea whether the variations follow a natural pattern and can be approximated to normal law of statistics. Graphs are commonly used to see the variations among two or three parameters along X–Y axes or X–Y–Z axes. A pareto chart along with a cause-and-effect analysis serves as an extremely useful tool to study the causes of problems and determine which ones are most vital or serious and what are the reasons for their occurrence. They help to interpret and decide which variations to control and how to go about. Scatter diagrams are a type of graphical representations which show the relationship between two or three interacting factors and depict how the points are distributed or scattered about a theoretical curve or a straight line. Control charts are extremely popular and simple statistical tools used to study the performance of any process, indicating how it has worked in the past, how it is operating at present and how it would work and whether any problems are anticipated in the near future. They are used to continually improve the process performance repeating the fundamental steps of collection of data, preparing control charts and showing control limits on it, and assessing process capability for further improvement. These control charts can be either for attributes or for variables.

Failure mode and effects analysis have similar use as cause-and-effect analysis and they help to analyse problems and indicate the potential effects and failure causes for each problem, called a *failure mode*. The actions to be taken to overcome a problem are also indicated on the chart. Figures 7.9 (A to H) show some of these tools which are commonly applied prior to the adoption of SPC.

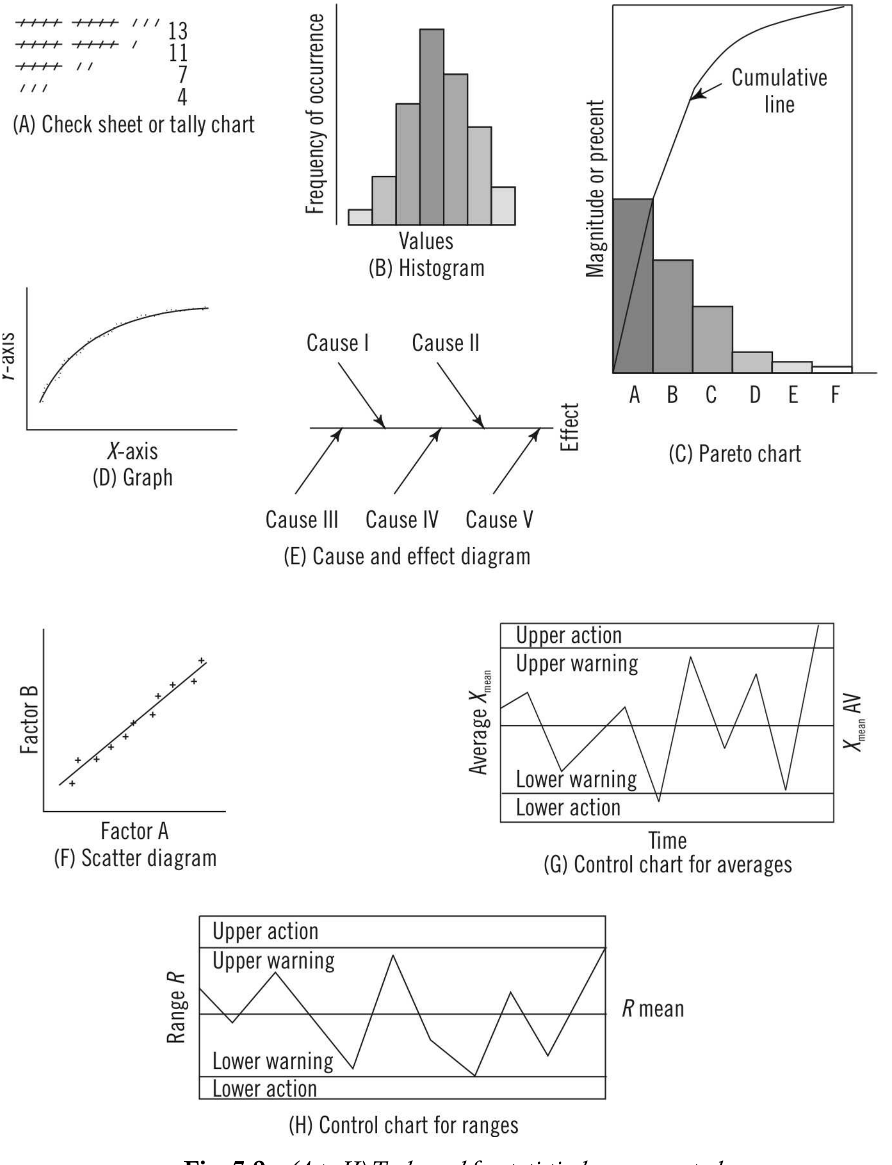


Fig. 7.9 *(A to H) Tools used for statistical process control*

Table 7.7 *Sample FMEA sheet*

Potential failure mode	Potential failure effect	Potential failure causes	Current controls	Occurrence	Severity	Detection	Rank No.	Action
Chill layer in grey iron casting	1. Machining problem 2. Brittle at thin sections and corners	1. Low carbon equivalent, 2. Low silicon % 3. Incorrect inoculation 4. Fading of inoculant 5. Hydrogen pick-up		7	6	8	26	Use wedge test, Check CE value before pouring. Improve inoculation. Check raw materials and charge. Thicken sections, use flow-offs.

Process Variables in Foundry Operations A number of integrated operations are involved during the production of a casting, from melting through moulding, pouring to knock out and finishing. At each stage, these operations must be so managed that the process variables which contribute to the quality (i.e., fitness for purpose) of the finished cast products are identified and controlled. The most effective method to identify the critical process variables is through *Cause and effect* analysis, such as a *Failure Modes and Effects Analysis* study (FMEA), which, like SPC, is also a requirement of ISO 9000.

An example of an FMEA sheet is shown in the Table 7.7, which shows carbon equivalent as an important factor to be controlled in avoiding chill. The basic aim of the study is to prevent defects. Hence, the order of control is kept as

Table 7.8 *Some applications of SPC control charts in an iron foundry*

S. No.	Operation	Tests prescribed
1.	Metal melting	Carbon equivalent Liquidus (CEL)
		Metal temperature
		% Mg level (in case of SG iron)
2.	Sand moulding	Moisture
		Green strength
		Permeability
		Compactability
		Strength of chemically bonded sands
		Mould hardness
3.	Core making	Dimensions (across the joint line)
		Weight
		Visual characteristics
4.	Casings	Dimensions (critical and/or across joints)
		Wall thickness
		Brinell hardness
		Mechanical properties
		Any other test if prescribed by the customer
5.	Heat treatment	Brinell hardness
		Mechanical properties
6.	Audit inspection	Visual characteristics
		Dimensions (Go-Not-go gauges)
		Acceptance fixtures (if any)

1. Preparation of molten metal
2. Preparation of mould and core materials and coatings
3. Production of moulds and cores

4. Mould assembly
5. Ladle treatment and pouring
6. Inspection before heat treatment
7. Inspection after heat treatment
8. Final audit inspection

Mean and range charts can be used where readings can be obtained from subgroups of consecutively produced items representing a single process stream, such as

(i) control of green sand mould hardness in case of iron casting production
(ii) weights of hollow cores, e.g., shell, investment moulds, etc.
(iii) critical dimensions of cores and castings
(iv) hardness of castings

In cases where only single measured values are taken, such as during measurement of molten metal temperature, sand testing, carbon equivalent determination, reading–moving range charts can be used.

For various reasons, production of castings is often subject to relatively high scrap levels. These reasons may include lack of process control, inadequate understanding of the casting process and poor producibility of castings due to defective designs. Foundries therefore often generate large amount of attributes data. Hence SPC can be easily introduced by making effective use of this data and plotting attribute control charts. These charts give an overall picture of the quality problems and can highlight instances in past production when scrap levels were significantly higher or lower than normal, i.e., out of control. This enables correct interpretation of process data. Heading to process improvements and improved productivity.

A Case study about Introduction of Statistical Process Control at a Gray Iron Foundry

The foundry unit is 100% export-oriented, supplying chilled cam shafts to automobile manufacturers in Europe. It is a QS 9000 company producing chilled cast-iron cam shafts and other automobile castings by the shell – moulding process. One of the important parameters to be controlled in these castings is *casting bend*. The specifications demand that castings having bend beyond 1.8 mm are to be rejected. To control the bend defect, the quality of shell mould needs to be controlled, which means the entire moulding process has to be controlled. One of the important moulding process parameters is *pattern temperature*. SPC was therefore introduced to study the problem.

The main shell parameters are colour of shell, shell thickness, and other visual parameters. The process parameters for shell moulding are quality of sand, pattern temperature, investment time and curing time. Figure 7.10 shows (a) initial variations in shell temperature, shell weight and rejection % due to bend defect, and (b) shows improvement in variations after applying SPC in the same three parameters—temperature, shell weight and percentage rejections.

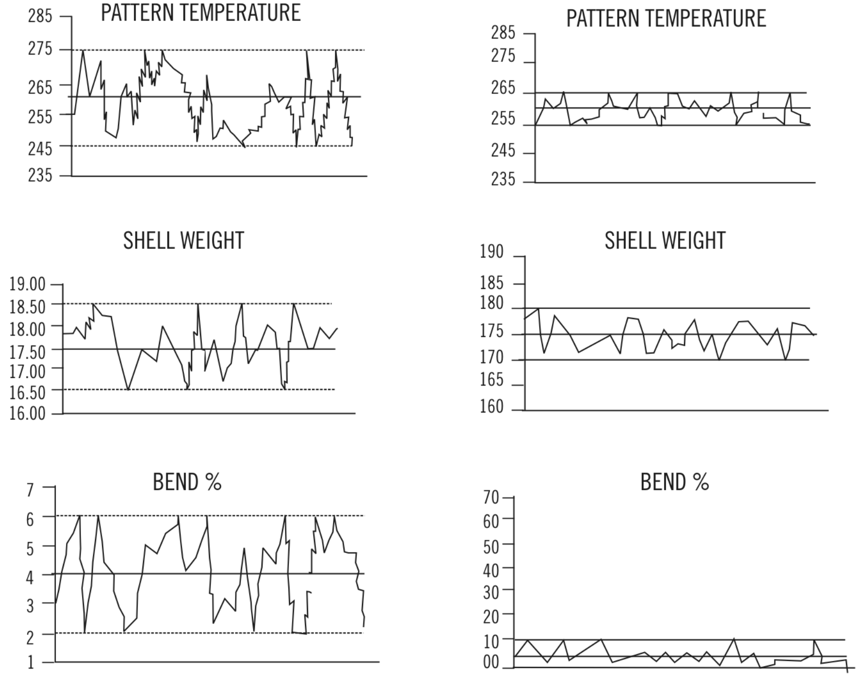


Fig. 7.10 *(a) Initial variations in pattern (b) Improvement in variations*

SIX SIGMA (6σ) CONCEPT IN FOUNDRIES 7.6

The objective of six-sigma is to reduce defect level below 3.4 parts per million, also known as *defects per million opportunities* (DPMO), reducing cycle time and costs dramatically, which in turn, impacts the bottom line. Reducing variability and defects is the essence of this concept. Most industries work on a 3σ–5σ concept. The parts per million defectives with respect to various sigma levels is given in Table 7.9 below:

Table 7.9 *Defects per million values for various sigma levels*

Sigma level	Yield %	Defects per million (PPM)
6	99.9997	3.4
5	99.98	233
4	99.4	6210
3	93.3	66,807
2	69.1	3,08,537
1	30.9	6,91,462

As can be observed from the above table, as the process sigma value increases from zero to 6, the variation of the process around the mean value decreases. With a high-enough value of process sigma, the process approaches zero variation and is known as zero defect. Six-sigma involves changing major business value streams that cut across organizational hurdle. It is the means by which the organization's strategic goals are to be achieved. Six-sigma must be implemented from top to bottom levels of hierarchy in the organization. The stages of implementing a six-sigma concept in an organization are

1. *Define* Such as, selecting raw material for achieving better mechanical properties and sound metallurgical structure.
2. *Measure and analyze* Identifying potential factors and their level for rejection control
3. *Improvement* Such as changing charge material composition, using better inoculants, improving ladle heating, maintaining pouring temperature, etc.,
4. *Control* Keeping the process under control while improvement actions are being taken, by making use of an m-chart.

Review Questions

1. Name the common types of defects appearing in castings. Give their causes and remedies.
2. What techniques are used for inspection of castings? Explain each one briefly.
3. What systems are available for the measurement of temperature of molten metal? Give their relative merits and demerits.
4. What is the principle of working of an immersion pyrometer? For what range of temperatures can it be used?
5. Warpage is a common phenomenon in steel castings. Explain with illustrations, why is it caused and how it can be minimised.
6. Explain the methods of flaw detection by non-destructive testing.
7. Describe the use of X–ray and Y–ray techniques for casting inspection.
8. Explain the working of a coordinate measuring and marking machine. How does it help in inspection?
9. Explain the use of (i) magnetic particle inspection, (ii) dye-penetrant inspection, and (iii) ultrasonic testing.
10. What does the term 'quality control' signify? How can the use of statistical quality control help in ensuring high quality of castings produced?
11. What is the aim of statistical process control? What are its applications in the foundries?

12. How can process variations be controlled through the use of SPC? Explain with an example, using histogram and normal distribution.
13. What are the basic tools used in SPC? Explain each one briefly.
14. What are the common process variables in a foundry and how can these be kept under control?
15. Discuss the methods commonly used for dimensional inspection of castings. What is the principle of operation of a coordinate measuring and marking machine?
16. What methods are used for evaluating the surface roughness of cast surfaces? Discuss.
17. Name the common types of non-destructive methods of testing used for castings. Discuss their suitability for different applications.
18. Discuss the mechanism and use of ultrasonic method of testing for ferrous and non-ferrous castings.
19. What is the basic principle of radiographic examination of castings?
20. How is an expert system used for analysis of casting defects? How can it help in decision-making? What are the requirements for development of an expert system?

Chapter 8

Fettling and Heat Treatment of Castings

FETTLING AND REPAIR OF CASTINGS 8.1

8.1.1 Shaking of Moulds

After the metal has solidified and cooled in the sand mould, the casting is knocked out by breaking the mould. It is essential to ensure that the castings are removed from the mould as early as possible for economic reasons. Premature withdrawal may, however, give rise to distortion, cracks and a chilling effect and cause rejections. It is, therefore, advisable to establish temperatures at which castings of each type, alloy composition or complexity are to be withdrawn from moulds and sent for shake-out. Suggested temperatures at which steel castings can be withdrawn from moulds are shown below:

(i) Simple castings of uncritical nature and uniform sections–900°C

(ii) Parts with uneven wall thickness; cast with chills–600°C

(iii) Castings with critical shapes, prone to warping or cold cracking; subjected to variable impact loads–300°C

(iv) Thin-walled castings having abrupt changes in sections–100°C

The moulds may either be broken manually on the pouring floor itself or transferred to a separate shake-out station. In the latter case, the mould is dumped on the shake-out where it is rapidly jarred so that the sand falls through a grate or screen either into a pit or on a belt conveyor arranged below the floor. The casting and moulding boxes remain on the grate and are removed from there. Shaking may be done either manually or mechanically, but, generally, mechanical shake-outs are used for large-scale work. In the manual type, a stationary grating is mounted and the moulds break when dropped over the grating. The mechanical units consist of a perforated plate or heavy mesh screen fixed to a vibrating frame. The screen is vibrated mechanically, producing a jarring action and causing quick separation of sand from other parts.

8.1.2 Cleaning of Castings

After the casting is extracted from the mould, it is no longer fit for use as such, as it has sprue, risers, etc., attached to it. Besides, it is not completely free of sand particles. This operation of cutting off the unwanted parts, and cleaning and finishing the casting is known as *fettling*. The fettling operation may be divided into different stages:

(1) knocking out of dry sand cores;
(2) removal of gates and risers;
(3) extraction of fins and unwanted projections at places where the gates and risers have been removed and also elsewhere;
(4) cleaning and smoothening the surface; and
(5) repairing castings to fill up blowholes, straightening the warped or deformed castings.

(1) Knocking Out of Dry Sand Cores Dry sand cores may be removed by rapping or knocking with an iron bar. For quick knocking, pneumatic or hydraulic devices may be employed. These devices, besides knocking the cores, also help in cleaning and smoothening the casting.

(2) Removal of Gates and Risers The choice of method for removing gates and risers from the castings depends upon the size and the shape of the casting and the type of the metal. The options for such work are

(i) knocking off or breaking with a hammer, which is particularly suited in case of grey iron castings and other brittle metals
(ii) sawing with a metal cutting saw, which may be a band saw, a circular saw, or a power hacksaw (a metal band saw of the 'do-all' type is considered suitable for steel, malleable iron, and non-ferrous castings)
(iii) flame cutting with oxyacetylene gas, generally adopted for ferrous metals, especially for large-sized castings where the risers and the gates are very heavy
(iv) using a sprue cutter for shearing of the gates
(v) employing abrasive cut-off machines, which can work with all metals but are specially designed for hard metals, which are difficult to saw or shear
(vi) plasma arc cutting, now being increasingly used to cut sprues and risers of plate-shaped castings with a view to eliminate the manual operation of burning off and to make the work fast, clean and accurate, by using a programmable robot for holding and manipulating the castings

(3) Removal of Fins and Unwanted Projections The operation of removing unwanted metal fins, projections, etc., from the surface of the casting is called snagging. While snagging, care must be exercised to see that a proper casting contour is followed and too much metal is not removed.

The methods for snagging include

(i) using grinders of pedestal, bench, flexible shaft, or swing-frame type;
(ii) chipping with hand or pneumatic tools;
(iii) gouging and flame-cutting;
(iv) removing metal by arc-air equipment; and
(v) filing.

(4) Cleaning and Smoothening Castings

In the as-cast state, castings often have sand particles adhering to their surface in a fused form. When the castings are heat-treated, a scale is also formed on the surface. In order that the casting surface be clean and smooth, the adhering sand particles and the scale have to be removed. The various methods available for this purpose are now described briefly.

(i) Tumbling The castings to be cleaned are put in a large steel shell or barrel, which is closed at its ends by cast-iron lids. The barrel is supported on horizontal trunnions and is rotated at a speed varying from 25–50 rpm. Along with the castings, small pieces of white iron called stars are also charged to help complete the cleaning and polishing operations. When the barrel is rotated, it causes the castings to tumble over and over again, rubbing against each other. Thus, by a continuous preening action, not only do the castings get cleaned and polished but also the sharp edges and fins get eliminated and the internal stresses in the castings are relieved.

When the barrel is charged, care should be taken to ensure that the castings are packed tight enough to prevent any breakage. At the same time, these should not be so tight as to prevent the relative motion of the adjacent pieces. The capacities of tumbling barrels (Fig. 8.1) may vary from 1–12 cu m. The limitation of this process is that heavy castings cannot be charged with small ones of fragile nature. Generally, small-sized castings, which are not fragile in nature, are best suited for tumbling.

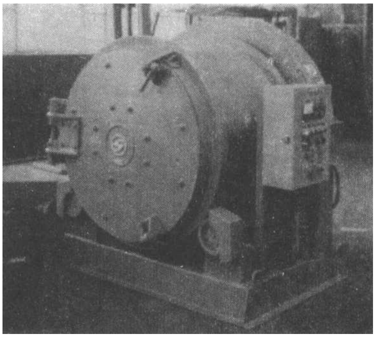


Fig. 8.1 *Tumbling barrel with shot blast*

(ii) Tumbling with Hydroblast In this method, the barrel is not horizontal but is arranged obliquely at an angle of about 30°. One end of the barrel, which is at a higher level than the other, may be kept open to enable observation of the cleaning

process. When the castings are tumbled, a high-velocity stream of water and sand is blasted on the castings at a velocity of about 6000 metres per minute. This action results in more efficient cleaning and polishing, and the tumbling time is also considerably reduced.

The method is better adapted to non-ferrous castings since ferrous ones tend to get corroded due to water treatment. The base of the barrel is perforated to facilitate removal of the sand-and-water mixture. For large castings, hydroblasting chambers are used. The castings are placed on a slowly rotating table and a high-velocity stream is emitted from an adjustable nozzle.

(iii) Cleaning with Compressed Air Impact (Sand Blasting) A high-velocity stream of compressed air along with abrasive particles is directed by means of a blast gun against the casting surface. The blast gun is designed to convey air at high velocity into a mixing chamber. The abrasive is fed into this chamber through a side tube by suction feed, gravity feed, or direct pressure. Generally, in the case of small guns, the abrasive is drawn in the mixing chamber due to vacuum created by the passage of high-velocity air. The abrasive used is either sand or steel grit. From the mixing chamber, air-borne sand particles are directed towards the casting. Figure 8.2 shows a complete sand-blasting arrangement which has a manually operated blast pipe.

The blasting operation is generally carried out in special cabinets or rooms where the operator directs the blast against the castings to be cleaned. The discharged sand drops through a perforated floor from where it is conveyed to the moulding shop for re-use. The room reserved for sand blasting is provided with an exhaust system for collecting the dust and suitable mechanical means for handling the castings. The small-sized castings are cleaned in cabinets equipped with windows through which the operator can manipulate the gun and direct the blast. While working, the operator must be thoroughly protected against harmful dust. He should wear large rubber gloves, protective clothing on the body, and an air-pressurised helmet.

Unlike tumbling, the sand-blasting method can be adopted for both fragile and large-sized castings. The method is also more efficient and ensures good polish.

(iv) Cleaning with Mechanical Impact (Shot Blasting) Instead of using air pressure for hurling the abrasive grit towards the casting, centrifugal force may be exerted by means of an impeller wheel. The abrasive applied in this case is steel shots. As the shots move from the hub of the impeller towards the periphery, their velocity gets accelerated and they finally leave the impeller at a very high velocity, hitting the casting surface with enormous impact. Large cleaning units may be equipped with one or more blasting impellers strategically positioned at different places all around the casting. The casting may also be mounted on a rotating table (Fig. 8.3). In some units, the castings are tumbled and at the same time the abrasive is hurled towards them. In a monorail-type shot blast, the castings are carried by a power conveyer into the machine from one side and taken out from the other side.

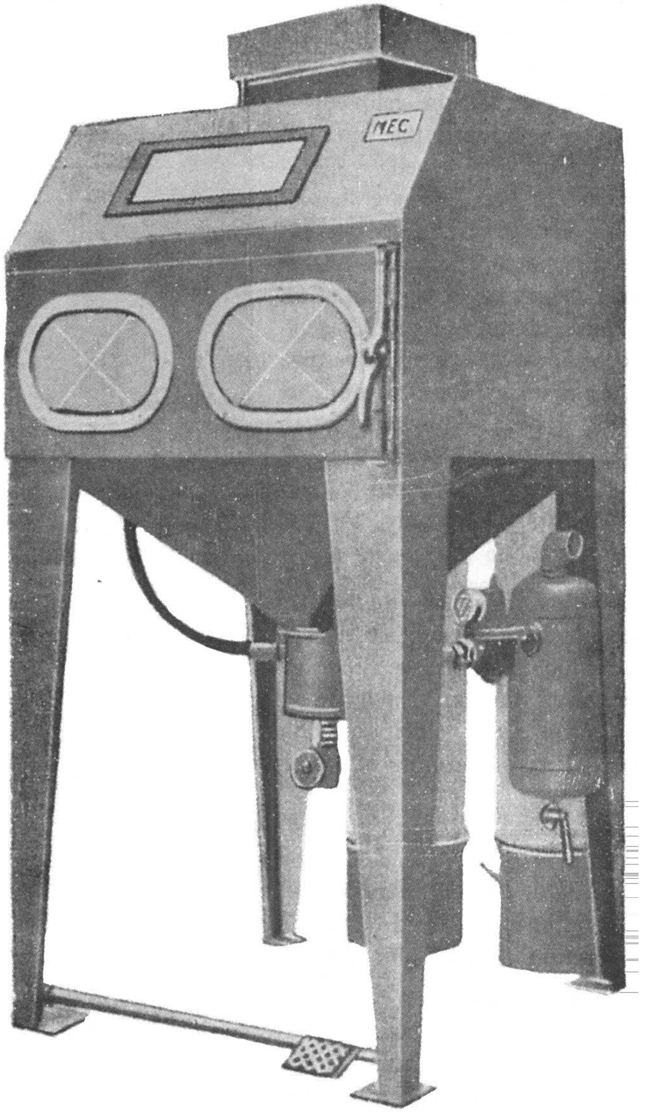


Fig. 8.2 *Sand blasting arrangement*

Effective use of shot blasting machines

For efficient shot blasting operation, the basic concept of shot blasting should be understood. The machine consists of six parts: (i) Blast wheel, (ii) Cabinet, (iii) Work-handling mechanism, (iv) Elevator, (v) Separator and (vi) Dust collector.

(i) Abrasive particles are projected by centrifugal force from different kinds of turbine wheels. The number of wheels installed in the machine depends on the type of jobs to be shot blasted and the rate of work. The wheel is the

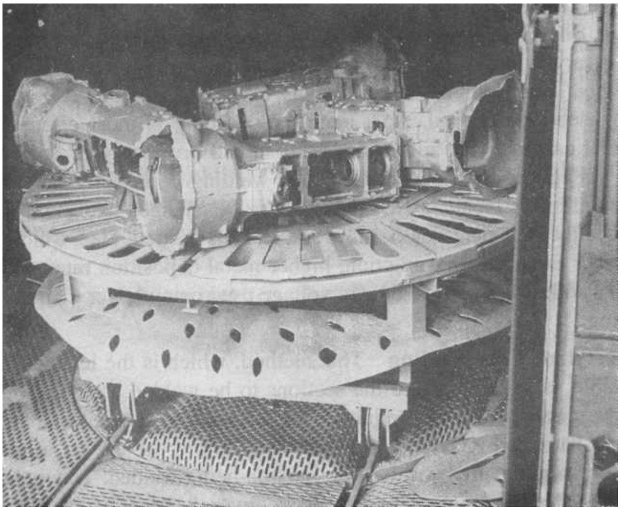


Fig. 8.3 *Inside view of shot blasting machine (Chamber type)*

most important part of the centrifugal shot blasting machine. The efficiency and cleaning effect depend on the quality of wheel and its components.

(ii) The speed of abrasive particles being very high (50–100 m/sec.) the items to be shot blasted have to be treated in closed, vibration-free booth or cabinet made of high strength steel lined with wear-resistant alloy liners.

(iii) For conveying the parts to be shot blasted, various systems are available, selection of which depends on the type, size and quality of the items to be treated, such as tumblast type, table type, monorail hanger type, roller and belt conveyer type and door hanger type.

(iv) The abrasives are recovered at the bottom of the cabinet by means of a screw conveyer and delivered to the base of the elavator, which then carries these to the separator.

(v) Before the abrasives enter the blast wheel for reuse, these have to cleaned of all the contaminants. This is done in an air separator.

(vi) The last essential feature of the shot-blasting unit is the filtration, which retrieves dust-laden air from the separator and cabinet ventilation system and discharges clean air into atmosphere for pollution-free environment.

The economy and performance of blast cleaning depends on the abrasive used, proper size and type of abrasives is of utmost importance. While selecting size and type of abrasive, major factors to be considered are area of job surface that can be cleaned, quality of jobs to be produced and cost of shots. Chilled iron shots made of cast iron, by quenching the stream of malten gray iron over a high pressure jet are common use but parts produced do not have very good finish and the maintenance cost is high. On the other hand, heat-treated steel shots having hardness of 45 Rockwell C (424 BHN) have been found to be most suitable and economical.

(v) Arc-air Process This method involves arc heating of the casting surface and blowing off the melted metal with compressed air. The projections or surface imperfections are heated by the arc so that they reach the molten state when the air simultaneously blows them away, leaving behind a clean and smooth surface. The process is used on large castings in steel foundries. The equipment is portable and comprises a gun which is equipped for producing the arc and blowing the air.

(vi) Pickling It essentially involves cleaning of the casting surface by dilute acid treatment. The castings are suspended by means of nickel-plated steel or monel metal hooks, into a pickling tank containing equal parts of hydrofluoric acid and sulphuric acid, or only sulphuric acid, for about four hours. The tank is made of mild steel plates but is lined with lead sheets on the inner walls. The castings are then washed with plain water in a washing tank and they are further immersed in a neutralising tank, containing 10% solution of washing soda, preferably maintained at about 75°C. The castings are once again rinsed in plain water and dried. The pickling treatment is a cheap and yet effective method of dislodging sand, scales or tentacles of metal and producing a clean and bright surface on iron and steel castings.

