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Testing of Metals

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To
My wife, Payal, and
Our Children, Mohit and Radhika

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Preface

Testing of Metals is a comprehensive source of information on commonly used testing methods for metals and their products. This book is intended for all engineers, technical professionals and undergraduate and graduate students of metallurgical and mechanical engineering, who are involved in the testing and evaluation of metallic materials.

Testing of Metals contains 23 chapters covering standard test methods for tensile testing, formability testing, hardness testing, impact testing, nondestructive testing, and metallographic and other methods of testing. Each test method describes the principle, apparatus, general precautions and the test procedure.

The book also contains information on equivalent national and international standards on testing of metals, hardness conversion tables, macroetchants and microetchants for metals, and a directory of selected standards organizations, technical associations, and testing equipment manufacturers.

The information included in this book has been extracted primarily from Indian Standards, and also from ASTM, BS, DIN, ISO and JIS standards, reference books, and technical publications of testing equipment manufacturers. The organization of the book is such that it is easy for the user to quickly locate the information of interest through the table of contents, and subject index.

The work on this book has involved a lot of effort. While I am obliged to many organizations and individuals for the strengths of the book, the weaknesses are entirely my responsibility. Any feedback on the quality of information provided by way of suggestions would be highly appreciated.

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Finally, and most importantly, I am indebted to my wife, Payal, and our children, Mohit and Radhika, for their encouragement, patience and understanding during the preparation of this book.

Abbreviations and Symbols

Chemical Elements

C	Carbon	**K**	Potassium
Cl	Chlorine	**Mg**	Magnesium
Cr	Chromium	**N**	Nitrogen
Cu	Copper	**Na**	Sodium
F	Fluorine	**O**	Oxygen
H	Hydrogen	**S**	Sulphur

Mechanical Properties

A	Percentage elongation after fracture on original gauge length (L_o) of $5.65\sqrt{S_o}$
$A_{x\ mm}$	Percentage elongation on original gauge length (L_o) of x mm, e.g. $A_{50\ mm}$
HB	Brinell hardness
HK	Knoop hardness
HR	Rockwell hardness (should be followed by the scale designation, e.g. HRC, HRB, or HR30N)
HV	Vickers hardness
KU	Impact strength of longitudinal ISO U-notch test pieces
KV	Impact strength of longitudinal ISO V-notch test pieces
L_o	Original gauge length
R_e	Yield strength
R_{eH}	Upper yield strength
R_{eL}	Lower yield strength
R_m	Tensile strength
$R_{p0.2}$	0.2% Proof strength
S_o	Original cross-sectional area of the parallel length
Z	Percentage reduction of area

Standards Organizations

AFNOR	Association francaise de normalisation
ANSI	American National Standards Institute
BIS	Bureau of Indian Standards
BSI	British Standards Institution
CEN	European Committee for Standardization
DIN	Deutsches Institut für Normung e.V.
ISO	International Organization for Standardization
JISC	Japanese Industrial Standards Committee

Units

A	*Ampere*	MPa	*Megapascal*
cm	*Centimetre*	N	*Newton*
g	*Gram*	S	*Second*
h	*Hour*	T	*Tesla*
J	*Joule*	W	*Watt*
K	*Kelvin*	°	*Degree*
kg	*Kilogram*	°C	*Degree Celsius*
m	*Metre*	%	*Per cent*
min	*Minute*	% (*m*/*m*)	*Per cent by mass*
mm	*Millimetre*		

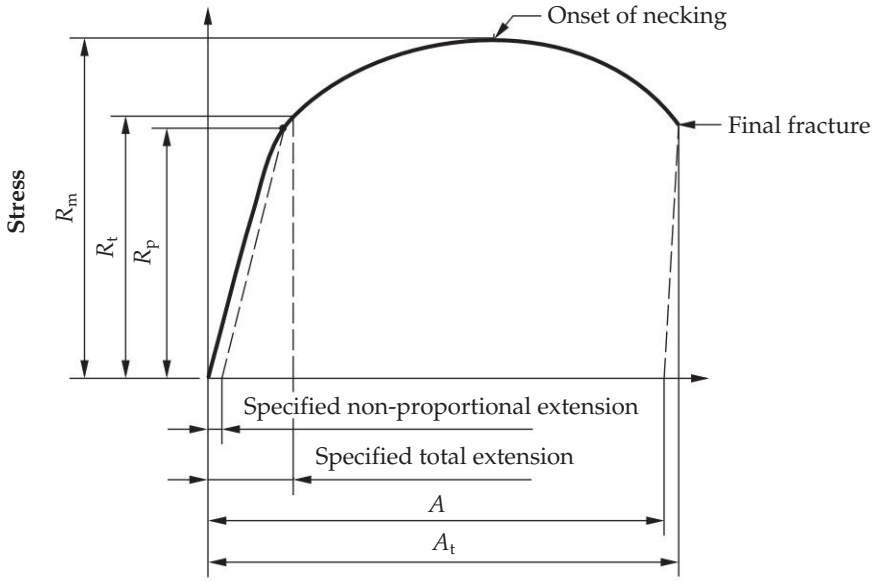
Contents

1

Tensile Testing

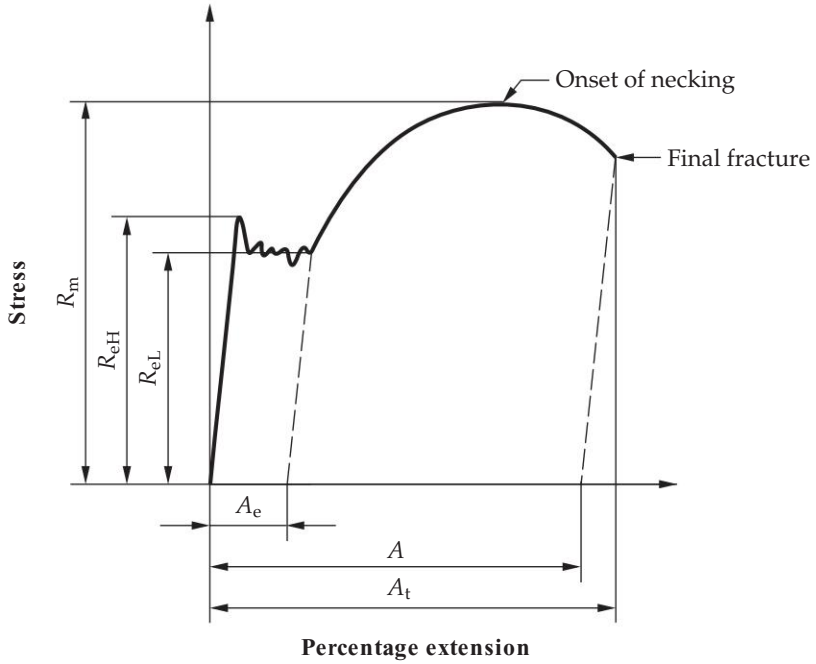
1 PRINCIPLE

The tensile test consists of subjecting a test piece to a continually increasing tensile strain, generally to fracture, for the purpose of determining one or more of the following tensile properties (see Figs. 1.1 and 1.2): Tensile strength, proof strength, upper and lower yield strength, elongation and percentage reduction of area.



Key:
R_m = Tensile strength
R_p = Proof strength (non-proportional extension)
R_t = Proof strength (total extension)
A = Percentage elongation after fracture
A_t = Percentage total elongation at fracture

Fig. 1.1 *Typical stress/extension diagram for a ductile metallic material not exhibiting yield phenomenon* (*Source:* Ref. 2)



Key:
R_m = Tensile strength
R_{eH} = Upper yield strength
R_{eL} = Lower yield strength
A = Percentage elongation after fracture
A_e = Percentage yield point extension
A_t = Percentage total elongation at fracture

Fig. 1.2 *Typical stress/extension diagram for a ductile metallic material exhibiting yield phenomenon* (*Source:* Ref. 3)

2 DEFINITIONS

2.1 Test Piece

2.1.1 Proportional Test Piece

Test piece whose original gauge length (L_o) is related to the original cross-sectional area (S_o) by the equation $L_o = k\sqrt{S_o}$.

2.1.2 Non-Proportional Test Piece

Test piece whose original gauge length (L_o) is taken independent of the original cross-sectional area (S_o).

2.1.3 Coefficient of Proportionality (k)

Ratio of the original gauge length (L_o) to the square root of the original cross-sectional area (S_o).

2.2 Cross-Sectional Area

2.2.1 Original Cross-Sectional Area (S_o)

Cross-sectional area of the parallel length before application of force (see Fig. 1.3).

2.2.2 Cross-Sectional Area After Rupture (S_u)

Minimum cross-sectional area of the parallel length after rupture (see Fig. 1.3).

2.3 Gauge Length *(L)*

Length of the cylindrical or prismatic portion of the test piece on which elongation is measured.

2.3.1 Original Gauge Length (L_o)

Gauge length before application of force, measured at ambient temperature (see Fig. 1.3).

2.3.2 Final Gauge Length (L_u)

Gauge length after rupture, measured at ambient temperature (see Fig. 1.3).

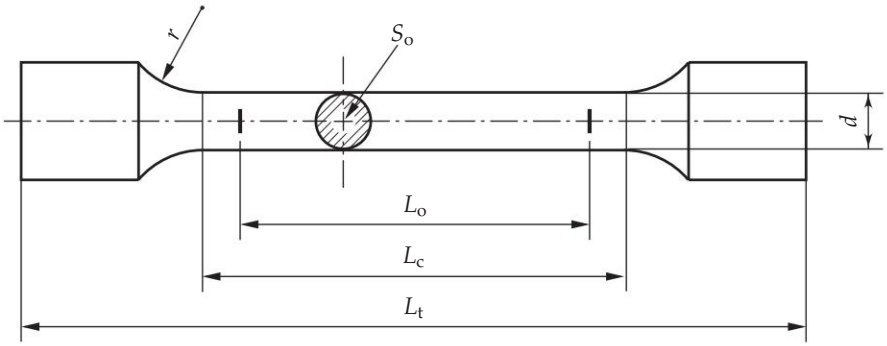
2.3.3 Extensometer Gauge Length (L_e)

Length of the parallel portion of the test piece used for the measurement of extension by means of an extensometer.

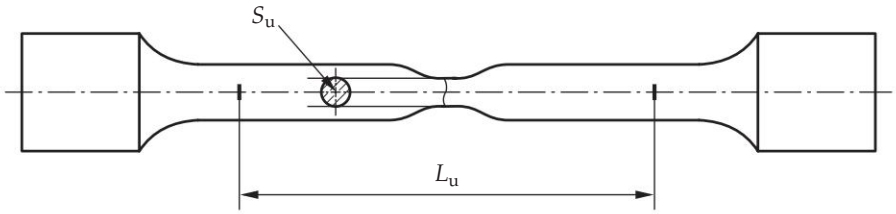
2.4 Parallel Length (L_c)

Length of the parallel portion of the reduced section of the test piece (see Fig. 1.3).

Note: The concept of parallel length is replaced by the concept of distance between grips for non-machined test pieces.



(a) Before test



(b) After test

Key:
d = Diameter of the parallel length of a circular test piece
L_o = Original gauge length
L_c = Parallel length
L_t = Total length of test piece
L_u = Final gauge length
r = Transition radius
S_o = Original cross-sectional area of the parallel length
S_u = Cross-sectional area after rupture

Fig. 1.3 *Typical tensile test piece* (*Source:* Ref. 1)

2.5 Elongation

Increase in the original gauge length (L_o) at any moment during the test.

2.5.1 Percentage Elongation

Elongation expressed as a percentage of the original gauge length (L_o).

2.5.2 Percentage Permanent Elongation

Increase in the original gauge length of a test piece after removal of a specified stress, expressed as a percentage of the original gauge length (L_o).

2.5.3 Percentage Elongation after Fracture (A)

Permanent elongation of the gauge length after fracture ($L_u - L_o$), expressed as a percentage of the original gauge length (L_o) (see Figs. 1.1 and 1.2).

Notes:

1) In the case of proportional test pieces, the symbol A should be supplemented by a subscript indicating the coefficient of proportionality used, only if the original gauge length is other than $5.65\sqrt{S_o}$, for example, $A_{11.3}$ indicates a percentage elongation after fracture on a gauge length (L_o) of $11.3\sqrt{S_o}$.
2) In the case of non-proportional test pieces, the symbol A should be supplemented by a subscript indicating the original gauge length used, expressed in mm, for example, $A_{80\,mm}$ indicates a percentage elongation after fracture on a gauge length (L_o) of 80 mm.

2.5.4 Percentage Total Elongation at Fracture (A_t)

Total elongation (elastic elongation plus plastic elongation) of the gauge length at the moment of fracture, expressed as a percentage of the original gauge length (L_o) (see Figs. 1.1 and 1.2).

2.6 Extension

Increase in the extensometer gauge length (L_e) at a given moment of the test.

2.6.1 Percentage Permanent Extension

Increase in the extensometer gauge length, after removal of a specified stress from the test piece, expressed as a percentage of the extensometer gauge length (L_e).

2.6.2 Percentage Yield Point Extension (A_e)

In discontinuous yielding materials, the extension between the start of yielding and the start of uniform work hardening, expressed as a percentage of the extensometer gauge length (L_e) (see Fig. 1.2).

2.6.3 Strain

Ratio of extension to the extensometer gauge length (L_e), expressed as a decimal value or as a percentage.

2.7 Percentage Reduction of Area (Z)

Maximum change in cross-sectional area ($S_o - S_u$) which has occurred during the test, expressed as a percentage of the original cross-sectional area (S_o).

2.8 Maximum Force (F_m)

The greatest force which the test piece withstands during the test once the yield point has been passed.

Note: For materials without yield point, it is the maximum value during the test.

2.9 Stress

Force at any moment during the test divided by the original cross-sectional area (S_o) of the test piece.

2.9.1 Tensile Strength (R_m)

Stress corresponding to the maximum force (F_m) (see Figs. 1.1 and 1.2).

2.9.2 Yield Strength

When the metallic material exhibits a yield phenomenon, a point during the test at which plastic deformation occurs without any increase in the force.

2.9.2.1 Upper yield strength (R_{eH})

Value of stress at the moment when the first decrease in force is observed (see Fig. 1.2).

2.9.2.2 Lower Yield Strength (R_{eL})

Lowest value of stress during plastic yielding, ignoring any initial transient effects (see Fig. 1.2).

2.9.3 Proof Strength, Non-Proportional Extension (R_p)

Stress at which a non-proportional extension is equal to a specified percentage of the extensometer gauge length (L_e) (see Fig. 1.1).

Note: The symbol used should be supplemented by a subscript indicating the specified percentage of the extensometer gauge length, for example, $R_{p0.2}$.

2.9.4 Proof Strength, Total Extension (R_t)

Stress at which total extension (elastic extension plus plastic extension) is equal to a specified percentage of the extensometer gauge length (L_e) (see Fig. 1.1).

Note: The symbol used should be followed by a subscript indicating the specified percentage of the extensometer gauge length, for example, $R_{t0.5}$.

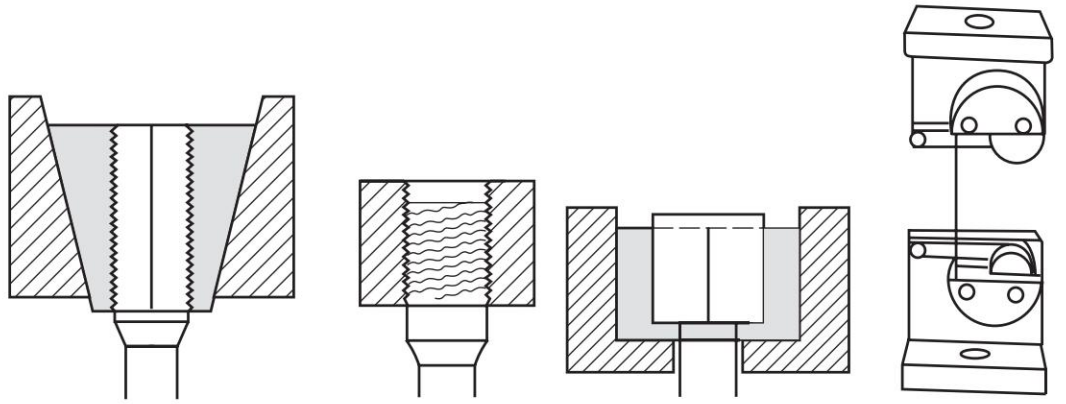
3 APPARATUS

3.1 Testing Machine

The tensile testing machine (see Fig. 1.4, Plate 1), should be verified in accordance with IS 1828-1, and should be of Class 1 or better. It should possess sufficient force capacity to break the test piece.

3.2 Gripping Device

The gripping device (see Fig. 1.5) should properly fit the test piece so that the test piece does not slip in relation to the gripping device at the maximum force. It should also possess sufficient force capacity so that it is not damaged during testing.



(a) Wedge-type grips for round and flat test pieces (b) Grips for threaded test pieces (c) Buttonhead grips for shouldered test pieces (d) Snubber-type grips for wire

Fig. 1.5 *Gripping devices used in tensile testing* (*Source:* Ref. 2)

3.3 Extensometer

The extensometer should be verified in accordance with IS 12872, and should be of Class 1 for the determination of the upper and lower yield strengths and proof strength (non-proportional extension), and of Class 2 for the determination of other tensile properties (corresponding to higher extension).

4 TEST CONDITIONS

4.1 Speed of Testing

4.1.1 Determination of Upper and Lower Yield Strengths (R_{eH} and R_{eL})

4.1.1.1

When the upper yield strength (R_{eH}) is being determined, the rate of separation of the cross-heads of the machine, within the elastic range and up to the upper yield strength, should be kept as constant as possible and within the limits corresponding to the rate of stressing given in Table 1.1.

Table 1.1 *Rate of Stressing*

Modulus of elasticity of the material GPa	Rate of stressing $MPa \cdot s^{-1}$
< 150	2–20
≥ 150	6–60
Source: Ref. 1	

4.1.1.2

When only the lower yield strength (R_{eL}) is being determined, the strain rate during yield of the parallel length of the test piece should be between 0.00025/ s and 0.0025/ s, and should be kept as constant as possible.

The rate of stressing in the elastic range should not exceed the maximum rates given in Table 1.1.

4.1.1.3

When both the upper and lower yield strengths (R_{eH} and R_{eL}) are being determined during the same test, the conditions for determining the lower yield strength should be complied with (see Section 4.1.1.2).

4.1.2 Determination of Proof Strength (Non-Proportional Extension) and Proof Strength (Total Extension) (R_p and R_t)

The rate of stressing in the elastic range should be within the limits given in Table 1.1. The strain rate within the plastic range and up to the proof strength (non-proportional extension or total extension) should not exceed 0.0025/ s.

4.1.3 Determination of Tensile Strength (R_m)

In the plastic range, the strain rate of the parallel length of the test piece should not exceed 0.008/ s.

If the test does not include the determination of the yield strength or proof strength, the strain rate in the elastic range may reach the maximum permitted in the plastic range.

4.2 Test Piece

4.2.1 Sampling

The location of the test pieces should be as specified in the product standard (see Annexure B).

4.2.2 Types

The type of test piece should be as specified in the product standard. For wrought products, the types of test pieces most commonly used are given in Table 1.2.

4.2.3 Preparation

The test piece should be prepared in such a way that there is no change in its tensile properties due to heat or cold working.

4.3 Test Temperature

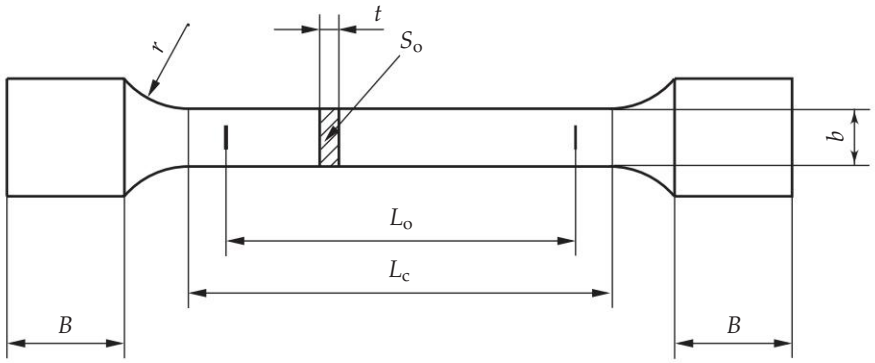
The test should be carried out at a temperature between 10 °C and 35 °C.

Table 1.2 *Types of Test Piece for Wrought Products*

Product		Type of test piece
Form	**Size (s)**[1)]	
Flat products	$0.1 \leq s < 3$	A machined, non-proportional test piece (see Fig. 1.6). The test piece may also consist of a strip with parallel sides (see Fig. 1.7).
	$s \geq 3$	A machined, proportional test piece (see Figs. 1.8 and 1.9).
Bars, wires, and sections	$s < 4$	An unmachined portion of the product (see Fig. 1.10).
	$s \geq 4$	A machined, proportional test piece (see Fig. 1.8).
Tubes	–	• A length of tube (see Fig. 1.11). • A longitudinal or transverse strip cut from the tube having the full thickness of the wall of the tube (see Figs. 1.6 and 1.7). • A proportional test piece of circular cross-section machined from the wall of the tube (see Fig. 1.8).

[1)] The size (s) refers to the diameter of rounds, the lateral length of squares, the width across flats of hexagons, and the thickness of flat products.

Source: Ref. 1



Width of parallel length *b* mm	Thickness of test piece *t* mm	Original cross-sectional area S_o mm²	Original gauge length L_o mm	Parallel length L_c mm	Minimum transition radius *r* mm	Width of gripped ends *B* mm
12.5±1	Full thickness of flat product or wall thickness of tube	[1]	50	75	20	20–40
20±1			80	120	20	30–40

[1] Original cross-sectional area (S_o):

- For flat products: $S_o = bt$.
- For test piece cut from a tube: $S_o = bt\left[1+\frac{b^2}{6D(D-2t)}\right]$ when $\frac{b}{D} < 0.25$, or

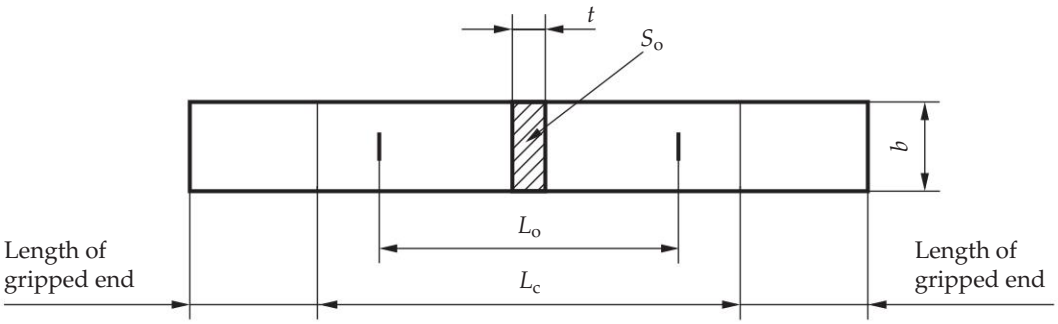
$S_o = bt$ when $\frac{b}{D} < 0.17$.

where:

D = external diameter of tube

b = average width of strip

Fig. 1.6 *Machined, non-proportional test piece for flat products of thickness between 0.1 mm and 3 mm, and tubes of wall thickness less than 3 mm* (*Source:* Ref. 1)



Width of parallel length **b** mm	Thickness of test piece **t** mm	Original cross-sectional area S_o mm²	Original gauge length L_o mm	Free length between grips L_c mm
12.5±1	Full thickness of flat product or wall thickness of tube	[1)]	50	87.5
20±1			80	140

[1)] Original cross-sectional area (S_o):

- For flat products: $S_o = bt$.
- For test piece cut from a tube: $S_o = bt\left[1 + \frac{b^2}{6D(D-2t)}\right]$ when $\frac{b}{D} < 0.25$, or

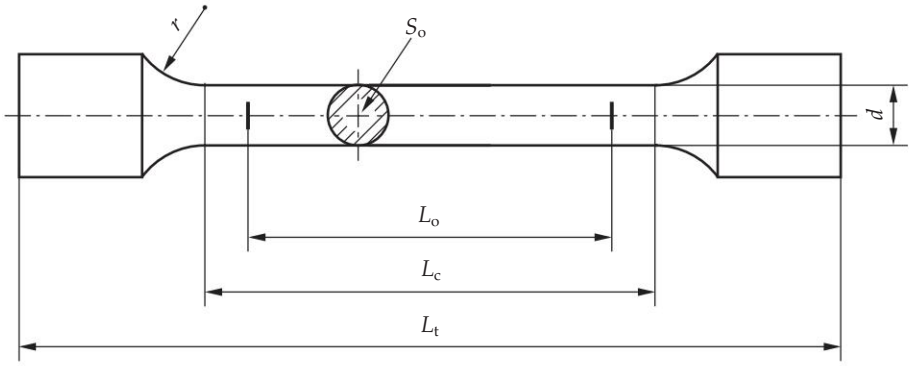
$S_o = bt$ when $\frac{b}{D} < 0.17$.

where:

D = external diameter of tube

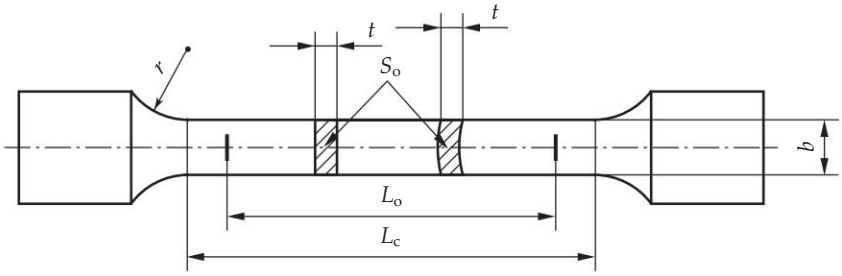
b = average width of strip.