(5) Repairing the Castings

Defects such as blowholes, gas holes, cracks, etc., may often occur in castings. Sometimes the castings get broken, bent, or deformed during shake-out or because of rough handling. Often the castings get, warped during heat treatment or while they cool down in the mould. Such defective castings cannot be rejected outright for reasons of economy. They are therefore repaired by suitable means and put to use unless the defects are such that they cannot be remedied. The common methods of repair are now dealt with.

(i) Metal-Arc Welding Large-sized cracks, blowholes, and other imperfections can be rectified by metal-arc welding. The area to be welded must first be cleaned by chipping, filing, gouging, or grinding. Then the joint must be accurately prepared and, if necessary, widened before welding is commenced. Metals that can be welded by this method include almost all cast metals, except magnesium. A proper selection of welding electrode is vital. AC metal-arc welding is most often selected for welding steel castings. The electrodes used should preferably be coated so that a dense and strong joint is produced. DC arc welding is preferred for welding cast irons and non-ferrous metals as the polarity can be changed and more heat can be obtained on either the electrode or the workpiece, as desired. DC welding can thus give lower electrode consumption, higher metal deposition rates and smoother welds. It is also less dangerous, the arc voltage used being lower than in the case of AC welding.

(ii) Oxy-acetylene Gas Welding This method, which is the least expensive and easily portable, is suitable where the sections to be welded are not too heavy and where slower cooling rates are required, for instance, to prevent hardenable steels from

getting hardened. Gas welding can easily allow the use of a broad flame, which can pre-heat the area ahead of the section being welded. This is not possible in arc welding. The flame temperature is also lower than that of the arc, so cooling rates are slow. The flame can be adjusted so as to make it oxidising, reducing, or neutral. An oxidising flame is used for welding brasses and bronzes, reducing flame for high carbon and alloy steels, nickel alloys, and other hard-facing materials, and a neutral flame for low carbon steels. By using the proper technique, almost all cast metals and alloys, except magnesium, can be gas welded. Liquefied petroleum gas (LPG) or natural gas is also used in place of acetylene where a broad flame is desired.

(iii) Carbon Arc Welding Here the electrode is not made of consumable metal but of carbon, and a separate filler rod is fed into the arc to acquire deposition. The method is suitable for all foundry alloys except magnesium and particularly suited for welding copper base and aluminium alloys.

(iv) Inert Gas Tungsten Arc Welding (TIG Process) This process uses a non-consumable type of tungsten electrode together with a shield of inert gas, such as helium and argon for protection of the welding zone. It is most suitable for metals that tend to get quickly oxidised, for instance, magnesium and magnesium alloys. It is also widely used for welding thin aluminium castings as also for stainless steels and alloys of copper and nickel.

(v) Inert-Gas Metal-Arc Welding (MIG Welding) The electrode is made of metal similar to the work metal and is of the consumable type. The method is very fast as the electrode wire is automatically fed, and the inert gas protects the metal from oxidation. The gases used are argon, nitrogen, and carbon monoxide. The method is suitable for the repair and joining of large-sized steel castings and is economical where high speed of operation is required.

(vi) Submerged Arc Welding In this case, the entire welding action takes place beneath a granular mineral material which acts as flux (Fig. 8.4). The electrode used is in bare form. The flow of current melts the flux, spreading it over the weld zone and keeping the arc and weld metal submerged. The metal is thus completely protected from oxidation; besides, there is no visible arc, sparks, spatter, or smoke. This enables use of heavy welding currents, high welding speeds, deeper penetration, and superior quality of welds. The method is unsuitable for repair work as it is basically a production process, but it is adopted for building up large pressure vessels or structures by welding together smaller steel castings.

(vii) Atomic Hydrogen Welding A continuous stream of hydrogen is passed through the arc produced between two tungsten electrodes. Due to the heat of the arc, the gas dissociates from molecular to atomic form. When the atoms of hydrogen strike the cooler work surface, they again re-unite and emit an enormous amount of heat, thus melting the base metals that need to be joined. The heat input thus available is very high; moreover, hydrogen also acts as a shield against the action

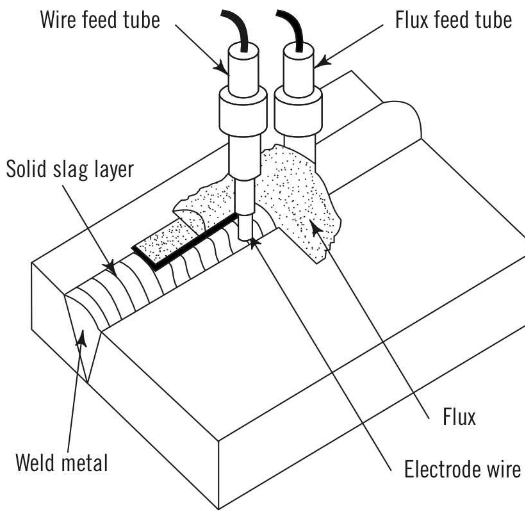


Fig. 8.4 *Submerged arc welding*

of atmospheric oxygen and nitrogen. Filler metal is fed separately from a wire. This process is ideal for the repair welding of metal moulds and dies made of alloy steels, and is also used for welding of thin castings in stainless steel, aluminium alloys, etc., It produces a very homogeneous and smooth joint with strength that equals that of the parent metal.

(viii) Thermit Welding The high temperature required for melting metal to fill up the joint is attained by employing an exothermic reaction. The method is more like a casting process. It entails igniting in a crucible a mixture of iron oxide and finely divided aluminium in the ratio of 3 : 1 and a special powder used to ignite the mixture. Due to the heat of ignition, the mixture explodes at a temperature of about 1540°C, and pure iron with aluminium oxide as slag is produced:

$$8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3$$

The joint, crack or cavity to be filled is arranged in a sand mould with a proper gating and feeding system and the metal from the thermit crucible is poured into the mould. Pure metal occupies the space between the pieces to be joined and slag floats at the top. To enable preparation of the sand mould in one piece, wax is placed in the joint space and around, and the gating system, also in wax, is attached. The whole assembly is embedded in moulding sand and the mould inverted and heated to cause the wax to melt and flow out, leaving the cavity around the metal parts to be joined as shown in Fig. 8.5.

Thermit welding is employed for repairing large and heavy steel castings such as steel mill rolls, ship-stern frames, and gears. It is also used for the fabrication of heavy units by joining relatively simple castings. The process is simpler, less time-consuming, and cheaper than other methods and produces good strength and better quality. Also, no stress relief is necessary as the cooling is very slow and the operation itself relieves the stresses.

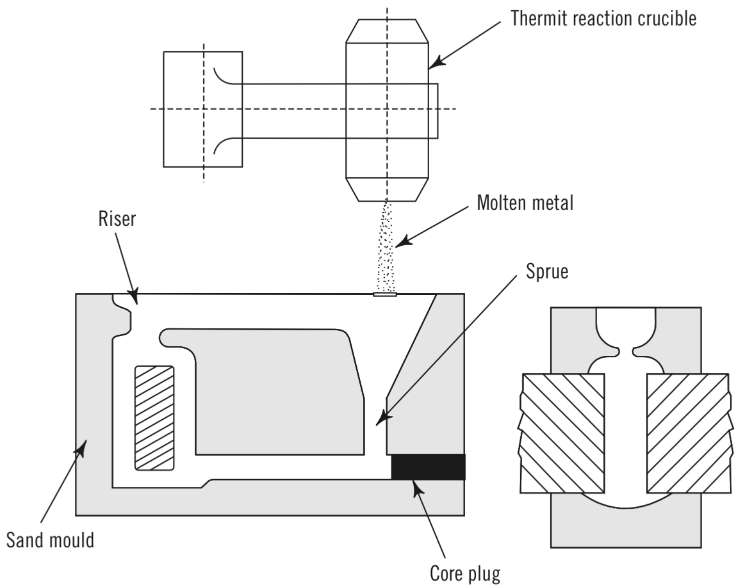


Fig. 8.5 *Arrangement of thermit welding for casting repair*

(ix) Flow Welding This entails melting the metal, in the same way as for casting purposes, and then continuously pouring the molten metal directly into the crack or cavity to be filled, till the surrounding area also starts melting. The excess metal is then removed by grinding or machining. This method is not much favoured now as easier and quicker methods of welding are available.

(x) Braze Welding This process is applied for such parts that tend to get distorted or cracked when welded by other means. A lower heat input is required as the base metal is not actually melted and the bond is obtained only by diffusion. A non-ferrous copper base or silver base alloy which melts at a temperature above 430°C is employed as filler metal. It is introduced in the liquid state in between the pieces that are to be joined. The method may be used to make castings watertight and to repair pipes and pipe fittings and other thin plate-type castings for filling fine cracks, crevices, porosity, etc.

(xi) Soldering This is similar to brazing, the difference being in the filler metal: a tin–lead alloy which melts at a much lower temperature (below 430°C) is preferred for soldering. The process serves to fill up surface imperfections when high strength is not required and porous areas in copper-base alloy castings are to be made pressure tight.

(xii) Resin Impregnation Where welding or brazing cannot effectively fill the porous areas of a casting, resin impregnation often admirably serves the purpose. The process entails forcing a resin to enter the pores under pressure while the casting is kept under vacuum. Resin impregnation equipment is expensive but works out worthwhile for foundries where pressure-tight castings, either ferrous

or non-ferrous, are regular products. IS: 12799–1989 describes the recommended practice for impregnation of castings.

(xiii) Epoxy Fillers Certain epoxy plastic fillers can be used to fill up pinholes, blowholes and cracks, and to impart enough strength to the casting. For good mechanical properties, fillers are also duly charged with metal powders to suit different cast metals. These fillers are of two types, viz., general purpose and fast-curing. The latter takes hardly two hours to harden whereas the former takes longer. Smooth-on cement, which is a pasty mixture of iron filings in a hardening agent, is also widely used to repair iron castings.

(xiv) Straightening Deformed or warped castings can be straightened in a press by applying pressure. This operation is possible only in the case of ductile materials, such as steel, aluminium, copper, and bronze. Generally, a hydraulic press is used along with formed dies. Small castings can also be straightened by hammering manually. Both cold and hot pressing are used according to size and material of casting.

(xv) Metal Spraying When the casting becomes undersized, it can be built up by providing a coat of metal in the desired thickness by a metal-spraying process. This is a simple and relatively inexpensive way of forming a layer of metal on the cast surface. The sprayed metal may be either the same as the base metal or a dissimilar one. The deposited metal is taken in wire form. The spray gun uses oxygen and acetylene to melt the wire and compressed air to atomise the molten metal in the form of spray. All types of metals and alloys can be sprayed. The bond obtained is of the mechanical type with negligible diffusion. The joint between the parent metal and the sprayed metal is not as strong as that obtained by welding or brazing. This technique is also used for providing an anticorrosive metal layer on iron and steel castings. Figure 8.6 explains the principle of metal spraying and Fig. 8.7 shows the set-up required for the process.

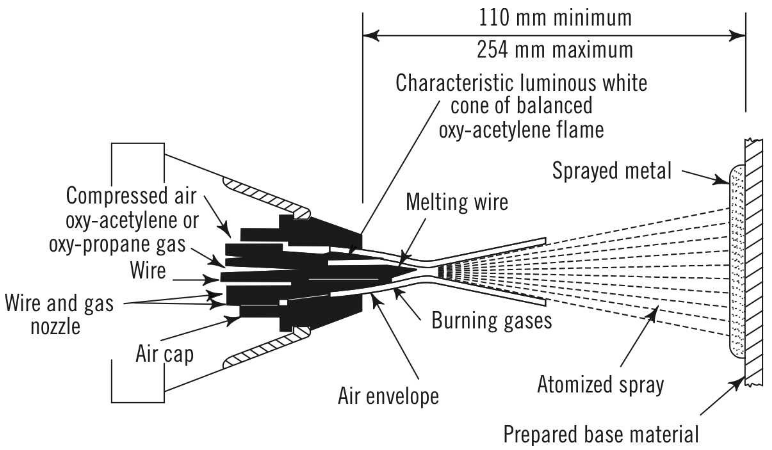


Fig. 8.6 *Principle of metal spraying*

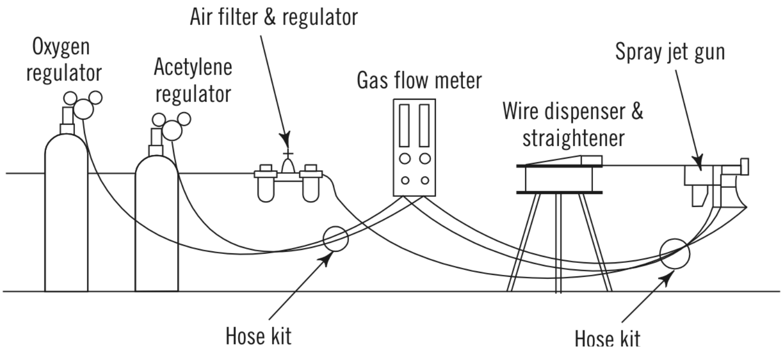


Fig. 8.7 *Set-up for metal spraying*

HEAT TREATMENT OF CASTINGS 8.2

Heat treatment involves the improvement of the properties of materials by bringing about certain permanent structural changes. Modern demands for high-quality castings have made heat treatment an indispensable step between the casting process and the finished product for engineering applications.

8.2.1 Fundamentals

The engineering properties of an element or a commercial material as an alloy of several elements depends solely on its structure, viz., atomic structure, crystal structure, microstructure, and macrostructure.

The atomic structure refers to the distribution of electrons, protons, neutrons, and other fundamental particles in the atom. The various elements have different atomic structures and hence different properties and behaviour. The crystal structure refers to the arrangement of atoms in the material. Most of the engineering metals and alloys have simple crystal structures, like face-centred cubic (fcc), hexagonal close packed (hcp) and body-centred cubic (bcc). It has now been established that mechanical yielding or deformation of materials takes place mainly by the movement of line imperfections, called *dislocations*, along definite slip systems (the combination of crystallographic planes and directions).

The microstructure (generally observed through a microscope by magnifying the specimen surface 100 times or more) is made up of microconstituents (phases) present in the material, the kind of phases present in a material being governed by the type of interaction among atoms of its constituent elements. The dependence of the engineering properties of a material on its microstructure entails the consideration of (i) the number of phases and the size and shape of grains present in each phase; (ii) the intrinsic properties of phases; (iii) the relative amount of each phase; and (iv) the distribution of the phases.

The macrostructure of a material, observed with the naked eye or smaller magnification of about five times, refers to the presence of inhomogeneity, segregation, dendritic growth, and inclusions. Unless these defects are eliminated the material remains weak and has poor plastic properties.

The atomic and crystal structures of materials are governed by the laws of nature and, as such, cannot be altered without imposing external constraints of temperature, pressure, electric field, magnetic field, etc., For example, it is by no means possible to make α-iron (bcc) as ductile and malleable as gold (fcc) because the plasticity of each is fixed by nature itself. The fundamentals may, however, be exploited in developing technological processes such as heating α-iron to over 910°C where it transforms to γ-iron, endowing the fcc structure with better plastic properties. This is the reason steel castings are always forged, rolled, and extruded within the austenitic temperature range. Similarly, the strength of a material, which is otherwise fixed by nature, may be improved by inhibiting dislocation movement with the help of coherent precipitates (Fig. 8.8), this fundamental principle being utilised in practice through the age-hardening of non-ferrous alloys and the secondary hardening of tool steels.

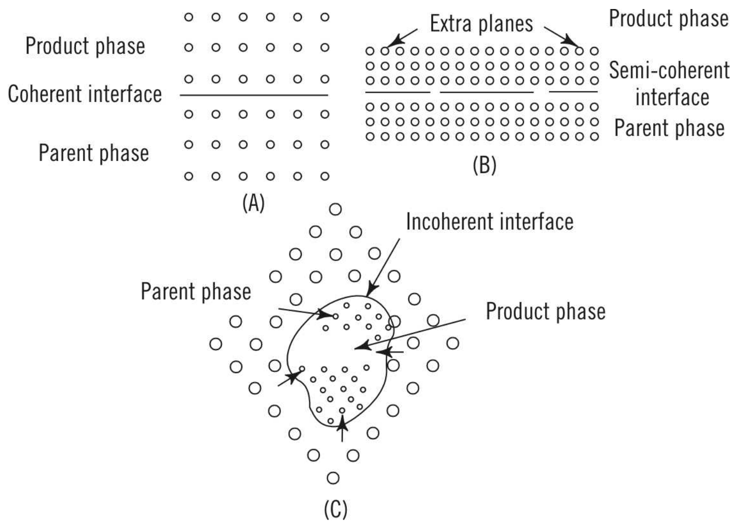


Fig. 8.8 *Schematic representation of coherent, semicoherent and incoherent interfaces:*
(A) A coherent interface between product phase and parent phase
(B) A semi-coherent interface between product phase and parent phase
(C) An incoherent interface between product phase and parent phase

The microstructure and macrostructure of a material are not rigidly fixed by natural laws and hence may be controlled in practice. Heat treatment generally involves control of these structures of the casting to suit the customer's requirements. During heat treatment, the casting invariably undergoes phase transformations involving changes of phase from one form to another. The control of phase, their distribution, etc., are achieved only through a comprehensive understanding of the theory of nucleation and growth. Phase transformation is caused by two basic mechanisms: (i) nucleation of the new phase at preferred sites such as impurities, and grain boundaries along certain crystallographic planes of its parent phase; and (ii) growth of the new phase at the cost of the parent phase. The interface between the parent phase and the nucleated new phase (Fig. 8.8) may be (a) coherent, in which case there is almost a 1 : 1 match of the atoms of the product phase and the parent phase, the coincidence in such dimension being achieved only by some lattice distortion associated with strain fields; or (b) semicoherent, in which case the atomic spacing in the product phase may be smaller than that in the parent phase, so that extra planes have to be accommodated at regular intervals; or (iii) incoherent, in which case there is no crystallographic match between atoms of the product and parent phase since there are no strain fields. The nucleation rate ($\dot{n}$) and the growth rate ($\dot{u}$) are very sensitive to the temperature at which the transformation takes place (Fig. 8.9a). The overall transformation rate ($\dot{x}$), i.e., the time required for a certain amount of parent phase to transform into product phase will obviously depend on the nucleation and growth rate. It, therefore, has a similar kind of temperature dependence. The graph of the overall transformation rate may be represented alternatively as a plot of time for different amounts of transformation, e.g., 0%, 1%, 50%, 99%, and 100% at various temperatures. This yields a set of C-curves called the time-temperature-transformation (T–T–T) diagram (Fig. 8.9b).

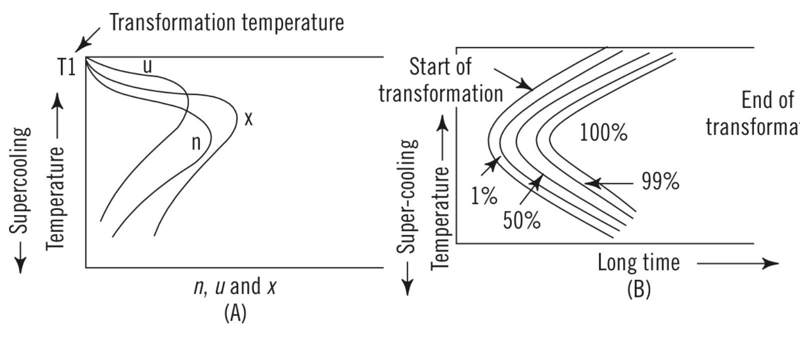


Fig. 8.9 *Effect of super-cooling and T–T–T-diagram*

(A) Variation (n), (u) and (x) with degree of supercooling (schematic);
(B) Each curve gives the time-temperature relation for the indicated percentage of overall transformation

Some of the features in Fig. 8.9 meriting scrutiny are (i) phase transformation is impossible at a temperature higher than or just equal to the transformation temperature, thus rendering supercooling essential; (ii) the nucleation, growth, and overall transformation rates all exhibit maxima although at different intermediate temperatures (supercooling); (iii) there is always a time lag for the start of transformation, although the time lag is minimum where transformation rate is maximum; (iv) the transformation products in the casting will be coarse at smaller supercooling because of higher growth rate; (v) the transformation products in the casting will be finer at larger supercooling because of the dominating effect of the nucleation rate.

The numerous heat-treatment processes in commercial use today fall under two categories: (i) anneal-quench-temper treatment for castings of plain carbon steels, alloy steels, and cast irons, and (ii) solutionise quench-age treatment for non-ferrous alloys. Both these processes may produce a material with substantially improved mechanical properties in comparison with the as-cast alloy.

8.2.2 Heat Treatment of Plain Carbon and Alloy Steel Castings

The heat treatment of steel is basically concerned with the control of the eutectoid decomposition, i.e., the transformation of austenite to pearlite by the reaction

$$\gamma\text{- Fe (0.8\% C)} \xrightleftharpoons{723^\circ\text{C}} \alpha\text{ - Fe (0.02\% C)} + \text{Fe}_3\text{C (6.67\% C)}$$

The rate of decomposition is governed by the rate at which the carbon atoms diffuse through austenite, because ferrite and cementite will not form in the microstructure until local concentrations of carbon are about 0.02% and 6.67% respectively. The eutectoid transformation may therefore be incomplete if sufficient time is not allowed for the redistribution of carbon atoms. The data for the transformation kinetics, etc., are represented in a condensed and handy form as T–T–T diagrams. The T–T–T-diagrams of a large number of commercial steels are listed in atlases. Such a diagram for the 0.8% C eutectoid steel is shown in Fig. 8.10.

Transformation Products in Steel It is observed that on slow cooling (indicated by path (1)–(1) or (2)–(2)), sufficient time is allowed for the redistribution of carbon atoms to about 0.02% in ferrite and 6.67% in cementite, causing their nucleation and growth in alternate layers (Fig. 8.11) and resulting in the formation of coarse pearlite. The nucleation rate increases with greater supercooling and, hence, a somewhat faster cooling, (indicated by path (3)–(3) yields fine crystals of ferrite and cementite, i.e., fine pearlite.

When the transformation to pearlite is suppressed by very rapid cooling, austenite is transformed into a product known as *bainite*, on holding at a temperature in the range of 220–400°C (cooling path (4)–(4)). Because of an extremely high nucleation rate, cementite and α-ferrite grow as extraordinarily fine needles instead of lamellae and, hence, bainite has a needle-like structure in which there is a dispersion of submicroscopic carbides in a highly strained ferrite matrix. The growth of bainite differs from that of pearlite in that ferrite nucleates before carbide, whereas in pearlite it is the carbide that nucleates first (Fig. 8.12).

On rapid quenching to temperatures lower than 220°C (cooling path (5)–(5) or path (6)–(6) which has a still higher cooling rate), austenite is transformed into a new highly distorted needle-like phase called *martensite*. This phase is extremely hard and brittle and has carbon atoms trapped as a supersaturated solid solution. This excess carbon distorts the fcc lattice to bct (body-centred tetragonal); the amount of distortion (measure of the hardness of the phase) is

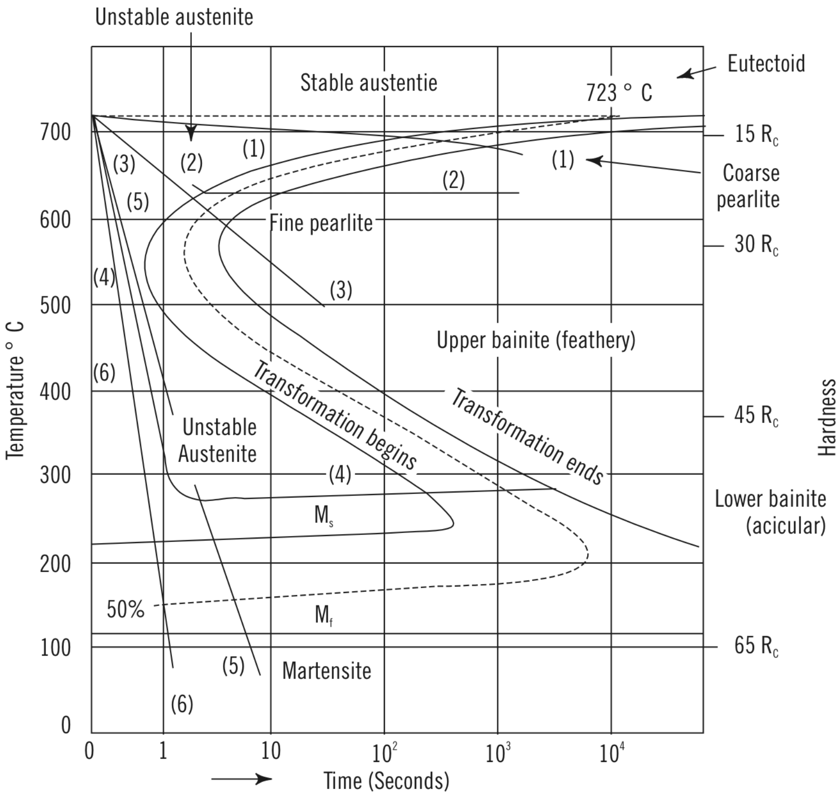


Fig. 8.10 *T–T–T diagram for plain carbon steel of euectoid composition*

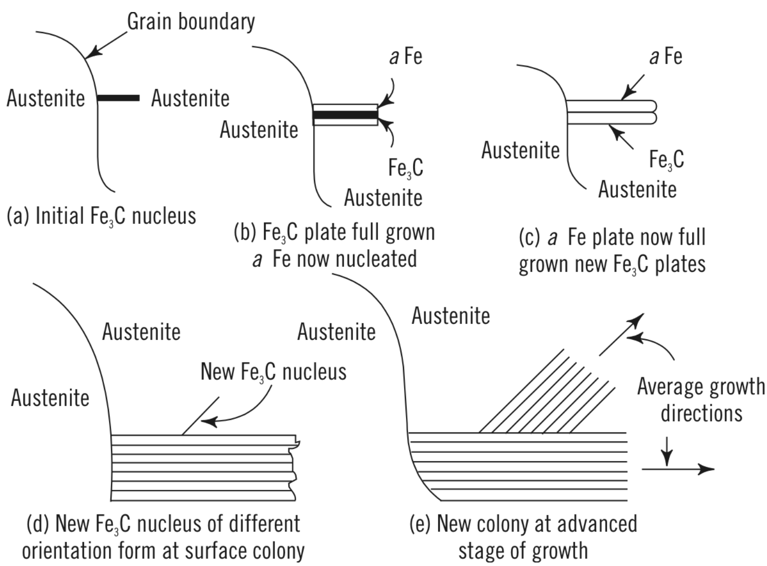


Fig. 8.11 *The nucleation and growth of pearlite (schematic)*

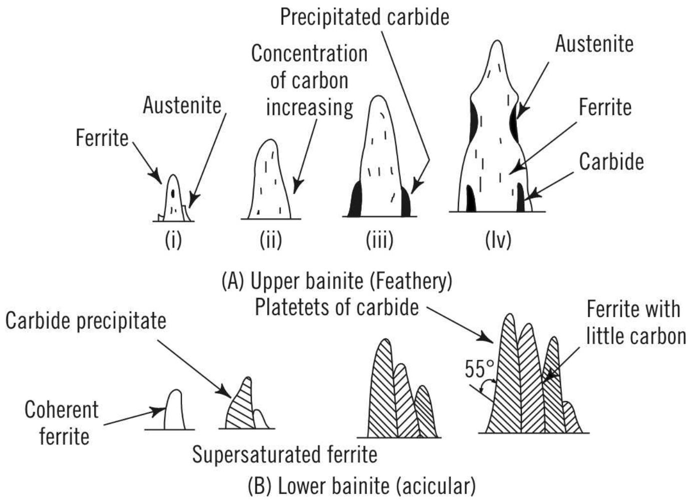


Fig. 8.12 *Diagrammatic representation of formation of upper and lower bainites*

approximately linearly proportional to the carbon content. Since austenite-to-martensite transformation is diffusionless (involving no long-range diffusion of the carbon atoms), it is independent of time and depends on temperature only. The martensite start, Ms, and martensite finish, Mf, temperatures are therefore indicated by horizontal lines.

The commercial heat-treatment processes of steel castings may be grouped into the following two categories:

(1) heating in the austenite range and subsequent cooling; and
(2) heating in the ferrite range and subsequent cooling.

(1) Processes Based on Heating in Austenite Range and Subsequent Cooling

(i) Normalising This is one of the most widely used heat-treatment processes. Almost all steel castings have to be normalised before engineering application. The method entails heating into the austenite range (about 50°C above AC3 for hypo-eutectoid and about 50°C above ACm for hyper-eutectoid steel castings), holding there for a few hours (usually 10 minutes per sq. cm cross-section), followed by cooling in air. The coarse austenite thus renucleates into fine grains which, on cooling, produce a uniform distribution of ferrite and pearlite with a fine grain size.

The influence of alloying elements on the technology of heat treatment is significant. The normalising temperature is decreased by alloying elements, such as Mn, Ni and Cu, all of which extend the austenite range and consequently decrease the AC3 temperature. On the other hand, alloying elements, such as Si, Al, Cr, Mo, W, V, Ti and Nb extend the ferrite range. The notch impact toughness and the tensile plastic properties are improved by normalising. The finer grain size increases the yield strength and the ultimate tensile strength. The quality of normalising, however, deteriorates as the size of the casting grows because of a slower cooling rate of the interior mass.

Figure 8.13 shows a heat-treatment furnace for normalising of steel castings. The furnace is 6.5 m long, 3.6 m wide, 3.0 m high, and the maximum temperature available is 1000°C. Two burners are provided for uniform heating, and close control of chamber pressure and temperature is possible. The furnace is served by bogie-type electrically operated transfer charger.

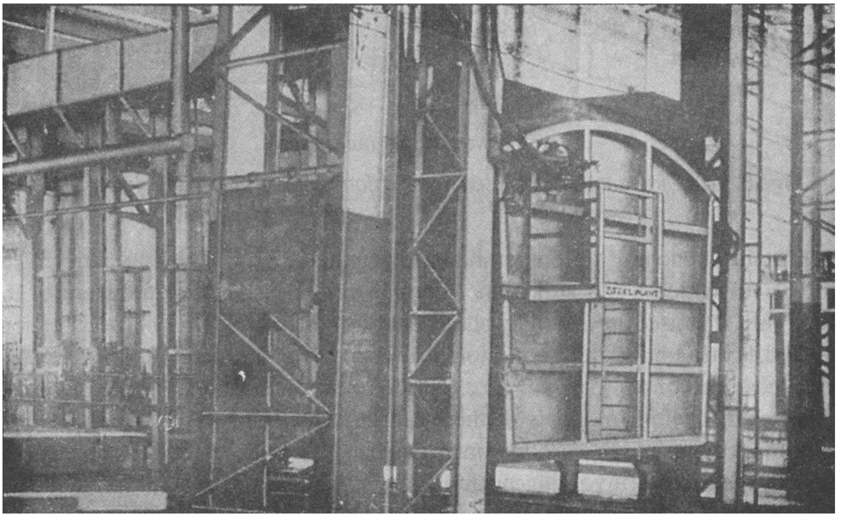


Fig. 8.13

(ii) Full Annealing This involves heating the steel castings to about 100°C, above AC3, holding there for a few hours (usually 10 minutes per sq. cm of cross section), and then cooling in the furnace. This heat-treatment process is extremely important for large castings, particularly those made of alloy steels where it significantly improves the machinability.

The austenitising temperature, which is higher than that used for normalising, leads to the formation of coarser austenite grains, which in turn gives rise to larger ferrite grains and larger colonies of pearlite. The slower cooling rate during furnace cooling (schematically represented by path (l)–(l)) in Fig. 8.10 results in coarse pearlite because of the dominating effect of the growth rate. The mechanical strength of annealed steel casting is lower than that of the normalised one (the difference increasing with increasing carbon content, i.e., pearlite content of the steel), but the tensile plastic properties are better. The elimination of the Widmanstatten structure is usually observed to a greater extent because of better homogenisation of austenite during annealing.

Full annealing has a beneficial effect on the machinability of medium carbon steels. In low carbon steels, the effect on machinability may be adverse on account of excessive softening. For hyper-eutectoid steels, it is not a standard commercial process. The effect of alloying elements on annealing temperature is similar to that on normalising temperature.

(iii) Isothermal Annealing This process involves heating castings in the austenite range for a required period, then holding at some temperature in the ferrite range to allow the eutectoid transformation to take place isothermally (cooling schematically is represented by path (2)–(2) in Fig. 8.10), and thus produce a structure that has optimum machinability. In most carbon, low and medium alloyed steels, these requirements are met in the temperature range of 650–680°C.

Usually, the isothermal holding is extended for 1–2 hours beyond the end of transformation. The partial spheroidisation of pearlitic cementite provides additional improvement in machinability. As a rule, machinability equivalent to that obtained in soft annealing is obtained.

(iv) Homogenisation Annealing Castings are heated at about 1100–1200°C in the austenite range for longer periods, usually 5–10 hours. The cooling conditions are not critical, but furnace cooling is often carried out. Homogenisation annealing considerably reduces the segregation of alloying elements, thus making the structure uniform and enhancing the plastic properties of heavy-duty components. The higher heating temperature of homogenisation annealing, however, results in considerable grain coarsening of austenite making it susceptible to the formation of the Widmanstatten structure. Therefore, normalising after homogenisation annealing is essential.

(v) Hardening Hardening is possibly the most versatile heat-treatment process for improving the strength of steel castings. It entails heating hypo-eutectoid steel about 50°C above AC3 and hyper-eutectoid steel about 50°C above ACm, holding there for sufficient time to solutionise the carbon, and finally quenching rapidly to achieve the martensitic structure. For austenite to martensite transformation, it is vital for the cooling rate to be high enough to prevent eutectoid transformation at any temperature during the course of cooling. This means that the cooling should be equal to or greater than the critical cooling path (5)–(5) in Fig. 8.10. The quenching medium is chosen according to the order of quenching speeds: 5% caustic soda, 5–20% brine, cold water, warm water, mineral oil, animal oil, and vegetable oil.

From the T–T–T diagram, it is observed that in eutectoid steel the transformation of austenite to pearlite commences even within less than 1 second at about 500°C, the time generally decreasing with decreasing carbon. Thus, even by extremely severe quenching in caustic soda or brine, large components of plain carbon steel may not be fully hardened because of the slower cooling rate of the interior mass. In addition, drastic quenching leads to undesirable thermal and structural stresses causing cracking, distortion, or warpage of components. The alloying elements play an important role and generally inhibit the eutectoid transformation because at this stage it is not only the carbon atoms that have to be redistributed but the atoms of alloying elements too. They thus shift the nose of the T–T–T curve towards the right, i.e., they increase the hardenability of the steel castings. Certain alloying elements, for instance Mn and Cr, increase the hardenability to such an extent that even air cooling renders the steel fully martensitic. The best alloying elements are those that shift the nose of the T–T–T curve as much right as possible without appreciably lowering the M_s and M_f temperature. The various factors affecting the hardenability of steel are listed in Table 8.1. The effect of alloying elements on the Ms temperature (in °C is obtained from the empirical formula:

$$M_s = 500 - 295\ (\%C) - 33(\%Mn) - 22(\%Cr) - 17(\%Ni) - 11(\%Si) - 11(\%Mo)$$

Table 8.1 *Factors affecting hardenability of steel*

Austenitic grain size	Coarser grains increase hardenabilily because of decrease in nucleation sites (grain boundary) of ferrite and cementite
Dispersed inclusions	Decrease hardenability to some extent because of their trigger action
Homogenisation	Increase hardenability
Alloying elements	Increase hardenability: Cr, Ni, Si, P, C, Mo, W, V, Ti, B, Al
	Decrease hardenability: Co

The M_f temperature is usually 150–200°C below the Ms temperature.

In plain carbon steels, the transformation of austenite to bainite is possible only by holding the castings isothermally, e.g., in the path (4)–(4) in Fig. 8.10, on continuous cooling either pearlite or martensite is formed, depending on the cooling rate. The alloying elements eliminate this restriction by changing the shape of the T–T–T diagram (Fig. 8.14) which exhibits an upper nose for the pearlitic transformation and a lower nose for the bainitic transformation. The continuous cooling paths a–a, a–b, and a–c lead to pearlitic, bainitic, and martensitic structures, respectively.

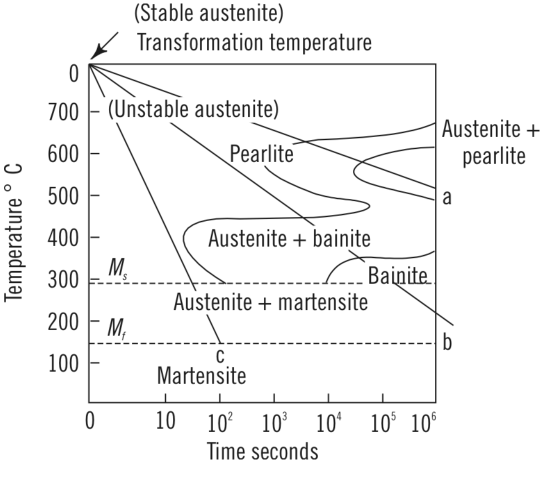


Fig. 8.14 *T–T–T diagram for low alloy steel of composition 0.4% C, 0.4% Mn, 3.3% Ni and 1.5% Cr*

(vi) Tempering Hardened steel casting is extremely hard and strong but so brittle that it is necessary to temper it before it is put to industrial use. Tempering involves heating the hardened steel components to a suitable temperature in the range 150–500°C for a suitable period (the temperature and time being decided on the basis of the final hardness desired). Tempering improves the tensile plastic property and notch impact toughness of the steel casting but to some extent decreases the strength and hardness.

Secondary hardening during tempering Most alloying elements have a significant effect on tempering characteristics. The elements Ni, Mn, Cu, and Al do not greatly affect the hardness–temperature–time characteristics, whereas Si produces an opposing effect on the reduction in hardness. This effect becomes pronounced at about 1% Si or more.

The strong carbide-forming elements Cr, W, Mo, V, Ti and Nb represent a specific group. Their ability to preserve hardness of tempered steel at higher temperature increases with their carbide-forming ability in the sequence Cr, W, Mo, V, Ti, and Nb. This result is achieved because of the nucleation of a coherent carbide precipitate, which counteracts the normal softening that occurs during tempering by inhibiting the dislocation movement. In some alloy steel castings, therefore, the hardness is maintained constant up to about 500°C and in some cases, it first increases (known as secondary hardening) and then gradually decreases due to the breaking down of the coherency of the carbide precipitates. In the presence of V and Mo, the coherent precipitates of V_4C_3 and Mo_2C, dispersed in the ferritic matrix are responsible for maintaining constant hardness at higher temperatures (i.e., secondary hardening). For elements with very high carbide-forming ability, for instance, Ti and Nb, this beneficial effect can be utilised only partially because they are bound in their very stable carbide, which resists the tendency to dissolve during austenitisation. The effect of alloying elements on tempering forms the basis for the development of high-speed steel tools and hot die steels.

(vii) Martempering and Austempering The transformation of austenite either to martensite or to bainite is accompanied by a volume increase, and as the cooling rate varies across the thickness of the section, distortion and cracking may occur by direct quenching.

In martempering (Fig. 8.15), the steel casting is heated in the austenitic range and quenched into a salt bath, which is maintained at a temperature just above the Ms until the temperature is uniform across the section. This treatment is followed by air cooling during which austenite changes into martensite. Martempering therefore results in lower thermal stresses, causing less warpage and distortion, and a reduced tendency to quench cracking, and enhancing the toughness of steel castings. Large sections cannot be martempered because the time required for temperature uniformity exceeds the commencement of bainite transformation. Technologically, the most essential merit of the process is the very marked decrease (40–70%) in distortion.

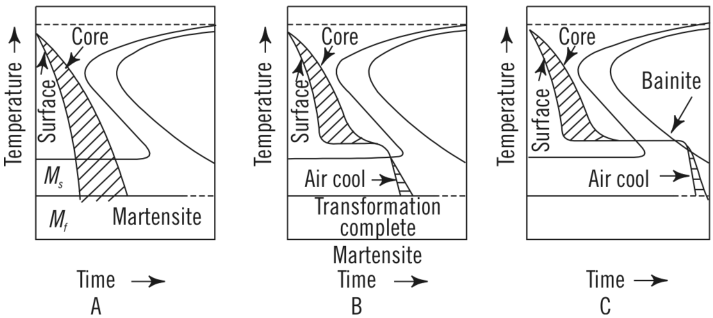


Fig. 8.15 *Cooling rates of surface and core during martempering and austempering: (A) Conventional quenching (B) Martempering (C) Austempering*

Austempering (Fig. 8.15) entails austenitisation, rapid cooling (at which pearlite formation is avoided) in the bainite range, followed by isothermal holding in the temperature range 250–500°C for a period sufficient to transform austenite into bainite. Subsequent cooling in air produces bainite without cracks or distortion of the steel castings. Austempered castings are characterised by superior toughness and tensile plastic properties at high strength levels, which, in the case of lower bainite, approaches the strength of martensite. The resultant properties are, however, not as superior as those obtained by full hardening and tempering, but distortion and cracking are avoided.

(2) Processes Based on Heating in the Ferrite Range and Subsequent Cooling

(i) Soft Annealing Soft annealing is carried out to improve machinability and, in some cases, the ductility of steel castings by converting lamellar pearlitic cementite into relatively coarse globular cementite particles embedded in the ferrite matrix. The desired result is achieved by heating the casting within the ferrite range at a temperature approximating AC_1 (but below AC_1 to avoid formation of austenite) and holding there for sufficient time. The driving force in the process is the decrease of surface free energy of the cementite–ferrite interface; the time required for soft annealing is, therefore, shorter for fine pearlitic structure castings than that for the coarse pearlitic ones. For steels with high hardenability, the starting structure may be bainite or even martensite. In such cases, soft annealing involves the thermal decomposition of bainite and/or martensite and gradual coarsening of globular cementite.

Soft annealing is most effective in medium carbon steels. In high carbon tool steel and steels for roller bearings, the treatment causes uniform distribution of globular cementite, which facilitates homogenisation of austenite during heating for hardening. Alloying elements have a pronounced effect on the temperature and time of soft annealing. The alloying elements extending the austenite decrease the AC1 temperature and thus the soft annealing temperature, too. The opposite is true for elements extending to the ferrite range. The strong carbide-forming elements (particularly Cr, W, Mo and V) reduce the coagulation rate of carbides and, therefore, increase the time for soft annealing.

(ii) Stress Relieving Stress relieving is one of the most important heat-treatment processes. Internal stress in steel castings may be one or more of the following types:

(a) thermal stresses caused by uneven cooling of different regions of the casting and steep temperature gradients;
(b) structural stresses resulting from sharp changes in the sectional sizes of the casting and volume difference between the parent and product phases of the phase transformations;
(c) rough machining stresses occurring during machining or grinding operations;
(d) welding stresses developing during the welding of castings for salvaging or fabrication; and
(e) high stress concentrations resulting from faulty heat-treatment processes developing cracks in the castings.

The technology of stress relieving involves heating the component in the temperature range of 400–600°C (temperature is chosen such that the final desired structure is not affected significantly), holding there for sufficient time (usually 6.25 sq. cm cross section per hour), and finally cooling slowly to avoid fresh internal thermal stresses. Stress relieving occurs by yielding of material through gliding and climbing of dislocations as well as sliding of grain boundaries. For hardened steels, the higher stress relieving temperature may change the martensitic structure altogether and, in such cases, there is a compromise between the degree of stress relieving and the final structure. Alloying elements, in general, increase the stress-relieving temperature.

(iii) Antiflaking Treatment During the melting process, hydrogen dissolves in the molten steel, which in the castings may be as high as 50–60 cm^3/kg of steel. Hydrogen present as supersaturated interstitial solid solution exerts high stresses, which, together with large-scale thermal and structural stresses, may give rise to internal cracks, the so-called *flakes*. This flaking tendency gets intensified with increasing alloying elements and the size of the castings.

The flaking tendency may be completely eliminated by vacuum melting or vacuum pouring, which brings about a strong reduction in the hydrogen content. Alternatively, the castings may be given the antiflaking treatment, which entails heating in the ferrite range close to the AC1 temperature, and holding there for sufficient time to diffuse the hydrogen. The holding time is significantly reduced by prior normalizing treatment. Slow cooling is extremely beneficial because it brings about further reduction in the hydrogen content and lessens thermal stresses, which would otherwise have facilitated the nucleation of flakes.

The simplest antiflaking cycle entails holding near AC1 (600–700°C) followed by slow cooling. For larger castings, the holding time may be as long as about 60–70 hours. An improved cycle involves prior austenitisation and cooling to about 400°C (normalising), which reduces the holding time by one-third. The most efficient cycle for larger castings involves double austenitisation with cooling to about 400°C, followed by holding under AC_1 and slow cooling to room temperature.

8.2.3 Common Heat-Treatment Problems, their Possible Causes and Remedial Measures

Table 8.2

PROBLEM *1*	POSSIBLE CAUSES *2*	REMEDIAL MEASURES *3*
Failure to fully harden	(1) Severe Decarburisation	(1) Use furnace with controlled atmosphere or salt bath for heating
	(2) Too low hardening temperature or insufficient holding time casusing nonuniform heating	(2) Check austenitising temperature
	(3) Quenching not quite severe	(3) Adopt more drastic quench
	(4) Tempering temperature and time too high	(4) Use specified temperature and time
Cracking	(1) Internal stresses as a result of thermal and structural stresses	(1) Cool slowly in martensitic range (apply interrupted quenching, oil quenching, martempering, etc.)
	(2) Failure in tempering just after quenching	(2) Temper before the temperature of the quenched casting reaches about 100°C
	(3) Improper quenching media	(3) Use less severe quenching media
	(4) Higher hardening temperature causing grain coarsening of austenite	(4) Check austenitising temperature and normalise before hardening
	(5) Poor design	(5) Avoid sharp corners, projections, sudden change in sections
	(6) Improper preheating	(6) Proper stress relieving is advisable, small holes in the massive sections should be plugged, and fixtures be used if required
Warpage	(1) Stresses reduced by nonuniform quenching (or heating)	(1) Hold the component in proper position and employ spray or agitated quenching
	(2) Improper support during heating	(2) Support with bricks, used coke, cast iron, etc.
	(3) Unbalanced design	(3) Use proper quenching, jigs, and fixtures, and straighten the job after treatment

(*Contd.*)

Table 8.2 (*Contd.*)

	(4) Insufficient stress relieving	(4) Stress relieve prior to heat treatment
Distortion	(1) Transformation or retained austenite	(1) Employ sub-zero quenching or multiple tempering
	(2) Severe quenching practice	(2) Use less severe quenching media
	(3) Upredicted thermal stresses	(3) Employ quench fixture to balance the mass
	(4) Improper tempering	(4) Apply stabilising elements or sub-zero quenching
	(5) Overheating or underheating	(5) Check austenitising temperature and furnace control
	(6) Insufficient stress relieving	(6) Stress relieve before hardening
Soft sports	(1) Decarburisation and excessive scale formation	(1) Use furnace with controlled atmosphere or heat in salt bath
	(2) Improper agitation	(2) Adopt spray quenching or a liquid bath with suitable agitating device
	(3) Quenching bath too hot	(3) Check the martensitic transformation temperature
	(4) Contaminated quenching liquid	(4) Clean, filter, or change the liquid periodically
Burning	Heating for longer periods at high temperature in oxidising atmosphere results in:	
	(1) First stage of burning (grain boundaries enriched in carbon)	(1) Use homogenising followed by double annealing
	(2) Second stage of burning (non-oxidised cavities and blowholes)	(2) Decide to forge and then anneal
	(3) Third stage of burning (iron oxide inclusions)	(3) No remedy
Oxidation and decarburisation	Higher heating temperature and oxidising atmosphere in the furnace	Apply controlled atmosphere furnace or heat in boxes with carburising agent or cast iron chips or heat in salt bath
Excessive or insufficient hardness after tempering	(1) Low tempering temperature or insufficient holding time	(1) Opt for second tempering with proper temperature and holding time
	(2) Tempering temperature too high	(2) Anneal, re-harden, and temper at correct temperature

8.2.4 Heat Treatment of Cast Iron

(1) Grey Cast Iron Castings of grey cast iron do not generally require heat treatment, because the desired strength and hardness are achieved by adjusting their composition. However, for castings of varying sections or close machining tolerances, stress relieving is sometimes essential. The machinability of grey iron is usually improved by soft annealing at about 700°C to convert any pearlite present into graphite. If massive carbides occur in the cast structure, annealing at 900–950°C dissolves them.

For significant improvement in hardness and wear resistance, the grey iron is subjected first to hardening and then to tempering. Surface hardening treatments are quite often used. In this case, the surface of the casting is hardened by heating through a gas torch or an induction coil and then quenched before tempering, while the interior region of the casting essentially retains its as-cast structure.

(2) Malleable Cast Iron Castings of white cast iron are too brittle to have engineering applications without suitable heat treatment called malleabilising. Depending on the heat-treatment cycle, the white iron castings may turn to black-heart, white-heart, or high-strength pearlitic malleable iron. Black-heart or ferritic malleable iron is obtained by healing within the temperature range 850–950°C for 50–70 hours (the temperature and time being dependent on composition). In modern annealing furnaces, where castings need not be packed with insulating materials because of the provision of a controlled non-oxidising atmosphere, the malleabilising time is reduced to 48 hours or even less, as shown in Fig. 8.16. The effect of prolonged annealing is to decompose cementite in the form of small rosettes of

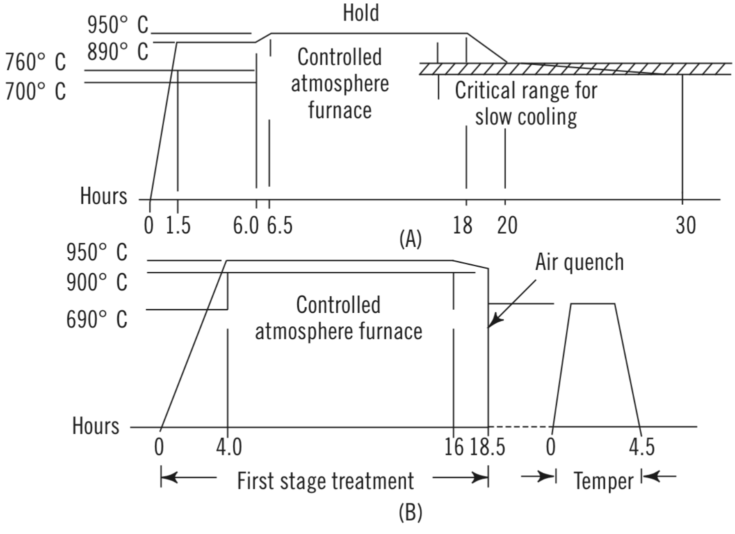


Fig. 8.16 *Malleabilising cycles for ferritic and pearilitic malleable iron; (a) Ferritic (black-heart) malleable iron (heat treatment cycle: 30hrs) (b) Malleable air-quenched iron (heat treatment cycle: above 23 hrs)*

temper carbon. A fractured section appears black, hence the term black-heart. The final structure, which consists entirely of ferrite and finely divided temper carbon, is soft with excellent machinability and almost as ductile as cast steel.

White-heart malleable iron is produced by heating the castings at a temperature of about 1000°C for 72–100 hours in contact with some oxidising material, such as hematite ore. During annealing, the carbon at the surface of the castings is oxidised and lost as carbon dioxide. More carbon, therefore, diffuses outwards from the interior, which in turn is lost by oxidation. The final structure of thin section castings may be completely ferritic with good ductility which on fracture appears steel white; hence the name white-heart.

Pearlitic malleable iron with increasing demand because of its high strength and toughness, is produced by first malleabilising it either fully or partially at about 950°C. It is then reheated to 900°C so that carbon will dissolve in the austenite present at that temperature. Subsequent treatment involves either air cooling or oil-quenching and tempering to produce pearlitic type of matrix. Figure 8.17 shows typical malleable iron castings.

Short-Cycle Annealing of Malleable Iron In view of the extensive use of ferritic malleable iron in automobile industry, it is necessary that minimum time is lost between the production and supply of castings to meet the demand. The time required for its annealing varies from 70 to 200 hours depending on the type of furnace used. The cycle time for oil-fired furnace varies from 120 to 200 hours and therefore these have been replaced mostly by electric furnaces of the bell or elevator type. The cycle time can be shortened considerably by giving due consideration to type of equipment used, type of castings to be annealed, metal chemistry and process control.

During the first stage of heat treatment, the cementite existing in white iron has to be decomposed. Since the carbon content is much higher than the maximum solubility in austenite, the process goes on from metastable equilibrium to stable equilibrium with the formation of graphite nodules. The agglomerate is formed at the interface of primary carbides and the austenite is saturated with the carbon during the first stage of malleabilisation. By decomposition of the carbides and by diffusion effect, the nodules grow around the centres of nucleation. During the second stage of annealing, the transformation may occur in one of the two ways:

(i) Austenite $\rightarrow$ Ferrite + Graphite

(ii) Austenite $\rightarrow$ Pearlite $\rightarrow$ Ferrite + Graphite

The first reaction is fast and therefore preferred to the second one which is very slow. Completion of annealing depends on the chemical composition of the metal, thermal cycle adopted and the presence of ferrite-forming elements for accelerating transformation of carbide to graphite. The graphitising elements, therefore, should be present to offset the effect of carbide-forming elements which retard transformation. However, during the first stage of solidification, the graphitising

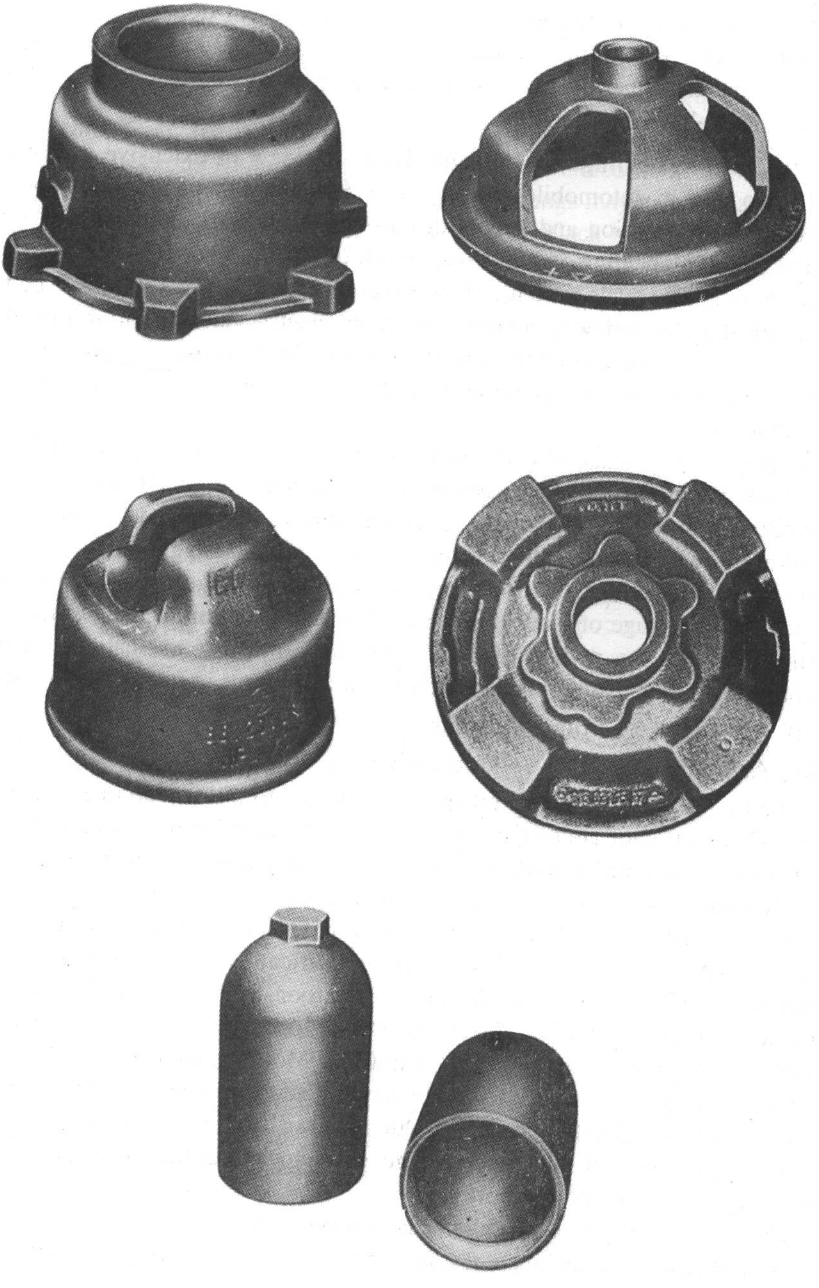


Fig. 8.17 *Malleable cast irons*

tendency must be controlled as the lamellar forms of carbon will affect the final mechanical properties to be achieved in the metal. During the process of annealing, mottling tendency also has to be carefully controlled. Mottling tendency depends on the amount of graphitiser used, the method of melting adopted, composition of the charge material and the velocity of freezing. Other factors being constant, mottling depends directly on carbon and silicon percentage and shape of casting. Bi and Te have been used successfully to control mottling.