Fig. 1.7 *Parallel-sided, non-proportional test piece for flat products of thickness between 0.1 mm and 3 mm, and tubes of wall thickness less than 3 mm* (*Source:* Ref. 1)



Coefficient of proportionality k	Diameter of parallel length d mm	Original cross-sectional area S_o mm²	Original gauge length $L_o = k\sqrt{S_o}$ mm	Minimum parallel length L_c mm	Minimum transition radius r mm	Approximate total length L_t mm
5.65	5±0.04	19.6	25±0.25	28	6	$L_c + 2d$ or $L_c + 4d$
	10±0.075	78.5	50±0.5	55	9	
	20±0.15	314	100±1	110	15	

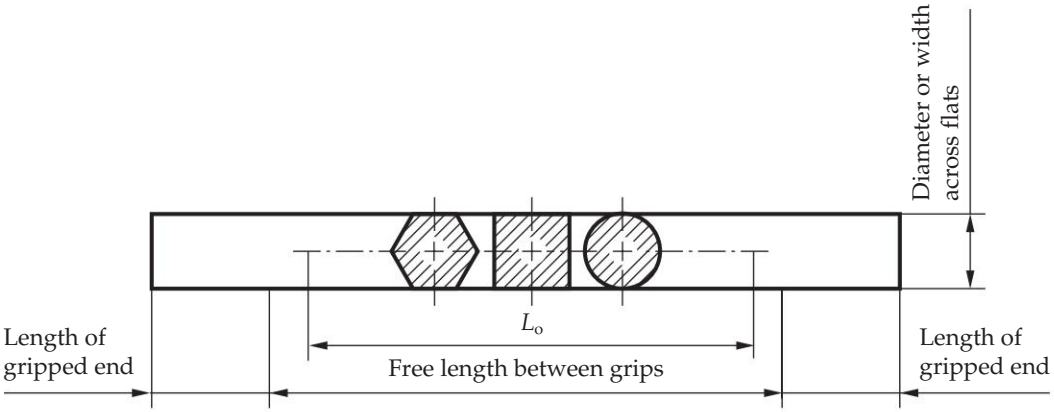
Fig. 1.8 *Machined, proportional test piece of circular cross-section* (*Source*: Ref. 1)



Coefficient of proportionality k	Width b mm	Thickness t mm	Original cross-sectional area S_o mm²	Original gauge length $L_o = k\sqrt{S_o}$ mm	Minimum parallel length L_c mm	Minimum transition radius r mm
5.65	b[1)]	t[1)]	bt	$L_o = 5.65\sqrt{S_o}$	$L_o + 1.5\sqrt{S_o}$	12

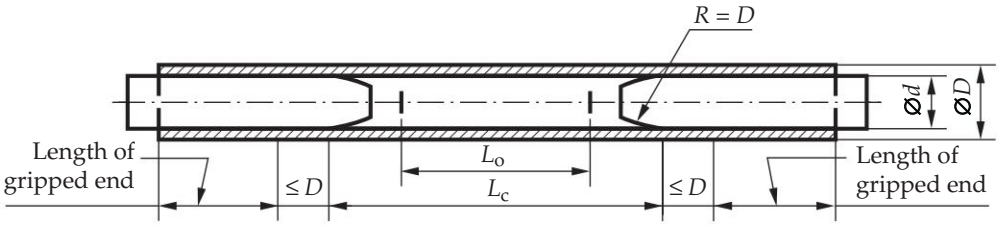
[1)] $b/t \leq 8$.

Fig. 1.9 *Machined, proportional test piece of rectangular cross-section* (*Source:* Ref. 1)



Original gauge length L_o mm	Free length between grips mm
100±1	150
200±2	250

Fig. 1.10 *Unmachined, non-proportional test piece for bars and rod of diameter or thickness less than 4 mm* (*Source:* Ref. 1)



External diameter D mm	Internal diameter d mm	Wall thickness t mm	Original cross-sectional area S_o mm²	Original gauge length L_o mm	Parallel length L_c mm	Free length between each plug and nearest gauge mark mm	Length of plug projecting relative to the grips mm
D	d	$(D - d)/2$	[1]	[2]	$L_o + 2D$	D	$\leq D$

[1] $S_o = \pi t(D - t)$.

[2] $L_o = 5.65\sqrt{S_o}$, but not less than 30 mm.

Fig. 1.11 *Tensile test piece comprising a length of tube* (*Source*: Ref. 1)

5 TEST PROCEDURE

5.1 Determination of Original Cross-Sectional Area (S_o)

Calculate the original cross-sectional area (S_o) from the measurements of the appropriate dimensions of the test piece.

5.2 Marking the Original Gauge Length (L_o)

Mark each end of the original gauge length (L_o) by means of fine marks or scribed lines, but not by notches which may cause a premature fracture.

If the parallel length (L_c) is much longer than the original gauge length, draw a series of overlapping gauge lengths.

Note: On an automatic testing machine, the gauge length is defined by the distance between the two knife-edges of the extensometer.

5.3 Gripping of Test Piece

Clamp the test piece in a suitable gripping device in such a way that the force is applied as axially as possible. Attach the extensometer to the test piece.

5.4 Loading of the Test Piece

Apply a tensile force on the test piece so as to strain the test piece in a non-decreasing manner, without shock or vibration. Maintain the speed of testing within the limits specified in Section 4.1.

Record the force and the corresponding extension. Accurately plot the force/ extension diagram.

5.5 Determination of Tensile Strength (R_m)

Calculate the tensile strength (R_m) by dividing the maximum force (F_m) by the original cross-sectional area (S_o) of the test piece.

$$R_m = \frac{F_m}{S_o}$$

5.6 Determination of Upper Yield Strength (R_{eH})

Calculate the upper yield strength (R_{eH}) by dividing the maximum force at the commencement of yielding (see Fig. 1.12) by the original cross-sectional area (S_o) of the test piece.

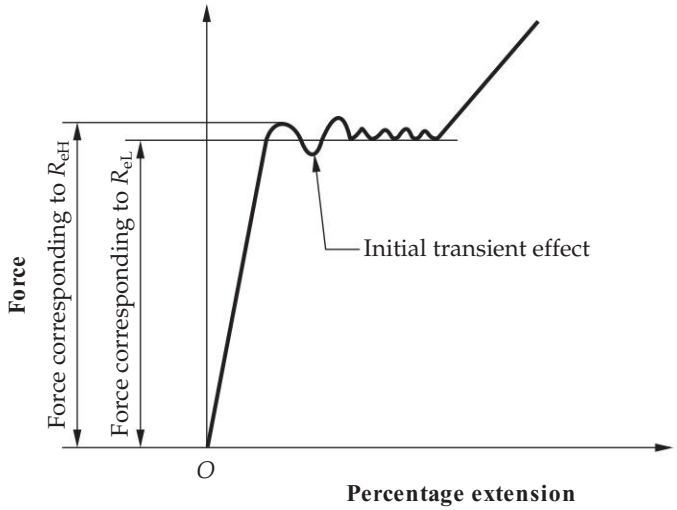


Fig. 1.12 *Force/extension diagram illustrating the determination of upper and lower yield strengths (R_{eH} and R_{eL})* (*Source:* Ref. 1)

5.7 Determination of Lower Yield Strength (R_{eL})

Calculate the lower yield strength (R_{eL}) by dividing the lowest value of force during plastic yielding (see Fig. 1.12) by the original cross-sectional area (S_o) of the test piece.

5.8 Determination of Proof Strength (Non-proportional Extension) (R_p)

Construct a line parallel to the linear portion of the force/ extension diagram at a distance equal to the specified non-proportional percentage, for example 0.2%. Record the force corresponding to the point at which this line intersects the curve [see Fig. 1.13(a)]. Calculate the proof strength (non-proportional extension) by dividing this force by the original cross-sectional area (S_o) of the test piece.

Note: If the linear portion of the force/ extension diagram is not clearly defined, thereby preventing drawing the parallel line with sufficient precision, the procedure detailed below should be followed [see Fig. 1.13 (b)].

Load the test piece to beyond the presumed proof strength, and then reduce the force to a value equal to about 10% of the force obtained. Once again increase the force on the test

piece until it exceeds the value obtained originally. Plot the force/ extension diagram and draw a line through the hysteresis loop. Construct another line parallel to this line, at a distance from the origin of the curve, measured along the abscissa, equal to the specified non-proportional percentage. Record the force corresponding to the point at which this line intersects the curve. Calculate the proof strength by dividing this force by the original cross-sectional area (S_o) of the test piece.

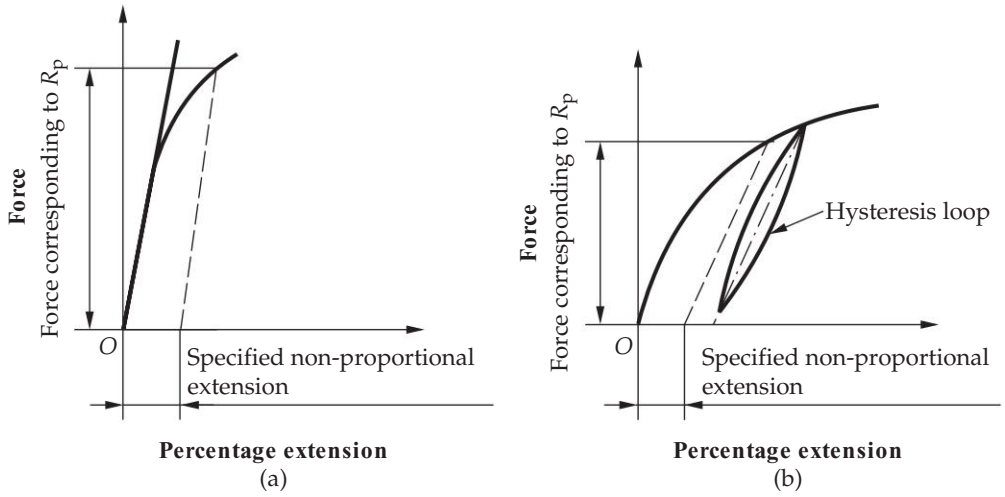


Fig. 1.13 *Force/extension diagram illustrating the determination of proof strength (non-proportional extension) (R_p)* (*Source:* Ref. 1)

5.9 Determination of Proof Strength (Total Elongation) (R_t)

Draw a line parallel to the ordinate axis (force axis) of the force/ extension diagram, at a distance equal to the specified total percentage elongation, for example 0.5%. Record the force corresponding to the point at which this line intersects the curve. Calculate the proof strength (total elongation) by dividing this force by the original cross-sectional area (S_o) of the test piece (see Fig. 1.14).

5.10 Determination of Percentage Elongation after Fracture (*A*)

Fit the ends of the two broken pieces of the test piece together so that their axes lie in a straight line. Measure the final gauge length (L_u) (see Fig. 1.3), to the nearest 0.25 mm, and calculate the percentage elongation after fracture (A) from the formula given below:

$$A = \frac{L_u - L_o}{L_o} \times 100$$

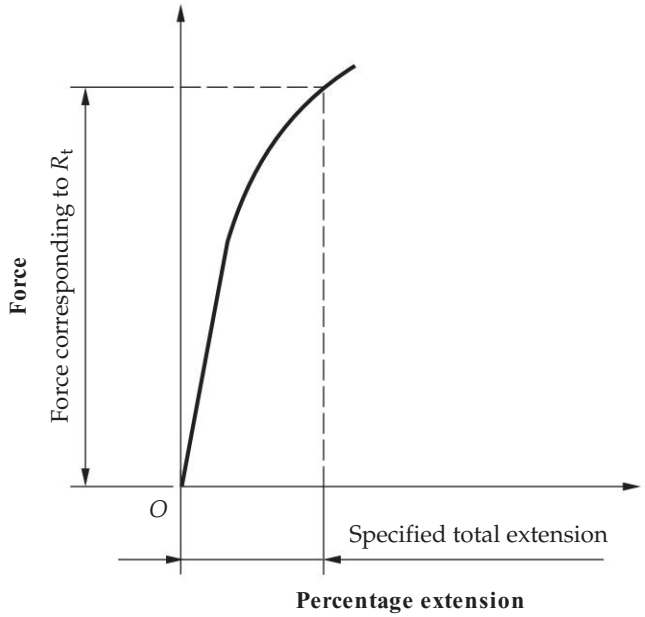


Fig. 1.14 *Force/extension diagram illustrating the determination of proof strength (total extension) (R_t)* (*Source:* Ref. 1)

Notes:

1) If the distance between the fracture and the nearest gauge mark is less than one-third the original gauge length (L_o), the measured elongation, though greater than the specified value, may not be representative of the material.
2) If elongation is measured over a fixed gauge length, it can be converted to proportional gauge length, using the conversion formulae or tables given in IS 3803-1 and IS 3803-2.

5.11 Determination of Percentage Reduction of Area (Z)

Fit the ends of the two broken pieces of the test piece together so that their axes lie in a straight line. Determine the minimum cross-sectional area after fracture (S_u) (see Fig. 1.3), and calculate the percentage reduction of area from the formula given below:

$$Z = \frac{S_o - S_u}{S_o} \times 100$$

6 REFERENCES

1. IS 1608:1995, *Mechanical Testing of Metals — Tensile Testing.*
2. *ASM Handbook*, Vol. 9, ASM International, Materials Park, Ohio, USA, 1985.
3. G. E. Dieter, *Mechanical Metallurgy*, 2nd Edition, McGraw-Hill, New York, USA, 1981.

4. IS 12872:1990, *Metallic Materials — Verification of Extensometers used in Uniaxial Testing.*
5. IS 3803-1:1989, *Steel — Conversion of Elongation Values — Part 1: Carbon and Low Alloy Steels.*
6. IS 3803-2:1989, *Steel — Conversion of Elongation Values — Part 1: Austenitic Steels.*
7. ISO 783:1999, *Metallic Materials — Tensile Testing at Elevated Temperature.*
8. ISO 6892:1998, *Metallic Materials — Tensile Testing at Ambient Temperature.*
9. ISO 15579:2000, *Metallic Materials — Tensile Testing at Low Temperature.*

2

Bend Test

1 PRINCIPLE

The bend test is a ductility test which is employed to evaluate the ability of metallic materials to undergo plastic deformation in bending. The test consists of submitting a test piece of round, square, rectangular, or polygonal cross-section to plastic deformation by bending, without changing the direction of loading, until a specified angle of bend is reached.

2 APPARATUS

The bend test should be carried out on a universal testing machine or press equipped with the following devices:

1) Bending device with two supports and a mandrel (see Fig. 2.1);
2) Bending device with a V-block and a mandrel (see Fig. 2.2); and
3) Bending device with a clamp (see Fig. 2.3).

3 TEST CONDITIONS

3.1 Test Piece

Round, square, rectangular, or polygonal cross-sectional test pieces should be used in the test. Any area of the material affected by shearing or flame cutting, and similar operations during the sampling of test pieces should be removed.

The edges of the rectangular test pieces should be rounded to a radius not exceeding one-tenth of the thickness of the test pieces. The rounding should be made to prevent the formation of transverse burrs, scratches or marks, which may adversely affect the test results.

The width of the test piece should be as follows:

1) The same as the product width, if the latter is equal to or less than 20 mm; and
2) *When the width of a product is more than 20 mm*: 20±5 mm for products of thickness of less than 3 mm, and between 20 mm and 50 mm for products of thickness equal to or greater than 3 mm.

3.1.1 Thickness of the Test Piece

The thickness of the test pieces from plates, sheets, strips and sections should be equal to the thickness of the product to be tested. If the thickness of the product is greater than 25 mm, it may be reduced by machining one surface to give a thickness of not less than 25 mm.

The round or polygonal cross-section test pieces should be submitted to the bend test while having a cross-section equal to that of the product if the diameter (for a round cross-section) or the inscribed circle diameter (for a polygonal cross-section) does not exceed 50 mm. When the diameter, or the inscribed circle diameter, of the test piece exceeds 30 mm up to and including 50 mm, it may be reduced to not less than 25 mm. When the diameter, or the inscribed circle diameter, of the test piece exceeds 50 mm, it should be reduced to not less than 25 mm.

Note: During bending, the unmachined side should be on the tension side surface of the test piece.

In the case of forgings, castings and semi-finished products, the dimensions of the test piece should be defined in the relevant standard.

The length of a test piece depends on the thickness of the test piece and the test equipment used.

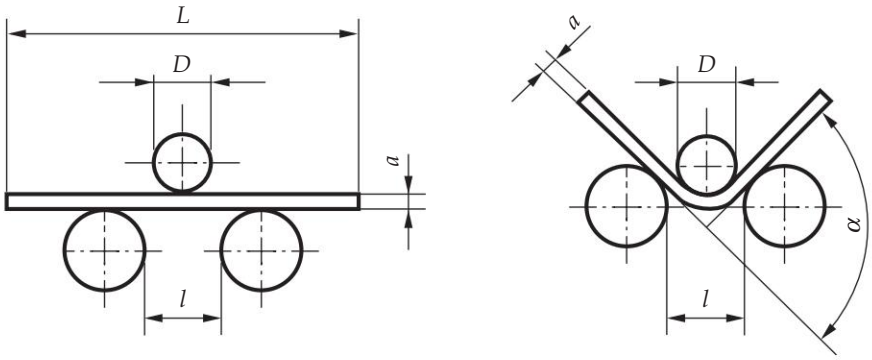
3.2 Test Temperature

The test should be carried out at temperature between 10 °C and 35 °C.

4 TEST PROCEDURE

The bend test should be carried out using one of the following methods specified in the relevant standard:

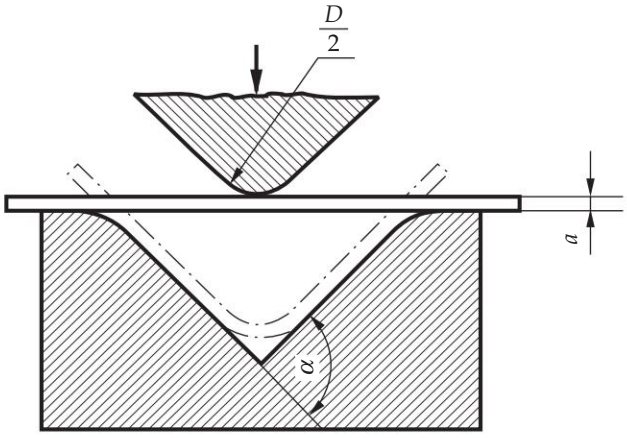
1) **Guided Bend Test**: Ensure that the length of the supports and the width of the mandrel are greater than the width or diameter of the test piece. Place the test piece on the supports and apply a continuously increasing bending force through the mandrel (see Fig. 2.1) in the middle of the test piece until a specified angle of bend is achieved or until failure occurs.
2) **Semi-Guided Bend Test:** Place the test piece on the V-block and apply a continuously increasing bending force in the middle (see Fig. 2.2) until a specified angle of bend is achieved or until failure occurs.



Key:

a = Diameter or thickness of the test piece
D = Diameter of the mandrel
L = Length of the test piece
l = Distance between supports
α = Angle of the bend

Fig. 2.1 *Guided bend test — Bending device with two supports and a mandrel* (*Source:* Ref. 1)



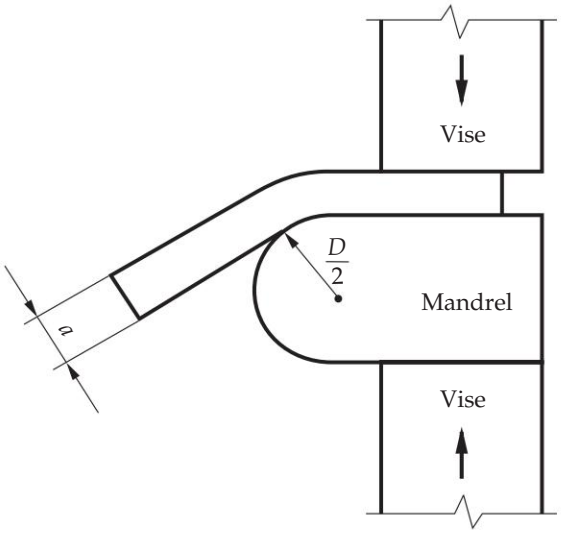
Key:

a = Diameter or thickness of the test piece
D = Diameter of the mandrel
α = Angle of the bend

Fig. 2.2 *Semi-guided bend test — Bending device with a V-block and a mandrel* (*Source:* Ref. 1)

Alternatively, securely clamp the test piece and the mandrel in a vise and apply a bending force (see Fig. 2.3) with a hand-operated lever or hammer the test piece over the rounded edge of the bending die with a plastic or rawhide mallet until a specified angle of bend is achieved or until failure occurs. Do not strike the test piece in an area that will form part of the bend.

3) **Free Bend Test:** Give a preliminary bend to the test piece in a bending fixture (see Fig. 2.1), and then position the test piece vertically between the parallel plates of the press.



Key:

a = Diameter or thickness of the test piece
D = Diameter of the mandrel

Fig. 2.3 *Semi-guided bend test — Bending device with a clamp* (*Source:* Ref. 1)

Press directly on the ends of the legs of the test piece [see Fig. 2.4(a)] to obtain parallelism of the legs [see Fig. 2.4(b)]. Carry out the test with or without insert. The thickness of the insert should be defined in the product standard. If specified, bend the test piece further between the parallel plates of the press, by applying a continuously increasing force, to obtain direct contact between the legs of the test piece [see Fig. 2.4(c)].

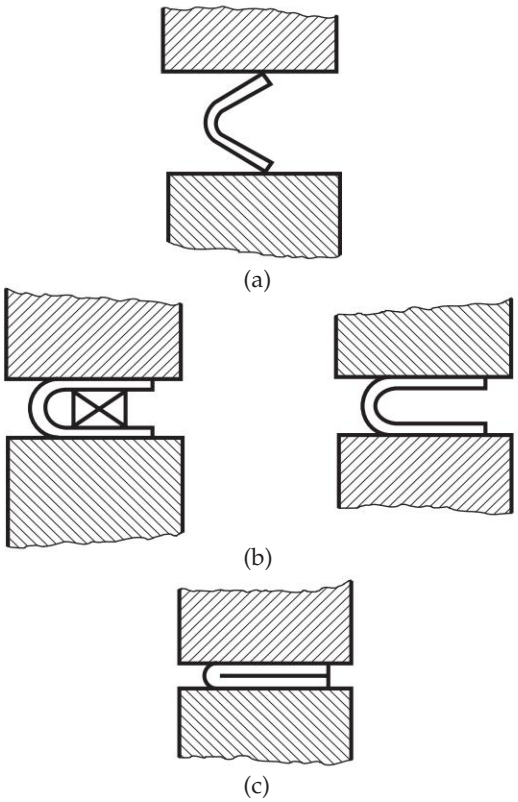


Fig. 2.4 *Free bend test* (*Source:* Ref. 1)

5 REFERENCES

1. IS 1599:1985, *Method for Bend Test*.
2. ASTM E 290:1997a, *Test Methods for Bend Testing of Material for Ductility*.
3. ISO 7438:1985, *Metallic Materials — Bend Test*.
4. ASM Handbook, Vol. 8, ASM International, Materials Park, Ohio, USA, 1985.

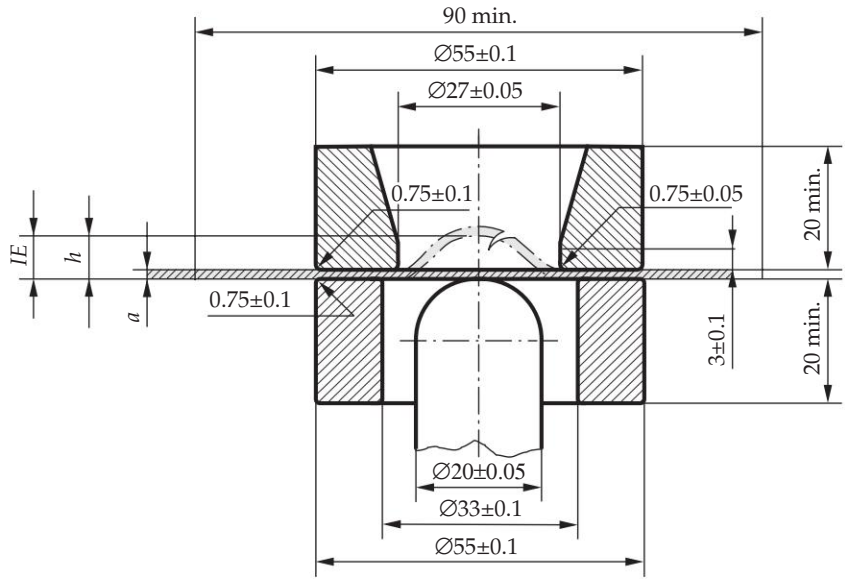
3

Erichsen Cupping Test for Metallic Sheet and Strip

1 PRINCIPLE

The Erichsen cupping test is a ductility test which is employed to evaluate the ability of metallic sheets and strips to undergo plastic deformation in stretch forming. The test consists of forming an indentation by pressing a punch with a spherical end against a test piece clamped between a blank holder and a die, until a through crack appears. The depth of the cup is measured (see Fig. 3.1).

(Dimensions in millimetres)



Key:

a = Thickness of the test piece
h = Depth of the indentation during the test
IE = Erichsen cupping index

Fig. 3.1 *Principle of the Erichsen cupping test* (*Source:* Ref. 1)

2 DEFINITION

Through Crack

A crack that goes through the full thickness of the test piece and is just sufficiently wide to allow light to pass through part of its length.

3 APPARATUS

The Erichsen cupping test should be carried out on a machine (see Fig. 3.2) equipped with a die, punch and blank holder.

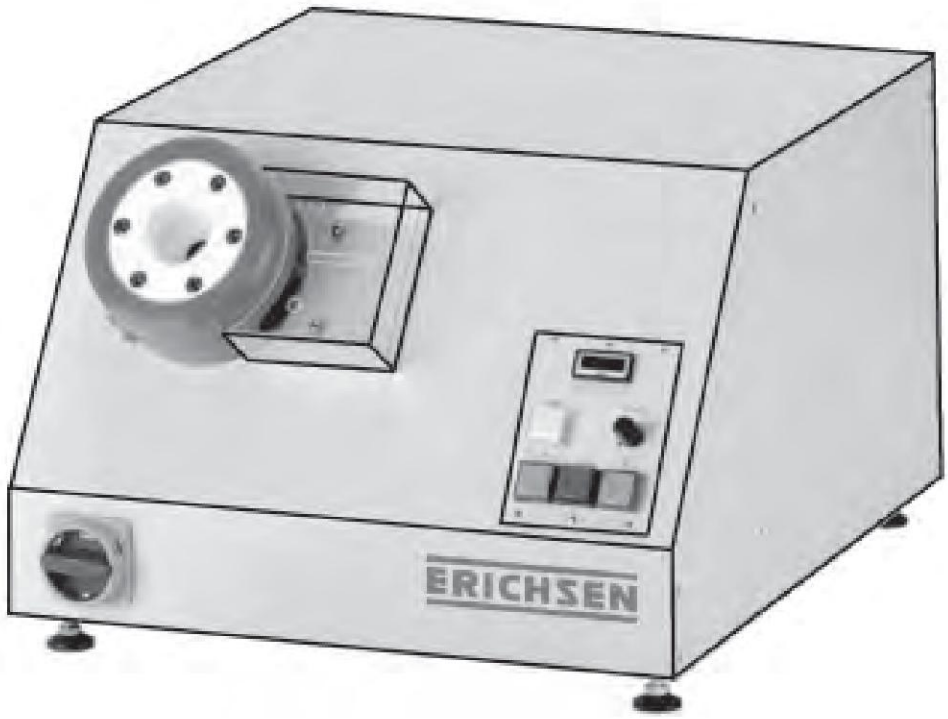


Fig. 3.2 *Erichsen cupping testing machine (Courtesy of ERICHSEN)*

The construction of the testing machine should be such that it is possible to observe the outside of the test piece during the test to be able to determine the instant when a through crack appears.

The die, the blank holder and the punch should be sufficiently rigid so as not to deform during the test. The hardness of the working surfaces of the die, the blank holder and the

punch should be at least 750 HV 30. The punch should not turn during the test. The working surface of the punch should be spherical and polished. This spherical portion should be in contact with the test piece during the test.

The machine should be capable of holding the test piece with a constant holding force of approximately 10 kN.

4 TEST CONDITIONS

4.1 Test Piece

4.1.1 Surface

The test piece should be flat, smooth and free from foreign matter, such as dirt and oil.

4.1.2 Preparation

The preparation of the test piece should not produce any burr or distortion on the edges, which would prevent it from being placed in the machine and which could interfere with the performance of the test.

Before it is tested, the test piece should not be submitted to any hammering or hot or cold working.

4.1.3 Dimensions

The test piece should be circular or rectangular in shape. Its thickness should be that of the sheet or strip to be tested. The width or diameter of the test piece should be at least 90 mm.

Note: The upper limit of the width or diameter is guided by the corresponding dimension of the aperture in the testing machine.

4.1.4 Spacing of Indentations

The distance between the centre of any indentation and the edge of the test piece should be at least 45 mm.

The distance between the centres of two adjacent indentations should be at least 90 mm.

4.2 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

5 TEST PROCEDURE

Measure the thickness of the test piece to the nearest 0.01 mm.

Lightly lubricate the surfaces of the test piece, which will be in contact with the punch and die, with graphite grease.

Clamp the test piece between the blank holder and the die with a force of about 10 kN.

Bring the punch into contact with the test piece, without shock. Make the measurement of penetration from this point.

Form the indentation smoothly, at a rate between 5 mm/ min and 10 mm/ min. Towards the end of the operation, reduce the speed to the vicinity of the lower limit in order to accurately determine the moment when a through crack appears.

Note: When using computer controlled testing machines, the reduction of rate at the end of the test is not necessary.

Terminate the movement of the punch at the instant when a crack appears through the full thickness of the test piece.

Measure the depth of penetration to the nearest 0.1 mm. Conduct a minimum of three tests, and calculate the arithmetic mean of the values of depth of penetration. This depth, expressed in millimetres, is the value of the Erichsen cupping index *IE*.

6 REFERENCES

1. IS 10175-1:1993, *Mechanical Testing of Metals— Modified Erichsen Cupping Test — Sheet and Strip— Part 1: Thickness up to 2 mm*.
2. ISO 20482:2003, *Metallic Materials— Sheet and Strip— Erichsen Cupping Test*.
3. *ASM Handbook*, Vol. 8, ASM International, Materials Park, Ohio, USA, 1985.

4

Simple Torsion Test for Metallic Wire

1 PRINCIPLE

The simple torsion test is a ductility test which is employed to evaluate the ability of a metallic wire to undergo plastic deformation during simple torsion in one direction. The test consists of twisting a test piece of wire around its own axis in one direction (see Fig. 4.1), until the test piece breaks or until a specified number of turns is reached.

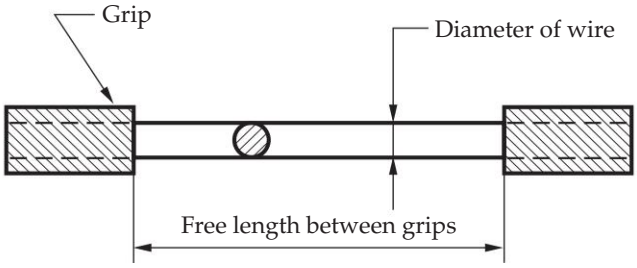


Fig. 4.1 *Principle of simple torsion test for metallic wire* (*Source:* Ref. 1)

2 APPARATUS

The testing machine (see Fig. 4.2, Plate 2) should consist of a pair of grips having a minimum hardness of 55 HRC. The grips should be placed in the testing machine in such a way that during testing they remain on the same axis and do not apply any bending force to the test piece.

The testing machine should be constructed in such a way that a change of length between the grips, caused by the contraction of the test piece during testing, is not prevented and that an appropriate tensile stress may be applied to the test piece.

One of the grips should be capable of being rotated around the axis of the test piece while the other should be fixed.

It should be possible to adjust the distance between the grips for different test lengths.

3 TEST CONDITIONS

3.1 Test Piece

The length of wire to be used as the test piece should be of sufficient length and as straight as possible.

If straightening is necessary, it should be done by hand or, by any other suitable method (see Ref. 2—Annex B for recommended method).

During straightening, the surface of the wire should not be damaged and the test piece should not be subjected to any twisting.

A wire with a localized sharp curvature should not be straightened.

3.2 Test Temperature

The test should be carried out at a temperature between 10 °C to 35 °C.

4 TEST PROCEDURE

Measure the diameter or characteristic dimension of the wire.

Clamp the test piece in the grips of the testing machine in such a way that its longitudinal axis coincides with the axis of the grips and so that it remains straight during the test. To ensure this apply to the test piece a constant tensile stress just sufficient to straighten it, but not exceeding 2 % of the value of the nominal tensile strength of the wire.

Adjust the free length between grips to the values given in Table 4.1.

Table 4.1 *Free Length between Grips for Various Wire Diameters or Characteristic Dimensions*

Diameter or characteristic dimension mm	Free length between grips[1)]
≥ 0.3 < 1	$200d$[2)]
≥ 1 < 5	$100d$[2)]
≥ 5 ≤ 10	$50d$[2)]

[1)] Free length between grips should not exceed 300 mm.

[2)] d = diameter of round wire or characteristic dimension of non-circular wire.

Source: Ref. 1

Rotate one grip at a constant speed, not exceeding the value given in Table 4.2 until the test piece breaks or until a specified number of turns is achieved.

Note: If necessary, reduce the speed of testing to ensure that the temperature of the test piece does not exceed 60 °C.

Count the number of complete turns imparted to the wire by the rotating grip. If the number of turns meets the specified value the test piece is considered to have passed the test.

Table 4.2 *Speed of Testing*

Diameter or characteristic dimension mm	Maximum number of turns per second		
	Steel	Copper and copper alloys	Aluminium and aluminium alloys
< 1.0	1	5	1
≥ 1.0 < 1.5	0.5	2	
≥ 1.5 < 3.0		1.5	
≥ 3.0 < 3.6		1	
≥ 3.6 < 5.0			
≥ 5.0 ≤ 10.0	0.25	0.5	

Source: Refs. 1 and 2

5 REFERENCES

1. IS 1717:1985, *Method for Simple Torsion Test for Wire.*
2. ISO 7800:2003, *Metallic Materials— Wire— Simple Torsion Test.*
3. *ASM Handbook,* Vol. 8, ASM International, Materials Park, Ohio, USA, 1985.

5

Wrapping Test for Metallic Wire

1 PRINCIPLE

The wrapping test is a ductility test which is employed to evaluate the ability of metallic wire to undergo plastic deformation during wrapping. The test consists of winding a wire to a specified number of turns around a mandrel of specified diameter to form a closely wrapped helix (see Fig. 5.1).

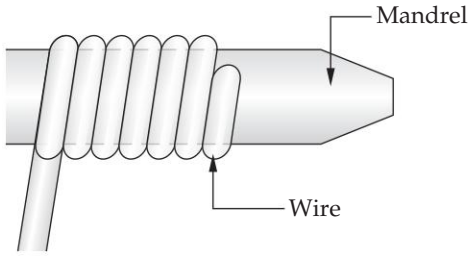


Fig. 5.1 *Principle of the wrapping test for metallic wire*

2 APPARATUS

The testing machine should be capable of winding a wire around a mandrel in a helix so that adjacent wraps of the coil are in contact with each other.

3 TEST CONDITIONS

3.1 Test Piece

The length of wire to be used as the test piece should be of sufficient length and as straight as possible.

3.2 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

4 TEST PROCEDURE

Wind the wire in a helix tightly around the mandrel at a constant speed not exceeding one turn per second, so that the adjacent wraps of the coil are in contact with each other. If necessary, reduce the rate of wrapping to ensure that the heat generated does not affect the result of the test.

In order to ensure tight winding, apply a constant tensile stress not exceeding 5 % of the nominal tensile strength of the wire during winding.

After the test, examine the test piece with the naked eye for wire with a diameter or thickness between 0.5 and 10 mm, and at a magnification of about 10× for wire with a diameter or thickness of less than 0.5 mm. The absence of cracks is evidence of the fact that the test piece has withstood the test.

5 REFERENCES

1. IS 1755:1983, *Method for Wrapping Test for Metallic Wire*.
2. ISO 7802:1983, *Metallic Materials— Wire— Wrapping Test*.

6

Flattening Test on Metallic Tubes

1 PRINCIPLE

The flattening test is a ductility test which is employed to evaluate the ability of metallic tubes of circular cross-section to undergo plastic deformation by flattening. It may also be used to reveal defects in the tubes. The flattening test consists of flattening a test piece of specified length cut from a tube, in a direction perpendicular to the longitudinal axis of the tube until the distance between the platens reaches a specified value [see Figs. 6.1(a) and 6.1(b)].

In the case of close flattening, the internal surfaces of the test piece should be in contact with each other over at least half of the internal width of the flattened test piece [see Fig. 6.1(c)].

2 APPARATUS

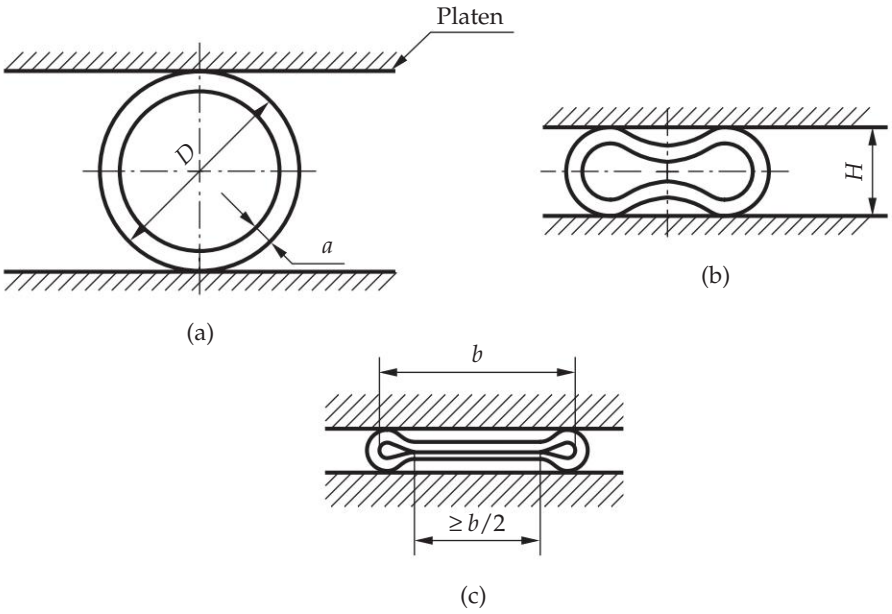
The testing machine should be capable of flattening the test piece to the specified distance between plane, parallel, rigid platens.

The width of the platens should exceed the width of the test piece after flattening, i.e. 1.6 times the outside diameter of the tube, and the length of the platens should extend over the whole length of the test piece.

3 TEST CONDITIONS

3.1 Test Piece

The length of the test piece should be not less than 10 mm nor greater than 100 mm. A length of 40 mm is generally used. The edges of the test piece should be rounded by filing.



Key:

D = Outside diameter of the tube

a = Wall thickness of the tube

b = Inside width of the flattened test piece

H = Distance between platens measured under load

Fig. 6.1 *Principle of the flattening test on metallic tubes* (*Source:* Ref. 1)

3.2 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

4 TEST PROCEDURE

Place the test piece between the two platens.

Unless otherwise specified, ensure that the position of the weld in the welded tube is in the 3 o'clock or 9 o'clock position.

Flatten the test piece by moving the platens in a direction perpendicular to the longitudinal axis of the tube.

Ensure that the rate of movement of the platens does not exceed 25 mm/ min.

After the test, examine the test piece with the naked eye. Evaluate the test piece in accordance with the criteria for approval or rejection. The absence of cracks is evidence of the fact that the test piece has passed the test. Slight cracking at the edges should not be considered as a cause for rejection.

5 REFERENCES

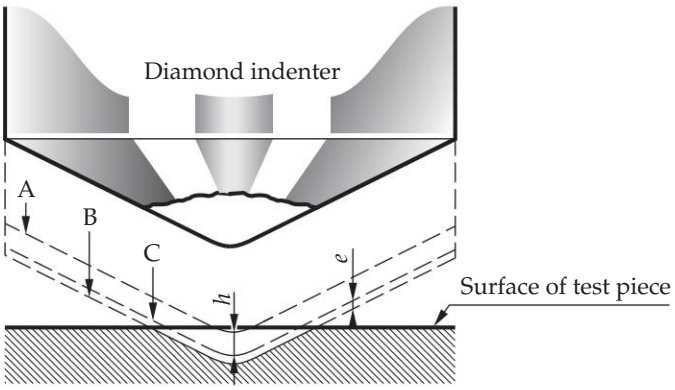
1. IS 2328:1983, *Method for Flattening Test on Metallic Tubes.*
2. ISO 8492:1998, *Metallic Materials— Tube— Flattening Test.*

7

Rockwell and Rockwell Superficial Hardness Tests

1 PRINCIPLE

The Rockwell and Rockwell superficial hardness tests are indentation hardness tests in which a diamond cone having an included angle of 120° and a radius of curvature at the tip of 0.2 mm, or a hardened steel or hardmetal ball having a diameter of 1.5875 mm or 3.175 mm, is forced into the surface of a test piece in two steps (see Fig. 7.1), and the permanent depth



Key:

A = Position of indenter under preliminary test force before application of additional test force
B = Position of indenter under total test force
C = Position of indenter under preliminary test force just after removal of additional test force
h = Permanent depth of indentation under preliminary test force just after removal of additional test force
e = Elastic recovery just after removal of additional test force

Fig. 7.1 *Principle of the Rockwell and Rockwell superficial hardness tests*
(Although a diamond indenter is illustrated, the same principle applies for a hardened steel or hardmetal ball indenter)
(Courtesy of ASM International)

of indentation under preliminary test force (minor load) after removal of the additional test force is measured.

The Rockwell hardness value is derived from the permanent depth of indentation. It is calculated by using the following formula:

$$\text{Rockwell hardness value} = N - \frac{h}{S}$$

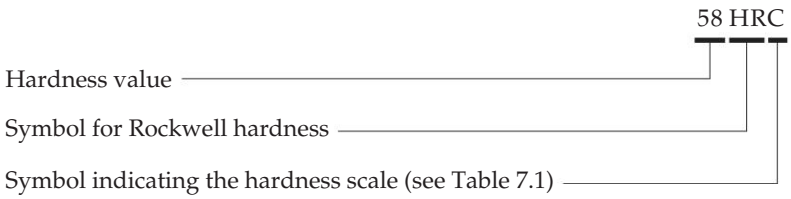
where:

N = number specific to the Rockwell hardness scale; 100 for scales A, C, D, 15N, 30N, 45N, 15T, 30T and 45T, and 130 for scales B, E, F, G, H and K,

h = permanent depth of indentation, in mm, under preliminary test force (minor load) just after removal of the additional test force, and

S = scale unit, specific to the Rockwell hardness scale; 0.002 mm for scales A, B, C, D, E, F, G, H and K, and 0.001 mm for scales 15N, 30N, 45N, 15T, 30T and 45T.

2 DESIGNATION OF ROCKWELL AND ROCKWELL SUPERFICIAL HARDNESS



Example

1) 58 HRC indicates a Rockwell hardness value of 58, measured on the C scale.
2) 89 HR15N indicates a Rockwell superficial hardness value of 89, measured on the 15N scale with a total test force of 147.1 N (15 kgf).

3 APPARATUS

3.1 Testing Machine

The Rockwell and Rockwell superficial hardness testing machine (see Fig. 7.2, Plate 3) should comply with the requirements given in IS 1586. It should be capable of applying the test force(s) given in Table 7.1.