The ratio of manganese to sulphur is also very important in affecting the form of graphite obtained. Annealing at the second stage is rendered very difficult if any uncombined sulphur is present in the metal. Manganese must be kept to a minimum, between 0.2 to 0.25% to have short cycle annealing. Proper furnace control is equally necessary in this process. The atmosphere of the annealing furnace has a marked effect on the results of annealing. Excessive oxidising or moist atmosphere may cause varying degrees of incomplete annealing or too much surface scaling. It is desirable to have an atmosphere which produces or retains the required percentage of carbon at the surface of the casting. Best results are obtained when the ratio of CO to CO_2 is kept around 2:1.

(3) Nodular Cast Iron Spheroidal graphitic or nodular cast iron is generally used in the as-cast condition. However, annealing and normalising treatments at about 760°C are sometimes essential for ferritic ductile iron (all ferritic matrix) and pearlitic ductile iron (all pearlitic structure). High strength and wear-resistant martensitic ductile iron is produced by hardening and tempering.

8.2.5 Heat Treatment of Non-ferrous Alloys

Non-ferrous alloy castings are generally subjected to two types of heat treatment to improve their engineering properties.

(1) Homogenisation Whenever a liquid alloy solidifies in a range of temperature, coring or dendritic segregation associated with inhomogeneity in composition occurs because of thermal and constitutional supercooling. This observation is common in isomorphous alloys, viz., Cu–Ni, Au–Ag, etc., and, as a result, the castings have low toughness and poor plastic properties. The cored cast structure is therefore undesirable and must be eliminated by suitable heat treatment. The process involves heating the cast alloys at elevated temperatures for several hours. The equalisation or homogenisation of the composition occurs spontaneously through the action of diffusion. The choice of suitable homogenisation temperature is, however, limited on one side by the onset of melting if the solidus curve is crossed and on the other side by the marked retardation of the process as the temperature is decreased. Allowance must be made for some of the solid, which is richer in the low melting component than the average composition of the alloy, and may melt below the equilibrium temperature.

(2) Solutionise-quench-age Treatment The treatment is compulsorily given to almost all the non-ferrous alloy castings in which the solute component has waning solubility with decreasing temperature, e.g., the alloys of Al–Cu, Al–Ag, Al–Mg, Al–Si, Al–Zn, Al–Mg–Cu, Al–Mg–Si, Al–Mg–Zn, Cu–Be, etc., The strength and hardness of heat-treated alloys are much higher than those of as-cast-alloys. The heat-treatment process (also called age-hardening) involves heating the alloy casting to a temperature T where it forms a homogeneous single phase (Fig. 8.18), followed by quenching to retain the solute component in unstable supersaturated state and subsequent ageing in the temperature range of 100–200°C. During ageing, the solute atoms are rejected and form a cluster as a coherent or semi-coherent precipitate. The strained fields around a coherent or semi-coherent precipitate inhibit the movement of dislocations with resultant increase in the hardness and strength of the casting. On over-ageing (heating for longer period and/or higher temperature), the coherent and semi-coherent precipitates grow into incoherent beta-precipitate particles; incoherent precipitates are not associated with strain fields to be able to interact with the dislocation motion and thus the hardness and strength of the casting are reduced.

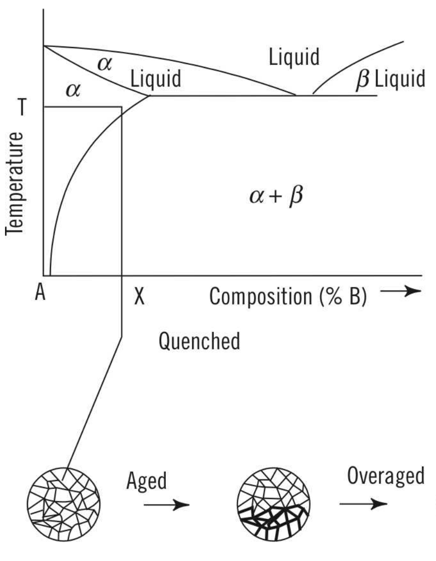


Fig. 8.18 *Schematic representation of a typical age-hardenable system:*
(A) Supersaturated a which contains solute component β in super-saturated solid solution in A
(B) Clustering of solute in the form of coherent or semi-coherent precipitate causing rise in strength
(C) Incoherent precipitates of β causing decrease in strength

Review Questions

1. What operations are involved in a fettling shop? Explain each one briefly.
2. What are the various techniques used in repair of castings? Discuss with examples.
3. Why is heat treatment performed for castings? Which cast metals are normally heat treated and why? What is the role of heat treatment in improving the quality of castings?
4. Describe the various processes involved in the heat-treatment of cast products. Explain the metallurgical phenomenon occurring in the heat-treatment process.
5. Show diagrammatically the heat-treatment cycle to be followed in case of
   (i) steel castings, and (ii) aluminium alloys.
6. What is short-cycle annealing? How is it carried out? What gains are achieved by its use?
7. Explain the use of tumbling and hydro-blasting processes. For what sort fo castings are these processes suited?
8. Describe the working of sand-boasting and shot-blasting processes. What factors affect their choice of selection? How is shot peening different from shot blasting?
9. What is the use of pickling in the fettling shop of a foundry? How is it carried out? What precautions are essential during the use of this process?
10. Discuss the suitability of various types of welding processes for repair of castings.
11. For what sort of castings is the thermit welding process suitable? Mention its advantages.
12. Explain the malleabilishing cycles for ferritic and pearlitic malleableirons. What is meant by short-cycle annealing?

Chapter 9

Modernisation, Mechanisation and Computerisation of Foundries

9.1 NEED FOR MODERNISATION AND MECHANISATION

An average person visualises a foundry as a dark, dirty place dotted with mounds of sand, coal, ashes and metal, an atmosphere filled with smoke; an enclosure where workers swear and breathe noxious fumes produced during the casting process. This picture is true to a fair extent of many foundries even today. There is thus a vital need for modernisation in this particular field of industry. Measures that lead to increased production, improved working conditions in the shop with an eye to ensuring a safe, healthy and happy life for the worker deserve enthusiastic support. The areas in which such measures are possible may be broadly classified under two heads—modernisation of production and equipment and modernisation of working conditions.

In the past four decades, a great deal of work has been carried out towards mechanization of foundry industry. It is, therefore, essential that the foundry industry provides the technology to meet the ever-changing requirements of its customers. Foundries must offer a complete casting development service involving operations not by hand but by automatic, self-actuated computer-controlled machines, robots and self-correcting systems.

The foundry unit involves basic operations like patternmaking, mould-and core-making, metal melting, pouring, knocking out of castings after solidification, cleaning and fettling, and finally inspection and quality control. The review of a detailed sequence of production steps from start to finish is a significant step towards reduction in production cost. A proper production plan is to be assessed resulting in saving of time and manufacturing cost.

Materials Handling Costs in metal-casting operations account for 20 to 40% of the total cost of producing castings. The efficiency of a manufacturing system is dependent upon the ability to move the parts/materials effectively, timely and rapidly. Traditional methods of materials handing in foundry are based on manual work. This does not respond to meeting changes in the requirements. One possible answer to reducing costs and increasing productivity, particularly in a high-production foundry, its to automate more materials handling functions.

Use of improved equipment to separate castings from moulds is making a significant contribution to better productivity, particularly in sand-cast foundries. Shake-out functions include separation of moulds and sand from flasks, castings from sand, cores from castings and even shots from shot-blasted castings.

High-quality castings depend on the ability of a foundry to test and inspect all raw materials—sand, metals and alloys. *Testing, inspection and measurement* are critical in each casting production process, beginning with pattern and die design, mould-and core-making, chemical analysis of metals and alloys and also for finished castings themselves.

9.1.1 Modernisation of Production Methods and Equipment Mechanisation

In the simplest terms, mechanisation means the utilisation of machinery for work previously done by hand. Machinery may be used for preparing sand, moulds and cores for transporting the sand and moulds, and for transporting and pouring the molten metal.

The extent to which mechanisation can be adopted in a foundry varies according to the quantity and type of production. For small orders as well as for the production of large-sized castings, mechanisation is both uneconomical and inpractical. On the other hand, foundries mass producing relatively few types of castings can be profitably, sometimes even completely, mechanised. Examples of complete mechanisation are evident in foundries manufacturing automobile parts, electric motors, portable tools, and consumer goods such as sewing machines and electric fans where bulk orders of small-sized parts are undertaken and the jobs are of a repetitive nature.

9.1.2 Modernisation of Working Conditions

The means to improved working conditions also help indirectly in increasing production and cutting costs. Mechanisation and modernisation when properly planned carry several advantages, including

(i) increased production from a given floor area and higher productivity;
(ii) production of castings that feature a higher degree of accuracy, closer tolerances, and better surface finish;
(iii) enormous saving of labour, due to the elimination of many time-consuming manual operations, such as mixing and preparing sands, preparing moulds, and handling various foundry materials;
(iv) better working conditions and improved job satisfaction; and
(v) reduced cost of production and higher profits.

But mechanisation has its limitations too. First, it is not adaptable for small-job foundries, especially those involving little or no repetitive work; second, it may give rise to unemployment or retrenchment of workers since the use of machines displaces the labourer; and third, the substitution of men by machines may lead to a gradual disappearance of the skilful art of hand moulding.

AREAS FOR MECHANISATION 9.2

Mechanisation has a distinct impact on areas concerned with the preparation and control of sand; moulding and core-making; melting, pouring, and shake-out operations and material handling.

9.2.1 Sand Preparation and Control, Moulding and Core-Making

Sand preparation equipment (see Section 3.2.2) is invaluable in both jobbing and mass-production foundries. The riddle which rids sand of refuse, the muller which kneads the sand for re-use, the magnetic separator which removes iron particles from return sand, the aerator which helps to improve the flowability of sand, hoppers which act as storage for sand before it is sent for mulling, all such equipment are essential for maintaining the homogeneity of sand mixtures. If sand is initially wet, it has to be dried in sand driers. In case the sand gets overheated in the mould, it has to be cooled down to room temperature in special coolers, before it can be re-used.

Continuous Mixer Continuous mixers (Fig. 9.1) are now coming increasingly into use with the development of organic no-bake resin systems based on phenolic binders. These two-part no-bake systems are fast-acting, need less sand, generate low nitrogen, give high productivity and the sands are reclaimed easily. Two types of mixers are used—*pivotal type* for small to medium sizes, and the *mobile type* for heavy jobs.

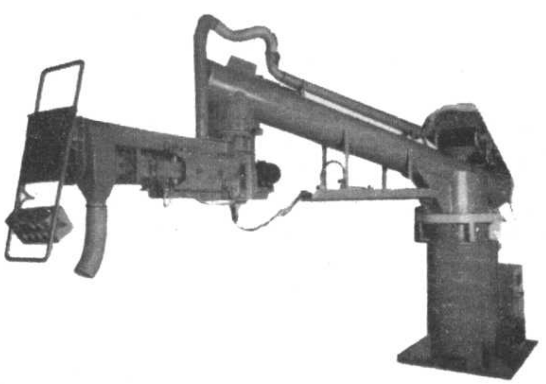


Fig. 9.1 *Continuous mixer unit*

The mixer consists of a horizontal trough fixed to a column at one end with a rotating shaft with blades around fastened to it. The sand along with resin and hardener are introduced at one end in the trough in measured quantities using a pneumatic metering device. As the constituents travel in the trough from one end to the other, they get thoroughly mixed and the sand grains are uniformly coated with resin. The sand mix is finally discharged from a spout directly into the moulding box placed below on a compaction table. The sand is compacted by means of low amplitude and high-frequency vibrations caused to the table using two unbalanced motors. The moulds are then painted, cores laid in place, closed and poured. The poured moulds after cooling down are transferred on a conveyer line to the shake-out and reclamation.

Integrated systems, now available, consist of a sand-preparation unit supplying mixed resin sand continuously, discharging it into a moulding box placed on a vibratory compaction table, a pattern loop-mould stripping device, and a shake-out with a reclamation plant (Fig. 9.2) The reclamation unit consists of a fluidised sand cooler cum classifier which allows about 80–90% of the used sand to be reclaimed and re-used, thus affecting considerable savings in sand costs. The castings are removed from the mould, the sand lumps are reduced to grain size in a scrubber and oversized grains, lumps, tramp metal and other degradable material along with sand fines are separated. The dust is removed using a bag filter-type dust-extractor unit. The sand is cooled in a cooler unit using cooling water circulating through copper tubes placed in the fluidised bed. The water is cooled continuously in an evaporative type water-cooling tower. The reclaimed sand is conveyed pneumatically to the mixer unit. The new sand is added to reclaimed sand in the desired proportion by adjusting a pneumatic slide-gate valve.

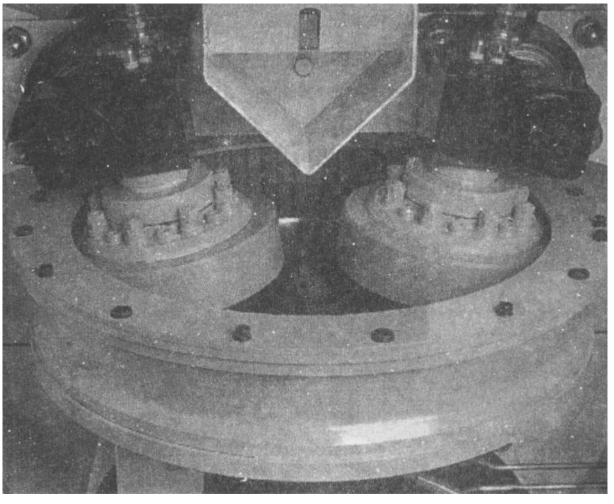


Fig. 9.2 *Reclaimer unit*

Thus, the use of a continuous mixer enables the quality of castings produced to be much higher than those produced by the CO_2 process. Also, sand and fettling costs are reduced and labour productivity is greatly increased.

Sand-testing facilities are essential for controlling the characteristics affecting the properties of moulds and cores. The conventional approach to sand control in foundries is to maintain a constant, predetermined moisture level. At constant moisture, however, there is no regulation of the variation in the composition and temperature of sand, in the nature or the amount of additives, all of which affect the working and ramming properties of sand. Consequently, improved methods of sand control have come into vogue. In one method, sand is prepared to a constant degree of mouldability. The apparatus, called the mouldability controller (Fig. 9.3), adjusts the moisture addition to compensate for the variations in sand composition.

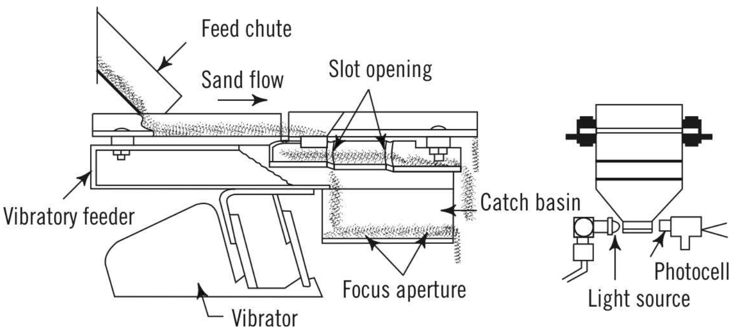


Fig. 9.3 *Mouldability controller*

The mouldability controller has a slotted vibratory feeder trough and a system of photoelectric cells. The controller is positioned at the sand mixer from where a small amount of sand enters the controller. The sand falls on to the vibratory feeder and moves towards the slots. When the sand is dry, it falls through the slots and blocks off the focussing apertures through which two light sources are directed towards two photocells. The interruption of these light beams opens two water valves in the mixer to add more moisture to the sand. When the required amount of water has been received by the sand and the desired mouldability level attained, sand moving on the vibratory feeder tends to bridge the slots rather than fall through them. It, therefore, no longer obstructs the light beams, and so the water valves get closed. This system of adjusting water additions by the opening and closing of water valves operates continually according to the requirements of the sand and thus maintains a constant workability, producing moulds of an exceptionally high quality.

Moulding and core-making equipment have been briefly described in Chapter 3. The extent to which this equipment can be used depends on the nature of production.

9.2.2 Melting, Pouring and Shake-out Equipment

In a mechanised foundry, the attempt is to substitute manual labour by mechanical devices wherever possible. However, the extent to which the machine can be exploited is dependent on factors such as the type and condition of equipment, the economical feasibility of installing such devices, and the floor space available. Although the mechanical gear varies from foundry to foundry, it generally includes a crane, lift truck, turnover truck, belt conveyer, or bucket conveyer system for handling charges, such as pig iron, scrap, and coke and flux, and transporting to the furnace.

Machines are also essential for sending the charge up to the charging door, as in the cupola, and discharging it into the furnace. A skip-hoist type of conveyor is customarily used to send the charge-up. In this arrangement, the charging bucket is mounted on wheels, and guided by a vertical or inclined track. The bucket is raised and lowered along the track by the working of a reversible electric motor through a cable. When the bucket reaches the charging door, it operates an electrical limit switch which brakes the motor instantly and, after some time lag, reverses it. For convenient loading, the bucket is lowered into a pit. The discharge bucket used is usually the top-discharge type which is automatically inverted as it enters the charging door of the cupola.

For large-sized cupolas, the crane type of conveyance is suitable. Here, the bucket is raised by a crane from the loading station and carried horizontally into the charging door. The bottom of the discharge bucket has a hinged door which swings open for discharging.

In the case of other furnaces, such as the open-hearth furnace, air furnace, and electric furnace, the crane arrangement with either the top discharge or the bottom discharge bucket is commonly employed.

The variety of equipment used for melting the metals has already been discussed in Chapter 6. Factors such as the metal to be melted, the quantity of metal required, the quality and purity of metal desired, and the availability of fuel determine the type of equipment needed in the foundry shop.

After the metal is melted, it is scooped into ladles and carried to the pouring floor by means of a crane. The metal may be poured either by keeping the ladle stationary in the crane and moving the moulds one after another on a roller conveyer or by keeping the moulds fixed in a line and shifting the ladle forward every time a mould is filled with the metal.

When the castings are sufficiently cool, the moulds are transported by a crane or conveyer to the shake-out station where they are vibrated or shaken in such a way that the castings along with the sand are eased out of the moulding boxes. The shaking operation is conducted on a grating which has a sand conveyer beneath. The sand duly separated from the castings passes through the grate and is carried away to a sand-reclamation plant whereas the castings and the emptied moulding boxes remain on the grating. The castings are then sent to the fettling and inspection shop and the moulding boxes are returned to the moulding section.

Shake-out machines are of many types. For small-sized moulds, a stationary grating installed at a small incline is most suitable. The moulds break, when jolted and dropped, allowing the sand to pass through the grating and leaving the casting and the moulding box above it. For small- and medium-sized castings, the vibrating type of shake-out is commonly used. It consists of a perforated plate or a heavy grille fastened to a vibrating frame. After the mould is placed on the grille, the frame is vibrated by means of a motor-driven eccentric arrangement to extract the sand from the mould and release it through the grille. The vibrating frame is connected to the machine structure by compression springs, thus largely eliminating the transmission of vibrations into the foundation.

For heavy moulds, the ideal shake-out is the bumper type. The mould is positioned on two heavy beams which are hinged at one end. The free ends of the beams rest on motor-driven cams. When the cams are rotated, the beams get first lifted slightly, then dropped back into place. This action jolts the mould. All shake-outs should be fitted with a hood and a powerful dust-suction device to prevent fine sand and dust particles from escaping into the air around.

Automatic Pouring System During the last ten years, several foundries in the country have installed automatic pouring systems as an adjunct to large-capacity induction furnaces with the objective of maintaining consistent quality of castings produced, and for controlling pouring rate and pouring time of molten metal and reducing metal losses. This has reduced manpower requirements considerably, improving yield of the castings and productivity of the foundry, and, further, the quality of work life. These systems are well-suited in innovative and quality-oriented foundries engaged in large-scale mass production or continuous type of production of gray and ductile iron castings using automatic moulding lines.

Their success is leading the way for more widespread adoption of this modern technology. Thus, increased casting production, higher casting quality and enhanced worker safety is made possible by applying automatic pouring technology. The pouring system uses a high response stopper-rod pouring mechanism and a vision-based control technology, which can allow precise pours mould-after-mould, without any operator intervention or interruption. Ladles bring hot metal from the furnaces at carefully timed intervals to maintain the desired pouring temperature range in the pouring tundish. Automatic pouring continues as the tundish is replenished.

The moulding lines are so arranged that perfectly filled moulds move from the automatic pouring system along the now-empty manual pouring line. Apart from the advantages enumerated above, other savings and efficiencies are obtained in several other areas, such as reduced maintenance requirements, improved working environment, commitment to quality and productivity and finally rapid payback of capital expenditure.

Fig. 9.4 *Automatic Pouring System installed by M/S Inductotherm at the Automotive Castings Foundry of M/S Mahindra Hinoday Industries, Pune.*

(By courtesy of M/S Inductotherm (india) Pvt. Ltd., Ahmedabad)

9.2.3 Material Handling

Material handling equipment is an invaluable asset in the rapid and economic production of castings on a large-scale. The foundry which is the receiving centre of huge quantities of diverse materials, requires to be suitably equipped to ensure efficient handling and treatment of items, such as

1. sand;
2. moulds and cores;
3. molten metal; and
4. castings.

1. Handling Sands Sands are required to be conveyed from one part of the production foundry to another for various purposes. For example, sand is taken from the shake-out station to the riddle for screening; from the screen to the magnetic separator; from the magnetic separator to the reconditioning plant, i.e., muller and aerator or to the hoppers for storage; and from the storage to the mixing or conditioning plant. Reconditioned sand has to be sent to distribution mains and then to workstations. All this travelling to and fro is conducted on a sand conveyer. The wide range of sand conveyers covers specified areas of work in the foundry shop.

(i) Belt Conveyer The belt conveyer is commonly used for transferring sand from one place to another in travel that requires a horizontal or an inclined direction of movement. It consists of an endless belt, two pulleys (called head and tail pulleys), rollers or idlers for carrying the loaded belt and returning the empty belt, a

belt-tightening mechanism, and bell cleaners. The belts are available in various sizes and strengths and are made of cotton plies bonded with synthetic rubber. Since such material cannot withstand more than about 150°C, the belt conveyer can be used only when the temperature of the sand is within the limit. Where hot sand is to be transported, a metal conveyer is used.

The head pulley is used for driving the belt and is connected to an electric motor through reduction gear. Its diameter should be large enough lo ensure full traction. To prevent sand from spilling and to keep it in the centre, the idlers which support the belt are arranged in three pieces, i.e., each set of idlers has three rollers, one horizontal in the centre and two slightly inclined on the sides. These idlers should not be spaced very far apart, otherwise the belt will sag too much under load. When the sand conveyer is used for inclined travel, the angle of incline should not exceed 15° for dry and 25° for tempered sand to keep it from rolling backwards.

(ii) Bucket Elevator When the sand is to be conveyed vertically upwards, a bucket elevator is ideal. There are two pulleys, one at the top and the other at the bottom which carry an endless belt. The belt carries a number of buckets all around and the whole assembly is enclosed in a steel casing which has two openings, one at the bottom for feeding and the other at the top for discharge. The bucket elevator is generally preferred to the inclined belt conveyer owing to a saving in space and cost.

(iii) Apron Conveyer The apron conveyer's overlapping steel plates, hinged at the ends, serve, when assembled, the same purpose as a belt. The advantage of an apron conveyer is that it can be used for transporting materials that are too hot to be carried by a belt. The drawbacks are that it cannot be used at high speeds, there are chances of sand spillage and leakage through the plates, and the cost of maintenance as well as the initial costs are higher.

(iv) Flight Conveyer The flight conveyer is generally used for distributing sand to workstations from an overhead trough. It has two endless chains moving on sprockets, fixed at both ends, and carrying steel plates, called 'flights', at certain intervals. When the chain moves, it causes the flights to shift in the trough and force the sand to enter the openings in the hoppers.

(v) Reciprocating and Oscillating Conveyer Occasionally, the reciprocating and oscillating conveyers are also considered suitable for transporting sand. The reciprocating action is produced by a crank-pin and connecting-rod arrangement. This type of conveyer is used for short travels where the depth of excavation needed for continuous conveyance is not a requisite. The oscillating conveyer is also sometimes selected for transporting hot sand and hot castings. It is made of steel plates which are fastened together and secured by two beams. The oscillating action is produced by means of an eccentric.

(vi) Mono-rail Conveyer The mono-rail conveyer is frequently used for carrying sand and other items, such as castings, molten metal, and furnace charge. The

sand is filled in buckets or containers of the drop-bottom type and transported from one place to another on an overhead mono-rail. The conveyer may be either manually or electrically operated.

(vii) Crane For small foundries engaged in jobbing work, an overhead travelling crane may be more convenient for carrying sand. The sand is filled in a bottom discharge type of bucket which is transferred with the help of a crane.

2. Handling Moulds In a production foundry, moulds may be conveyed from the mould-production section to the storage where they remain stationary for pouring or they may be conveyed past a pouring station where molten metal is poured into them while they are in motion. The moulds when cool are conveyed to a shake-out station and, after shake-out operation, the emptied flasks, moulding boards, etc., are returned to the mould-production area. All these transport operations in a mechanised foundry are conducted on a suitable conveyer system.

Like sand conveyers, mould conveyers also are of many types, each suited to particular working conditions.

(i) Roller Conveyer The roller conveyer has two beams fixed on trestles of suitable height and supporting laterally arranged rollers above. It may be either of the gravity or the power-driven type. Gravity conveyers are those in which no power is used to drive the rollers and move the moulds. Instead, the ends of the rollers are fitted in sealed bearings and the moulds need to be pushed by the operator to cause them to move on the rollers. The beams may be fixed at a slight incline to facilitate the moulds' movement by the force of gravity.

In the case of power-driven conveyers, some of the rollers at fixed intervals along the length of the conveyer are driven by an electric motor which has a variable speed to enable coordination of the mould movement with mould-production. This type of conveyer is expensive and is, therefore, considered worthwhile only for mass-production foundries whereas the gravity conveyer is suitable for both jobbing and mass-production foundries.

(ii) Pallet (Car-Type) Conveyer The pallet or car-type conveyer is the most efficient means of moving moulds in large-scale foundries from the mould-production area to the pouring department and after allowing adequate time for cooling, to the shake-out station. It has pallets made for cast iron or steel plates mounted on wheels which can roll along a narrow gauge track. The moulds are placed on the pallets and pushed manually. In the case of continuous drives, however, the pallets may be connected by a chain and driven from one end by power. Pallet conveyers have made completely mechanised work possible.

(iii) Overhead Conveyer Sometimes an overhead conveyer of the mono-rail type is also employed for transporting moulds in small foundries. The completed moulds are placed on the platform of the conveyer and the platform is carried to the pouring area by an overhead mono-rail. After the casting has solidified, the same carrier is moved to the shake-out station.

3. Handling Molten Metal For pouring molten metal into moulds, two systems are commonly followed. Where a continuous conveyer is not used, the moulds after completion are carried on a roller conveyer to the storage area. The molten metal is transferred in ladles to this area with the help of a travelling crane or hoist and is poured into the stored moulds. Where the moulds are constantly moving, the metal is brought on a mono-rail conveyer and poured into the moving moulds.

4. Handling Castings After the castings are removed from the moulds at the shake-out station, they are transported on a suitable conveyer to the clearing and fettling section. The range of conveyers includes the plate-band, roller, oscillating and overhead varieties.

(i) Plate-band Conveyer A plate-band conveyer is used in many foundries for carrying castings to the fettling or inspection sections. It is excellent for both horizontal and inclined travels and for short as well as long distances. The plates are joined together and mounted on a continuous chain moving on power-driven sprockets.

(ii) Roller Conveyer The roller conveyer can carry castings in the same way as it carries moulds. The gravity type is particularly cheap to install, and satisfies the need of small foundries.

(iii) Oscillating Conveyer The oscillating conveyer, which is the frequent choice for sands, is sparingly used for transferring castings.