Table 7.1 *Conditions for Rockwell and Rockwell Superficial Hardness Tests*

Rockwell hardness scale	Hardness symbol	Type of indenter	Preliminary test force (minor load)		Additional test force (major load)		Total test force		Field of application (Rockwell hardness range)	Typical applications
			N	kgf	N	kgf	N	kgf		
Rockwell hardness test										
A	HRA	Diamond cone	98.07	10	490.3	50	588.4	60	20–88 HRA	Cemented carbides, thin steel and shallow case [1] hardened steel
B	HRB	Steel or hardmetal ball (∅1.5875 mm)	98.07	10	882.6	90	980.7	90	20–100 HRB	Copper and its alloys, soft steels, aluminium and its alloys, and malleable cast iron
C	HRC	Diamond cone	98.07	10	1373	140	1471	150	20–70 HRC	Steel, hard cast irons, pearlitic malleable cast iron, titanium and its alloys, deep case [1] hardened steel and other materials harder than 100 HRB
D	HRD	Diamond cone	98.07	10	882.6	90	980.7	100	40–77 HRD	Thin steeland medium case [1] hardened steel, and pearlitic malleable cast iron
E	HRE	Steel or hardmetal ball (∅3.175 mm)	98.07	10	882.6	90	980.7	100	70–100 HRE	Cast iron, aluminium and magnesium, and their alloys, and bearing metals
F	HRF	Steel or hardmetal (∅1.5875 mm)	98.07	10	490.3	50	588.4	60	60–100 HRF	Annealed copper and its alloys, and thin soft sheet metals
G	HRG	Steel or hardmetal ball ∅1.5875 mm)	98.07	10	1373	140	1471	150	30–94 HRG	Phosphor bronze, beryllium copper and malleable cast iron
H	HRH	Steel or hardmetal ball (∅3.175 mm)	98.07	10	490.3	50	588.4	60	80–100 HRH	Aluminium, zinc and lead, and their alloys
K	HRK	Steel or hardmetal ball (∅3.175 mm)	98.07	10	1373	140	1471	150	40–100 HRK	Bearing metals and other very soft or thin materials

Table 7.1 *contd.*

Rockwell hardness scale	Hardness symbol	Type of indenter	Preliminary test force (minor load)		Additional test force (major load)		Total test force		Field of application (Rockwell hardness range)	Typical applications
			N	kgf	N	kgf	N	kgf		
Rockwell superficial hardness test										
15N	HR15N	Diamond cone	29.42	3	117.7	12	147.1	15	70–94 HR51N	Similar to those for the Rockwell A, C and D scales, but for thinner materials or case depths
30N	HR30N	Diamond cone	29.42	3	264.8	27	294.2	30	42–86 HR30N	
45N	HR45N	Diamond cone	29.42	3	411.9	42	441.3	45	20–77 HR45N	
15T	HR15T	Steel or hardmetal ball (Ø1.5875 mm)	29.42	3	117.7	12	147.1	15	67–93 HR15T	Similar to those for the Rockwell B, F and G scales, but for thinner materials
30T	HR30T	Steel or hardmetal ball (Ø1.5875 mm)	29.42	3	264.8	27	294.2	30	29–82 HR30T	
45T	HR45T	Steel or hardmetal ball (Ø1.5875 mm)	29.42	3	411.9	42	441.3	45	10–72 HR45T	

[1)] Recommended minimum effective case depth on case hardened parts which will allow accurate determination of surface hardness:

Rockwell hardness scale	Effective case depth measured up to 513 HV
A	≥ 0.40 mm
C	≥ 0.50 mm
D	≥ 0.45 mm
15N	≥ 0.20 mm
30N	≥ 0.25 mm
45N	≥ 0.30 mm

Source: Ref. 1 and Instron Corporation

The testing machine should be verified at planned intervals in accordance with IS 1586. For routine checking, the testing machine should be verified on each day that it is used, on a reference block with approximately the same hardness level as the material being tested.

3.2 Anvil

Flat test pieces should be tested on a flat anvil [see Fig. 7.3(a)]. An anvil with a large flat surface should be used for supporting large parts. Anvils with a surface diameter greater than about 75 mm should be attached to the elevating screw by a threaded section [see Fig. 7.3(b)], rather than inserted in the anvil hole in the elevating screw.

Sheet metal, small pieces or other pieces which do not have a flat, supporting surface should be tested on the pedestal spot anvil [see Fig. 7.3(c)] which has a small elevated flat bearing surface.

Products of cylindrical shape should be supported in a hardened V-anvil [see Fig. 7.3(d)] or in a Cylindron anvil [see Fig. 7.3(e)] which consists of two hardened parallel cylinders.

Note: When testing small diameter rounds, it is essential that the center of the V be aligned with the axis of the indenter. The smaller the diameter of the round, the more critical this alignment becomes.

For long test pieces that cannot be firmly held on an anvil by the preliminary test force (minor load), because manual support is not practical, a jack-rest [see Fig. 7.3(f)] or vari-rest [see Fig. 7.3(g)] should be provided at the overhang end to prevent pressure between the test piece and the indenter.

Irregular shaped test pieces should be properly supported on specially designed fixtures if an accurate test is to be made.

Tubes and hollow pieces should be supported by a mandrel to ensure rigidity under test loads.

4 TEST CONDITIONS

4.1 Hardness Scale

The hardness scale selected (see Table 7.1) should be compatible with the type of material, thickness of the test piece or of the layer under test, width of area to be tested, and field of application of the hardness scale. If a choice exists between two or more hardness scales, the scale specifying the heavier total test force should be used.

4.2 Test Piece

4.2.1 Surface

The top and bottom surfaces of the test piece should be flat, smooth and parallel. They should also be free from oxide scale and foreign matter, such as dirt and oil.

The finish of the test surface (top surface) should permit accurate measurement of the hardness. A fine ground surface is usually adequate for the Rockwell hardness test, whereas a polished surface is recommended for the Rockwell superficial hardness test.

When determining the hardness of a test piece with a curved surface, the correction factors given in Tables 7.2 to 7.4 should be applied. Alternatively, a flat surface should be prepared in the area to be tested.

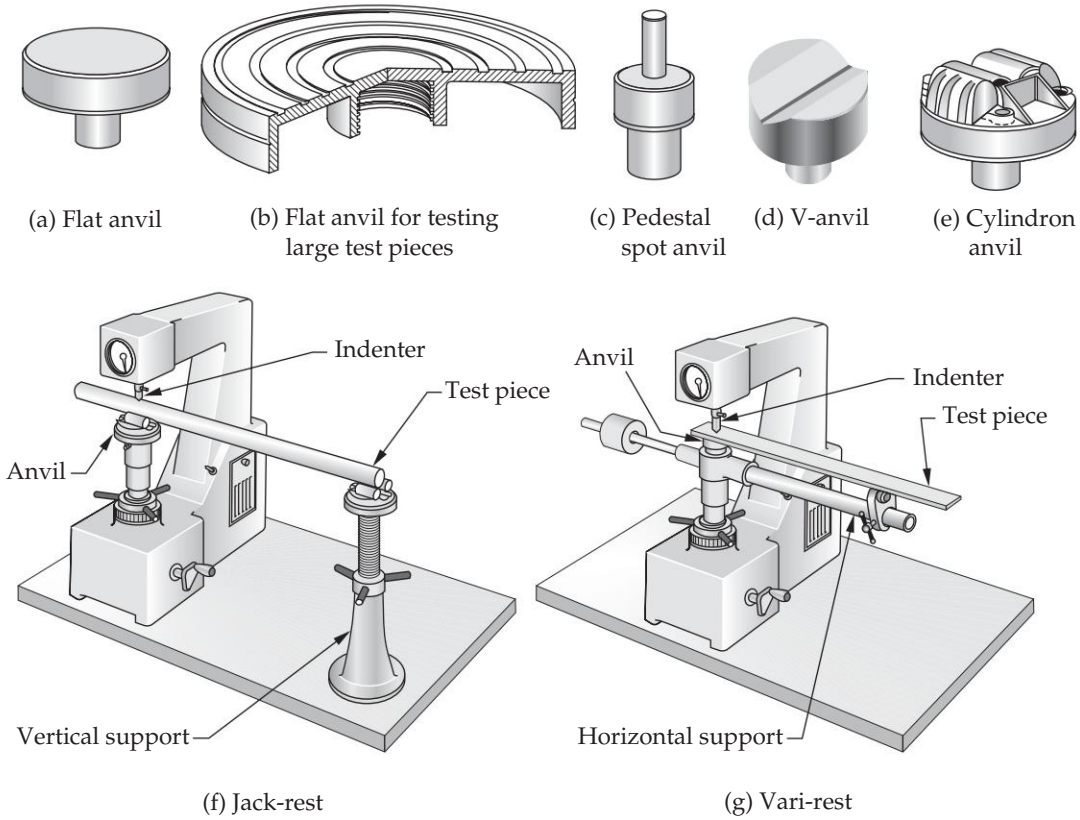


Fig. 7.3 *Common anvil types designed to support various shapes of test pieces during Rockwell and Rockwell superficial hardness testing (Courtesy of ASM International)*

4.2.2 Surface Preparation

The test piece should be prepared in such a way that there is no change in the surface hardness due to heat or cold working.

4.2.3 Thickness

The thickness of the test piece or of the layer under test should be at least ten times the permanent depth of indentation for the diamond cone indenter, and at least fifteen times the permanent depth of indentation for hardened steel or hardmetal ball indenter (see Figs. 7.4, 7.5 and 7.6).

After the test, no bulge or other marking showing the effect of the test force should be visible on the surface of the test piece opposite the indentation.

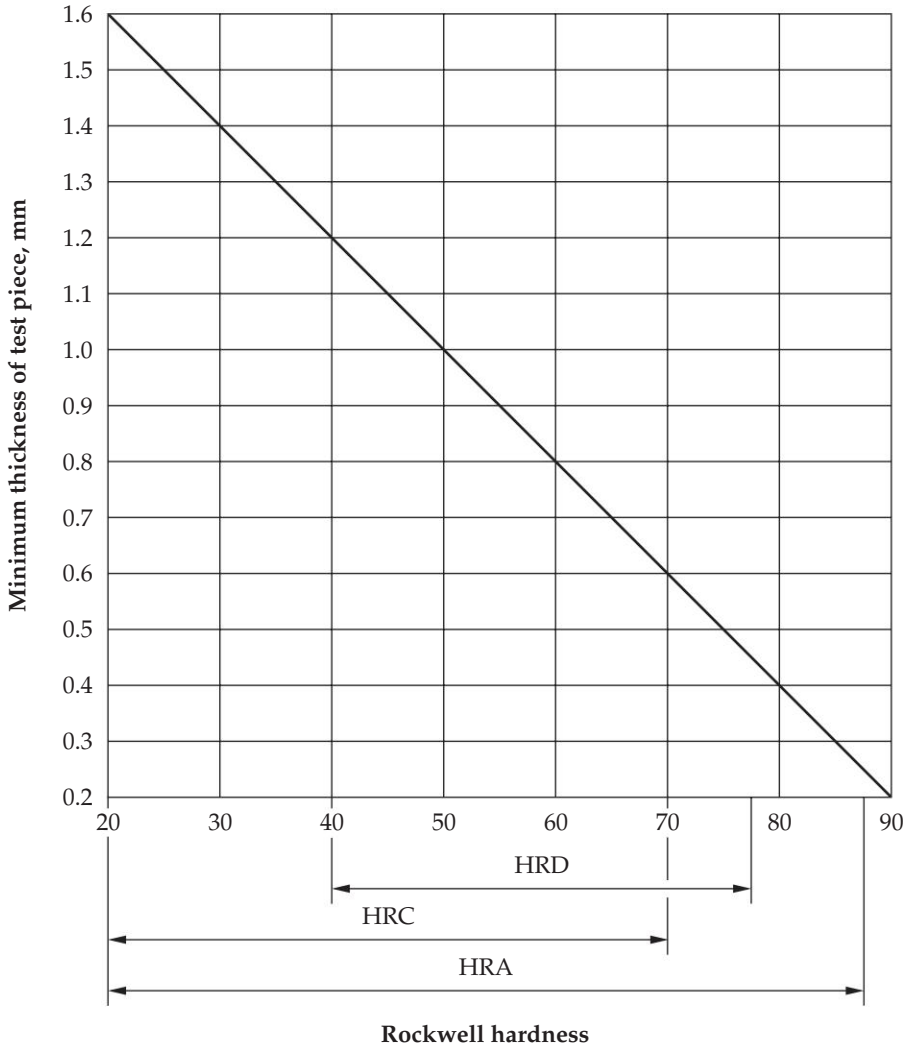


Fig. 7.4 *Minimum thickness of the test piece or of the layer under test in relation to the Rockwell hardness— Scales A, C and D* (*Source:* Ref. 1)

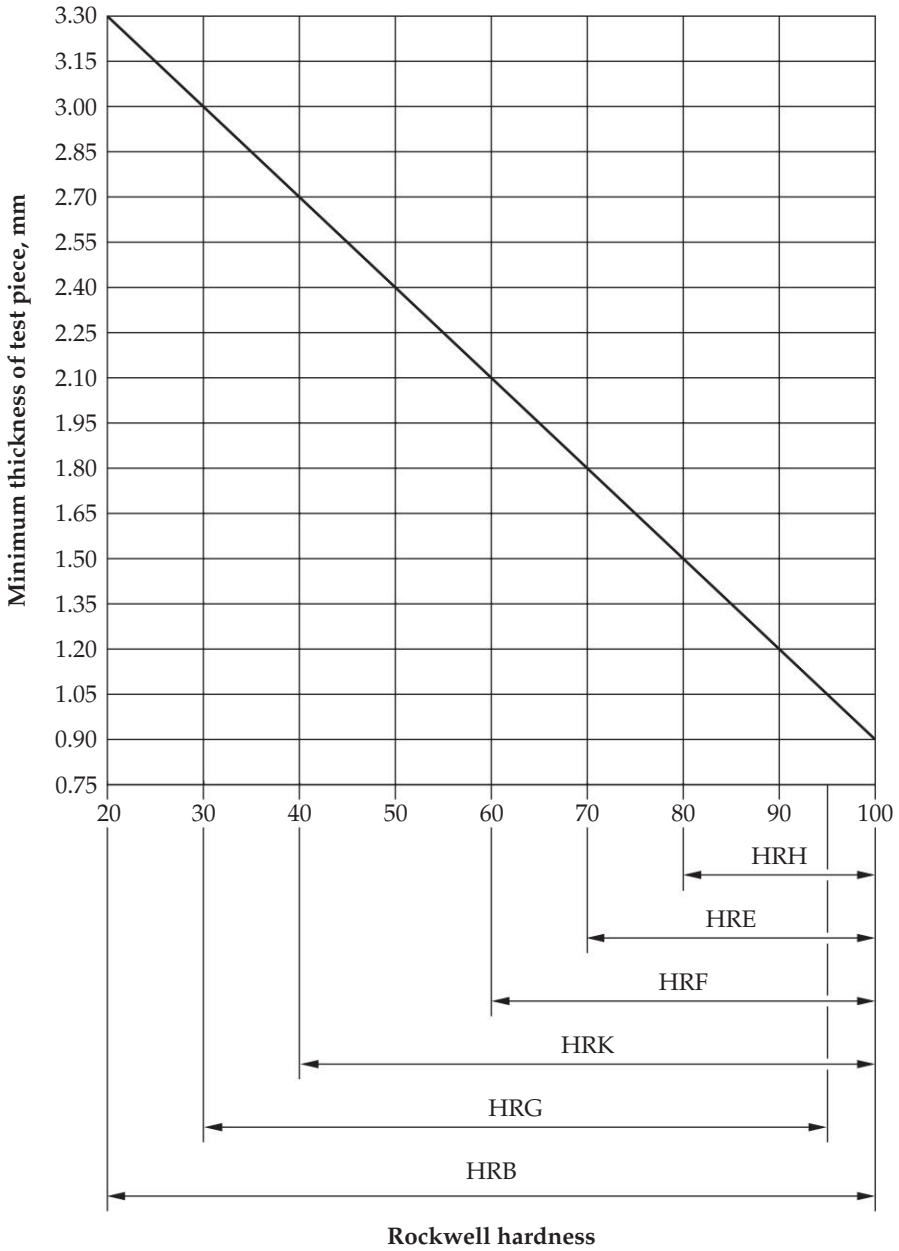


Fig. 7.5 *Minimum thickness of the test piece or of the layer under test in relation to the Rockwell hardness scales — B, E, F, G, H and K* (*Source:* Ref. 1)

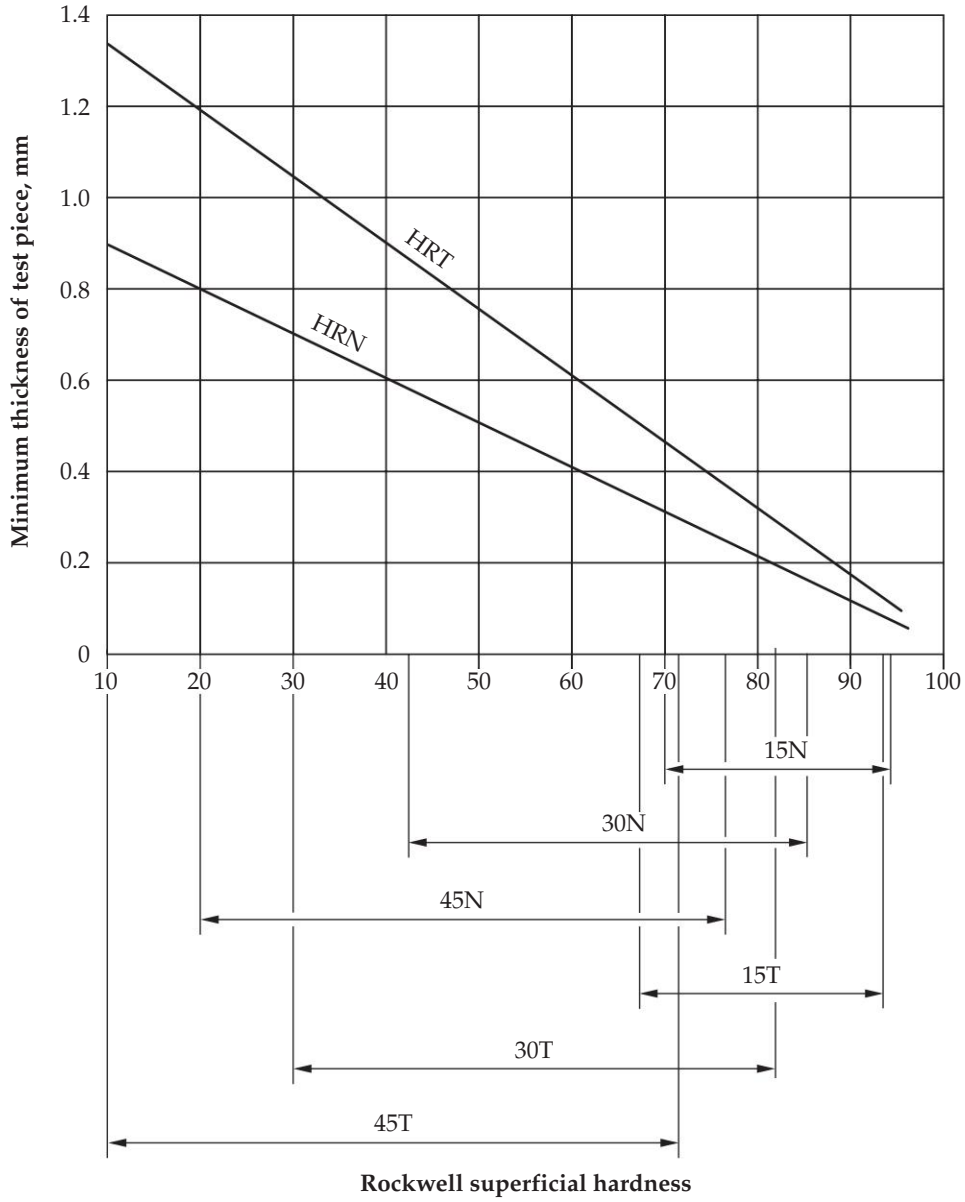


Fig. 7.6 *Minimum thickness of the test piece or of the layer under test in relation to the Rockwell superficial hardness — Scales 15N, 30N, 45N, 15T, 30T and 45T* (*Source:* Ref. 1)

4.3 Spacing of Indentations

The distance between the centre of any indentation and the edge of the test piece should be at least two-and-a-half times the diameter of the indentation, but not less than 1 mm.

The distance between the centres of two adjacent indentations should be at least four times the diameter of the indentation, but not less than 2 mm.

4.4 Anvil

The anvil surface in contact with the test piece should be smooth, and free from oxide scale and foreign matter, such as dirt and oil.

4.5 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

5 TEST PROCEDURE

Select the appropriate Rockwell hardness scale.

Place the test piece on a suitable anvil so that displacement cannot occur during the test.

Bring the indenter into contact with the test surface and apply the preliminary test force (minor load) in a direction perpendicular to the test surface, without shock or vibration.

Set the measuring device to its datum position and, without shock or vibration, apply the additional test force. Maintain the total test force (major load) for 2 s to 6 s.

While maintaining the preliminary test force (minor load), remove the additional test force and read the Rockwell hardness value directly from the measuring device after a brief period of stabilization.

For tests on convex cylindrical surfaces and spherical surfaces, apply the correction factors given in Tables 7.2 to 7.4.

Note: The Rockwell hardness value will be lower on the convex surface than on a flat test piece of the same material. For a concave surface or internal diameter the opposite is true i.e., the Rockwell hardness value will be higher.

Table 7.2 *Correction Factors to be Added to Rockwell Hardness Values Obtained on Convex Cylindrical Surfaces*

Rockwell hardness reading	Correction factor for a radius of curvature, in mm, of								
	3	5	6.5	8	9.5	11	12.5	16	19
Rockwell hardness test—Scales A, C and D									
20	–	–	–	2.5	2.0	1.5	1.5	1.0	1.0
25	–	–	3.0	2.5	2.0	1.5	1.0	1.0	1.0
30	–	–	2.5	2.0	1.5	1.5	1.0	1.0	0.5
35	–	3.0	2.0	1.5	1.5	1.0	1.0	0.5	0.5
40	–	2.5	2.0	1.5	1.0	1.0	1.0	0.5	0.5
45	3.0	2.0	1.5	1.0	1.0	1.0	0.5	0.5	0.5
50	2.5	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5
55	2.0	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0
60	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
65	1.5	1.0	1.0	0.5	0.5	0.5	0.5	0	0
70	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0	0
75	1.0	0.5	0.5	0.5	0.5	0.5	0	0	0
80	0.5	0.5	0.5	0.5	0.5	0	0	0	0
85	0.5	0.5	0.5	0	0	0	0	0	0
90	0.5	0	0	0	0	0	0	0	0
Rockwell hardness test—Scales B, F, and G									
20	–	–	–	4.5	4.0	3.5	3.0	–	–
30	–	–	5.0	4.5	3.5	3.0	2.5	–	–
40	–	–	4.5	4.0	3.0	2.5	2.5	–	–
50	–	–	4.0	3.5	3.0	2.5	2.0	–	–
60	–	5.0	3.5	3.0	2.5	2.0	2.0	–	–
70	–	4.0	3.0	2.5	2.0	2.0	1.5	–	–
80	5.0	3.5	2.5	2.0	1.5	1.5	1.5	–	–
90	4.0	3.0	2.0	1.5	1.5	1.5	1.0	–	–
100	3.5	2.5	1.5	1.5	1.0	1.0	0.5	–	–

[1] For radii other than those given in the table, the correction factors may be derived by linear interpolation.

Source: Ref. 1

Table 7.3 *Correction Factors to be Added to Rockwell Hardness C Scale Values Obtained on Convex Spherical Surfaces of Various Diameters*

Rockwell hardness reading	Correction factor [1] for a diameter, in mm, of								
	4	6.5	8	9.5	11	12.5	15	20	25
55 HRC	6.4	3.9	3.2	2.7	2.3	2.0	1.7	1.3	1.0
60 HRC	5.8	3.6	2.9	2.4	2.1	1.8	1.5	1.2	0.9
65 HRC	5.2	3.2	2.6	2.2	1.9	1.7	1.4	1.0	0.8

[1] Correction factor = $59 \times \left(1 - \frac{H}{\quad}\right)^2$

where:
H is the Rockwell hardness reading, and
d is the diameter of the sphere, in mm.