(iv) Overhead Conveyer The overhead conveyer is considered suitable for carrying castings from the shake-out station to the shot-blasting rooms for cleaning. It carries the castings by means of hooks suspended from a chain. The conveyer along with the castings enters the shot-blasting chamber from one side and leaves it through the exit on the rear side.

(v) Industrial Trucks Lift trucks and front-end loaders are in use in foundaries for decades. For industrial trucks, a careful evaluation of the factors that limit their efficiency can help in improving the foundry productivity. It can also help to evaluate the function of trucks in the planning of overall materials handling, involving cranes, monorail carriers and belt conveyers, which may lead to saving in time and manufacturing costs.

(vi) Robots Several operations in a foundry shop are assumed to be hazardous, unpleasant, suffocating, tiring and unattractive to workers. Robots are most suitable to operate in such locations to enhance productivity, quality and to decrease manufacturing cost of the operations, which are repetitive in nature requiring consistency in quality and quantity of production. A robot, being a programmable device, is capable of performing complex actions in a wide variety of operations without human intervention.

APPLICATION OF COMPUTERS IN FOUNDRIES 9.3

Computers have now become an indispensable tool in every walk of life and for all sorts of applications, may it be administrative, operational, technological, trading, sports, communications or even domestic fields. From the industrial point of view, they have been in use in the administrative areas of finance, accounting, personnel records, wage and salaries and inventory control for a long period. However, lately, computers have been introduced increasingly for various technological applications, such as drawing and design, process selection and methoding, tooling design, component design, machine design, production planning and control, process control, quality control and defect analysis. Many machine systems are computerised. Automation has also come in a big way in engineering industries, especially foundries, and computers have become an essential part of the control system for all the automatically operated machines. Robotics have further made their headway into many foundries, which also operate through pre-planned computer programs. In fact, the advent of computers has revolutionised the entire industrial structure, helping in enhancing production and productivity, maintaining and improving quality and controlling costs. In the fields of engineering production, CNC, CAD, CAM expert systems and artificial intelligence have further raised the level of advancement.

At the present juncture when the demand on the foundry industry to produce castings in large quantities, of superior metallurgical quality and to close dimensional accuracy is fast increasing from sophisticated users, especially automobile, aeronautical, electrical, power plant and machine tool industries, there are no options but to consider adopting new technological processes, new materials and go for automation and computerisation. Modernisation is now the only key to improve quality and productivity. With fast-increasing international competition to sell castings and to be able to compete with overseas buyers, especially those from the Far East, it is necessary to control costs as far as possible, explore new marketing strategies and enhance productivity. Computers, though not essential for adoption at every stage of production, hold great promise in ensuring better and consistent quality, higher yields and lower costs. Apart from the tangible gains, visible at first sight, there are several intangible gains, such as better prestige of the company among the customers, improved morale among the workers and staff, less fatigue and strain during working and improved work culture. Improved work culture and greater interest in work can lead to a sense of participation, involvement and creativity.

Computers, through the use of standard as well as specially designed softwares have been playing a wide role in the foundry industry. More importantly, their use has been widespread in the following areas:

1. Casting design and development for optimum quality, weight and cost, and easy producibility

2. Carrying out and maintaining pattern designs, history and life and usage data and repair data
3. Sand control for obtaining desired sand and mould characteristics
4. Process optimisation and process selection for ensuring both quality and cost of products
5. Methoding and laying down correct technology of pattern and other foundry tooling design, mould design, and die design, gating and risering design, requirement of insulating and exothermic materials, moulding, pouring, mould cooling, fettling and heat treatment
6. Controlling heat-treatment cycles
7. Production planning and control, such as preparing technology sheets for every item and updating it from time to time, job cards, tool tickets, inspection cards, scheduling charts and production control charts.
8. Material procurement and selection, material procurement, suppliers, vendor-rating, EOQ determination for various important items, lead times, re-order points and reserve stocks, ABC analysis, maintaining stock positions of different items of inventory
9. Deciding chemical composition to obtain desired properties, charge control melting and melt control
10. Process control
11. Quality evaluation, quality records, inspection and testing
12. Cost control at every stage of production
13. Maintaining database for the entire data about production quantities, sand testing, production schedules, heat numbers, melt cycles, process controls, quality records, defect analysis reports and heat-treatment cycles in order to maintain quality and achieve easy identification and traceability of products on a long-term basis.
14. Maintaining data about calibrations of tools, gauges, instruments and equipment, corrective actions taken to salvage products, quality records, including quality manual, quality procedures, work instructions, quality plans and quality records
15. Records about wages and salaries to staff and workers, labour inputs, incentive schemes, work orders, job evaluation and merit rating
16. Maintaining data about daily, weekly and monthly production and productivity.

The softwares required to operate computers for specific uses consist of

(i) Operating system, to enable start up, shutting down, performing various administrative functions, such as directory, editing, cut, copy, paste, data transfer and retrieval, saving for future use, printing or plotting on hard copy, and so on

(ii) Standard softwares, such as those for text writing, publishing, database management, tabulation, worksheet preparation, drawing, drafting and graphics, preparing slides for presentation, mathematical calculations, music and games

(iii) Special-purpose software packages, such as those which are designed for specific applications; for example, design of gating, feeding systems for castings, casting and pattern design, inventory control, melt calculations, heat transfer, fluid flow and solidification studies, quality and soundness evaluation

Many of these computer applications are so simple that there is no need to use sophisticated and proprietary softwares. These can be developed in-house using suitable programming languages, such as BASIC, Pascal, C, Fortran, etc. Standard softwares, such as Excel, D-Base, Autocad, Harvard Graphics, Acrobat and Corel can also be used with ease for developing in-house programs. A separate chapter has been added in the book for CAD/CAM applications in the foundry industry.

For fast communication, which may be within the company, within the country or outside the country with overseas buyers, suppliers or customers, the Internet has now emerged in a big way as a boon. A large amount of paper work is saved, communication, which took days or weeks to reach from one place to an other can now be transmitted and received in a matter of seconds. Sending enquiries to prospective customers, receiving quotations, placing purchase orders, keeping follow-up, having discussions with individuals or a group of people, exchanging reports and data, drawings or pictures can all be possible through the Internet. Foundries can have their own web pages and web sites to publicise their products and services and explore markets at a global level.

9.4 POLLUTION CONTROL IN FOUNDRIES

9.4.1 Pollutants in a Foundry

Foundries are among the industrial plants causing environmental pollution, producing substantial quantities of air pollutants. The numerous processes available for moulding, melting and casting are accompanied by evolution of heat, noise, dust and gases. Dust, fines, fly ash, oxides, etc., which form particulate matter are generated in large quantities when preparing mould and core sands and moulds, melting metals, pouring moulds, knocking out poured moulds and loading and unloading raw materials. Gaseous matter like gases, vapours, fumes and smoke are produced during melting and pouring operations. The major pollutants emitted from various work areas in a foundry are given in Table 9.1. The basic means of controlling the emission of pollutants are changing the production process, supplying adequate make-up air, proper aeration and ventilation of the shop, reduction of pollutants at source by taking appropriate control measures, dispersion and dilution of pollutants in the air space and good housekeeping.

Table 9.1 *Major pollutants emitted in a foundry*

Work area	Pollutant	Emission concentration g/m3
Pattern shop	Sawdust, wood chips	Heavy
Sand preparation	Dust and fines,	100–175
	powder materials	75–150
Moulding and core-making	Sand	50–100
	Fines	100–175
	Binder dust	75–150
	Vapours	Light
Mould drying and ladle heating	CO, SO_2	Light
Cupola	SO_2	Light
	CO	Heavy
	Unburnt hydrocarbons, smoke	Heavy
	Metallic oxides	Moderate
	Coke dust	100 –175
	Limestone dust, fly ash	Moderate
Electric arc furnance	Dust, CO, SO_2 oxides,	Moderate
	Nitrogen cyanide, fluoride, etc.	Light
Electric induction furance	Dust, oxides, smoke	Light
Pouring and mould cooling	CO	Light
	Binder fumes	Moderate
	Oil vapours	Heavy
Knock-out	Sand, fines and dust	200–350
	Smoke, steam, vapours	Heavy
Fettling	Dust, metal dust, sand fines	≥100
	Abrasive powder	10–50
Heat treatment	CO, SO_2, oil vapours	Light

9.4.2 Emissions during Melting Operations

The emissions from melting units need special attention as they may carry large quantities of constituents harmful to ecology and the environment.

Emissions from Cupola Furnace The particulate emissions from a cupola may be of three types:

(a) metallic oxides

(b) silicon and calcium oxides, resulting from lining erosion, embedded moulding or core sands, dust from scrap and limestone

(c) combustible materials, which include coke particles or coke dust, vaporised or partly burnt oil or grease

The actual amount of each constituent may depend on the type of raw material used, the lining quality and its condition and operating conditions. The particle sizes of these emission vary from 1 micron to 500 microns. The distribution of particle sizes does not have any regular pattern but it may broadly be as shown in Table 9.2.

The total quantity of these emissions also varies widely, but usually ranges from 18 to 22 kg per tonne of metal.

Table 9.2 *Distribution of particle sizes*

Particle size	Per cent (by weight) obtained	Source
> 50 μm	40–80	Mechanical abrasion of refractory and charge materials
5 to 50 μm	20–40	Undissolved coke as emanating from upper portions of charge column
< 5 μm	5–20	Oxides of melting loss and other constituents

The gaseous emissions from the cupola are composed of CO_2, CO, N_2, and smaller amounts of SO_2 and H_2. Sufficient air generally infiltrates through the charging door, as the gases ascend, to burn CO to CO_2. The rate of evolution of CO, which is due to incomplete combustion of carbon, is about 680 to 800 m^3/h and the total exhaust gas volume is 4500 to 5400 m^3/h in case of a five-tonne capacity cold-blast cupola. These volumes increase almost in direct proportion to the capacity of the cupola.

Sulphur is introduced in the exhaust gases as SO_2 because of its presence in coke and metallic charge. The range of SO_2 emissions which are most harmful to the environment and to plant ecology may vary from 25 to 250 ppm. Low-sulphur fuels should be used as far as possible in the absence of an economical method for the removal of sulphur from fuel or stack gases. Efforts should be made to improve cupola operation to decrease the quantity of emissions requiring collection and reduce the cost of collection. Gases carried in the exhaust, like CO_2, N_2 and H_2 are harmless and need not be collected. Table 9.3 shows the content of CO and dust in waste gases from cupola.

Emissions from Electric Furnaces Compared to cupola furnaces, emissions from electric furnaces are small. Arc furnaces emit large amounts of pollutants, such as dust, smoke, CO, oxides of nitrogen and sulphur, and cyanides, along with process gases. The actual amount of these constituents depends on the nature of the raw material used, the manufacturing process and the exhaust system for the gases.

Table 9.3 *Content of carbon monoxide and dust in waste gases from cupolas*

Capacity of cupola t/h	Amount of gases exhausted into atmosphere, m^3/h	CO			Dust kg/t of metal
		m^3/h	kg/t of metal	g/m^3	
1	*2*	*3*	*4*	*5*	*6*
5	4,500–5,400	680–810	170–200	20*	18–22*
				13	12–14
10	9,000–10,000	1,350–1,500	170–190	20	18–20*
				13	12–13
15	12,000–14,000	1,800–2,100	150–175	20	16–18
				13	11–12
20	17,000–20,000	2,500–3,000	155–190	20	17–20
				13	10–13

*Numerator denotes the amount of dust in the gases before the spark extinguisher; the denominator, after the spark extinguishers.

The amount of dust exhaust from arc furnaces varies from 7 to 9 kg/tonne of steel and the volume of gases evolved varies from 350 to 450 m^3/tonne of steel.

Emissions from induction furnaces are relatively much smaller than arc furnaces. Emissions originating from charge materials may consist of rust, dust, dirt, paint or grease, and those originating from chemical reactions consist of metallurgical smoke due to oxidation. In case clean scrap is used, emissions range from 0.12 to 0.70 kg/tonne of metal, in particle sizes of 25 to 100 microns.

Emissions in Other Areas of Foundry

(a) Moulding and Core-Making Sections The pollutant generated in the moulding and core making sections contain mainly dust. However, the amount of dust generated is much less as compared to other departments.

Drying of Moulds and Cores Harmful substances such as carbon monoxide and sulphur dioxide are evolved while drying moulds and cores. The above depend on the type of fuel and the quantity of the same consumed during drying moulds and cores.

(b) Sand Preparation, Knock-out Sand Handling

(i) Amount of Dust Generated in Sand Mixers The moulding and core sands in foundries are prepared in sand mixers of various designs. The ingredients mixed are also different at different times. With edge runner mill of capacity up to 1×5 tonnes/batch, and with approximately 3000 m^3/h of air drawn off, the dust in the air will be approx. 7.5 g/m^3 with density of dust as 2.14 g/cm^3. The particle size distribution in the dust is as follows:

Dia. of particle μm	< 5	5–10	10–20	20–40	40–60	60
Content of fraction, %	0	12	1.9	10	1.4	74.7

From sand mixers of centrifugal type with capacity up to 120 t/h and with approx. 15000 m^3/h of air drawn off, the dust in the air would be approx. 4 g/m^3. The particle size distribution of dust will be as follows:

Dia of particle μm	< 5	5–10	10–20	20–40	40–60	> 60
Content of fraction, %	4.7	6	20	23.3	16	30

(ii) Generation of Dust in Knockout Section In steel foundries, knocking out of the castings out of mould boxes is most detrimental to health because of the evolution of harmful vapours, gases and dust containing approximate 68% of particles of size 0–2 μm in diameter and 32% between 2–10 μm in diameter.

The particle-size distribution when removing sand crest from steel castings would be as follows:

Dia. of particles μm	5	5–10	10–20	20–40	40–60	> 60
Content of fraction %	6	8	22	25	26	13

However, in foundries with hydro-cleaning chambers, the amount of dust generated will be 2.5–2.7 times less than foundries without the same.

(iii) Sand-Handling System The various transfer points of sand movement generates considerable dust. The volumes of exhaust air necessary for dust elimination is calculated based on the fact that negative pressure must be created in the casing which normally varies from 0.1–0.2 kg/m^2 for most of the equipment.

(iv) Amount of Gases Evolved when Pouring Moulds The amount of CO evolved when pouring molten cast iron depends on the mass of the castings and the time of cooling in the moulds.

The type of exhaust hood employed has a great effect on the efficiency of the dust-removing equipment. The most effective hood is one that covers the grating from all sides and is provided with aperture for admitting the moulding boxes and for removing the castings. It is sufficient to draw off 5000–8000 cu m of air an hour per m^2 of grate area.

In plants where the castings are knocked out of the moulds and are loaded on to underground conveyers, the amount of dust and gases evolved is much less. In such cases it is advisable to draw off the dust-laden air from below. Where stripping of the boxes is done with the help of EOT cranes, lateral hoods may be employed.

In case when overhead exhaust hoods are installed, the air contains fro 2–7g/m^3 of particles of 1.5–32 μm in diameter. When lateral hoods are installed, the air contains from 2–7 g/m^3 of particles of dust particles of 1.5–3 m in diameter. When lateral hoods are installed, the amount of dust in the air is decreased to 1.2– 2.5 g/m^3.

(c) Fettling Shop Following the knockout, the castings usually require further cleaning. Depending upon the type and size of castings involved, this may be done by grinding, abrasive blasting, tumbling barrels, chipping, sawing, cutting, etc.

Grinding wheels whether they are mounted on a stand, supported from a swing frame of portable-need hooding and swing-frame grinders should be arranged so that the dust is thrown into an exhaust booth or where possible a local hood may be mounted on a frame and exhausted using a flexible duct.

For shot-blast chambers, a fabric-arrestor type of dust collector is usually used. Mechanical pre-cleaners are recommended to reduce the dust load on the dust collectors.

Welding operations for repair of castings should be done under controlled conditions. An exhaust booth to gather and remove the smoke and fumes generated should be provided and used whenever such operations are performed. Normally no air cleaning equipment is needed, in as much as the air volumes used dilute the exhaust to an acceptable limit.

A large amount of dust is generated when runner and riser of cast steel is cut. Its concentration in the air reaches 6–8 g/m^3 and in the immediate vicinity of work points up to 20 g/m^3. The particle size distribution of the dust formed when cutting cast steel is as follows:

Dia. of particles, μm	< 2	2–5	5–10	> 10
Content of fraction %	89–92	4.9–8.2	1.7–1.8	1.3–1.1

(vi) Heat-Treatment Furnaces The main pollutants in gases from heat-treatment furnaces are carbon monoxide and sulphur dioxide. The gases are normally discharged into the atmosphere through high stack which will facilitate dispersion of sulphur dioxide into the upper atmosphere and will reduce its ground-level concentration within permissible limits.

(vii) Pattern Shop In a pattern shop, where wood-working machineries are installed, a local exhaust system to capture the saw dust, chips, etc., should be provided. Normally, a mechanical type of dust collector such as a cyclone is sufficient to remove the entrained particulate because the dust particles are much larger than encountered in other foundry exhaust. The saws, planers, sanders, drills, etc., may have built-up hoods which require only a dust collection.

9.4.3 Dust and Fume Control

It is of utmost importance that the air polluted by foundry work be cleansed to maintain hygienic working conditions. The atmosphere in the pattern shop is charged with fine particles of sawdust. Dust sand particles are exuded when sand is mixed and prepared during moulding, shake-out fettling operations. Fumes are produced during melting, metal-transfer, and pouring operations. It is essential to devise a system for collecting all the dust and fumes so produced and disposing them so that they do not pollute the atmosphere in the foundry and pose a threat to the health of the workers. When a foundry layout is planned, provision should be made for dust and fume control. If this vital aspect is attended to as an afterthought, it becomes difficult to incorporate the necessary equipment.

Materials requiring to be separated may be classified into two broad categories: particulate matter, where the particles are either solid, such as dust, fume, smoke, and fly ash, or liquid, such as mist and fog; and gaseous matter, where the contaminant may be either gas over the entire range of atmospheric and process temperatures and pressures, or liquid at lower temperature, and gas at the temperature and pressure of its release into the atmosphere.

The method of separation depends on the category to which the pollutant belongs. Some separation processes are applicable to several types of pollutants whereas others to only one of them. The methods commonly used in foundries are now outlined.

1. Filter The filter serves for removing particulate matter from gas or air streams by retaining it in or on the porous structure through which the gas flows (Fig. 9.5). The porous structure is usually a woven or felted fabric. The filter must be continuously or periodically cleaned, or replaced.

The filtering action may be obtained in various ways, such as direct interception, impaction, diffusion, and electrostatic precipitation. In direct interception, the particle is carried by a streamline of gas, which heads it directly towards a part of the solid surface comprising the filter. In impaction, the particle is in a streamline of gas, which sweeps by the solid material of the filter and allows the particle to touch the filter material. In diffusion, a blow from a molecule of the gas projects the particle to the filter surface. In electrostatic precipitation, electrical charges on the particle and filter attract the particle towards the filter. One or more high-intensity electrical fields are maintained to cause the particles to acquire an electrical charge and be forced to move towards the collecting surface.

Filters are commonly employed in pattern shops on various woodworking machines, such as band saw, circular saw, and sanding machines. They are also used on cupola collection systems in conjunction with other equipment, such as after-burners, gas cooler, recuperators and exhaust blower. Sand-reclamation plants also use bag filters for separating ‘fines’ from sand grains.

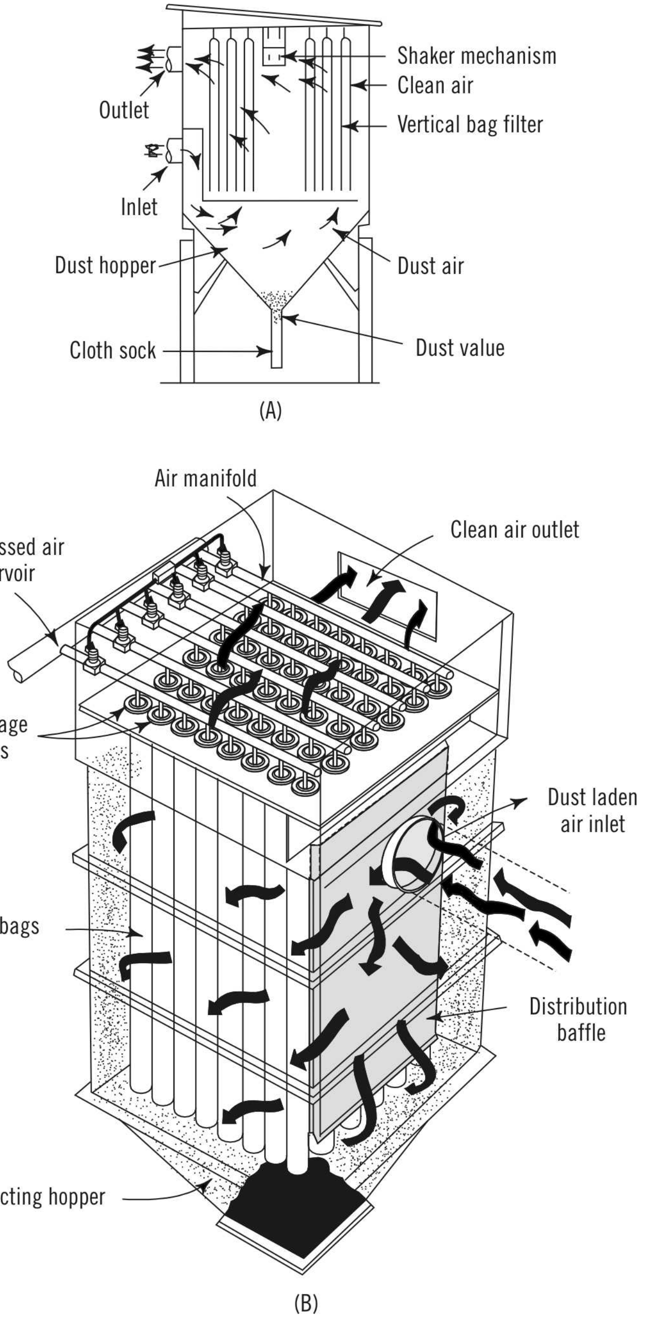


Fig. 9.5 *(A) Bag filter (B) Schematic arrangement of an ultra-jet type filter*

2. Cyclone The cyclone (Fig. 9.6) works on the principle of centrifugal separation in which a vortex motion of the particulate matter is created within the collector. This motion provides the centrifugal force which propels the particles to locations from where they may be removed. Cyclones may be operated either dry or wet. Also, they may either deposit the particulate matter in a hopper or concentrate it into a stream of gas which flows to another separator for ultimate collection. The cyclone is used in sand-preparation plants for separating sand particles from air, in cleaning the cupola exhaust, in moulding shops, and on shake-out stations.

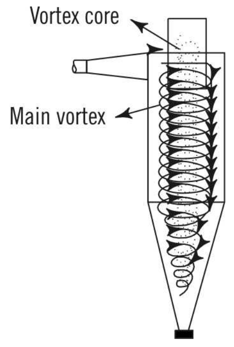


Fig. 9.6 *Cyclone*

3. Mechanical Collectors These devices include settling chambers, baffled chambers, and fan arrangement, which collect particulate matter by gravity or centrifugal force but do not depend upon a vortex as in the case of cyclones. As their efficiency of collection is generally rated low, they are used as precleaning devices before other types of collectors. They also function in combination with filters or scrubbers. Cupola exhaust systems often make use of mechanical collectors (Fig. 9.7).

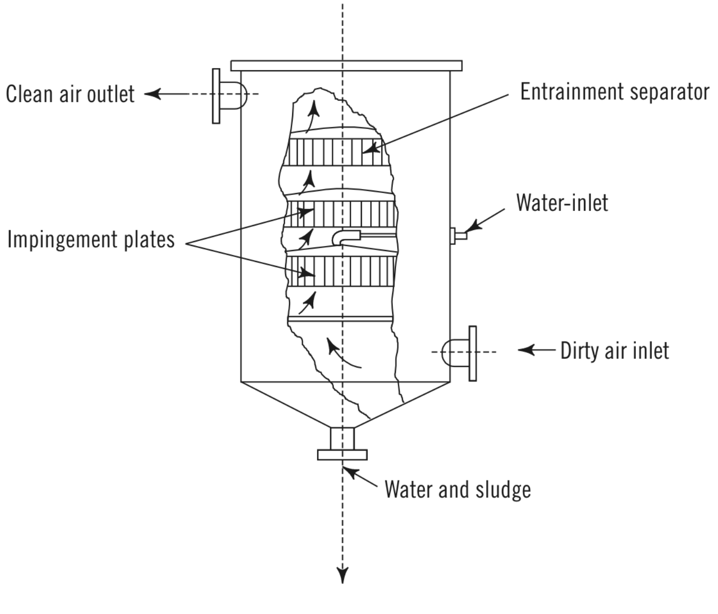


Fig. 9.7 *Wet centrifugal dust collector*

4. Scrubbers The scrubber is employed primarily for removing gases and vapour-phase contaminants from the carrier gas, though it can also remove particulate matter. A liquid, usually water, is introduced into the collector and it either dissolves or chemically reacts with the contaminant collected. Methods used to effect a contact between scrubbing liquid and carrier gas includes (i) spraying the liquid into chambers containing baffles, grille, or packing; (ii) flowing the liquid over weirs; and (iii) bubbling the gas through tanks or troughs of liquid. Scrubbers are ideal for cleaning the exhausts of cupola and arc furnaces.

5. After Burners The after-burner assists in oxidising the solid combustible material present in the particulate matter and converts it into gaseous form. It also helps to convert carbon monoxide into carbon dioxide as in the case of cupola gases. After-burning may be accomplished by using furnace oil as a fuel and introducing it along with air into a combustion chamber through which the carrier gas passes.

6. Combination Devicess Some devices combine features of the aforementioned equipment so that dust and fumes are controlled most economically and with a minimum pressure drop. For instance, there are cyclones in which liquid is sprayed, and scrubbers in which cyclonic action is used. Packed-bed filters, operated wet, and packed-bed scrubbers are similar to each other, the only difference being that the equipment designed to separate particulate matter is called a filter and the same when designed to separate gaseous contaminants is called a scrubber. Often, equipment of different types are used in series. Figure 6.9 shows a common arrangement of exhaust cleaning used on large-sized cupolas.

ENERGY SAVING IN FOUNDRIES 9.5

Metal casting involves melting of metal (scrap, pig iron, ferro alloys or any other group of metals and alloys) to a temperature high enough to pour into a mould. This process of melting, holding and processing the liquid metal consumes large energy. It accounts for about 50% (in highly mechanised large-scale foundries) to 75% (in medium and small-scale foundries) of the total energy consumption.

Whenever heat-treatment is required, as is the case in almost all steel and alloy steel castings, heat-treatable, non-ferrous alloy castings and some grades of ductile iron or alloyed cast-iron castings, it consumes large amount of energy, next to that needed in melting and pouring.

Sand preparation, moulding, core-making (and baking, if needed), core and mould painting and drying, consume a large quantum of energy, some of which is used in the form of compressed air.

Other sand plant activities, viz., knock-out, magnetic separation, sand transfer back to hoppers, dust extraction, are all energy consuming.

Removal of runners and risers (mainly in steel castings and other highly ductile non-ferrous castings), fettling, grinding and other operations also consume energy.

Thus the entire process of metal casting demands energy. Hence, foundry industry is energy intensive.

First, let us try to understand theoretically what happens during melting. Let us represent the melting and subsequent cooling process by plotting a Temperature. Time Curve (see Fig. 9.8). Line *OY* indicates temperature on the vertical scale and line *OX* indicates time of the horizontal scale. Two horizontal dotted lines TS and TL indicate solidus and liquidus temperature, respectively, of the alloy being melted. In case of pure metal or eutectic alloy, these two temperatures TS and TL would coincide with each other.