Source: Ref. 1

Table 7.4 *Correction Factors to be Added to Rockwell Superficial Hardness Values Obtained on Convex Cylindrical Surfaces*

Rockwell superficial hardness reading	Correction factor for a radius of curvature[1, 2], in mm, of						
	1.6	3.2	5	6.5	8	9.5	12.5
Rockwell superficial hardness test — Scales 15N, 30N and 45N							
20	(6.0)	3.0	2.0	1.5	–	1.5	1.5
25	(5.5)	3.0	2.0	1.5	–	1.5	1.0
30	(5.5)	3.0	2.0	1.5	–	1.0	1.0
35	(5.0)	2.5	2.0	1.5	–	1.0	1.0
40	(4.5)	2.5	1.5	1.5	–	1.0	1.0
45	(4.0)	2.0	1.5	1.0	–	1.0	1.0
50	(3.5)	2.0	1.5	1.0	–	1.0	1.0
55	(3.5)	2.0	1.5	1.0	–	0.5	0.5
60	3.0	1.5	1.0	1.0	–	0.5	0.5
65	2.5	1.5	1.0	0.5	–	0.5	0.5
70	2.0	1.0	1.0	0.5	–	0.5	0.5
75	1.5	1.0	0.5	0.5	–	0.5	0
80	1.0	0.5	0.5	0.5	–	0	0
85	0.5	0.5	0.5	0.5	–	0	0
90	0	0	0	0	–	0	0

Table 7.4 *contd.*

Rockwell superficial hardness reading	Correction factor for a radius of curvature[1), 2)], in mm, of						
	1.6	3.2	5	6.5	8	9.5	12.5
Rockwell superficial hardness test — Scales 15N, 30N and 45N							
20	(13.0)	(9.0)	(6.0)	(4.5)	(3.5)	(3.0)	(2.0)
30	(11.5)	(7.5)	(5.0)	(4.0)	(3.5)	2.5	2.0
40	(10.0)	(6.5)	(4.5)	(3.5)	3.0	2.5	2.0
50	(8.5)	(5.5)	(4.0)	3.0	2.5	2.0	1.5
60	(6.5)	(4.5)	3.0	2.5	2.0	1.5	1.5
70	(5.0)	(3.5)	2.5	2.0	1.5	1.0	1.0
80	3.0	2.0	1.5	1.5	1.0	1.0	0.5
90	1.5	1.0	1.0	0.5	0.5	0.5	0.5

[1)] For radii other than those given in the Table, the correction factors may be derived by linear interpolation.

[2)] The correction factors given in parentheses should not be used except by agreement.

Source: Ref. 1

6 REFERENCES

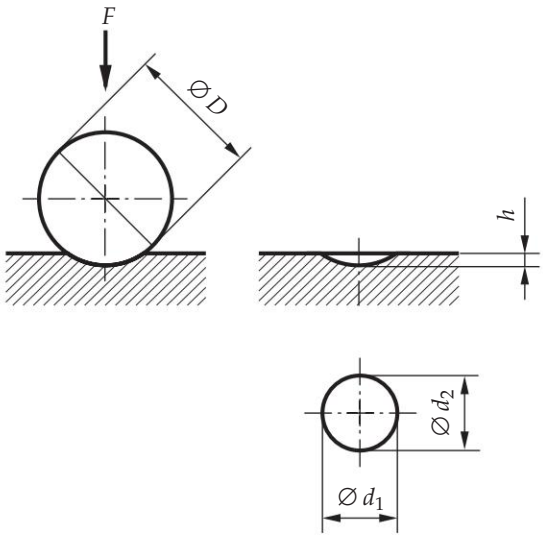
1. IS 1586:2000, *Method for Rockwell Hardness Test for Metallic Materials* (*Scales A, B, C, D, E, F, G, H, K, 15N, 30N, 45N, 15T, 30T and 45T*).
2. ISO 6508-1:1999, *Metallic Materials — Rockwell Hardness Test — Part 1: Test Method* (*Scales A, B, C, D, E, F, G, H, K, N, T*).
3. *ASM Handbook,* Vol. 8, ASM International, Materials Park, Ohio, USA, 1985.
4. SAE J417:1983, *Hardness Tests and Hardness Number Conversions.*

8

Brinell Hardness Test

1 PRINCIPLE

The Brinell hardness test is an indentation hardness test in which a hardmetal ball is forced into the surface of a test piece and the mean diameter of the indentation left in the surface after removal of the test force, is measured (see Fig. 8.1).



Key:

F	= Test force, in N
D	= Diameter of the ball, in mm
d_1 and d_2	= Diameters of the indentation, in mm, in two directions at right angles to each other
h	= Depth of the indentation, in mm

Fig. 8.1 *Principle of the Brinell hardness test* (*Source:* Ref. 1 and 4)

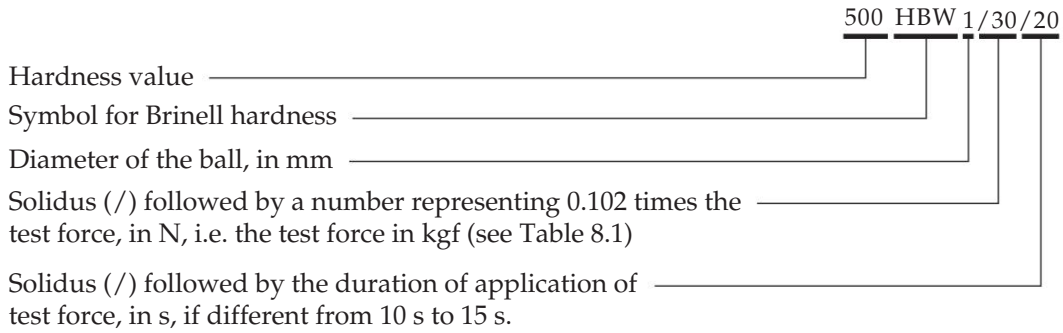
The Brinell hardness is obtained by dividing the test force by the curved surface area of the indentation. It is calculated by using the following formula:

$$\text{Brinell hardness value} = 0.102 \times \frac{2 \times F}{\pi \times D \times \left(D - \sqrt{D^2 - d^2} \right)}$$

where:

F = test force, in N,
D = diameter of the ball, in mm, and
d = mean diameter of the indentation, in mm.

2 DESIGNATION OF BRINELL HARDNESS



Examples

1) 229 HBW 2.5/ 187.5 indicates a Brinell hardness value of 229 determined with a hardmetal ball of 2.5 mm diameter and with a test force of 1839 N (187.5 kgf) applied for 10 s to 15 s.
2) 500 HBW 1/ 30/ 20 indicates a Brinell hardness value of 500 determined with a hardmetal ball of 1 mm diameter and with a test force of 294.2 N (30 kgf) applied for 20 s.

Table 8.1 *Test Forces for Determination of Brinell Hardness*

Diameter of ball mm	Test force for a force-diameter ratio[1] of											
	1		2.5		5		10		15		30	
	N	kgf	N	kgf	N	kgf	N	kgf	N	kgf	N	kgf
1	9.807	1	24.52	2.5	49.03	5	98.07	10	–	–	294.2	30
2.5	61.29	6.25	153.2	15.625	306.5	31.25	612.9	62.5	–	–	1839	187.5
5	245.2	25	612.9	62.5	1226	125	2452	250	–	–	7355	750
10	980.7	100	2452	250	4903	500	9807	1000	14710	1500	29420	3000

[1] See Section 4.1.

3 APPARATUS

3.1 Testing Machine

The Brinell hardness testing machine (see Fig. 8.2, Plates 4 and 5) should comply with the requirements given in IS 2281. It should be capable of applying the test force(s) given in Table 8. 1.

The testing machine should be verified at planned intervals in accordance with IS 2281. For routine checking, the testing machine should be verified on each day that it is used, on a reference block with approximately the same hardness level as the material being tested.

4 TEST CONDITIONS

4.1 Force-Diameter Ratio

The force-diameter ratio should be compatible with the type of material and the hardness of the test piece as indicated in Table 8.2. It is calculated by using the following formula:

$$\text{Force-diameter ratio} = 0.102 \times \frac{F}{D^2}$$

where:

F = test force, in N, and

D = diameter of the ball, in mm.

Table 8.2 *Force-Diameter Ratio for Different Metallic Materials*

Material	Brinell hardness HBW	Force-diameter ratio N/mm²
Steel, nickel alloys and titanium alloys		30
Cast iron[1)]	< 140	10
	≥ 140	30
Copper and its alloys	< 35	5
	35 to 200	10
	> 200	30
Light metals and their alloys	< 35	2.5
	35 to 80	5
		10
		15
	> 80	10
		15
Lead, tin		1

[1)] For the testing of cast iron, the nominal diameter of the ball should be 2.5 mm, 5 mm or 10 mm.

Source: Ref. 1

4.2 Test Force

The test forces given in Table 8.1 should be used. The test force should be chosen to ensure that the diameter of the indentation lies in the range 0.25 to 0.60 times the ball diameter. If a choice exists between two or more test forces, the heavier test force should be used.

4.3 Indenter

Hardmetal balls of diameter 1 mm, 2.5 mm, 5 mm or 10 mm should be used. The diameter of the hardmetal ball should be as large as possible in order to test the largest representative area of the test piece.

4.4 Test Piece

4.4.1 Surface

The top and bottom surfaces of the test piece should be flat, smooth and parallel. They should also be free from oxide scale and foreign matter, such as dirt and oil.

The finish of the test surface (top surface) should be such that a well-defined indentation is obtained.

When the hardness of a test piece with a curved surface is being determined, a flat surface should be prepared in the area to be tested.

4.4.2 Surface Preparation

The test piece should be prepared in such a way that there is no change in the surface hardness due to heat or cold working.

4.4.3 Thickness

The thickness of the test piece should be at least eight times the depth of indentation (see Table 8.3). The depth of indentation is calculated by using the following formula:

$$h = \frac{D - \sqrt{D^2 - d^2}}{2}$$
$$= \frac{0{\cdot}102 \times F}{\pi \times D \times \mathrm{HBW}}$$

where:

h = depth of indentation, in mm,
D = diameter of the ball, in mm,
d = mean diameter of the indentation, in mm,
F = test force, in N, and
HBW = Brinell hardness value.

After the test, no bulge or other marking showing the effect of the test force should be visible on the surface of the test piece opposite the indentation.

4.5 Spacing of Indentations

The distance between the centre of any indentation and the edge of the test piece should be at least two-and-a-half times the mean diameter of the indentation.

The distance between the centres of two adjacent indentations should be at least three times the mean diameter of the indentation.

4.6 Anvil

The anvil surface in contact with the test piece should be smooth, and free from oxide scale and foreign matter, such as dirt and oil.

4.7 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

Table 8.3 *Minimum Thickness of Test Piece in Relation to the Mean Diameter of Indentation*

Mean diameter of indentation	Minimum thickness of test piece for a ball diameter, in mm, of			
	1	2.5	5	10
mm	mm			
0.2	0.08			
0.3	0.18			
0.4	0.33			
0.5	0.54			
0.6	0.80	0.29		
0.7		0.40		
0.8		0.53		
0.9		0.67		
1.0		0.83		
1.1		1.02		
1.2		1.23	0.58	
1.3		1.46	0.69	
1.4		1.72	0.80	
1.5		2.00	0.92	

(Contd.)

Table 8.3 *Contd.*

Mean diameter of indentation	Minimum thickness of test piece for a ball diameter, in mm, of			
	1	2.5	5	10
mm	mm			
1.6			1.05	
1.7			1.19	
1.8			1.34	
1.9			1.50	
2.0			1.67	
2.2			2.04	
2.4			2.46	1.17
2.6			2.92	1.38
2.8			3.43	1.60
3.0			4.00	1.84
3.2				2.10
3.4				2.38
3.6				2.68
3.8				3.00
4.0				3.34
4.2				3.70
4.4				4.08
4.6				4.48
4,8				4.91
5.0				5.36
5.2				5.83
5.4				6.33
5.6				6.86
5.8				7.42
6.0				8.00

Source: Ref. 1

5 TEST PROCEDURE

Select the appropriate test force and ball diameter.

Place the test piece on a suitable anvil so that displacement cannot occur during the test.

Bring the indenter into contact with the test surface and apply the test force in a direction perpendicular to the surface, without shock or vibration. Maintain the test force for 10 s to 15 s, unless otherwise specified.

Remove the test force. Measure the diameter of the indentation in two directions at right angles to each other and calculate the arithmetic mean of the two readings.

Calculate the Brinell hardness value from the formula given in Section 1 or read directly from the calculation tables given in IS 10588.

6 REFERENCES

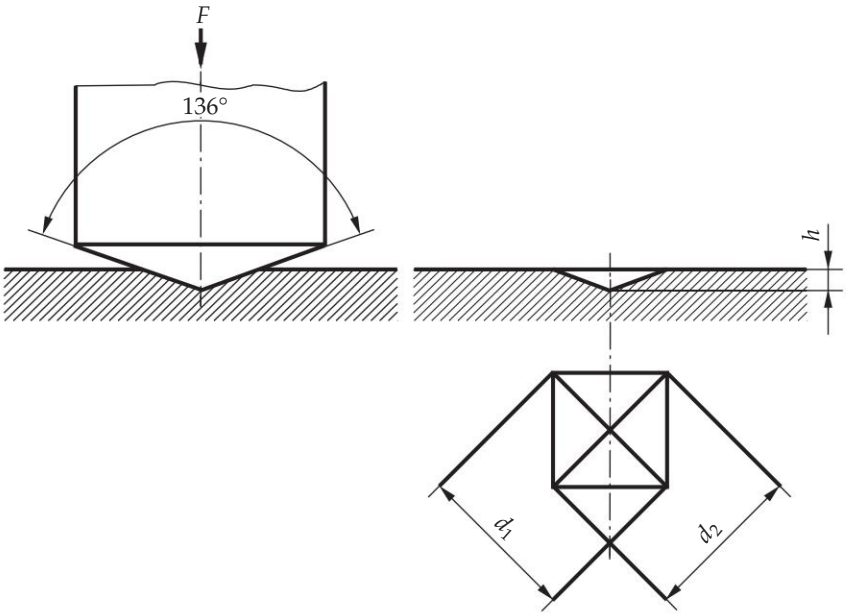
1. IS 1500:1983, *Method for Brinell Hardness Test for Metallic Materials.*
2. IS 2281:1983, *Method for Verification of Brinell Hardness Testing Machines.*
3. IS 10588:1983, *Tables of Brinell Hardness Values for Use in Tests Made on Flat Surfaces.*
4. ISO 6506-1:1999, *Metallic Materials — Brinell Hardness Test — Part 1: Test Method.*

9

Vickers Hardness Test

1 PRINCIPLE

The Vickers hardness test is an indentation hardness test in which a square-based diamond pyramid, having an angle of 136° between the opposite faces at the vertex, is forced into the surface of a test piece and the length of the diagonals of the indentation left in the surface after removal of the test force is measured (see Fig. 9.1).



Key:

F = Test force, in N
d_1 and d_2 = Length of the diagonals of the indentation, in mm
h = Depth of the indentation, in mm

Fig. 9.1 *Principle of the Vickers hardness test (Courtesy of Instron Corporation)*

The Vickers hardness is obtained by dividing the test force by the area of the sloping faces of the indentation. It is calculated by using the following formula:

$$\text{Vickers hardness value} = 0.102 \times \frac{2 \times F \times \sin\frac{136°}{2}}{d^2}$$

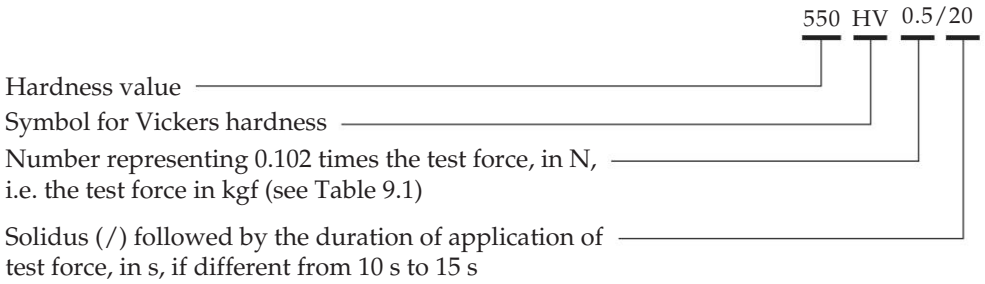
$$\approx 0.1891 \times \frac{F}{d^2}$$

where:

F = test force, in N, and

d = arithmetic mean of the length of the two diagonals of the indentation, in mm.

2 DESIGNATION OF VICKERS HARDNESS



Examples

1) 350 HV 10 indicates a Vickers hardness value of 350 determined with a test force of 98.07 N (10 kgf) applied for 10 s to 15 s.
2) 550 HV 0.5/ 20 indicates a Vickers hardness value of 550 determined with a test force of 4.903 N (0.5 kgf) applied for 20 s.

Table 9.1 *Recommended Values of Test Force for the Three Types of Vickers Hardness Test*

Vickers microhardness test			Low force Vickers hardness test			Vickers hardness test		
Hardness symbol	Test force		Hardness symbol	Test force		Hardness symbol	Test force	
	N	kgf		N	kgf		N	kgf
HV 0.01	0.09807	0.010	HV 0.2	1.961	0.200	HV 5	49.03	5
HV 0.015	0.1471	0.015	HV 0.3	2.942	0.300	HV 10	98.07	10
HV 0.02	0.1961	0.020	HV 0.5	4.903	0.500	HV 20	196.1	20
HV 0.025	0.2452	0.025	HV 1	9.807	1	HV 30	294.2	30
HV 0.05	0.4903	0.050	HV 2	19.61	2	HV 50	490.3	50
HV 0.1	0.9807	0.100	HV 3	29.42	3	HV 100	980.7	100
Note: 1 kgf = 1000 gf								

3 APPARATUS

3.1 Testing Machine

The Vickers hardness testing machine (see Fig. 9.2, Plate 6) should comply with the requirements given in IS 1754. It should be capable of applying the test force(s) given in Table 9.1.

Note: The Vickers hardness testing machine should be located in an area as free from vibrations as possible in order to avoid erroneous results.

The testing machine should be verified at planned intervals in accordance with IS 1754. For routine checking, the testing machine should be verified on each day that it is used, on a reference block with approximately the same hardness level as the material being tested.

4 TEST CONDITIONS

4.1 Test Force

The test force selected (see Table 9.1) should be compatible with the hardness of the test piece, thickness of the test piece or of the layer under test, and the width of the area to be tested. If a choice exists between two or more test forces, the heavier test force should be used.

4.2 Test Piece

4.2.1 Surface

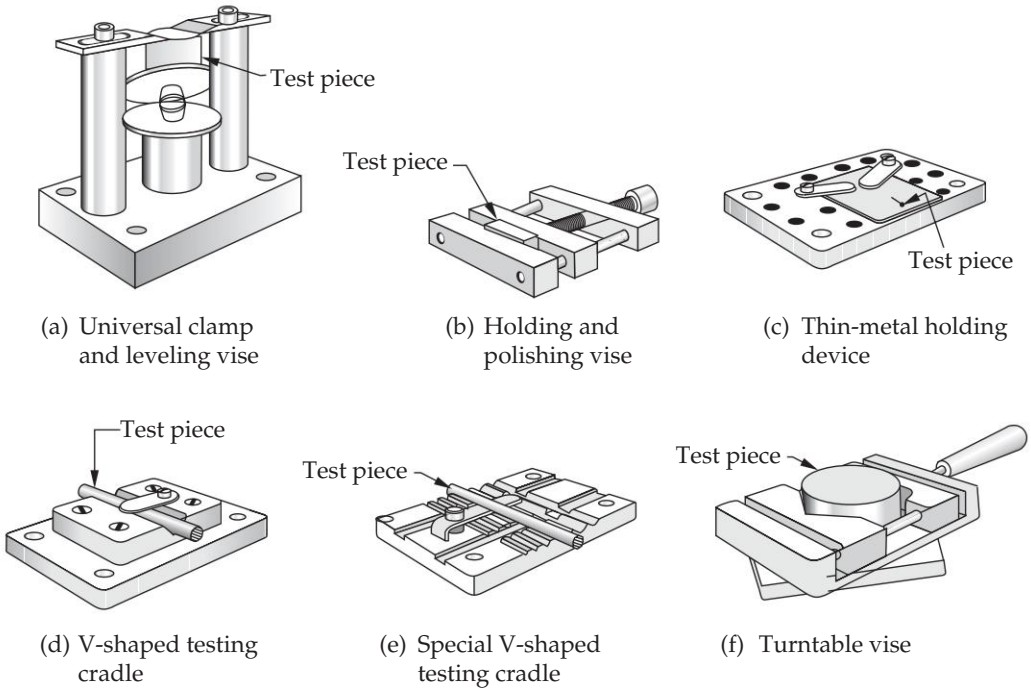
The top and bottom surfaces of the test piece should be flat, smooth and parallel. These surfaces should also be free from oxide scale and foreign matter, such as dirt and oil.

Note: If the universal clamp and levelling device [see Fig. 9.3(a)] is used the condition for parallelism of the top and bottom surfaces is automatically corrected.

The finish of the test surface (top surface) should be such that a well-defined indentation is obtained. The Vickers microhardness test and the low force Vickers hardness test should be carried out on a polished surface.

4.2.2 Surface Preparation

The test piece should be prepared in such a way that there is no change in surface hardness due to heat or cold working.



(a) Universal clamp and leveling vise

(b) Holding and polishing vise

(c) Thin-metal holding device

(d) V-shaped testing cradle

(e) Special V-shaped testing cradle

(f) Turntable vise

Fig. 9.3 *Typical fixtures used for holding and clamping test pieces for Vickers microhardness test and low force Vickers hardness test (Courtesy of ASM International)*

4.2.3 Thickness

The thickness of the test piece or of the layer under test should be at least one-and-a-half times the diagonal of the indentation (see Figs. 9.4, 9.5 and 9.6).

After the test, no bulge or marking showing the effect of the test force should be visible on the surface of the test piece opposite the indentation.

4.2.4 Mounting of Test Piece

Test pieces of small cross-section or of irregular shape may be mounted in a plastic material to facilitate surface preparation and hardness testing.

4.3 Spacing of Indentations

The distance between the centre of any indentation and the edge of the test piece should be:

1) At least two-and-a-half times the mean diagonal of the indentation in the case of steel, copper and copper alloy, and
2) At least three times the mean diagonal of the indentation in the case of light metals, lead and tin, and their alloys.

The distance between the centres of two adjacent indentations should be:

1) At least three times the mean diagonal of the indentation in the case of steel, copper and copper alloys, and
2) At least six times the mean diagonal in the case of light metals, lead and tin, and their alloys.

If two adjacent indentations differ in size, the spacing should be based on the mean diagonal of the larger indentation.

4.4 Anvil

The anvil surface in contact with the test piece should be smooth, and from oxide scale and foreign matter, such as dirt and oil.

4.5 Test Temperature

The test should be carried out at a temperature between 10°C and 35°C.

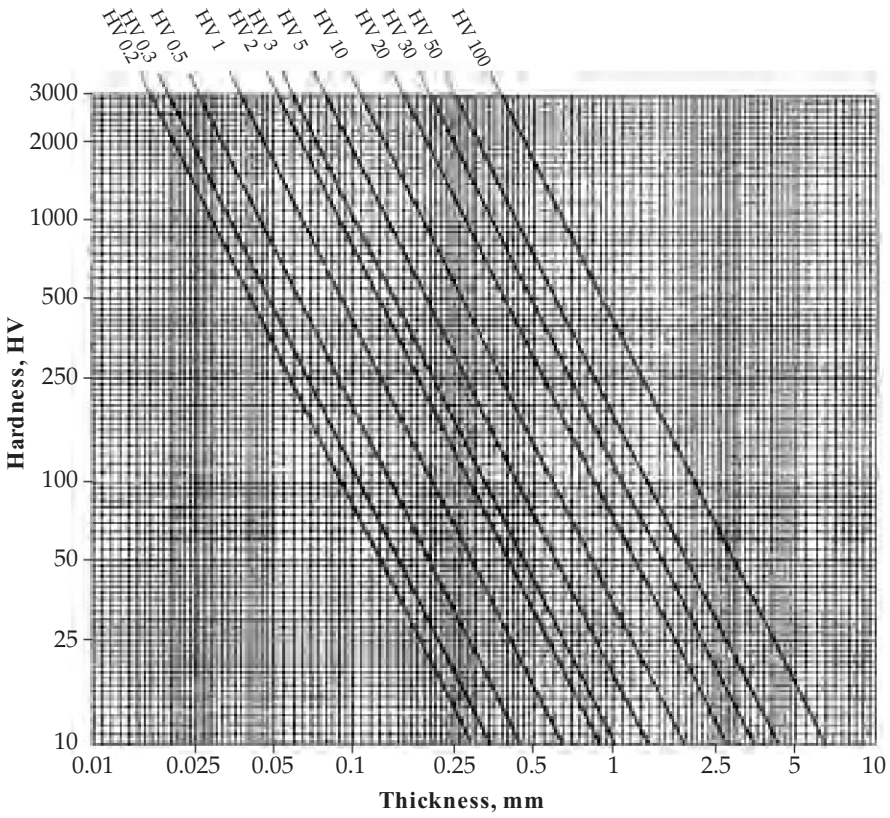
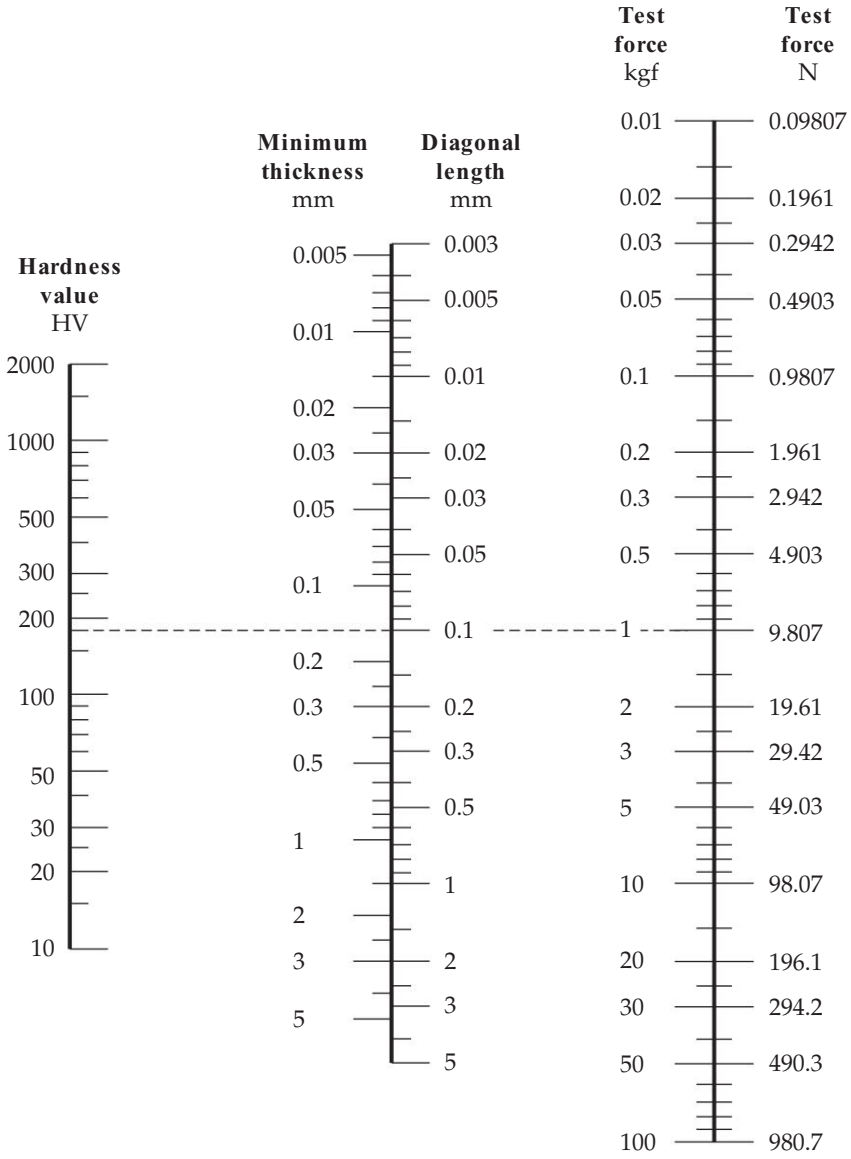


Fig. 9.4 *Minimum thickness of test piece in relation to the test force and to the hardness (HV 0.2 To HV 100)* (*Source:* Ref. 6)



How to use the nomogram The minimum thickness of test piece is given by the point of intersection of the minimum thickness scale and a line (shown dotted in the example above) joining the test force (right hand scale) with the hardness value (left hand scale).

Fig. 9.5 *Minimum thickness of test piece in relation to the test force and to the hardness* (HV 0.01 to HV 100) (*Source:* Ref. 6)

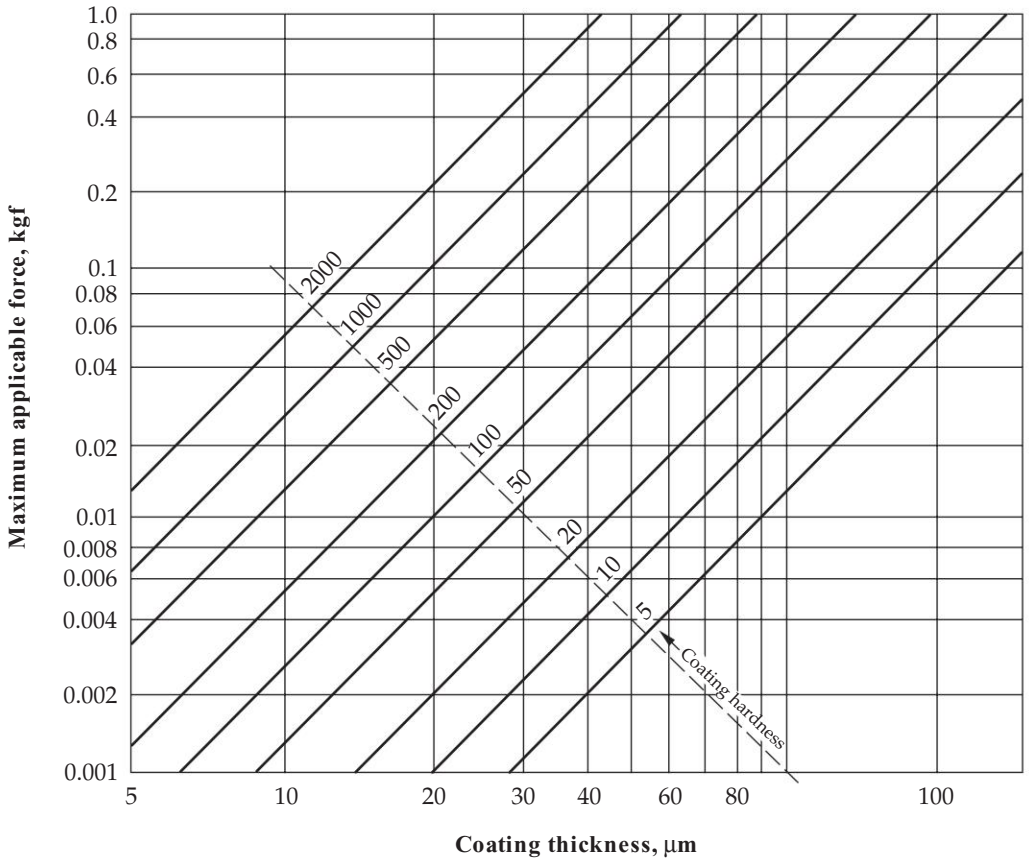


Fig. 9.6 *Minimum thickness of coating in relation to the test force and to the coating hardness* (*Source:* Ref. 7)

5 TEST PROCEDURE

Select the appropriate test force.

Place the test piece on a rigid support so that displacement cannot occur during the test. Bring the test piece surface into focus under the objective of the microscope and select the area to be indented.

Bring the indenter into contact with the test surface and apply the test force in a direction perpendicular to the test surface, without shock or vibration. Maintain the test force for 10 *s* to 15 s, unless otherwise specified.

Remove the test force. Measure the lengths of the two diagonals of the indentation and calculate the arithmetic mean of the two readings.

Note: If the difference between the lengths of the two legs of the same diagonal is greater that 5 %, or if the four corners of the indentation are not in sharp focus, the surface of the test piece may not be normal to the axis of the indenter. In such cases align the test piece surface properly and repeat the test.

Calculate the Vickers hardness value from the formula given in Section 1 or read directly from the calculation tables given in IS 10927 (Parts 1, 2 and 3).

For tests on curved surfaces apply the correction factors given in Annexure 9.A, Tables 9.A.1 to 9.A.6.

6 REFERENCES

1. IS 1501:2002, *Method for Vickers Hardness Test for Metallic Materials.*
2. IS 1754:2002, *Method for Verification of Vickers Hardness Testing Machines.*
3. IS 10927-1:1984, *Tables of Vickers Hardness Values for Use in Tests Made on Flat Surfaces — Part 1: HV 5 to HV 100.*
4. IS 10927-2:1984, *Tables of Vickers Hardness Values for Use in Tests Made on Flat Surfaces — Part 2: HV 0.2 to Less than HV 5.*
5. IS 10927-3:1991, *Tables of Vickers Hardness Values for Use in Tests Made on Flat Surfaces — Part 3: Less than HV 0.2.*
6. DIN EN ISO 6507-1:1998, *Metallic Materials— Vickers Hardness Test — Part 1: Test Method.*
7. BS 5411-6:1980, *Methods of Test for Metallic and Related Coatings— Part 6: Vickers and Knoop Microhardness Tests.*

ANNEXURE 9.A

Tables of Correction Factors for Use in Tests Made on Curved Surfaces (*Source:* Ref. 1)

9.A.1 Spherical Surfaces

Tables 9.A.1 and 9.A.2 give the correction factors for the hardness values obtained from tests carried out on spherical surfaces. The correction factors are tabulated as a function of the ratio of the mean length of the diagonal of the indentation (d) to the diameter of the sphere (D).

Example

Test force (F) = 98.07 N
Diameter of sphere (D) = 10 mm
Mean length of the diagonal of indentation (d) = 0.150 mm

$$\frac{d}{D} = \frac{0.150}{10} = 0.015$$

$$\text{Vickers hardness} = 0.1891 \times \frac{98.07}{0.15^2} = 824 \text{ HV } 10$$

Correction factor from Table 9.A.1, obtained by interpolation = 0.983
Hardness of sphere = $824 \times 0.983 = 810$ HV 10

Table 9.A.1 *Convex Spherical Surfaces*

d/D	Correction factor	d/D	Correction factor
0.004	0.995	0.086	0.920
0.009	0.990	0.093	0.915
0.013	0.985	0.100	0.910
0.018	0.980	0.107	0.905
0.023	0.975	0.114	0.900
0.028	0.970	0.122	0.895
0.033	0.965	0.130	0.890
0.038	0.960	0.139	0.885
0.043	0.955	0.147	0.880
0.049	0.950	0.156	0.875
0.055	0.945	0.165	0.870
0.061	0.940	0.175	0.865
0.067	0.935	0.185	0.860
0.073	0.930	0.195	0.855
0.079	0.925	0.206	0.850

Table 9.A.2 *Concave Spherical Surfaces*

d/*D*	Correction factor	*d*/*D*	Correction factor
0.004	1.005	0.057	1.080
0.008	1.010	0.060	1.085
0.012	1.015	0.063	1.090
0.016	1.020	0.066	1.095
0.020	1.025	0.069	1.100
0.024	1.030	0.071	1.105
0.028	1.035	0.074	1.110
0.031	1.040	0.077	1.115
0.035	1.045	0.079	1.120
0.038	1.050	0.082	1.125
0.041	1.055	0.084	1.130
0.045	1.060	0.087	1.135
0.048	1.065	0.089	1.140
0.051	1.070	0.091	1.145
0.054	1.075	0.094	1.150

9.A.2 Cylindrical Surfaces

Tables 9.A.3 to 9.A.6 give the correction factors for the hardness values obtained from tests carried out on cylindrical surfaces. The correction factors are tabulated as a function of the the ratio of the mean length of the diagonal of the indentation (d) to the diameter of the cylinder (D).

Example

Test force (F) = 9.807 N
Diameter of concave cylinder (D) with one diagonal of the indentation parallel to cylinder axis = 5 mm
Mean length of the diagonal of the indentation (d) = 0.100 mm

$$\frac{d}{D} = \frac{0.100}{5} = 0.02$$

$$\text{Vickers hardness} = 0.1891 \times \frac{9.807}{0.100^2} = 185 \text{ HV } 1$$

Correction factor from Table 9.A.6, obtained by interpolation = 1.013
Hardness of cylinder = 185 × 1.013 = 187 HV 1

Table 9.A.3 *Convex Cylindrical Surfaces — Diagonals at 45° to the Cylinder Axis*

d/*D*	Correction factor	*d*/*D*	Correction factor
0.009	0.995	0.109	0.940
0.017	0.990	0.119	0.935
0.026	0.985	0.129	0.930
0.035	0.980	0.139	0.925
0.044	0.975	0.149	0.920
0.053	0.970	0.159	0.915
0.062	0.965	0.169	0.910
0.071	0.960	0.179	0.905
0.081	0.955	0.189	0.900
0.090	0.950	0.200	0.895
0.100	0.945		

Table 9.A.4 *Concave Cylindrical Surfaces — Diagonals at 45° to the Cylinder Axis*

d/*D*	Correction factor	*d*/*D*	Correction factor
0.009	1.005	0.127	1.080
0.017	1.010	0.134	1.085
0.025	1.015	0.141	1.090
0.034	1.020	0.148	1.095
0.042	1.025	0.155	1.100
0.050	1.030	0.162	1.105
0.058	1.035	0.169	1.110
0.066	1.040	0.176	1.115
0.074	1.045	0.183	1.120
0.082	1.050	0.189	1.125
0.089	1.055	0.196	1.130
0.097	1.060	0.203	1.135
0.104	1.065	0.209	1.140
0.112	1.070	0.216	1.145
0.119	1.075	0.222	1.150

Table 9.A.5 *Convex Cylindrical Surfaces — One Diagonal Parallel to the Cylinder Axis*

d/*D*	Correction factor	*d*/*D*	Correction factor
0.009	0.995	0.085	0.965
0.019	0.990	0.104	0.960
0.029	0.985	0.126	0.955
0.041	0.980	0.153	0.950
0.054	0.975	0.189	0.945
0.068	0.970	0.243	0.940

Table 9.A.6 *Concave Cylindrical Surfaces — One Diagonal Parallel to the Cylinder Axis*

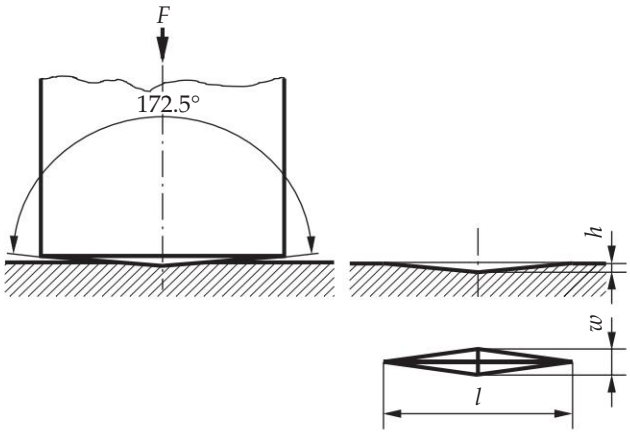
d/*D*	Correction factor	*d*/*D*	Correction factor
0.008	1.005	0.087	1.080
0.016	1.010	0.090	1.085
0.023	1.015	0.093	1.090
0.030	1.020	0.097	1.095
0.036	1.025	0.100	1.100
0.042	1.030	0.103	1.105
0.048	1.035	0.105	1.110
0.053	1.040	0.108	1.115
0.058	1.045	0.111	1.120
0.063	1.050	0.113	1.125
0.067	1.055	0.116	1.130
0.071	1.060	0.118	1.135
0.076	1.065	0.120	1.140
0.079	1.070	0.123	1.145
0.083	1.075	0.125	1.150

10

Knoop Hardness Test

1 PRINCIPLE

The Knoop hardness test is an indentation hardness test in which a rhombic-based diamond pyramid, having an included longitudinal edge angle of 172.5° and an included transverse edge angle of 130°, is forced into the surface of a test piece and the length of the long diagonal of the indentation left in the surface after removal of the test force is measured (see Fig. 10.1).



Key:

F = Test force, in N
l = Length of the long diagonal of the indentation, in mm
w = Length of the short diagonal of the indentation, in mm
h = Depth of the indentation, in mm

Fig. 10.1 *Principle of the Knoop hardness test (Courtesy of Instron Corporation)*

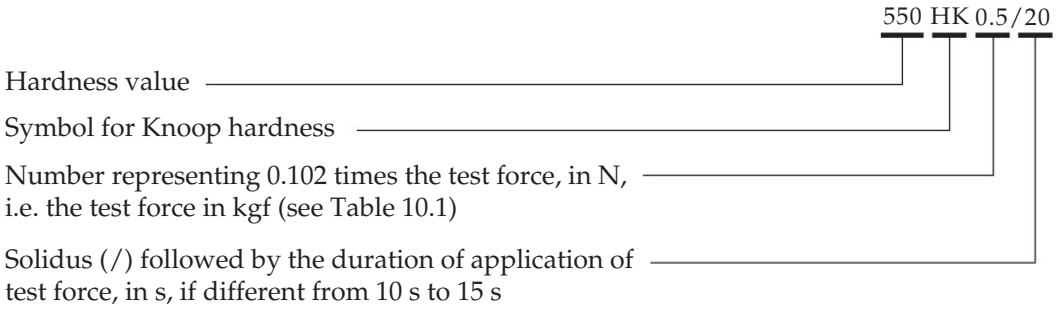
The Knoop hardness is obtained by dividing the test force by the projected area of the indentation. It is calculated by using the following formula:

$$\text{Knoop hardness value} = 0.102 \times \frac{F}{l^2 \times c}$$

$$\approx 1.451 \times \frac{F}{l^2}$$

where:
F = test force, in N,
l = length of the long diagonal of the indentation, in mm, and
c = indenter constant (= 0.07028), relating the projected area of the indentation to the square of the length of the long diagonal.

2 DESIGNATION OF KNOOP HARDNESS



Examples

1) 550 HK 1 indicates a Knoop hardness value of 550 determined with a test force of 9.807 N (1 kgf) applied for 10 s to 15 s.
2) 550 HK 0.5/ 20 indicates a Knoop hardness value of 550 determined with a test force of 4.903 N (0.5 kgf) applied for 20 s.

Table 10.1 *Recommended Values of Test Force for the Knoop Hardness Test*

Hardness symbol	Test force		Hardness symbol	Test force	
	N	kgf		N	kgf
HK 0.001	0.009807	0.001	HK 0.05	0.4903	0.050
HK 0.002	0.01961	0.002	HK 0.1	0.9807	0.100
HK 0.003	0.02942	0.003	HK 0.2	1.961	0.200
HK 0.005	0.04903	0.005	HK 0.3	2.942	0.300
HK 0.01	0.09807	0.010	HK 0.5	4.903	0.500
HK 0.02	0.1961	0.020	HK 1	9.807	1
HK 0.025	0.2452	0.025			
Note: 1 kgf = 1000 gf					

3 APPARATUS

3.1 Testing Machine

The Knoop hardness testing machine (see Fig. 10.2, Plate 7) should comply with the requirements given in IS 7095. It should be capable of applying the test force(s) given in Table 10.1.

Note: The Knoop hardness testing machine should be located in an area as free from vibrations as possible in order to avoid erroneous results.

The testing machine should be verified at planned intervals in accordance with IS 7095. For routine checking, the testing machine should be verified on each day that it is used, on a reference block with approximately the same hardness level as the material being tested.

4 TEST CONDITIONS

4.1 Test Force

The test force selected (see Table 10.1) should be compatible with the hardness of the test piece, thickness of the test piece or of the layer under test, and the width of the area to be tested. If a choice exists between two or more test forces, the heavier test force should be used.

4.2 Test Piece

4.2.1 Surface

The top and bottom surfaces of the test piece should be flat, smooth and parallel. These surfaces should also be free from oxide scale and foreign matter, such as dirt and oil.

Note: If the universal clamp and levelling device [see Fig. 9.3(a)] is used the condition for parallelism of the top and bottom surfaces is automatically corrected.

The test surface (top surface) should be polished in order to obtain a well-defined indentation.

4.2.2 Surface Preparation

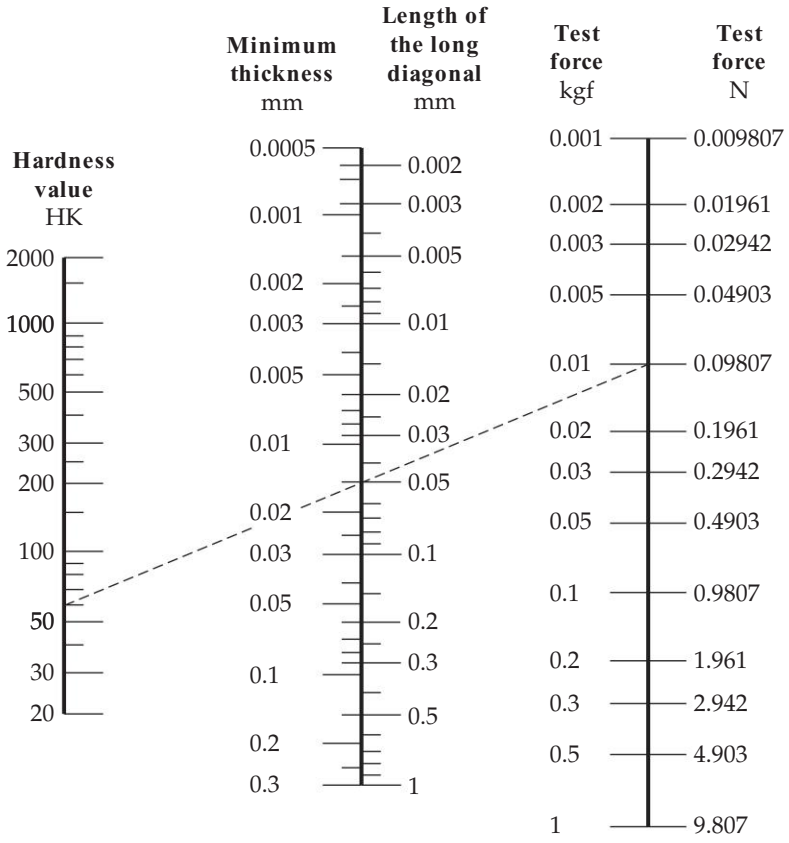
The test piece should be prepared in such a way that there is no change in surface hardness due to heat or cold working.

4.2.3 Thickness

The thickness of the test piece or of the layer under test should be at least 0.3 times the length of the long diagonal of the indentation (see Fig. 10.3). After the test, no bulge or other marking showing the effect of the test force should be visible on the surface of the test piece opposite the indentation.

4.2.4 Mounting of Test Piece

Test pieces of small cross-section or of irregular shape may be mounted in a plastic material to facilitate surface preparation and hardness testing.



How to use the nomogram The minimum thickness of the test piece is given by the point of intersection of the minimum thickness scale and a line (shown dotted in the example above) joining the test force (right hand scale) with the hardness value (left hand scale).