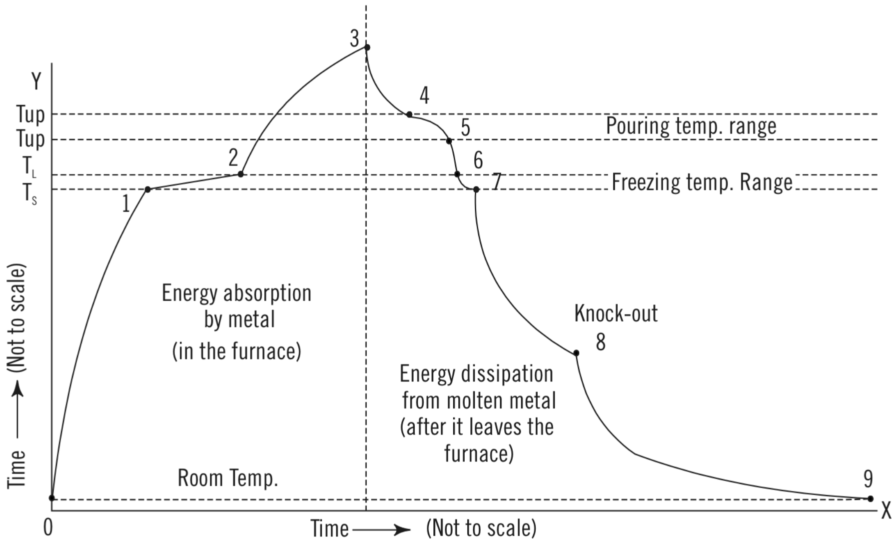


Fig. 9.8 *Schematic representation of the phenomenon during (i) melting and (ii) Freezing of metal and its cooling to room temperature*

A vertical dotted line at the centre indicates the time at which the molten metal leaves the furnace on its way towards the mould. The entire area towards the left of this line indicates energy consumption by the metal to reach the peak temperature (i.e., tapping temperature). The area on the right of this line highlights the dissipation of this energy while the metal gets transferred to the ladle, gets processed, poured into the mould, cools inside the mould, gets knocked out from the mould and then cools back to the room temperature.

Hence, the total energy absorbed by the metal (shown at the left of the vertical line) gets dissipated to the surroundings when the metal cools back to the room temperature (shown at the right of the line).

The theoretical requirement of energy for melting the metal and to superheat to the tapping temperature consists of three main segments:

(i) Sensible heat to heat the metal from room temperature to its solidus temperature

(ii) Latent heat to entirely melt the metal, by which time the liquidus temperature is also reached

(iii) Sensible heat to superheat the molten metal up to its tapping temperature

This is the theoretical requirement of heat. In the furnace, much more heat is to be generated from the heat source (either the fuel or electricity) depending on the operating efficiency of the heating/melting furnace. The excess heat also gets dissipated to the surroundings via furnace body and other parts.

Metallic components enter the foundry at room temperature, and the finished castings also leave the foundry at room temperature. Hence all the energy consumed in the foundry gets dissipated in the form of heat in the surroundings only. (Figure 9.8 and Table 9.6).

9.5.1 Energy Saving in Coreless Induction Furnace

There are three main areas through which energy saving can be achieved in induction melting.

(i) Furnace design/construction
(ii) Furnace power supply
(iii) Furnace operating practices.

Furnace Design and Construction A large quantum of electrical energy continuously flows through the furnace coil as well as the other electrical/electronic components of the furnace power pack and other parts of the power circuit. Continuous energy loss in the form of heat (generated through I^2R losses) takes place while the energy is flowing through the coil and other components. This loss is unavoidable but can be minimized.

The latest developments in furnace design and construction, viz., higher power densities, changeover from mains frequency power supply to appropriate medium frequency power supply by the use of modern highly efficient electronic circuits, increased coil voltages and related insulation techniques have all made coreless induction furnaces highly efficient melting units. These modern furnaces are much more efficient in comparison to the older generation of furnaces. Hence, many foundries are replacing the older mains frequency furnaces by the more efficient medium frequency furnaces of the latest designs.

Furnace Power Supply Further reduction in energy consumption is possible, considering the impact of I^2R losses passing through the main cable(s), bus bars, main and auxiliary contactors and other components, if power cables sizes and bus bar sections are generously decided and main contactors of higher ratings are selected. Selection of a power transformer of appropriate rating and higher efficiency also provides permanent saving in energy.

The scope of reduction in energy consumption through this route is limited, and may need some increase in furnace installation cost, but the resulting savings are continuous throughout the life of the furnace, and without incurring any additional running cost. A simple calculation similar to that given in Table 9.4 would assist in deciding the justification for marginal increase in the investment.

Table 9.4 *Saving in energy bills in coreless induction furnace*

Furnace rating (kW)	Maximum power consumption* during one year (kWh)	Annual power consumption @ 75% of furnace use (kWh)	Yearly energy bill @Rs 3/kWh (Rs)	Yearly saving for 1% drop in energy bill (Rs)
500	36 lakh	27 lakh	81 lakh	81,000
1000	72 lakh	54 lakh	162 lakh	1,62,000
2000	144 lakh	108 lakh	324 lakh	3,24,000

* (Considering full power for 24 hours a day, 25 days a month).

Furnace Operating Practices This aspect is being regularly highlighted by various experts in a number of seminars and papers. But as this forms a part of 'Operating Practices', at times it is neglected either due to ignorance, lack of interest or due to plant infrastructure problems.

The aim should be *to utilize the furnace as near to the maximum rated capacity as possible.* If this is done, the overall impact would lead to large energy saving.

For instance, consider are furnace of 1000 kW rating in Table 9.4. Its theoretical monthly power consumption is 6 lakh units. If a foundry is operating this furnace continuously throughout the year (without any power cut or major break down), the melting energy used in any three months would be as shown in Table 9.5.

Table 9.5 *Energy consumption month-wise*

Month	Total energy used (kWh)	Power utilization (%)
1.	4.2 lakh	70%
2.	5.1 lakh	85%
3.	4.8 lakh	80%

In all probability, one would find energy consumption per tonne melting lowest for the month no. 2 and highest for the month no. 1. And the variation would be quite large, most probably around 5%. If this is confirmed, the management would stress for maximum furnace utilization, and monitor its execution.

Table 9.6 *(i) Energy consumption during metal melting, and (ii) Energy dissipation during cooling of the molten metal*

(Please refer Figure 9.7 to identify the curve segments.)

Curve segment	Physical phenomenon	Thermal phenomenon	Possible ways of energy saving*
0–1	Heating of metal in the solid state from room temperature to melting point (or solidus temperature)	Absorption of the sensible heat in the solid state	— Charge pre-heating using recoverable heat, if feasible. — Faster heating — Use of high efficiency furnace
1–2	Melting (i.e. Fusion) of the metal at the Melting point (or within Solidus/Liquidus temperature range)	Absorption of the latent heat of fusion	— Use of efficient furnace — Faster melting
2–3	Super-heating of molten metal up to the tapping temperature	Absorption of sensible heat in liquid (i.e. molten) state	— Minimize superheating temperature level. — Minimize holding duration — Use furnace which is more efficient to superheat the molten metal (*e.g. Cupola is the least efficient, and induction furnace is the best of all*).
3–4	Temperature drop during tapping, metal treatment, if any; and heat absorbed by the ladle	Loss of some sensible heat of molten metal to atmosphere through radiation as well as via ladle body. Some heat absorbed by the ladle additives/inoculants.	— Use insulation — Minimize heat loss through radiation and conduction — Pre-heat the ladle

(Contd.)

Table 9.6 (*Contd.*)

4–5	Temperature drop in the ladle, and also inside the mould *during metal pouring.*	Loss of some more sensible heat of molten metal to atmosphere, ladle walls and mould walls	—	Minimize this loss by reducing molten metal handing, *distance and duration*.
5–6	Cooling of molten metal *inside* the mould.	Left over sensible heat of the molten metal being absorbed by the mould.	—	Little knowledge about recovery of this energy.*
6–7	Solidification of the metal inside the mould.	Latent heat of solidification being absorbed by the mould.	—	Little knowledge about recovery of this energy.*
7–8	Cooling of solidified casting inside the mould till knock-out.	Some sensible heat of solidified metal being absorbed by the mould.	—	Little knowledge about recovery of this energy.*
8–9	Cooling of casting to room temperature after mould knock-out.	The remaining sensible heat of the hot metal being dissipated to the atmosphere.	—	Little knowledge about recovery of this energy.*

The following operating points would then emerge themselves!

1. Keep the furnace *full* as far as practicable.
   (i) Do not keep the heel too low, and for too long a duration.
   (ii) Charge without delay.
   (iii) Be selective in furnace charge. Avoid rusty, oily scrap and loosely packed charge.
2. Minimize periods of low power/no power.
   (i) Minimize slagging time.
   (ii) Synchronize slagging/testing time to avoid any furnace tapping delay.
   (iii) Minimize tapping time and, if necessary, tapping frequency.
3. Avoid heat wastage.
   (i) Do not superheat beyond the required level.
   (ii) Keep the furnace cover closed for as long as possible.

PLANT LAYOUT FOR FOUNDRIES 9.6

Plant layout involves arranging and coordinating the physical plant facilities in a pattern that affects the maximum efficiency in the combination of men, materials, and machines for operation of any unit of a business.

Plant layout has also been defined as a floor plan for determining and arranging the desired machinery and equipment of a plant, whether established or contemplated, in one best place, to permit the quickest flow of material at the lowest cost and with the least amount of handling in processing the product from the time of the receipt of raw materials to the shipment of finished products.

As the foundry industry has moved from a seller's to a buyer's market, it is characterised by stiff competition and reduced profits. Since profits are lower, it is logical that a plant with lower production costs and overheads is better able to maintain its relative production activity.

One of the most effective ways to cut down production costs is to eliminate or reduce to a minimum all non-productive plant activities. A good layout is one that provides for full utilisation of available equipment for production, material handling devices and manpower, and that effects maximum saving in process inventory.

9.6.1 Advantage of a Good Layout

Some of the advantages to be gained from good plant layout in a foundry are the following:

(1) Improvement in the Manufacturing Process These improvements may be both in the method of processing and the control of the process. They may result from

(a) elimination or reduction of delays through improved arrangement or better work balance between machines or operators;
(b) smoother materials flow in the process; plant layout allows new analysis of the materials handling problem and incorporation of new methods and equipment; a major factor in this area may be the possibility of incorporating the techniques of automation or automatic handling, thereby reducing interruptions in the flow;
(c) improved control by incorporating methods for identifying, counting, and inspecting goods in process.

(2) Improved Quality Control An analysis of the production necessary for proper plant layout also requires the determination of quality control factors and inspection locations. A good layout incorporates these quality considerations in a manner that ensures maximum control and minimum cost.

(3) Improved Materials Handling Materials handling is improved by proper location of equipment, reduced handling distances, and closer coordination of the entire handling activity. The application of the principle of standardisation to material handling reduces the variety of handling units and equipment, permitting greater flexibility without sacrificing efficiency. Standardisation may also reduce the investment required for materials handling.

(4) Minimum Equipment Investment Planned machine balance and location, with minimum handling load distances, and planned machine loading reduces the inclusion of idle or partially loaded units in production areas, thereby reducing investment requirements. The reduction of equipment investment applies to service and maintenance equipment, materials handling equipment, and office equipment, as well as production machines.

(5) Effective Use of Available Area In many plants, expansion and growth has taken place in such a manner that plant arrangement has been a matter of immediate convenience. A well-planned plant layout offers an opportunity to place equipment and services in such a manner that the most effective coordination is possible. Locating equipment and services such that they can perform multiple functions, development of up-to-date work areas, and operator job assignment for full utilisation of the labour force, help to improve utilisation of plant areas.

(6) Improved Utilisation of Labour Proper plant layout allows the design of individual operations, the process, the flow, and material handling in such a manner that each worker can effectively apply his activities to the best overall plant effort. Balancing of labour to production needs and machine requirements eliminates many situations in which the operator's time is not utilised to the maximum. Layout of equipment for ease of maintenance reduces maintenance personnel requirement. Improved handling, which frequently means further incorporation of mechanical means, minimises both direct and indirect labour requirements.

(7) Improved Employee Morale A layout that provides for employee convenience and comfort inevitably boosts employee morale. A design that incorporates such items as correct lighting, proper cooling and ventilation, noise and vibration control, sufficient and convenient rest rooms and lunch facilities leads to efficient job performance and to reduced idle time, otherwise spent in travelling to facilities or in grievance actions that result from dissatisfaction.

(8) Improved Efficiency in Plant Services Efficiency is obtained by considering the problems of maintenance and service equipment and buildings during the arrangement and layout planning. New utility distribution systems giving maximum flexibility and capacity become an integral part of the new layout, thereby facilitating future re-arrangement or expansion.

9.6.2 Steps in Planning a Foundry Layout

In order to realise the maximum potential of a layout for a new foundry, a systematic procedure must be followed. The final layout can be no better than the data upon which it is based. Certain steps if followed assure the collection and analysis of the necessary supporting data.

(1) Analyse the Product to be Manufactured This implies having available or deciding

(a) the annual tonnage;
(b) the type of castings to be produced: their range of sizes, weights, composition, and product mix; and
(c) the maximum piece weight.

(2) Determine the Process Required to Manufacture the Product Operation sheets must be prepared or developed for each manufactured product. For layout purposes, only the sequence of operations is required initially.

Castings may be classified as light, medium, and heavy or according to the quantity required. Logical location of workplaces like moulding, core-making, melting, inspection, etc., should be suitably determined. Green sand, skin dried, dry sand, machine moulding, shell moulding, CO_2 process, etc., are among the various processes to be broadly considered first to suit the casting requirements before the details of layout are decided.

(3) Prepare Layout Planning Charts The layout planning chart is of prime importance as it serves as the medium for first tabulating and then combining the various factors to be provided for in the final layout. It incorporates

(a) the flow process showing all operations, movements, storages, and inspections in sequence;
(b) standard times for each operation obtained from time studies or predetermined time standards;

(c) machine selection;
(d) machine balance;
(e) manpower requirements; and
(f) materials handling load, method, and equipment requirements.

To complete the layout planning chart, a full review and analysis is required at each step. Once this is done, the layout of the manufacturing area involves primarily a conversion of the layout planning chart data to the physical plant statistics. To achieve this, three additional jobs require attention:

(4) Determine Work Stations The requirements of machine, operator, materials, and service areas must be considered. This is accomplished by using man-machine and/or operation charts and scaled workstation sketches/models.

(5) Analyse Storage Area Requirements Before beginning the actual layout both the size and the location of the storage area should be studied with relation to production activities. At least three types of storage should be included in the survey:
(i) storage of raw-materials;
(ii) in-process storage; and
(iii) finished goods storage.

(6) Establish Minimum Aisle Widths Clearances around the various pieces of machinery and between departments should be determined before starting the layout. Aisle widths are dependent primarily upon materials handling methods and equipment, workstation clearance requirements, and pedestrian traffic and should be carefully decided lo avoid production problems in future.

(7) Establish Office Requirements These will depend upon the scope of operational activities. The exact requirements of space should be worked out and provided in the layout.

(8) Consider Personnel Facilities and Services Allow for such items as first aid, lunch and refreshment centres, lockers, rest rooms, and parking.

(9) Survey Plant Services These include utilities such as compressor room, pump house, waste disposal, equipment maintenance, cooling, dust extraction and ventilation.

(10) Provide for Future Expansion This may include sufficient provisions for the addition of new product lines or for increased demand for the existing products.

(11) Prepare Layout Plan The location of all plant and equipment, workstations, facilities, storage spaces, aisles etc., should be clearly indicated on this plan.

Figure 9.9 shows a typical layout for a small grey iron foundry which fulfils the essential requirements of a good plant layout for a small scale unit. Figure 9.10

shows a layout for a typical steel foundry for producing large-sized castings. Figure 9.11 shows a layout of a fully automatic moulding and casting line and Fig. 9.12 shows a perspective view for a whole plant depicting different areas of production and control room.

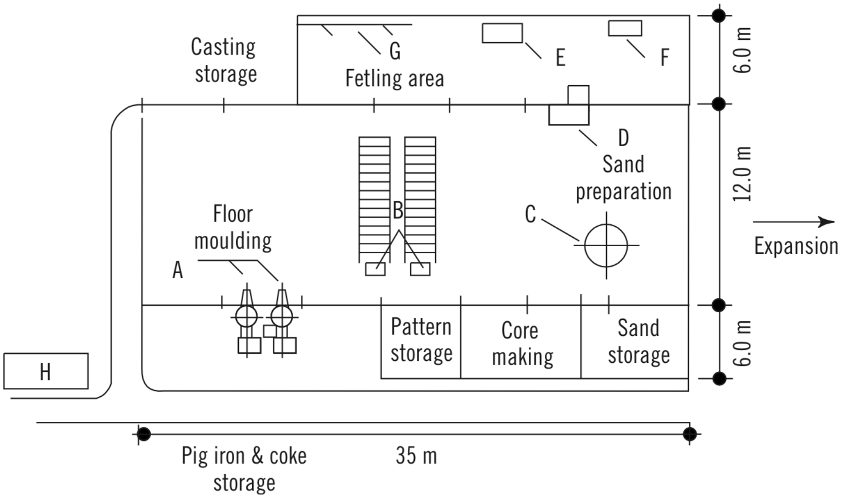


Fig. 9.9 *Layout of a small grey iron foundry*

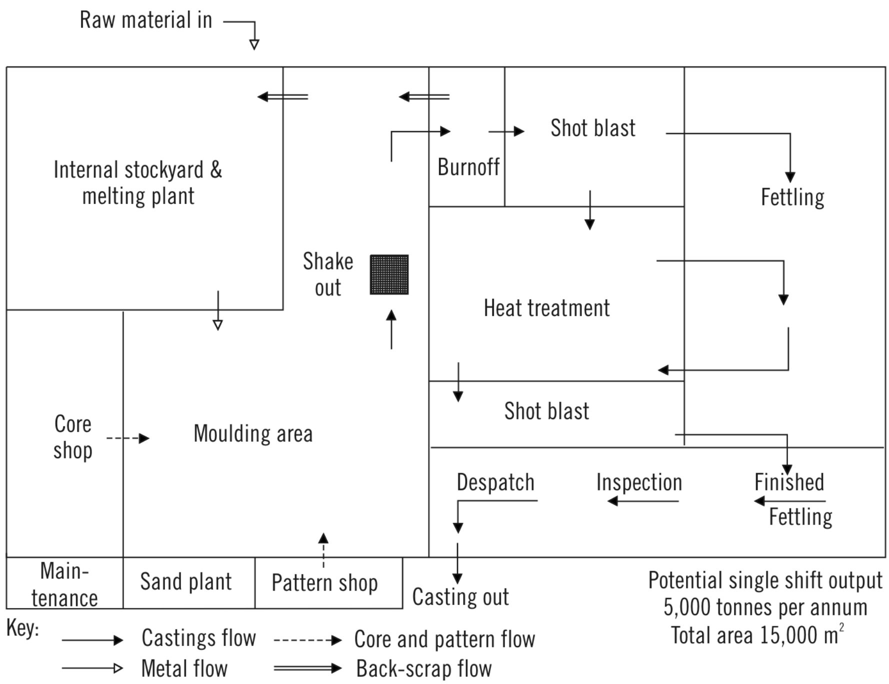


Fig. 9.10 *Typical Layout of a grey iron foundry*

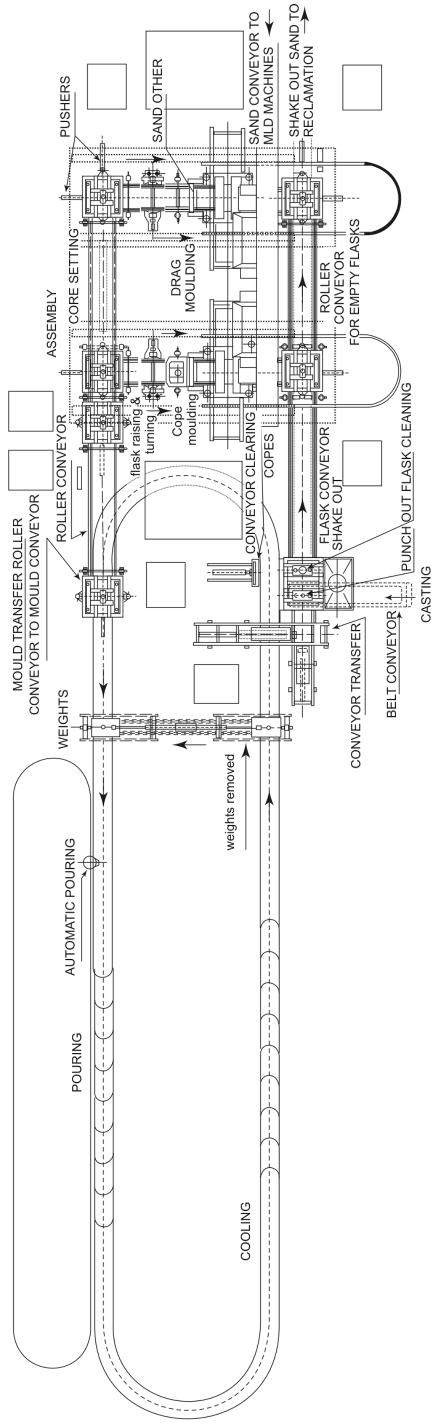


Fig. 9.11 *Layout of a modern automatic moulding line*

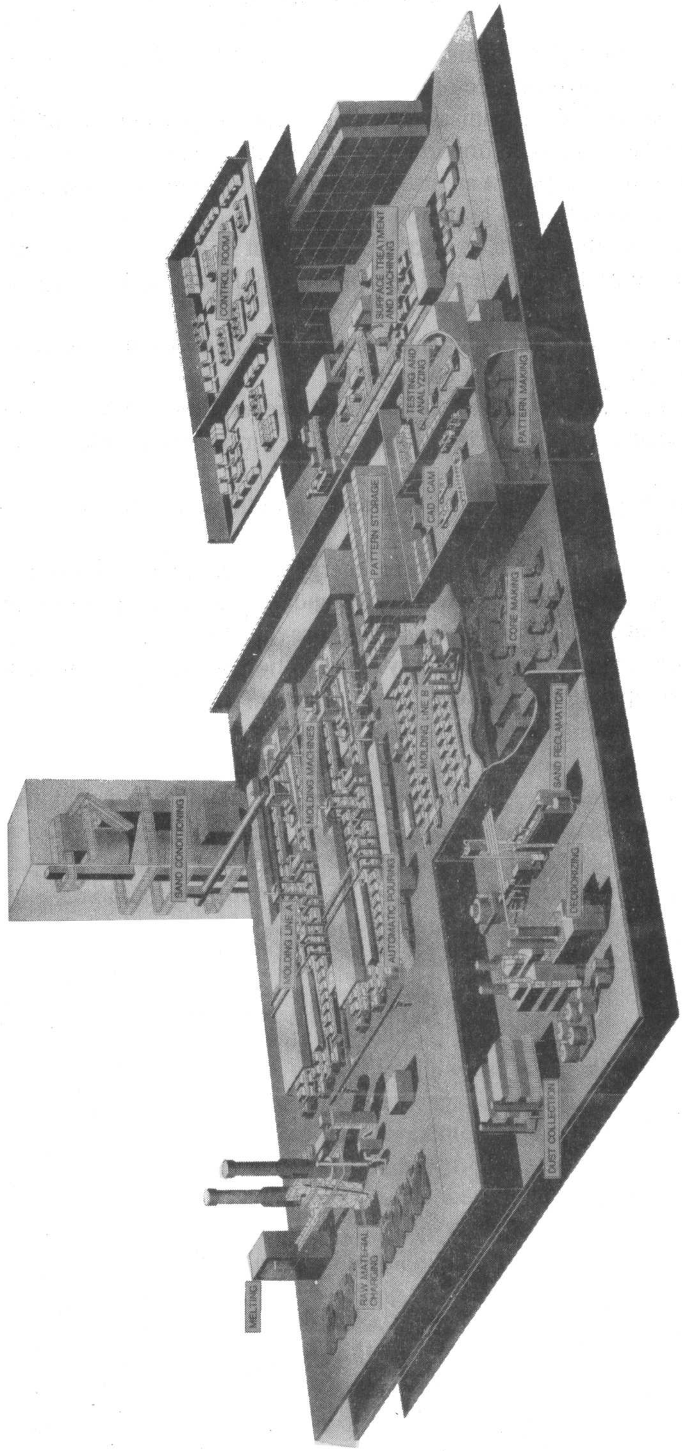


Fig. 9.12 *Completely automated foundry plant*

Review Questions

1. What is meant by modernisation of foundries? Explain how can it help in improving the performance of the unit?
2. What is the role of mechanisation in improving the productivity of foundries?
3. "Material handling is an important part of mechanisation and modernisation". Discuss. What equipment are used for material handling at various stages in a mass-production type of grey-iron foundry?
4. What are the advantages of a good plant layout in a large-scale foundry?
5. Pollution control is an essential part of foundry-layout design. Explain how is it achieved.
6. What different types of pollutants are produced in a foundry operating cupola furnaces. How can these be controlled?
7. What emissions are caused during sand preparation and knock-out operations? What are the prescribed limits for the emissions in different areas of a foundry?
8. What are the main reasons of pollution in fettling shop? How can these be controlled?
9. What are the various areas where energy conservation programmes can be effectively introduced in a foundry? How does proper operating practices and regular plant maintenance help in energy savings?
10. What steps can be taken for energy conservation during induction melting and re-heating operations? Discuss.
11. Discuss the need for modernization of foundries with special reference to Indian foundries. It is said that 'modernization is the key to productivity and mass production'. Justify the statement.
12. Continuous mixers have replaced conventional sand mullers in many large-scale production foundries. Discuss. What improvements have been introduced in recent years in the design of continuous mixer systems?
13. What does an integrated system of sand conditioning constitute? Explain its working.
14. Explain the working of an automatic pouring system in the melting shop of a foundry. What are the pre-conditions for adoption of this system?
15. Explain the use of different kinds of conveyer systems for handling various materials in a mass production foundry.
16. Robots have been introduced in mechanized foundries during the last couple of years. What gains are being achieved by the use of the robots? Discuss their economic and technical feasibility in Indian foundries.

Chapter 10

Application of CAD/CAM in Foundries

INTRODUCTION 10.1

In recent years, key developments have taken place in computer-aided-design, casting design, simulation, rapid tooling, intelligent advisory systems and Internet-based engineering, and most foundries are presently caught between change and survival. This is especially true in case of the foundries operating in the developing countries. However, they have to keep pace with the changing technological trends, if they have to survive in the global market. If properly adopted, these can lead to both immediate tangible benefits in terms of shorter lead time, higher productivity and lower rejections, and long-term intangible benefits, in terms of better company image, higher confidence, stronger partnerships and improved marketing. Some of the factors hindering the foundries in their full adaptation are price competition, manpower availability and high cost of trained technical manpower, lack of technical support and perception.

PRODUCT DESIGN AND ANALYSIS 10.2

Engineers in all the engineering companies now use a range of software tools for design and analysis. The first step is computer-aided-design or CAD, in which a solid geometric model of the component is created on a computer, often directly in 3D. From this model, 2D drawings are produced, plotted and sent to the foundry. A number of solid modeling systems are available today and these are all easy enough to learn and use (see Table 10.1).

Important advancements in CAD include parametric and feature-based modeling. Parametric modeling enables linking the part shape to its dimensions, so that the shape is automatically updated by specifying the new dimensions.

Feature-based modeling, on the other hand, allows a user to create a part in terms of holes, bosses, ribs, etc., which is a more intuitive approach as compared to earlier solid modeling systems. Most systems, now being available on the Windows platform, make extensive use of point-click-drag and cut-copy-paste functions to reduce the modeling time.

Table 10.1 *Solid Modeling (3D CAD) systems*

SYSTEM	VENDOR	WEBSITE: WWW
AUTOCAD MD	AUTODESK INC.	autodesk.com
CADCEUS	NIHON UNISYS LTD.	Unisys.co.jp
CADKEY	BAYSTATE TECHNOLOGIES	cadkey.com
CIMATRON	CIMATRON LTD.	Cimatron.com
I-DEAS	SDRC	sdrc.com
IronCAD	VISIONARY DESIGN SYSTEM	Sironcad.com
Pro/ENGINEER	PARAMETRIC TECHNOLOGY CORP	ptc.com
SOLIDEDGE	EDS UNIGRAPHICS	solid-edge.com
SOLIDWORKS	SOLIDWORKS CORP.	solidworks.com

Transferring geometric information from the human mind to a computer is a highly involved step, and it may take a long time for an intricate shape, such as a cylinder block to be created. However, once a part model is created, it can be used for many different applications. Computer-Aided Engineering or CAE and analysis involving simulation of stress, strain, heat transfer, vibration, fatigue and fracture, based on Finite Element Method (FEM) has been widely used to optimize the functionality and weight of the component. After the part design is finalized, it is sent to a Computer-Aided-Manufacturing (CAM) program to plan the tooling on a CNC machine and simulate the machining operation. The part model is also required for accurate and automatic calculation of geometric properties, such as volume, weight, centre of gravity, etc., and also as input for casting design and simulation programs. A recent trend has been to make designers responsible not only for functionality and weight but also for producibility or manufacturability of the component. 'Design for Manufacture' or DFM, a new theme, involves predicting and preventing potential manufacturing problems at the design stage itself. The common examples, which the designers can take care of, are the use of thick sections, which may lead to isolated hot spots, requiring chills or additional feeders, or sharp corners which can cause turbulence during filling and moulding difficulties. It is well accepted that the benefit accrued by having the modification at the very design stage or early in the product life-cycle is much greater than that carried out at the tooling or production stage.

CASTING DESIGN AND SIMULATION 10.3

Casting design involves converting the part design to the tooling design, showing orientation in the mould, parting line, application of draft and allowances, gating and feeding systems, core boxes, pattern plates and other elements. Simulation includes mould filling and casting solidification, useful for optimising the design of gating and risering systems respectively. Casting model is the main input for simulation. Since casting design essentially involves a series of geometric transformations of the part model, the 3D-CAD systems are used for the purpose. Some of these provide special features, such as automatic application of draft, after the user has selected the faces and specified the draw direction and customising facilities, such as creating a library of parametric shapes of feeders to partially automate the task of design. A few programs for deciding the dimensions of feeding and gating systems are available, but these are stand-alone types and cannot be connected to the 3D casting-design systems.

Casting simulation has received wide attention of researchers and several systems are now available. High-end simulation systems handle coupled equations for flow, solidification and eventual cooling to room temperature, taking into account a wide range of boundary conditions and material properties. The results include filling sequence in mould cavity, progress of solidification, location of shrinkage porosity, grain structure, residual stresses and distortion. These systems, though expensive, give accurate results if the input data, such as geometry mesh, material properties and boundary conditions, is correct. On the other hand, low-end simulation systems are limited to solidification phenomenon for common metals in sand moulds. They are affordable and easy to use, are mainly useful for verifying the feeder design, important for steel, aluminium and other alloys with positive volumetric shrinkage.

The purpose of simulation is to model the underlying physics so that important process variables can be identified and controlled, resulting in significant benefits. If the process of filling and solidifying a mould cavity is accurately modelled, shrinkage cavities and other casting defects can be predicted; the effects on metal fluid flow and solidification on changing gating or risering method or any other process variables can be simulated and molten metal trial iterations can be significantly reduced and used primarily for concept validation. There are three basic types of computer simulation tools: (i) empirical programs based on experimental results and experience; (ii) semi-empirical programs based on experimental results in addition to basic physics, and (iii) physics-based first principles programs that require complete mathematics and accurate material thermo-physical data.

The first two types of programs use tables of experimental results, rules and guidelines, and physical and algebraic equations to model a physical process. In the first-principles programs, complex physical relationships and equations are used along with detailed material physical data. The problem has to be broken down into small calculations via either a finite differencing method or a finite element method. This allows for calculations profile process changes as a function of time.

The aim of modeling the filling and solidification of a casting is to

(i) predict the effect of gating, methoding and casting design on turbulence
(ii) predict oxide entrapment and other flow-related defects in a casting
(iii) provide temperature profiles during and at the end of filling for more accurate solidification analysis
(iv) predict the pattern of solidification, indicating where shrinkage cavities, solidification defects, like hot tears and other associated defects may occur
(v) predict solidification times
(vi) predict micro-structure of the casting sections, showing segregation, etc.,
(vii) predict stress and strain

Mould filling can be predicted using a first-principles program. The approach has been time-tested in the aerospace industry for many years and it has been found to give accurate results. Casting solidification can be predicted using both semi-empirical and first-principles programs. The present and future of foundry industry lies in the supplier's ability to provide the customer a high-quality part at a competitive price within the assured delivery period. This requires the casting supplier to quickly develop a casting process design that will produce sound castings the very first time.

A casting simulation software provides the foundry industry the tool to help determine a process and gating system without the need of expensive timeconsuming and trial and error method on the shop floor. Such a tool assists the process engineer in designing the gating and risering system, which would ensure proper filling without turbulence and mis-fills, predict oxideentrapment and other filling defects. It may further help to indicate the pattern of solidification to detect, where the shrinkage porosity and other defects could originate. Microstructure evolution and stress generation both in the die and the casting during die casting process can be examined.

10.3.1 Casting Simulation in Foundries

Casting process simulation has become an industry standard. No foundry that produces high quality castings can consider simulation as unnecessary. Today's dynamic world requires quick responses to customer needs. Also, accurate and "right" costs need to be defined to each work. Simulation can prove to be a decisive factor in getting the order. It can help in calculating the real costs of the job, and it can be used as a tool in the negotiations in getting the quality right. Similarly, the need to "rig it on the safe side" will become unnecessary.

With the evolution of 3D CAD-programs, the modeling has been made easy for the designer. This means that modeling does not take much more time than just the making of the drawings but allowing much more applications to the model. Simulation is just one application of 3D-modelling. It has been estimated that about 90% of the defects in components are due to mistakes in design and only 10% are due to manufacturing problems. It has been calculated that the costs to change the design increase tenfold in every step of the design and manufacturing process. Hence, all the methods and tools used to ensure the success of the design will significantly affect the total manufacturing costs. Casting process simulation and castability analysis based on casting simulation are these kind of productivity tools.

Casting simulation is being adopted extensively as an important part of the casting process design and the quality system in foundry industry. In many cases where the foundry and the machine shop work together in optimizing the component weight, utilising simulation as a tool. This, however, indicates that there is a need for tools to optimise cast components—in early stages of the design—to be used by machine designers. Casting simulation has helped foundries to point out the factors that have a significant effect on the price of the casting.

Simulation has been a very effective tool in many foundries. Some foundries have found out it is worthwhile to simulate every new job before the start of the production. As an example, the foundries that use simulation program report the following benefits:

- Energy savings of 3-6%
- Improved product quality
- Less remelting and refinishing
- Shortened lead time, increased production
- Payback time of 1–2 years
- 84% wastage reduction
- 5% weight reduction

The aim of the foundry is to produce profitable components and, at the same time, secure that the pieces fulfill the quality standards set for the components. Still, in many cases foundries encounter difficulties to reach both of these goals, because of bad design or inappropriate quality requirements. This is one of the major reasons why the castability of the component should be checked in the early stages of the design, in machine shops, and then further optimised, together with the foundry engineers. It is quite common that the foundry will contact the customer only after the first unsuccessful test castings, and proposes changes to the design, to be able to produce defect-free castings profitably. Quite often it is a question of minor changes, e.g., in machining allowances, which will then be agreed.

However, because of the unsuccessful test castings already done, the costs of producing the castings—and the lead time—have already increased. If there are no simulation results of the component, it might become difficult to make a quote. The price formation does not necessarily correspond to the real costs, and might prove to be unprofitable, either to the foundry or to the customer. A long and confidential customer relationship necessitates mutual openness and "proper" price. If the customer has made the castability analysis, the foundry engineer can use it to estimate how complicated a casting system is needed, which is the basis for the price. Probably the problem areas can also be shown and a proposal of the changes can be made.

Very often foundries need to design gating and risering systems for components that were not originally designed to be cast. However, if the castability were checked and optimised already in the designing stage, a lot of useless work would be avoided, as well as time and money would be saved both in machine shops and foundries. It is a generally accepted fact that the later the changes are made in the design and production process, the more expensive they will be. Every step in the process chain multiplies the cost of changes roughly by a factor of ten.

The problem has been that the designers have not known enough about casting requirements. They are used to designing components and adding machining stocks, drafts, etc., but the castability has still remained somewhat a mystery. Efforts to overcome this problem have been made. One example of these efforts is the program CastCHECK. It is based on numerical simulation.

The idea of CastCHECK is to make a fast castability analysis, without the complexity of the regular casting simulation programs and the need to design the complete casting system with risers, sleeves, gates, chills, cores and mould. Very little information about casting process is needed to use CastCHECK. The designer needs to get the stereolithography file (STL) from any 3D-solid modeling program. Also, if the casting method and the material are known, the results will be more trend-setting. The minimum wall thickness of the component needs to be given to the program, to define how many calculation elements will be needed in the analysis. All information program needs is given in one dialog. The analysis results are shown as 3D 'X-ray pictures' which describe the potential defect areas in the component. The use of casting simulation software is now becoming almost a prerequisite for ensuring successful casting operations, especially for those, where process development for new products and determining solutions for complex casting problems is not an easy and foolproof exercise. Simulation software are now considered as a reliable engineering tool which can assist the foundry man with making effective design decisions, based on computer aided casting visualization of the mould-filling and solidification. Many factors can influence the reliability of the models used during simulation, such as material data, accuracy of boundary and processing conditions, accuracy of casting geometry definition and the method of simulation. The most common defects occurring during mould-filling include oxide and gas entrapment, incomplete filling, cold shuts and surface flow defects. The oxide entrapment occurs largely as a result of turbulence, where surface oxides get pulled up into the molten metal, causing inclusions and porosity defects. High turbulence is caused due to excessive flow velocities, irregularities in the part geometry, poor gating design, inadequate venting of the mould and material flow characteristics. Simulating the heat transfer, couples with flow, is a complex mathematical and computational exercise. The flow and heat transfer affect each other simultaneously. For instance, the flow accelerates the heat transfer and then causes a change in the viscosity of the flow. Such a dynamic interaction has to be studied by rigorous software simulation process.

Incomplete filling occurs when the liquid metal freezes before filling the die cavity completely. It may be caused mainly due to inefficient venting, too low die or casting temperature, too long filling times and extremely thin geometry sections. Sometimes, when two approaching liquid metal streams cool down to a critical temperature, the increase in viscosity and the presence of surface oxide film will prevent the two streams of liquid metal from joining, thus producing 'cold shut' defect. This defect severely weakens the component and it may give rise to cracking during service. Figure 10.1 shows a comparison between actual casting and a simulation. The simulation indicates a drop in temperature in the top manifold pipe section. The simulation shows incomplete filling during casting by blue areas. This cold-shut defect is largely caused due to poor runner design and very thin geometry sections in the casting. Casting simulation can greatly help in such cases so as to avoid the risk of facing problems later during production.

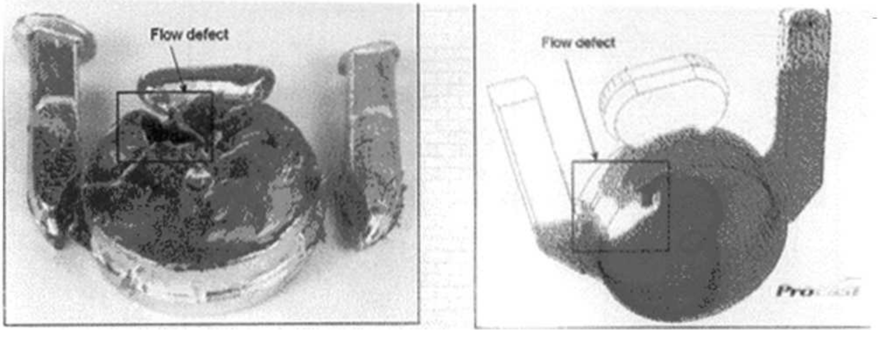


Fig. 10.1 *Comparison between actual casting and its simulation*

Usually, developing the optimum gating design for a component in the design stages is not easy. In any case, components are designed without giving due consideration to their manufacturability causing problems for the foundry engineer. Ideally, casting simulation should be used during the component design itself so that the risks of having problems later during production are avoided.

SOFTWARE PACKAGES FOR FOUNDRY USE 10.4

10.4.1 Magmasoft

Magmasoft has been developed by Magma Foundry Technologies Inc. Illinois. It offers comprehensive foundry competence, engineering services and powerful simulation tools for the optimization of castings and foundry processes. It is used worldwide and is a highly successful simulation tool for cost-effective process layout and prediction of casting quality. Many foundries have adopted this software for overcoming the problems in achieving good directional solidification. By the use of predictive tools, specific to iron, the units were able to visualize the porosity problems. Further, the use of simulation tools have helped the foundries in predicting mechanical properties of the iron for consistency in hardness, elongation and strength, ensuring the production of sound and cost-effective castings. Figure 10.2 (Plate-2) shows BHN plot obtained from thermal micro-modeling analysis.

The use of this package can enable quality improvement and cost reduction through robust and optimum methoding of gating and risering, optimization of metal treatment and metallurgy, minimising of production risks and making best use of all of the cast iron's potential for wide-ranging mechanical properties. In case of cast iron, quality is dependent, to a large degree, on the material, melt practice and melt handling used. This module considers all these special processing conditions in the prediction of feeding, microstructure and mechanical properties. It makes use of microscopic kinetic growth models to calculate the solidification behaviour of cast iron, and determines the type and quantity of precipitated graphite. The total shrinkage and the associated potential for porosity formation is determined from the sum of shrinkage and expansion of the individual phases that are present. Further, the microstructure distribution and the local mechanical properties are quantitatively predicted.

10.4.2 CastCAE

CastCAE, has been developed as a tool for mould filling and solidification simulation coupled with automated risering by CT-Castech Inc., Finland. The casting simulation program is designed for daily use. CastCAE predicts filling patterns, mis-runs, shrinkage and porosity defects reliably. Even iron expansion and pressurized feeding can be simulated accurately. CastCAE is fully based on physical models and is available for all casting processes and metals. CastCAE simulates the casting process, revealing the temperature drop and filling order during pouring, followed by the solidification of the casting in the mould, where shrinkage and porosity formation during cooling is shown clearly. All results come as independent movie files, enabling the user to send the results to those who need to view them, without additional software. The software calculates the feeding solution and is more accurate than the traditional Modulus and Heuvers' circle methods, as it is based on simulation, and thus the alloy and mould effects are taken into account. Another package, **CastDESIGN** uses all three dimensioning rules to determine the proper risers and their locations. All riser types—natural, insulating and exothermic—can be used. Chills are suggested where necessary. Final results also include the yield, pouring and casting weights, and suggestions for additional risers if needed. Rigging design process can be shortened dramatically, as most of the trial-and-error work is eliminated.

Some of the reported benefits to CastCAE users are:

- Yield improvement from 20% to 50%
- Scrap rate from 30% to <1%
- Need for 10 hours of repair welding per casting removed
- 4 risers replaced with 1 riser, 10 chills removed CastCAE

Case Studies A foundry used to cast various cast stainless steel components for the high pressure valves. The foundry experienced some defects in this particular model that resulted in repair welding. The foundry was considering investing in a simulation program, so this component was selected as a test case. The simulations were done at the foundry, with the purpose to acquaint the methods engineer with the system. The problem situation was simulated and defects were predicted exactly as the foundry had experienced. A change was made in the system with an added circular chill inside the hole and insulating sleeves were added to the risers. The result was a sound casting, which was later verified at the foundry.

(i) The Valve Body (Fig. 10.2)

In the old casting system (Fig. 10.4 Plate-2) the thin wall section feeding from the riser above is not cut, thus creating a long mushy zone and the defects cluster at the junction of the wall and the flange. The feeders in the lower flange have not functioned. In the new casting system, however, the feeding has been cut to two separate areas by placing a circular chill around the core. The geometry of the final solution is as seen in Fig. 10.4 (Plate-3), where red is casting, green is riser, tan is insulation and blue is chill. The outcome is a sound casting, where the defects have moved to the neck. The feeders in the lower flange have functioned properly.

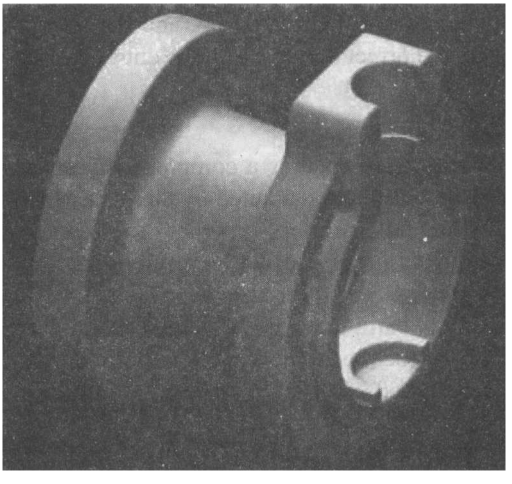


Fig. 10.3 *Valve body*

(ii) Valve Housing

This example demonstrates how redesigning the shape of the component can dramatically increase castability and reduce costs. It also shows the possibilities of using simulation both in the machine shop and in the foundry, to optimise and iterate the design and manufacturing and the price of the casting. The original shape of a duplex-steel valve housing used to have a constant wall thickness (21 mm) in the axi-symmetric part. The analysis showed that the defects were spread all over the axi-symmetric part and close to the flanges. After this, the original shape was re-designed so that material was added to the outer side of the component in order to reach directional solidification towards the two flanges opposite each other.

The risering system was designed for the redesigned component based on the analysis. Four risers with insulating sleeves and six chills were added to the system—two chills to each flange. CastCAE casting simulation program was used to check the functionality of the risering system. It clearly demonstrated that directional solidification was achieved towards the risers and the casting became sound. The same risering system was also tested for the original design to find out if it works for it. As expected, it did not. A constant wall thickness in the axi-symmetric part of the component led to simultaneous solidification which provided poor feeding conditions and caused porosity.

Another package, CastCHECK has been used to help in several ways, such as initial design of components, assessment of the feasibility of casting a component, assessment of quality requirements, assessing the proposals to change the design for better castability and inspection by the customer. Solidification simulation, using CastCAE is typically used in areas, like design of gating and risering, test casting of component and final test castings. With the electronic data transfer, and customer using CastCHECK and the foundry using simulation program, the designing effort can be reduced to a very large extent. Consultations become easy and fast and a great deal of time lost in communication can be saved. During inspection also, components can be checked with CastCHECK and the results can be analysed by the foundry engineers for correct and fast assessment of the outcome.

10.4.3 AFS Solid 2000

AFS Solid 2000 has been developed as a comprehensive package by Finite Solutions Inc. and is being serviced and marketed by the American Foundrymen's Society Inc. The general methodology adopted is that of finite difference. The software combines thermal and volumetric calculations providing accurate predictions of shrinkage porosity. Cast scan and slide shows provide X-ray and animated results that can be viewed without extra viewing software. The program can be installed on multiple machines at one location. The American Foundrymen's Society offers a selection of software designed specifically for use in foundries (Table 10.2).

Table 10.2 *Software available from AFS for use in foundries*

Software title	Operating system	Description
AFS Gating	DOS	Software for calculating dimensions for a system step-down gating system using several different types of sprues and runners.
DOEpack	DOS	Design of experimental software for optimal product quality.
GAGEpack	Windows 3.1, Windows 95, Windows NT	A powerful gauge calibration tracking software program that helps to maintain a complete history of the gauges.
Least Cost	DOS	Software for calculating the least expensive charge charge mix for the alloys, with the correct chemistry requirements; it also includes a non-optimizing charge calculator and a final additions calculator that brings an off spec heat back into specification.
Process Plus	Windows 3.1, Windows 95, Windows NT	Allows for the creation of useful process control sheets and reports.
AFS Risering	DOS	Combines the best of the geometric and modulus risering techniques to predict the best risers for your castings.
SQC Pack	Windows 3.1	Statistical quality control package, allows turning data into useful information.
Weight/Order	DOS	The Weight/Order program will calculate the weight of casting based on material density and casting volume; it also calculates a modulus value, so as to get an idea on the order of solidification.
AFS modeling Solidification System (3D) system	DOS	This 3-D solidification makes it possible to predict problems in castings and make changes to the part, risering or process to optimize part manufacture before the first part is made.
R&R Pack	DOS	Software designed to provide a complete statistical and graphical analysis of the measurement system.
Synchro-16	Windows 95, 98, or NT	Synchro for Windows is a management system for foundries of all sizes covering all aspects of foundry management. It enables to choose and integrate with any leading accounting system.

10.4.4 NovaFlow and NovaSolid

NovaFlow and NovaSolid foundry packages have been developed by NovaCast Ab, Sweden. These are also applicable to sand casting of grey iron, ductile iron, steel, aluminium, copper-based alloys, magnesium, lost wax, shell moulding and investment casting of different alloys, permanent mould and high-pressure, die-casting processes. The main features include advanced algorithms that take gravity and flow into consideration during mould filling and solidification. The common applications have been to optimise the risering requirements, improve yield and reduce time required for cleaning, finishing and machining castings. Both NovaSolid and NovaFlow have shown excellent performance and ease of use in setting new standards for mould-filling/solidification simulation, which are now considered to be the fastest solidification and mould-filling simulation systems in the market. Their speed and pin-point accuracy in result prediction and compatibility with the Windows NT/95/98 environment makes them the common choice.

10.4.5 ProCAST

Procast, another popular software, developed by UES Software, Inc., Ohio, using finite element technique has been adopted for thermalCalc database, micromodeling, stress and distortion and automatic meshing. It is also applicable for sand, shell, investment, die casting, permanent mould and lost foam processes. Foundries have used the software for improving the methoding and simulating the solidification process for producing radiographic quality castings, the very first time.

ProCAST suite consists of one base module and seven optional modules. The Base Module comes with thermal/solidification solver along with pre and post processors. The additional modules are Meshing, Fluid, Stress, Radiation, Microstructure, Electromagnetic, and Inverse.

Table 10.3 *Suggested proCAST modules for different casting processes*

MODULE	SANDCASTING	DIE CASTING	PERMANENT MOLD CASTING	INVESTMENT CASTING
Meshing	Suggested	Suggested	Suggested	Required
Fluid	Suggested	Required	Required	Required
Thermal	Required	Required	Required	Required
Stress	Suggested	Suggested	Suggested	Optional
Radiation	Optional	Optional	Optional	Required
Inverse	Optional	Optional	Optional	Optional
Micromodel	Optional	Optional	Optional	Optional

Key Features ProCAST modules are ideal for all types of heat transfer transient, non-linear 3-D heat conduction, heat convection and radiation, phase changes using enthalpy formulation, porosity predictions, fast mesh generation, cyclic analysis for die casting and permanent mould casting, virtual mould for sand casting, heat transfer between coincident or non-coincident meshes and dynamic memory allocation description. The Heat Simulation Module includes the heat transfer analysis and is the base module of the ProCAST System. The pre- and post-processors for the system are included with this base module, comprising a complete stand-alone package for performing solidification analyses. ProCAST can simulate all three primary modes of heat transfer: conduction, convection and radiation. Additionally, phase change (melting, solidification, solid-state transformation) and internal heat generation or dissipation are accounted for. At the macroscopic level, the thermal analysis uses an enthalpy formulation. This formulation offers several advantages including the removal of any discontinuity associated with a sharp phase transformation and a more accurate conservation of energy formulation than in the equivalent specific heat method.

ProCAST allows the input of thermal, fluid, mechanical and electromagnetic properties of material as constants or as functions of temperature. Once a material has been defined, it is then stored into a database for use in other simulations without having to re-enter property values.

This database functionality is also used in all other areas of condition assignment. It can automatically generate a material's thermodynamic properties based on the composition of that material. Developed by AEA Technology and ThermoTech Ltd., the integration of this material property generator allows the users to generate temperature dependent enthalpy and fraction solid data, as well as the fraction of phases at each temperature for use in simulations. Thus, the effects of composition changes in an alloy on the solidification behaviour of a casting can be examined.

ProCAST suite has two micro-modeling modules to offer. They are based on two different methods and each has their advantages depending on the process and material it is applied on. The modules are 1. Deterministic Modeling, and 2. CAFE 3D (Cellular Automaton—Finite Element)

(i) Deterministic Modelling This model can be applied for

- Equiaxed Dendritic (DAS)
- Coupled Eutectic
- Ductile Iron Eutectic (SGI)
- Grey/White Iron Eutectic
- Ductile Iron Eutectoid
- Grey Iron Eutectoid
- Peritectic Transformation
- Scheil Model
- Iron/Carbon Solid State Transformation

The ProCAST Micro-modeling Module performs deterministic modeling, which couples the thermal history at any location in a casting with the nucleation and growth of microstructures (coupled Thermal- Micro-modeling Simulation). The results of this type of simulation are as follows:

- Determination of microstructure size, distribution and characterization
- Prediction of mechanical properties
- Nodule count and graphite radius prediction for ductile Iron
- Prediction of primary and secondary dendrite arm spacing
- Micro-segregation calculation.

The key features of this package are

- Prediction of both columnar and equiaxed dendritic grain structures
- Columnar to equiaxed transition
- Grain selection in the columnar zone
- Prediction of stray crystals in single crystal parts
- Evolution of the crystallographic texture
- Stereological information
- Direct visualization of grain structure

(ii) CAFÉ Modeling Calcom and the Swiss Federal Institute of Technology in Lausanne, Switzerland, have developed a new module of ProCAST for the modeling of grain structures in castings. This module is based upon a coupling between 382 Principles of Foundry Technology stochastic methods (Cellular Automaton) and Finite Elements (CAFE model). Solidification grain structure can be analyzed using this modeling concept. Applications of this technology have shown that many features of dendritic grain structures can be reproduced for several solidification processes and cooling configurations. Stochastic modeling has been successfully applied and experimentally validated to the prediction of grain structures in investment casting processes for the production of turbine blades (Ni-base alloys).

The CAFE model combines the traditional approach of microstructure modeling (coupling of the thermal history with the nucleation and growth of microstructure) with random aspects such as the location and crystallographic orientation of the nuclei. It also takes into account the preferential growth directions of dendrite trunks and arms. The pre-processing module enables a quick and easy definition of the parameters for the CAFE calculation. A specific post-processing module has been designed to visualize the results such as grain structure at the skin of the casting (Figs 10.5—Plate-4 and 10.6—Plate-4), grain structure in cross sections, growth interface, nucleation centres, grain texture, pole figures, grain size distribution and histogram.

The key features of this package are

- Simulates all casting processes
  - ❖ High pressure die casting
  - ❖ Low pressure die casting
  - ❖ Permanent mould casting
  - ❖ Investment casting

    - ❖ Sand casting
    - ❖ Continuous casting
    - ❖ Lost foam casting
- Solves Full 3-D Navier–Stokes fluid flow equations
- Coordinates rotate for tilt pouring
- Gas modeling for simulating trapped gas and venting
- Non-Newtonian flow modeling (plastics and waxes)
- Filter modeling
- Turbulence modeling
- Compressible flow modeling
- Lost foam modeling
- Particle tracking

ProCAST offers outstanding fluid flow capabilities for the simulation of mould filling. The full three-dimensional Navier-stokes equations are solved along with the coupled energy equation. The free surface front tracking is handled using the Volume of Fluid approach. Natural convection and shrinkage-induce flow can be modelled throughout the solidification process.

ProCAST fluid flow module simulates a wide range of filling problems, including the very high velocities encountered in high-pressure die casting. A wide range of flow regimes can be handled, including turbulent flow, compressible flow and non-Newtonian flow. The non-Newtonian fluid model can provide flow modeling of plastics, waxes, and powdered metal (Fig. 10.8—Plate-5). A gas model is included in the fluid module to simulate trapped gas and venting effects. ProCAST can also model the injection of gas behind a liquid, providing a build-up of pressure driving the flow into the cavity during low-pressure die casting. The Filter Model allows the simulation of flow through a filter or other porous medium placed in the flow path, accounting for the thermal properties and permeability of the filter. The pressure drop across the filter and the loss of momentum and heat can be observed. The lost foam models fully account for the material properties of the foam, the gas generated when the foam burns, the heat loss from the advancing metal front, the back pressure exerted by the trapped gas, and the effect of the permeability of the shell or sand system on the escape of the gas.

10.4.6 MeshCAST

The package MeshCAST is used for fully automatic 3-D mesh generation (Figs 10.9 and 10.10) and is very convenient for design purposes.