Fig. 10.3 *Minimum thickness of test piece in relation to the test force and to the hardness* (HK 0.001 to HK 1) (*Source:* Ref. 3)

4.3 Spacing of Indentations

The distance between the limit of any indentation and the edge of the test piece should be:

a) At least two-and-a-half times the length of the short diagonal of the indentation in the case of steel, copper and copper alloys, and
b) At least three times the length of the short diagonal of the indentation in the case of light metals, lead and tin, and their alloys.

The distance between the limits of two adjacent indentations should be:

a) At least three times the length of the short diagonal of the indentation in the case of steel, copper and copper alloys, and
b) At least six times the length of the short diagonal of the indentation in the case of light metals, lead and tin, and their alloys.

If two adjacent indentations differ in size, the distance between the limits of two adjacent indentations should be based on the short diagonal of the larger indentation.

4.4 Test Temperature

The test should be carried out at a temperature between 10 °C and 35 °C.

5 TEST PROCEDURE

Select the appropriate test force.

Place the test piece on a rigid support so that displacement cannot occur during the test.

Bring the test piece surface into focus under the objective of the microscope and select the area to be indented.

Bring the indenter into contact with the test surface and apply the test force in a direction perpendicular to the test surface, without shock or vibration. Maintain the test force for 10 s to 15 s, unless otherwise specified.

Remove the test force and measure the length of the long diagonal of the indentation.

Notes:

1) If the difference between the lengths of the two legs of the long diagonal is greater than 20%, or if the ends of the diagonal are not in sharp focus, the surface of the test piece may not be normal to the axis of the indenter. In such cases align the test piece surface properly and repeat the test.
2) If a crack occurs during the indentation, repeat the test using a reduced test force.

Calculate the Knoop hardness value from the formula given in Section 1 or from the information given in IS 6885.

6 REFERENCES

1. IS 6885:1973, *Method for Knoop Hardness Testing of Metals.*
2. IS 7095:1973, *Method for Verification of Knoop Hardness Testing Machines.*
3. JIS Z 2251:1992, *Method of Knoop Hardness Test.*
4. ISO 4545:1993, *Metallic Materials — Hardness Test — Knoop Test.*

11

Charpy Impact Test

1 PRINCIPLE

The Charpy impact test is a dynamic test in which a test piece U-notched or V-notched in the middle and supported at each end, is broken by a single blow of a freely swinging pendulum (see Fig. 11.1). The energy absorbed is measured. This absorbed energy is a measure of the impact strength of the material.

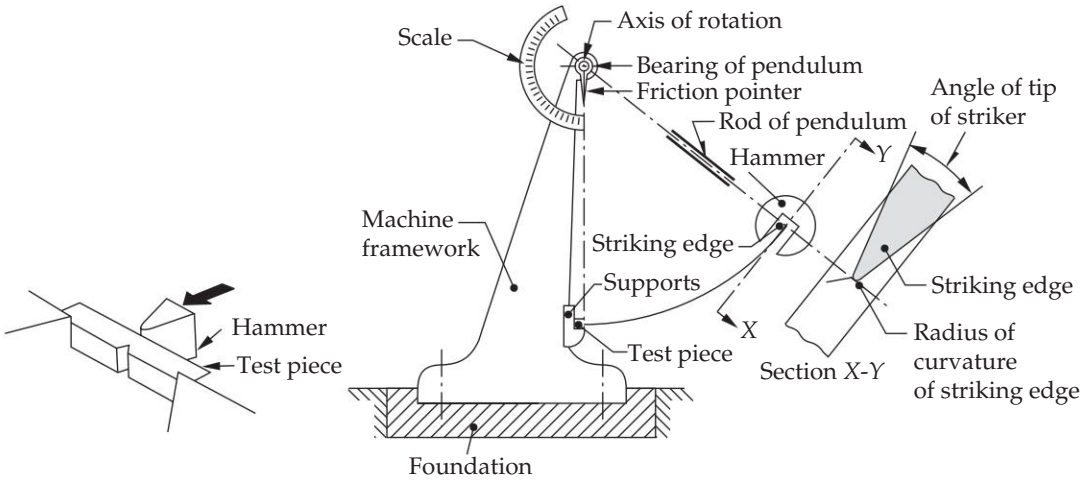


Fig. 11.1 *Charpy impact testing machine (Source:* Ref. 4*)*

2 DEFINITIONS

2.1 Lateral Expansion

Lateral expansion is the increase in specimen width on the compression side, opposite the notch of the Charpy V-notch test piece.

3 APPARATUS

3.1 Testing Machine

The Charpy impact testing machine (see Fig. 11.1) should comply with the requirements given in IS 3766. For a standard test, the striking energy of the testing machine should be 300±10 J. Testing machines with lower striking energies can be used, provided the striking energy of the machine is substantially greater than the energy absorbed by the test piece.

The testing machine should be verified in accordance with IS 3766, at least once a year.

3.2 Heating/Cooling Device

The heating/ cooling device should be capable of maintaining the test piece within ± 1°C of the specified temperature.

The temperature measuring equipment should be verified at least once every six months over the working temperature range.

3.2.1 Cooling Media

The cooling media are usually chilled fluids (such as water, ice plus water, dry ice plus organic solvents, or liquid nitrogen) or chilled gases.

3.2.2 Heating Media

The heating media are usually heated liquids (such as mineral or silicone oils) or hot air.

4 TEST CONDITIONS

4.1 Test Piece

4.1.1 Sampling

The number of test pieces and their location (see Annexure B) should be as specified in the product standard.

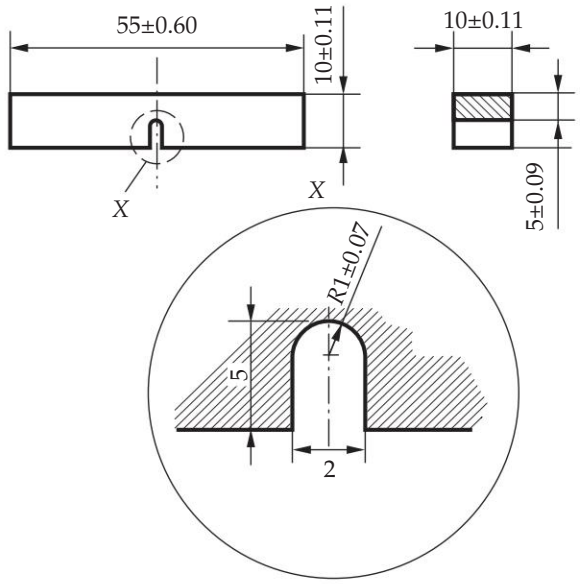
4.1.2 Preparation

The test piece should be machined all over. It should be prepared in such a way that there is no change in the mechanical properties due to heat or cold working. The notch should be carefully prepared so that no grooves appear at its base.

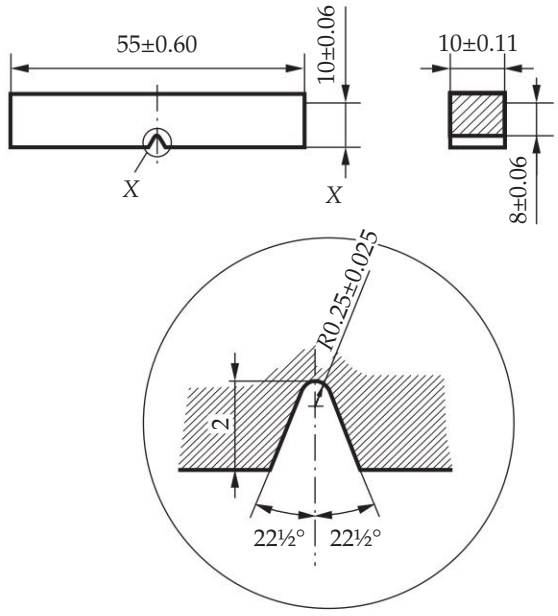
4.1.3 Dimensions

The dimensions of the Charpy U-notch and V-notch test pieces should be as given in Table 11.1 and Figs. 11.2 (a) and (b).

(Dimensions in millimetres)



(a) Charpy U-notch impact test piece



(b) Charpy V-notch impact test piece

Fig. 11.2 *Charpy impact test pieces* (*Source:* Refs. 1 and 2)

4.1.4 Marking

The identification mark on the test piece should not interfere with the test. The test piece should be marked on a face which is not in contact with the supports or anvils, and at a point located at least 15 mm from the plane of symmetry of the notch in order to avoid the effect of work hardening induced by stamping.

Table 11.1 *Dimensions of Charpy U-notch and V-notch Test Pieces*

Designation	Dimension	
	U-notch test piece	V-notch test piece[1)]
Length	55±0.60 mm	55±0.60 mm
Width • Standard test piece • Subsidiary test piece • Subsidiary test piece	 10±0.11 mm – –	 10±0.11 mm 7.5±0.11 mm 5±0.06 mm
Height	10±0.11 mm	10±0.06 mm
Angle of notch	–	45±2°
Height below notch	5±0.09 mm	8±0.06 mm
Radius of curvature of base of notch	1±0.07 mm	0.25±0.025 mm
Distance of plane of symmetry of notch from ends of test piece	27.5±0.42 mm	27.5±0.42 mm
Angle between plane of symmetry of notch and longitudinal axis of test piece	90±2°	90±2°
Angle between adjacent longitudinal faces of test piece	90±2°	90±2°

[1)] If the standard test piece cannot be obtained from the material, one of the subsidiary test pieces having a width of 7.5 mm or 5 mm should be used, the notch being cut in one of the narrower faces.

Source: Refs. 1 and 2

4.2 Test Temperature

Unless otherwise specified, the test should be carried out at a temperature between 18 °C and 28 °C.

For tests at temperatures other than the ambient temperature, the test piece should be immersed in the heating or cooling medium for sufficient time to ensure that the required

temperature is reached throughout the test piece (for example, at least 10 min in a liquid medium or at least 30 min in a gaseous medium). A suitable transfer device (for example, a self-centring tong) should be used to remove the test piece from the heating or cooling medium and placing it on the support. The parts of the transfer device which come into contact with the test piece should be at the same temperature as that of the test piece, in order to maintain the test piece within the permitted temperature range.

5 TEST PROCEDURE

Raise the pendulum to the latched position, and set the pointer at the maximum scale reading of the energy indicator, or initialize the digital display.

Accurately position the test piece on the supports against the anvils (see Fig. 11.3), with the plane of symmetry of the notch within 0.5 mm of the plane of swing of the striker.

Note: For tests at temperatures other than the ambient temperature, the test piece should be broken within 5 s from the time of removal from the heating or cooling medium.

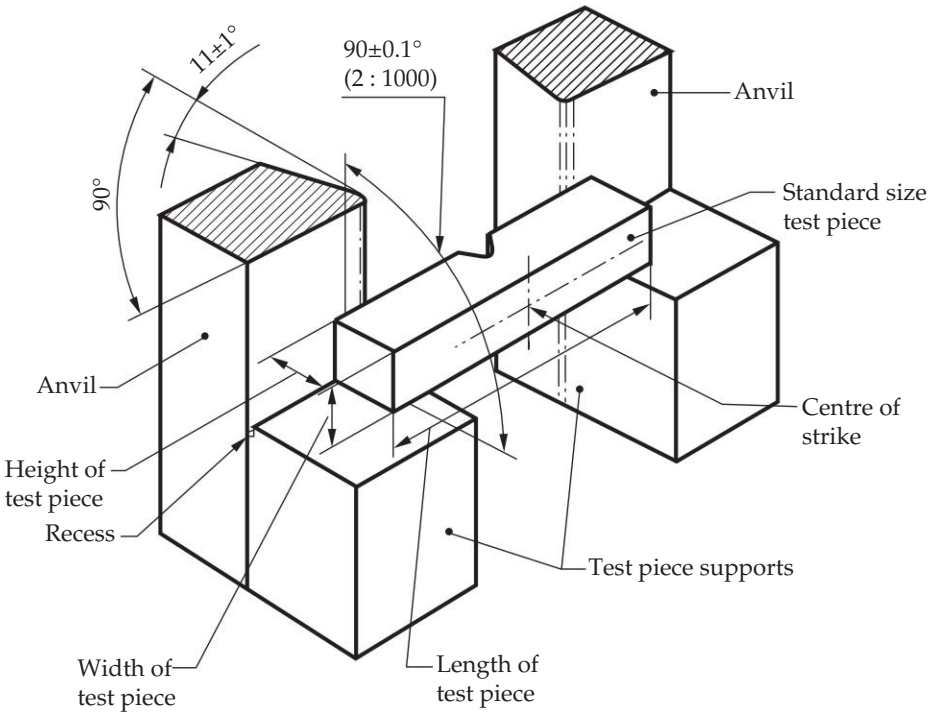


Fig. 11.3 *Configuration of test piece supports and anvils* (*Source:* Ref. 2)

Release the pendulum, without shock and vibration. After the hammer has made one full swing, press the brake.

5.1 Determination of Absorbed Energy

Read the absorbed energy directly from the measuring device.

Notes:

1) If, during the test, the test piece is deformed but not completely broken, report the test piece as unbroken.
2) If the energy absorbed by the test piece exceeds 80 % of the nominal striking energy of the testing machine, report the absorbed energy as approximate.
3) Only results on test pieces of identical dimensions should be compared.

5.2 Determination of Fracture Appearance

Determine the percentage of shear or cleavage fracture area by any of the following methods:

1) Compare the appearance of the fracture of the test piece with a fracture appearance chart (see Fig. 11.4).
2) Photograph the fractured surface at a suitable magnification and measure the percentage shear fracture by means of a planimeter.

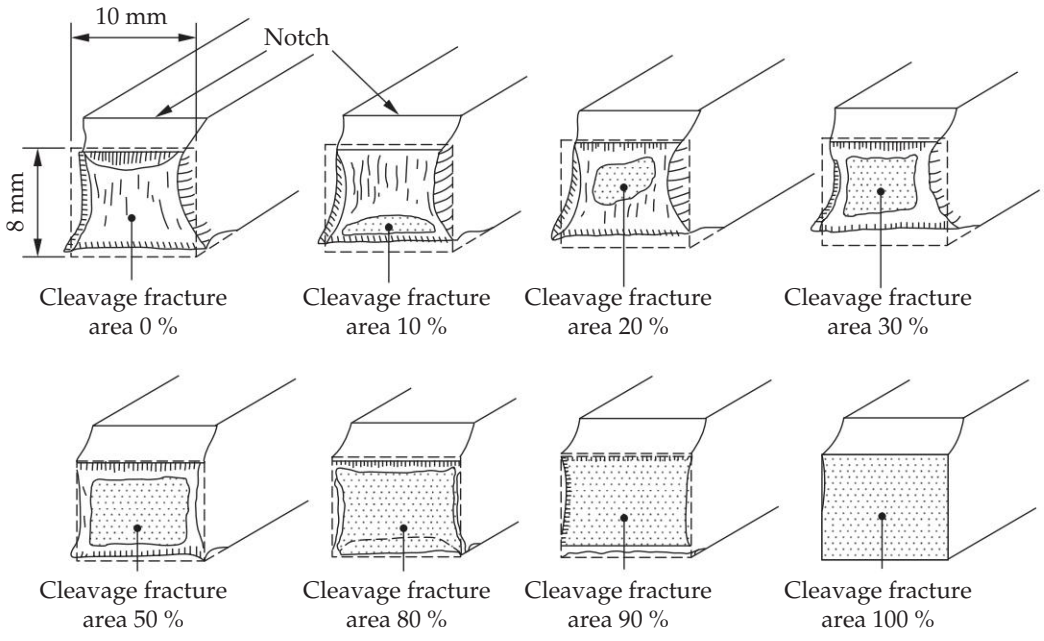


Fig. 11.4 *Fracture appearance chart* (*Source:* Ref. 7)

5.3 Determination of Lateral Expansion

Ensure that the protrusions on the fracture surface are not damaged. Carefully remove (using emery paper or similar abrasive surface) the burrs on the edges of the fracture faces, without damaging the protrusions.

Measure the protrusions on either side of the two fracture faces (see Fig. 11.5) to the nearest 0.01 mm. Of the four measurements taken (SB1 to SB4), add the larger value of SB1 and SB3 to the larger value of SB2 and SB4. The sum of these two measurements is the lateral expansion (SB) and is expressed to the nearest 0.01 mm.

Alternatively, a suitable measuring device (see Fig. 11.6) can be used to determine the lateral expansion on the basis of two measurements instead of the four described above. In this method, the increase in width is measured simultaneously on the same side of the two halves of the broken test piece (see Fig. 11.6). This method ensures that the larger of the two values for each side is always obtained.

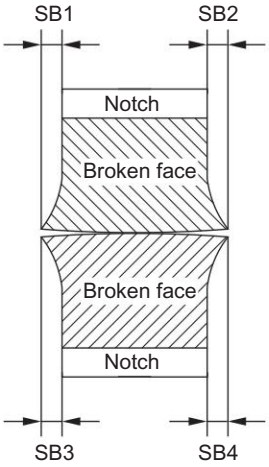


Fig. 11.5 *Dimensions to be measured for determination of lateral expansion* (*Source:* Ref. 8)

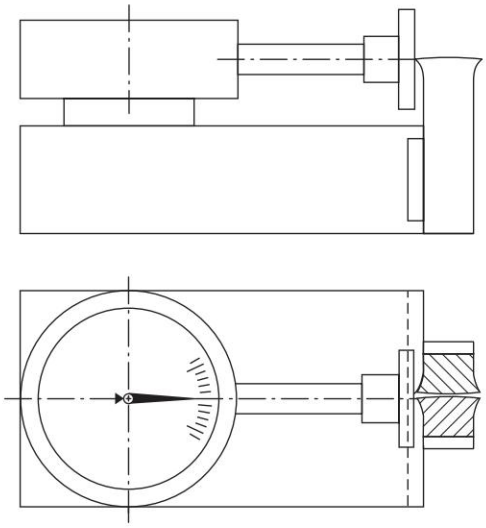


Fig. 11.6 *Arrangement for simplified method of determining lateral expansion* (*Source:* Ref. 8)

6 REFERENCES

1. IS 1499:1977, *Method for Charpy Impact Test (U-Notch) for Metals.*
2. IS 1757:1988, *Method for Charpy Impact Test (V-Notch) on Metallic Materials.*
3. *ASM Handbook*, Vol. 20, ASM International, Materials Park, Ohio, USA, 1997.
4. IS 3766:1977, *Method for Calibration of Pendulum Impact Testing Machines for Testing Metals.*
5. EN 10045-1:1990, *Metallic Materials— Charpy Impact Test — Part 1: Test Method.*
6. ASTM E 23:2002*a, Test Methods for Notched Bar Impact Testing of Metallic Materials.*
7. BS 131-5:1965, *Methods for Notched Bar Tests—Part 5: Determination of Crystallinity.*
8. DIN 50115:1991, *Notched Bar Impact Testing of Metallic Materials Using Test Pieces Other than ISO Test Pieces.*

12

Izod Impact Test

1 PRINCIPLE

The Izod impact test is a dynamic test in which a V-notched test piece, gripped vertically, is broken by a single blow of a freely swinging pendulum (see Fig. 12.1). The blow is struck on the same face as the notch and at a fixed height above it. The energy absorbed is measured. This absorbed energy is a measure of the impact strength of the material.

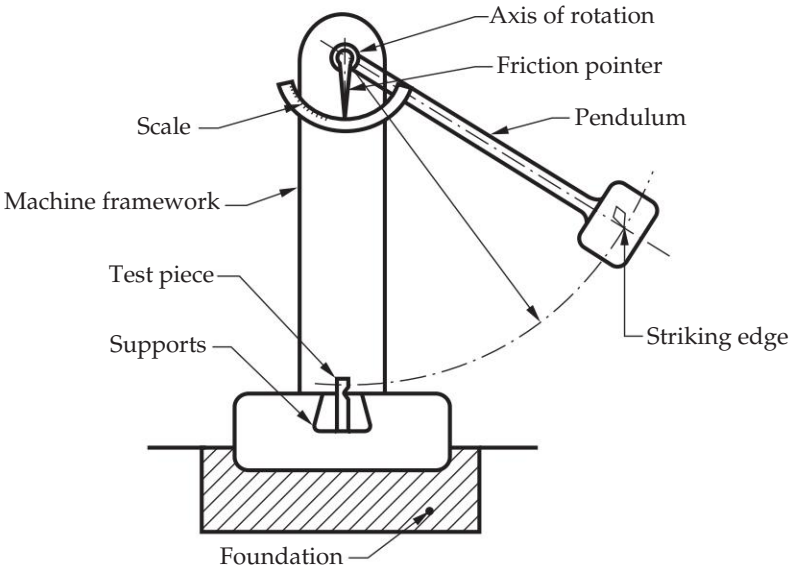


Fig. 12.1 *Izod impact testing machine* (*Source:* Ref. 1)

2 APPARATUS

2.1 Testing Machine

The Izod impact testing machine (see Fig. 12.1) should comply with the requirements given in IS 3766. The striking energy of the testing machine should be 165.6±3.4 J. Testing machines with lower striking energies can be used, provided the striking energy of the machine is substantially greater than the energy absorbed by the test piece.

The testing machine should be verified in accordance with IS 3766, at least once a year.

3 TEST CONDITIONS

3.1 Test Piece

3.1.1 Sampling

The number of test pieces and their location (see Annexure B) should be as specified in the product standard.

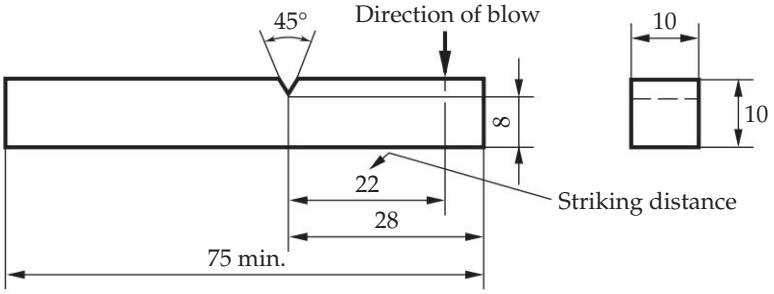
3.1.2 Preparation

The test piece should be machined all over. It should be prepared in such a way that there is no change in the mechanical properties due to heat or cold working. The notch should be carefully prepared so that no grooves appear at its base.

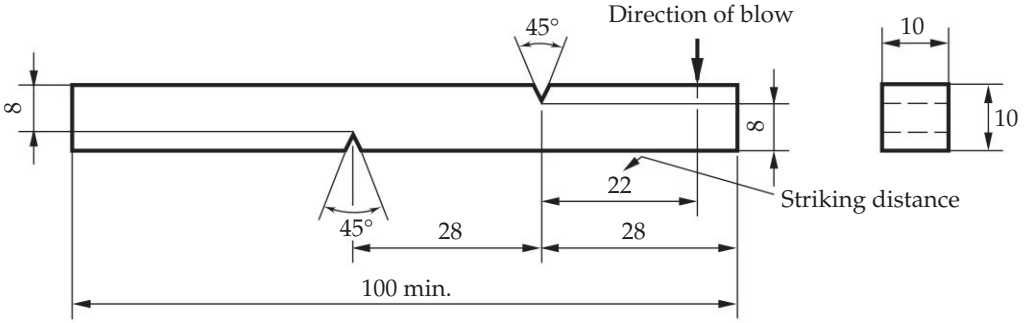
3.1.3 Dimensions

The dimensions of the Izod impact test pieces should be as given in Tables 12.1 and 12.2, and Figs. 12.2 and 12.3.