The key features are

- CAD/CAE geometry import via STEP, IGES, or parasolid formats
- Direct finite element mesh import

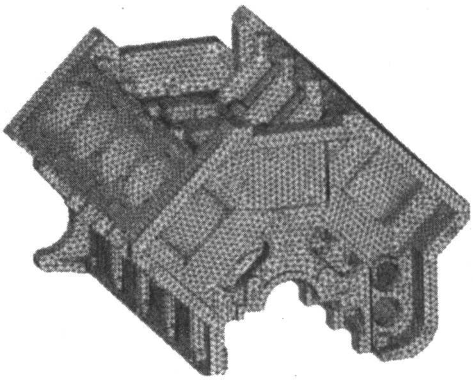


Fig. 10.9 *Automatically meshed cylinder block*

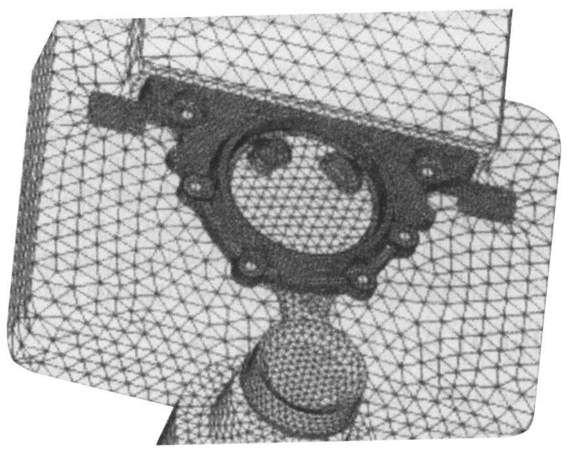


Fig. 10.10 *Non-coincidental meshing for fast results*

- Very fast mesh generation
- Excellent mesh quality and quality checks
- Handles complex geometries
- Multiple materials
- Variable mesh densities on edges and surfaces
- Guaranteed fluid flow analysis mesh
- Automatic shell generation

MeshCAST is a fully automatic 3-D tetrahedral mesh generator. The solid mesh can be generated either from CAD/CAE surface data or from a surface mesh generated in another meshing package. The CAD/CAE geometry may be entered using MeshCAST's STEP, IGES or Parasolid format interfaces. The user can define different mesh densities on different areas of the geometry. Thus, a fine mesh may be applied to detailed geometric features (thin sections) or volumes with high gradients, while at the same time, a coarse mesh may be used in regions where accuracy is not paramount or where little change occurs during the process. This variation of mesh densities allows for an excellent description without exorbitant simulation times.

Meshes from other packages, including Pro/E, I-DEAS, Patran, Ansys, Nastran, Hypermesh and others, may also be imported into MeshCAST. If a surface mesh is imported, MeshCAST can easily generate a solid mesh based upon that mesh definition. Users may also make use of MeshCAST's excellent mesh quality checks should a 3-D mesh be imported. The addition of one or more layers of shell material onto an investment casting geometry is greatly simplified using the automatic shell generator included with MeshCAST. After specifying the faces that are either on a plane of symmetry or that are not to be shelled, the thickness of the shell is entered and the shell is generated. A varying shell thickness can also be specified.

10.4.7 AutoCAST

AutoCAST software, developed by Advanced Reasoning Technologies Pvt. Ltd., Mumbai, has adopted a knowledge-based system involving large eddy simulation for combining all the three essential tasks—casting design decisions, casting model creation and process simulation. This approach reduces the overhead of importing and exporting data between the systems for each layout iteration, saving not only valuable time, but also the possibility of errors during data transfer.

INTELLIGENT ADVISORY SYSTEMS 10.5

A new breed of 'intelligent' CAD/CAM programs, based on geometric reasoning and knowledge engineering is now emerging to solve foundrymen's problems. Geometric reasoning mainly involves understanding the part model and recognising relevant features. Knowledge engineering involves storing and linking domain knowledge with a computer program for providing better decision-support to the users. The Feature Works program, marketed by Solid Works Corp., can automatically recognize machined features such as holes, pockets or slots from a 3-D CAD model. The user inputs the solid model obtained from a conventional (non-feature-based) CAD system. The program recognizes and organizes the part features in a tree structure with relevant dimensional data. Using other feature-based programs, the user can easily modify the part model (by entering the new dimensions), develop the pattern model (by deleting the holes, slots, etc.) and drive DFM check routines (based on the limiting values of hole diameter or rib thickness).

The intelligent CAD/CAM programs have to be developed for specific domains to be really useful. An intelligent CAD system for foundry application recognizes thick sections, suggests end connection points for feeders, computes section modulus, suggests feeder dimensions and analyses the results of simulation to provide a health-check-index for the entire casting design. The decisions are supported by relevant knowledge about the casting process (such as feeder placement, top or side risers). However, even such intelligent systems can at best be used for double-checking human decisions or for trying other alternatives at the same time.

Concurrent engineering is now adopted increasingly by the foundries with the objective of improving quality and enhancing profits. The methods used to achieve this are

- removing useless activities, like multiple inspection and ensuring preventive maintenance
- minimising lead time by proper planning and synchronizing of moulding and melting operations, and maintaining data base for moulding times, melting cycle and mould cooling times and using efficient information system
- minimising scrap rate by using correct methoding and process control, and use can be made of computerized optimisation techniques, simulation methods for studying flow patterns, hot spots and solidification

INTERNET-BASED ENGINEERING 10.6

The Internet has of late come as a revolutionary technique in collapsing distances and saving time otherwise spent in communication and information retrieval. Often a significant time is lost in processing, sending or waiting for information through physical channels. Using the Internet, a drawing, estimate or quotation, order of confirmation and even payments can be sent through electronic networks instantly from one part of the world to another. The Internet is also a convenient source of virtually unlimited information about technologies, processes, materials, products and companies. As an end result, its use can help in reducing lead time, lowering purchase costs, controlling production and marketing costs and achieving higher productivity. Long-term benefits also include better company image, higher confidence and stronger business partnerships.

Review Questions

1. How does CAD help in improving foundry operations? Write a brief note to explain their use.
2. What software tools are used for the casting design and analysis purposes? How are they applied?
3. Explain the use of FEM for optimisation of factors affecting performance of a foundry.
4. How does simulation help in (a) casting design, and (b) casting methoding.
5. Name and briefly describe various foundry softwares available at present.
6. What are the intelligence advisory systems and how are they useful in foundry operations?
7. (a) How is Internet communication useful in the modern production system? Explain its applications.

   (b) Write an explanatory note on 'concurrent engineering'.
8. Design and analysis software tools have come into wide use in large-scale foundries. Explain the essential features of these software tools.
9. Casting simulation has attracted wide attention of foundry technologists and several systems are now available. Explain some common types of simulation programs, mentioning their applications. Describe the aims of modeling the metal filling and solidification process of a casting.
10. What are the intelligent advisory systems and how do they function? What is the scope of concurrent engineering in a modern foundry?

Suggested Readings

FOUNDRY (GENERAL) (A)

American Society for Metals, Metals Handbook, Vol. 5, A.S.M., 1970.

Beeley, P R, Foundry Technology, Butterworths, 1972.

Flinn, R A, Fundamentals of Metal Casting, Addison-Wesley, 1963.

Heine, R W, et al, Principles of Metal Casting, McGraw-Hill, 1967.

Kondic, V, Metallurgical Principles of Founding, Arnold, 1968.

Marek, C T, Fundamentals in the Design and Production of Castings, John Wiley, 1961.

Rusinoff, S E, Foundry Practice, American Technical Society, 1970.

Salmon, W H and E N Simons, Foundry Practice, Pitman, 1972.

Strauss, K, Applied Science in the Casting of Metals, Pergamon, 1970.

Sylvia, J G, Cast Metals Technology, Addison-Wesley, 1972.

Rao, P N, Manufacturing Technology. Foundry, Forging, Welding, Tata McGraw-Hill, 1987.

Ammen, C W, The Metal Caster's Bible. Tab Books, 1980.

Mukherjee, P C, Fundamentals of Metal Casting Technology, Oxford & IBH, 1988.

The Metal Society, Clean Steel, The Metals Society, London, 1988.

A.F.S. & A.S.M., Foundry Technology Source Book, A.F.S., 1982.

A.S.M., Advanced Castings Technology, A.S.M., 1987.

CASTING DESIGN, GATING, AND RISERING OF CASTINGS (B)

American Foundrymen's Society, Basic Principles of Gating, A.F.S., 1967.

——, Basic Principles of Risering. A.F.S., 1968

——, Gating and Feeding for Light Metal Castings, A.F.S., 1962.

——, Gating and Risering Grey Iron Castings, A.F.S.

——, Gating of Die Castings. A.F.S., 1965.

——, Riser Design for Copper Alloys, A.F.S., 1966.

——, Riser Size and Placement for Copper Alloy Castings, A.F.S., 1965.

American Society for Metals, Casting Design Handbook, A.S.M., 1970.

Caine, J B, Design of Ferrous Castings, A.F.S., 1963.

Chalmers, B, Principles of Solidification, John Wiley, 1967.

Ruddle, R W, The Running and Gating of Castings, Inst. of Metals, London, 1956.

Wlodawer, R, Directional Solidification of Steel Castings, Pergamon, 1966.

PATTERNMAKING (C)

American Foundrymen's Society, Patternmaker's Manual, A.F.S., 1960 (Rev.)

Cox, L L, Advanced Patternmaking, Technical Press, 1967,

——, Beginner's Guide to Patternmaking, Newnes, 1967.

——, Patternmaking, Pitman, 1967.

Miner, H D and J G Miller, Exploring Patternmaking and Foundry, Van Nostrand, 1959.

Kiley, H E, and J H Paustian, Pattern Design, International Text, 1956.

H.M.S.O., Safety in the Use of Woodworking Machines, H.M.S.O., 1970.

Jain, P L, Tool Engineering for Metal Casting Processes, Standard Publishers, 1998.

MOULDING AND CORE MAKING (D)

American Foundrymen's Society, Design of Sand and Permanent Mould Castings, A.F.S., 1969.

——, Foundry Sand Handbook, A.F.S., 1963.

American Foundrymen's Society, Moulding Methods and Materials, A.F.S., 1968.

——, Safe Practice in Sand Preparation, Moulding and Core Making, A.F.S., 1970.

British Steel Castings Research Association, Data Sheet on Moulding Materials, B.S.C.R.A., 1967.

——, Foundry Processes and Moulding Materials, B.S.C.R.A., 1967.

Dietert, H W, Foundry Core Practice. A.F.S., 1966.

Mohan, J, et al., Indian Foundry Bentonite Clays, C.S.I.R., 1968.

——, Foundry Moulding Sands in India, C.S.I.R., 1961.

Parkes, W B, Behaviour of Clay Bonded Sands in a Foundry, B.C.I.R.A., 1961.

——, Conventional Oil Sands in Foundry, B.C.I.R.A., 1962.

Roper, F D, Core and Coremaking, George Allen, 1958.

Sarkar, A D, Foundry Core and Mould Making by CO2 Process, Pergamon, 1964.

——, Mould and Core Material for Steel Foundry, Pergamon, 1967.

A.F.S., Fundamentals of Core Technology, A.F.S., 1976.

——, Metal Casting and Moulding Processes, A.F.S., 1981.

DIE CASTING (E)

American Foundrymen's Society, Gustav Lieby, Design of Die Castings, A.F.S., 1957.
Doehler, H H, Die Casting, McGraw-Hill, 1951.
Fry's Die Casting Ltd., Designing for Die Casting, Fry's Die Casting.
Harcopos, B, Technology of Gravity Die Casting, Newnes, 1967.
Plyatskii, V M, Extrusion Casting, Primary Sons, 1965.
Society of Die Casting Engineers, Die Casting Dies. 1979.
Allsop, D F, Kennedy, D, Pressure Die Casting, Pergamon Press, 1983.
Bruner, R W, The Mettallurgy of Die Casting, Society of Die Casting Engineers, 1986.

SHELL MOULDING AND INVESTMENT CASTING (F)

American Foundrymen's Society, Shell Process Foundry Practice, A.F.S., 1973.
Dumond. T C, Shell Moulding and Shell Mould Castings, Reinhold, 1954.
Investment Casting Institute, Investment Casting Handbook, Inv. Cstg. Inst., 1968.
Wood, R L and D, Von Ludwig, Investment Casting for Engineers, Pergamon, 1960.
A.F.S., Investment Casting Waxes, A.F.S., 1988.

METALLURGY, MELTING AND CASTING (G)

American Foundrymen's Society, Analysis of Casting Defects, A.F.S., 1966.
——, Control of Emissions from Metal Melting Operations, Pergamon, 1966.
——, Cupola and its Operation, A.F.S., 1965.
——, Micro-inclusions in Steel Castings, A.F.S., 1966.
——, Safe Practices in Melting and Pouring Operations, A.F.S., 1970.
American Society for Metals, Furnace Atmosphere and Carbon Control, A.S.M., 1964.
Bidulya, P, Steel Foundry Practice, Mir, 1968.
Brace, A W and F A, Alien, Magnesium Casting Technology, Chapman and Hall, 1957.
Briggs, C W, Metallurgy of Steel Castings.
Briggs, C W, Steel Castings Handbook, Steel Founders' Society, 1960.
British Cast Iron Research Association, Cupola Operation and Control, B.C.I.R.A., 1965.
Etherington, H, Modern Furnace Technology, G C and Co., 1961.
Heine, R W, Melting Variable Effects on Malleable Iron Properties, A.F.S.
Iron and Steel Institute, UK, The Determination of Gases in Metals, Iron and Steel Inst., 1960.
Lipnitsky, A, Melting of Cast Iron and Non-ferrous Alloys, Peace.
Malleable Founder's Society, Malleable Castings, Oxford, 1969.
Murphy, A J, Non-ferrous Foundry Metallurgy.
Newell, W C, Casting of Steel. Pergamon, 1955.

Paschkis, V, Industrial Electric Furnaces and Appliances, Interscience, 1960.

Ramamurthy, S, Technique of Melting and Treating Non-ferrous Alloys, 1962.

Sharp. J D, Casting Pit Practice, Iliffe, 1968.

Reed, R D, Furnace Operations, Gulf Publishing, 1976.

Sarin, L V, Industrial Furnaces. Mir Publ., 1977.

Bohner, H O, Light Metals. A.I.M.E., 1985.

Trivedi, R, Sekhar, J A, Mazumdar, J, Principles of Solidification and Materials Processing, (2 Vol.) Oxford & IBH, 1989.

Kurz, W, Fisher, D J, Fundamentals of Solidification, Trans Tech Publishers, Germany, 1989.

Sinha, A K, Ferrous Physical Metallurgy, Butterworths, 1989.

REFRACTORIES (H)

American Foundrymen's Society, Refractories Manual, A.F.S., 1963.

Budnikov, P P, Technology of Ceramics and Refractories, Edward Arnold, 1964.

Norton, F N, Refractories, McGraw-HitI, 1968.

Nandi, D N, Handbook of Refractories. Tata McGraw-Hill, 1987.

FETTLING AND HEAT TREATMENT (I)

A.F.S., Safe Practices in Cleaning, Testing and Finishing, A.F.S., 1970.

Gregory, E and E N, Simons, Heat Treatment of Steel, Pitman, 1958.

A.S.M., Principles of Heat Treating, A.S.M.

——, Quenching and Martempering, Chapman and Hall, 1964.

Churchil, S C, Heat Treatment Fundamentals, M.P.C., 1958.

Grossman, M A et al., Principles of Heat Treatment, A.S.M., 1964.

Little, L, Welding & Welding Technology, Tata McGraw-Hill, 1976.

B.C.I.R.A, Fettling & Cleaning of Iron Castings, B.C.I.R.A., 1974.

Proceedings, International Conference, Shot Peening, Pergamon Press, 1981.

Davies, D J, Oelmann, L A, The Structure, Properties and Heat Treatment of Metals, Pitman, 1983.

Boyer. H E, Practical Heat Treating, A.S.M., 1984.

Galyen, J et al. Welding Fundamentals and Procedures, John Wiley, 1984.

Sinchcomb, C, Welding Technology Today, Prentice Hall, 1989.

INSPECTION AND QUALITY CONTROL (J)

American Foundrymen's Society, Control of Ductile Iron Through Microexamination, A.F.S.

——, Industrial Engineering in the Foundry, A.F.S., 1963.

——, Statistical Quality Control in Foundries, A.F.S., 1953.

Brandon, L C, Modern Techniques of Metallography, Butterworths, 1966.

British Cast Iron Research Association, Chemical Analysis for Iron Foundries, George Allen, 1967.

British Cast Iron Research Association, Recommended Procedure for Non-destructive Testings of Steel Castings by Visual Examination, B.S.C.R.A., 1967.

——, Recommended Procedure for Radiographic Flaw Detection of Steel Castings B.S.C.R.A., 1967.

——, Recommended Procedure for Ultrasonic Examination of Steel Castings, B.S.C.R.A., 1971.

Korolkov, A M, Castings Properties of Metals and Alloys, Consultants Bureau, 1963.

Norwitz, G, Rapid Analysis of Non-ferrous Metal and Alloys, Chem, Pub. Co., 1958.

Schall, W E, Non-destructive Testing, M.P.C., 1968.

Steel Castings Research and Trade Association, Atlas of Some Steel Casting Flaws as shown by Non-destructive Testing, S.C.R.A.T.A., 1968.

Turovtseva, Z M, Analysis of Gases in Metals. Consultants Bureau, 1961.

Walton, C F, Economic Considerations of Iron Castings. Grey Iron Founders' Society.

Welcher, F J, Standard Methods of Chemical Analysis. Van Nostrand, 1962.

S.C.R.A.T.A, Quality Assurance in Steel Foundry Industry, S.C.R.A.T.A., 1976.

American Society for Metals, Case Histories in Failure Analysis, A.S.M., 1979.

Jain P L, Quality Control and Total Quality Management, Tata McGraw-Hill, New Delhi, 2001.

ENVIRONMENT CONTROL (K)

British Cast Iron Research Association, The Working Environment in Iron Foundries, B.C.I.R.A., 1977.

Index

D

E

N

O

P

Q

R

S

T

Fig. 3.47 *Complete ceramic shell mold for producing stainless steel pump impellers, volutes, and diffusers for the chemical, food, petroleum, and other associated industries. Photo shows core being inserted into drag half prior to closure. Cast accuracy and surface finish matches investment casting at a fraction of the cost. Smooth cast surface vastly improves a pump operating efficiency over castings produced in sand molds*

+CMYK

Plate 2

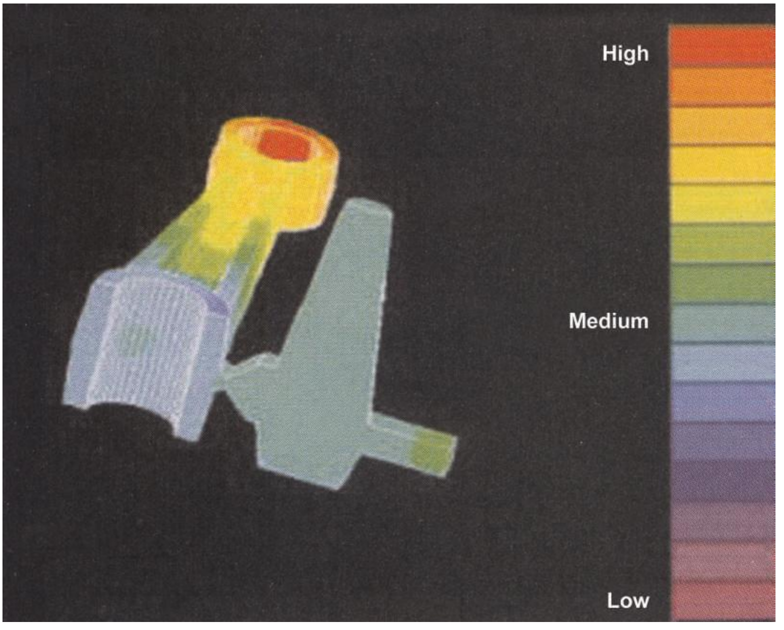


Fig. 10.1 *B.H.N. plot obtained from thermal micro-modelling analysis*

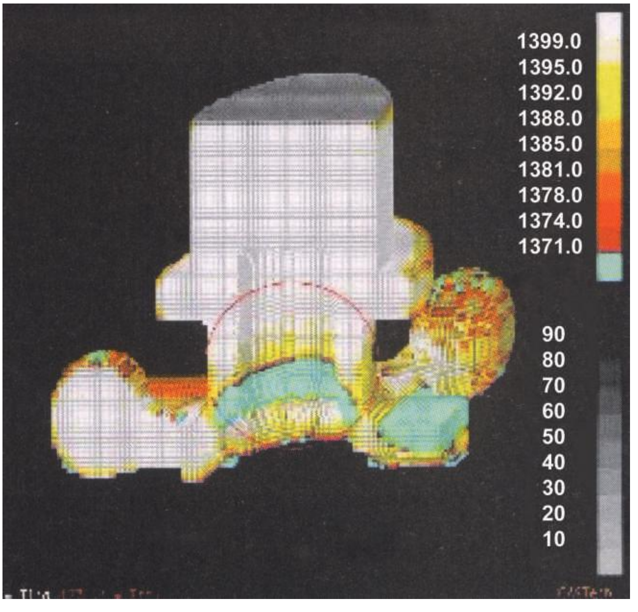


Fig. 10.3 *Old system of casting*

+CMYK

+CMYK

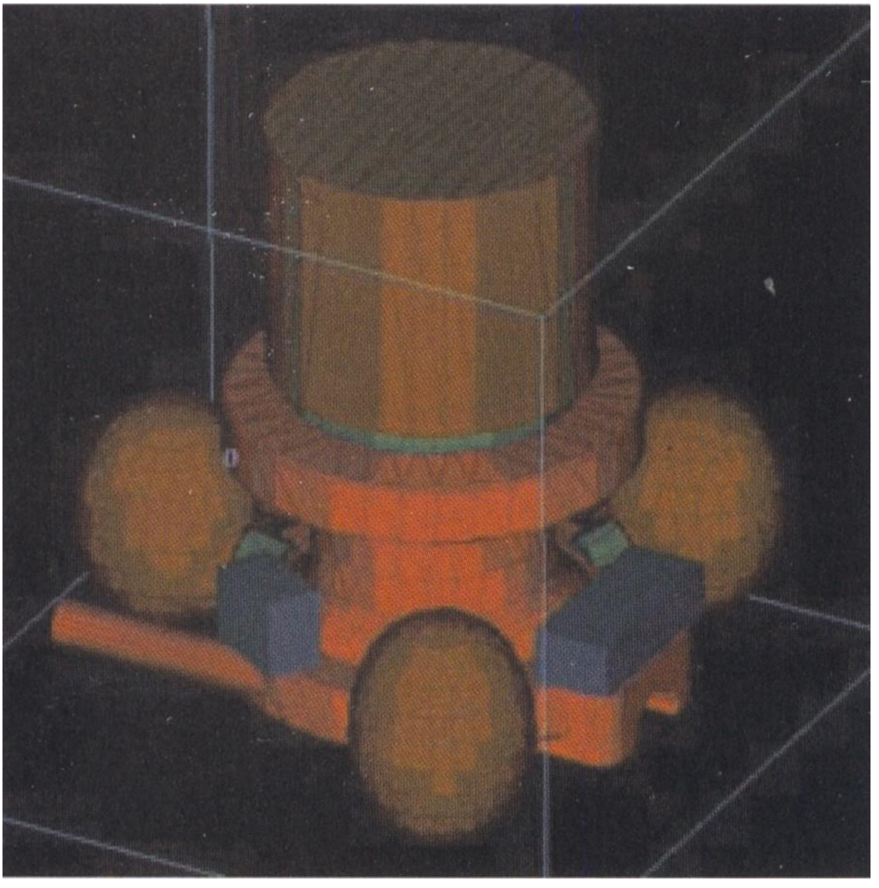


Fig. 10.4 *New system of casting*

+CMYK

+CMYK

Plate 4

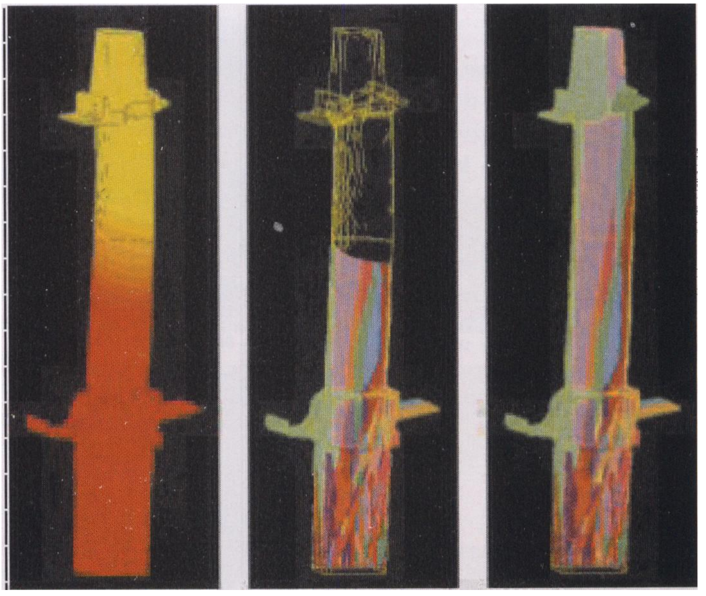


Fig. 10.5 *Gain structure in a single crystal*

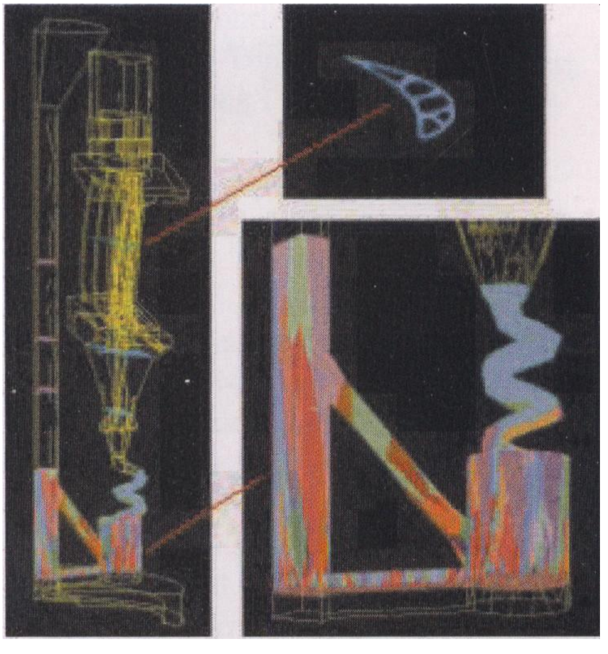
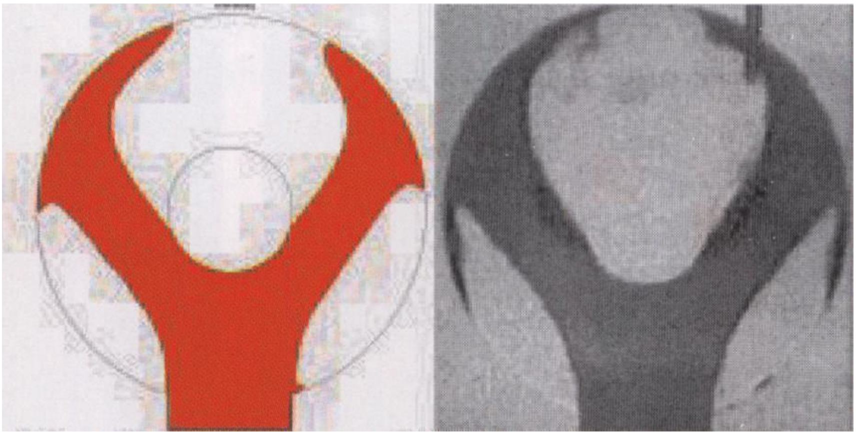


Fig. 10.6 *Gain structure in a blade*

+CMYK



(Courtesy of Arbeitsgemeinshaft, Metallguss, Aslen)

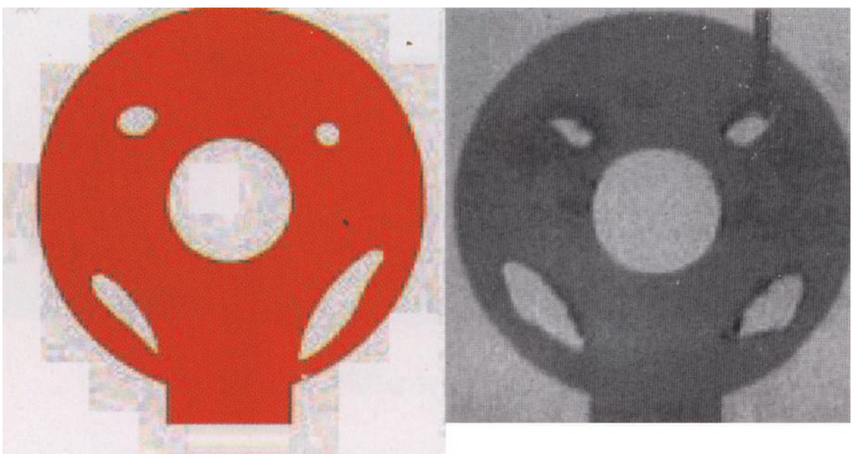


Fig. 10.7 *Fluid flow study*