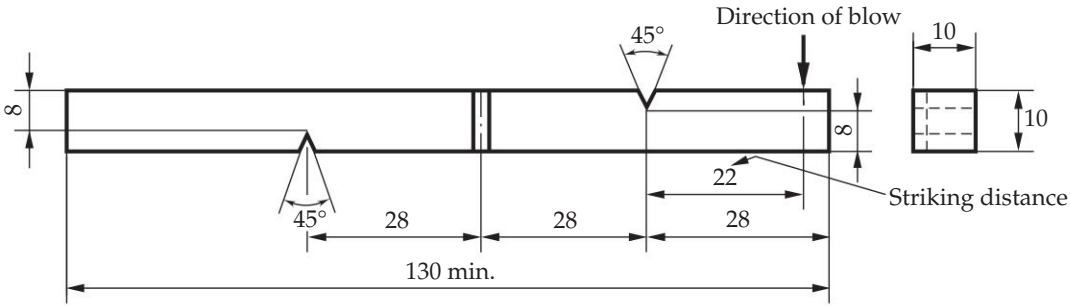
(Dimensions in millimetres)



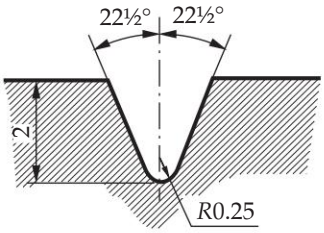
(a) Single-notch square section test piece



(b) Two-notch square section test piece



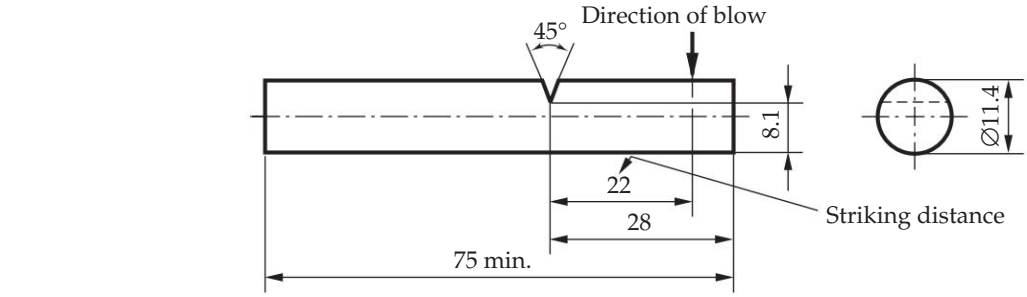
(c) Three-notch square section test piece



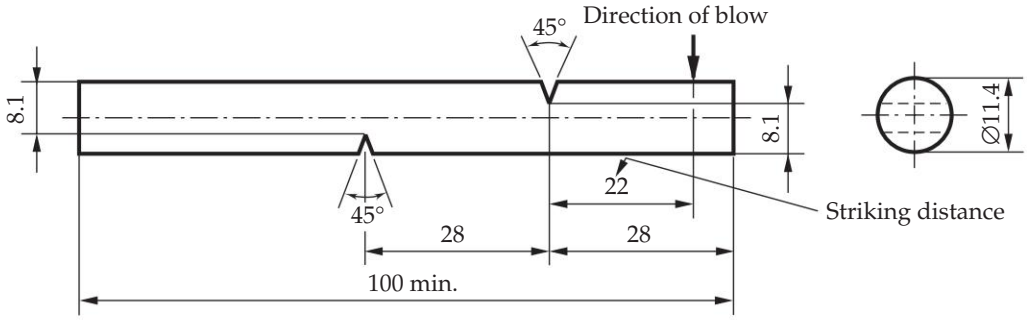
(d) Enlarged view of notch for square section test piece

Fig. 12.2 *Square section, Izod impact test pieces* (*Source:* Ref. 1)

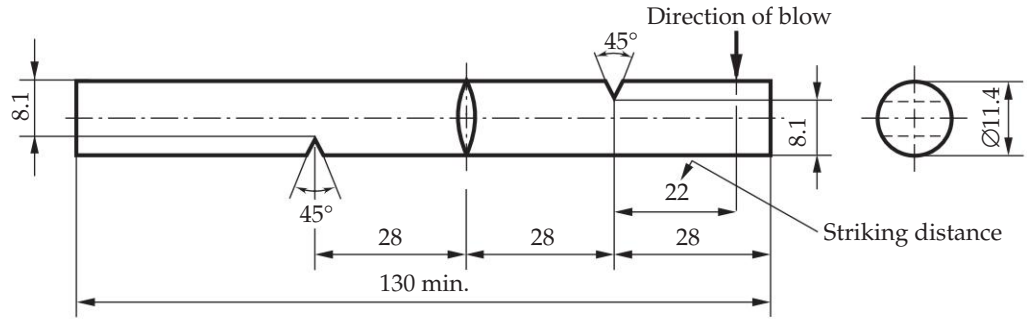
(Dimensions in millimetres)



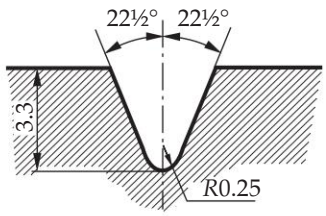
(a) Single-notch circular section test piece



(b) Two-notch circular section test piece



(c) Three-notch circular section test piece



(d) Enlarged view of notch for circular section test piece

Fig. 12.3 *Circular section, Izod impact test pieces* (*Source:* Ref. 1)

3.1.4 Marking

The identification mark on the test piece should not interfere with the test. The test piece should be marked on a face which is not in contact with the support, and at a position well away from the notch in order to avoid the effect of work hardening induced by stamping.

3.2 Test Temperature

The test should be carried out at a temperature between 18°C and 28°C.

Note: Izod impact test is not recommended at other than the ambient temperature.

Table 12.1 *Dimensions of Ferrous and Non-Ferrous, Square Section Test Pieces*

Designation	Dimension	
	Ferrous test piece	Non-ferrous test piece
Length • Single-notch test piece • Two-notch test piece • Three-notch test piece	 ≥ 75 mm ≥ 100 mm ≥ 130 mm	 ≥ 75 mm ≥ 100 mm ≥ 130 mm
Width	10±0.11 mm	10±0.05 mm
Height	10±0.11 mm	10±0.05 mm
Angle of notch	45±2°	45±1°
Depth below notch	8±0.045 mm	8±0.025 mm
Radius of curvature of base of notch	0.25±0.025 mm	0.25±0.025 mm
Distance of plane of symmetry of notch from free end of test piece and from adjacent notch	28±0.42 mm	28±0.42 mm
Angle between plane of symmetry of notch and longitudinal axis of test piece	90±2°	90±1°

Source: Ref. 1

Table 12.2 *Dimensions of Ferrous and Non-Ferrous, Circular Section Test Pieces*

Designation	Dimension	
	Ferrous test piece	Non-ferrous test piece
Length • Single-notch test piece • Two-notch test piece • Three-notch test piece	 ≥ 75 mm ≥ 100 mm ≥ 130 mm	 ≥ 75 mm ≥ 100 mm ≥ 130 mm
Diameter	11.4±0.14 mm	11.4±0.07 mm
Angle of notch	45±2°	45±1°
Depth below notch	8.1±0.045 mm	8.1±0.025 mm
Radius of curvature of base of notch	0.25±0.025 mm	0.25±0.025 mm
Distance of plane of symmetry of notch from free end of test piece and from adjacent notch	28±0.5 mm	28±0.5 mm
Angle between plane of symmetry of notch and longitudinal axis of test piece	90±2°	90±1°

Source: Ref. 1

4 TEST PROCEDURE

Raise the pendulum to the latched position, and set the pointer at the maximum scale reading of the energy indicator, or initialize the digital display.

Clamp the test piece firmly on the face containing the notch, in such a way that the plane of symmetry of the notch coincides with the top surface of the support (see Fig. 12.4). A positioning gauge is necessary to ensure that this condition is met.

Release the pendulum, without shock and vibration. After the hammer has made one full swing, press the brake. Read the absorbed energy directly from the measuring device.

When two-notch and three-notch test pieces are being tested, the material remaining after each test should be examined to ensure that any deformed metal does not interfere with the performance of the next test.

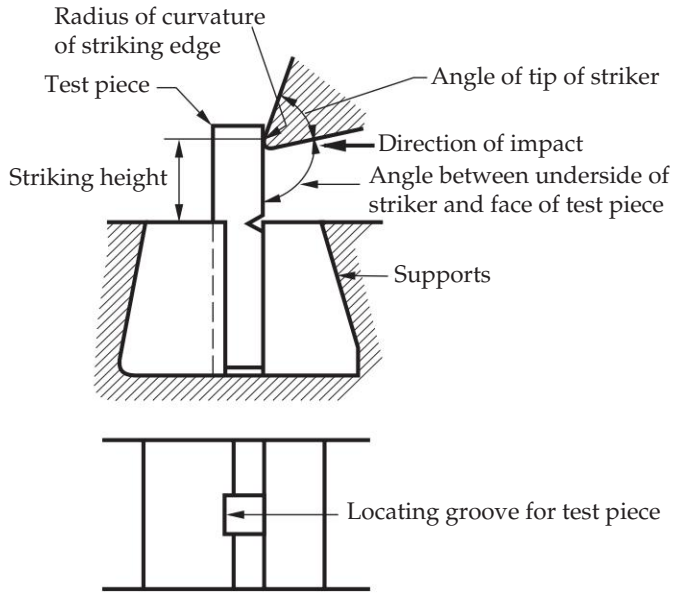


Fig. 12.4 *Configuration of test piece support* (*Source:* Ref. 1)

Notes:

1) If, during the test, the test piece is deformed but not completely broken, report the test piece as unbroken.
2) If the energy absorbed by the test piece exceeds 80% of the nominal striking energy of the testing machine, report the absorbed energy as approximate.

5 REFERENCES

1. IS 1598:1977, *Method for Izod Impact Test of Metals.*
2. BS 131-1:1961, *Methods for Notched Bar Test—Part 1: The Izod Impact Test on Metals.*
3. IS 3766:1977, *Method for Calibration of Pendulum Impact Testing Machines for Testing Metals.*
4. ASTM E 23:2002a, *Test Methods for Notched Bar Impact Testing of Metallic Materials.*

13

Magnetic Particle Inspection

1 PRINCIPLE

Magnetic particle inspection (MPI) is a non-destructive testing method, which is used for detecting surface or near sub-surface discontinuities in ferromagnetic materials. The test consists of examining a part submitted to a magnetic field, and coated with a dry magnetic powder or with a liquid containing a magnetic powder suspension. Surface or near sub-surface discontinuities cause a distortion in the induced magnetic field. This distortion attracts and holds the magnetic powder (see Fig. 13.1), giving visible indications (see Fig. 13.2, Plate 8).

Note: Magnetic particle inspection is only applicable to ferromagnetic materials. Ferromagnetic materials include most of the iron, nickel and cobalt alloys.

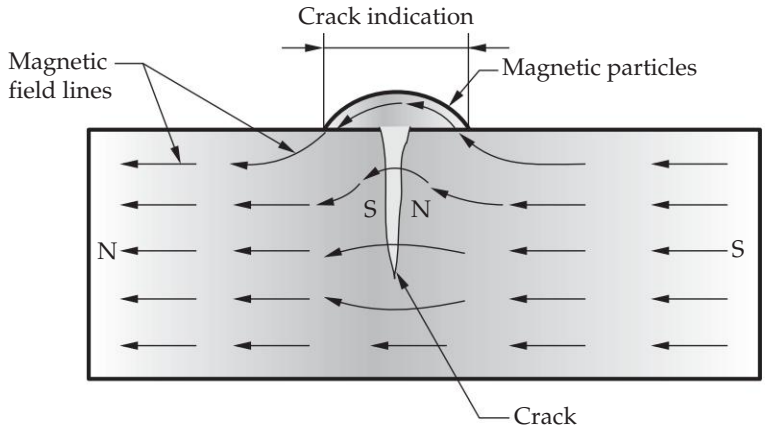


Fig. 13.1 *Principle of magnetic particle inspection (Courtesy of Iowa State University — NDT Resource Centre)*

2 APPARATUS

2.1 Magnetizing Equipment

The equipment intended to supply the magnetizing current or the magnetic flux are:

1) **Fixed**, on which the test piece to be inspected is placed. These equipments generally have the magnetic flux and/ or electric current passing through them;
2) **Moveable**
   Either with contacts for passage of the electric current or with poles for passage of the magnetic flux.

2.2 Demagnetization Equipment

The demagnetization equipment should be capable of reducing the residual magnetism to the necessary level (typically 0.4 kA/ m to 1.0 kA/ m) for the intended use of the part. Facilities for demagnetization may be included in the magnetizing equipment or, demagnetization may be carried out using a separate equipment.

2.3 Detection Media

The various types of detection media used in magnetic particle inspection are:

1) ***Dry magnetic powder with coloured pigment:*** They are generally less able to reveal fine surface discontinuities,
2) ***Magnetic powder suspended in an aqueous or a well refined, light petroleum distillate***, or
3) ***Fluorescent magnetic powder suspended in an aqueous or a well refined, light petroleum distillate:*** They usually give the highest sensitivity provided there is an appropriate surface finish, good drainage to maximize indication contrast, and will-controlled viewing conditions.

For aqueous suspensions, the liquid should contain a corrosion inhibitor and wetting agents.

In any case, the magnetic powders should be of a size, shape and colour such that they will ensure a suitable sensitivity and contrast when used in the intended manner.

2.4 Verification of Equipments and Products

2.4.1 Verification of Magnetizing and Demagnetizing Equipment

The magnetizing and demagnetizing equipment should be verified every six months.

2.4.2 Verification of Detection Media

The detection media should be verified before and periodically during testing.

2.4.2.1 Dry Powder

Verify that all of it can be attracted to the magnet.

2.4.2.2 Magnetic Ink

Verify the concentration of the magnetic powder. For fluorescent products, also verify the quality of luminous emission.

2.4.3 Overall Verification

The overall performance of the magnetic particle inspection system, including the magnetizing equipment and detection media should be verified on each day that it is used with the help of actual production parts with known discontinuities in the least favorable direction or on fabricated test pieces with artificial discontinuities (for example, a Pie Gage—see Fig. 13.3).

(Dimensions in millimetres)

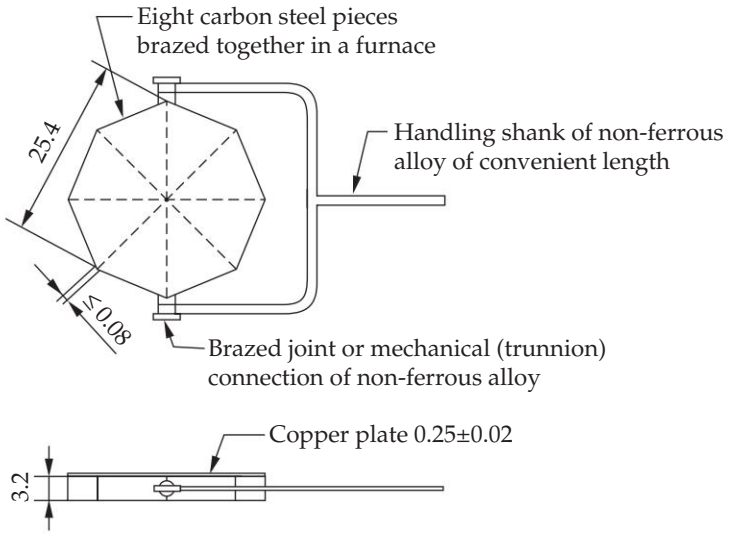


Fig. 13.3 *Pie gage* (*Source:* Ref. 2)

3 TEST CONDITIONS

3.1 Preparation of Parts for Testing

3.1.1 Pre-Inspection Demagnetization

The part should be demagnetized before testing, if prior operations have produced a residual magnetic field, which may interfere with the examination.

3.1.2 Surface Condition

The surface of the part to be inspected should be free from scale, dirt, oil, grease, paint, and other contaminants, or any other condition which may interfere with the correct interpretation of magnetic particle indications.

Note: Non-ferromagnetic coatings up to approximately 50 μm thick, such as unbroken, tightly adherent paint layers, do not normally impair detection sensitivity. Thicker coatings reduce sensitivity.

3.2 Magnetization

3.2.1 Magnetic Field Strength

The applied magnetic field should have sufficient strength to produce satisfactory indications, but it must not be so strong that it causes the masking of relevant indications by non-relevant accumulation of magnetic particles.

As a guide, the magnetic flux density in the surface of the part should be at least 1 T. This flux density is achieved in unalloyed and low alloy steels, with high relative permeability, with tangential field strength of 2 kA/ m. For other steels, with lower permeability, a higher tangential field strength may be necessary.

3.2.2 Magnetization Techniques

3.2.2.1 Technique of Magnetization by Passage of the Current

In this technique, magnetization is achieved by passing an electric current from one point to another in the part (see Figs. 13.4 and 13.5)

Note: Take care to avoid damage due to heating, burning or arcing at the areas of electrical contact.

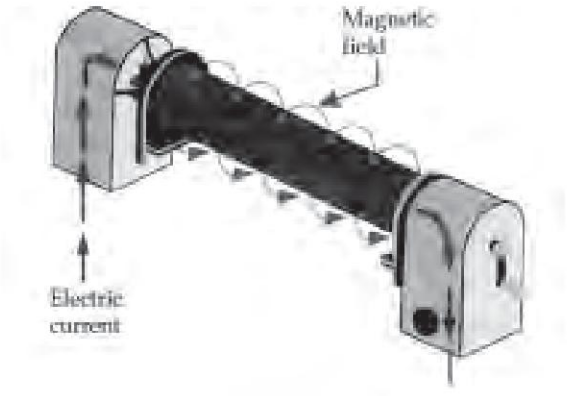


Fig. 13.4 *Axial Current flow*
(Courtesy of Iowa State University — NDT Resource Centre)

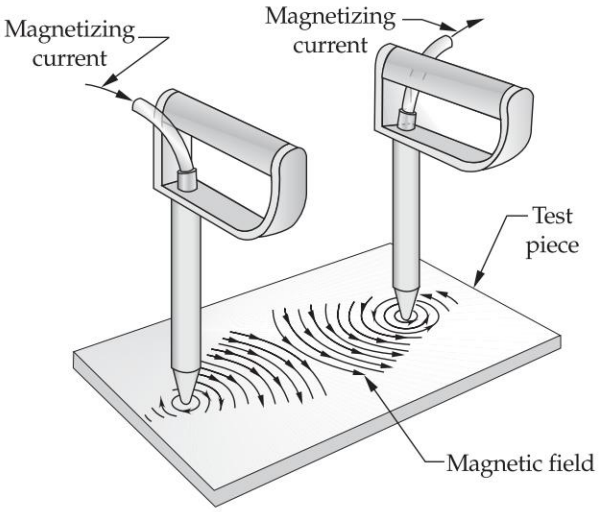
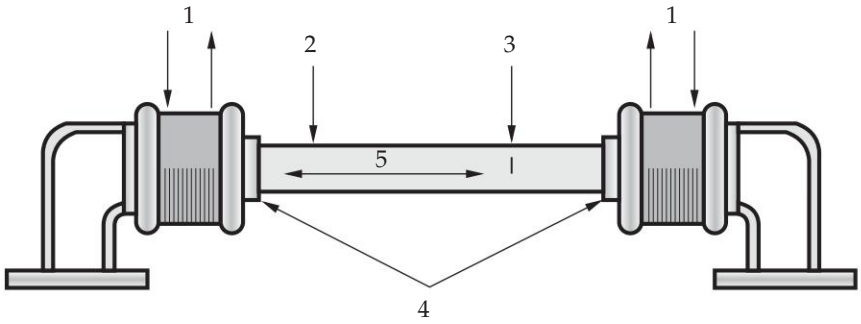


Fig. 13.5 *Prods — Current flow* (*Source:* Ref. 1)

3.2.2.2 Technique of Magnetization by Passage of the Magnetic Flux

In this technique, the magnetic flux is set up by one of the following means:

1) Use of an electromagnetic yoke with adjustable poles between which is placed the part through which the magnetic flux passes (see Fig. 13.6.);
2) Use of a portable electromagnet (see Fig. 13.7.);



Key:

1 = Current
2 = Specimen
3 = Flaw
4 = Pole piece
5 = Flux

Fig. 13.6 *Magnetic flow* (*Source:* Ref. 1)

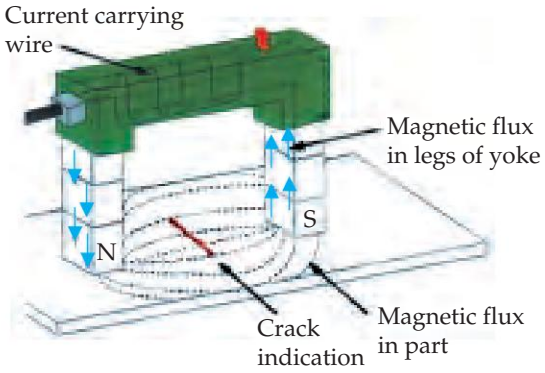


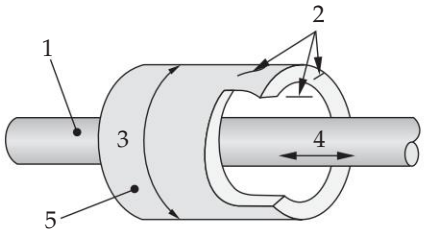
Fig. 13.7 *Portable electromagnet (Yoke)*
(Courtesy of Iowa State University — NDT Resource Centre)

3) Use of a conductor carrying an electric current which passes through the part (see Fig. 13.8.), or a coil carrying an electric current which surrounds the part to be examined (see Fig. 13.9).

3.2.3 Magnetizing Current

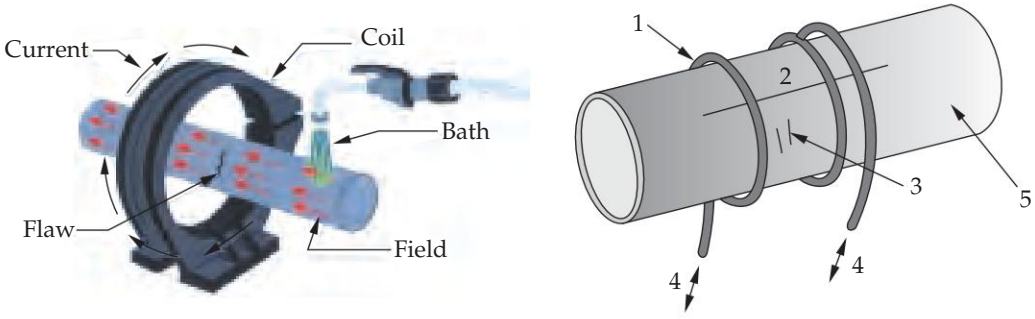
The types of current used in magnetic particle inspection are alternating current, half-wave or full-wave rectified alternating currents (three phase or single phase).

Alternating current should be used only for the detection of discontinuities open to the surface. Full-wave rectified alternating current has the deepest possible penetration and should be used for the detection of near sub-surface discontinuities when using the wet magnetic particle method. Half-wave rectified alternating current is advantageous for the dry powder method because it creates a pulsating unidirectional field, which gives increased mobility to the particles.



Key:
1 = Insulated threading bar
2 = Flaws
3 = Flux
4 = Current
5 = Specimen

Fig. 13.8 *Threading conductor* (*Source:* Ref. 1)



(a) Rigid coil

(b) Flexible coil

Key:

1 = Insulated cable
2 = Flux
3 = Flaws
4 = Current
5 = Specimen

Fig. 13.9 *Rigid and Flexible Coil*
(Courtesy of Iowa State University — NDT Resource Centre)

When magnetizing by passing current directly through the part (see Fig. 13.4), the current intensity should be 12–32 A per mm of part diameter. The diameter of the part should be taken as the greatest distance between any two points on the outside circumference of the part.

When using prods (see Fig. 13.5), the distance between contacts should not be less than 50 mm or greater than 200 mm. In general, a current intensity of 4.0–4.5 A per mm of prod spacing should be used.

Note: The current intensities indicated above are effective values for the alternating current and mean values for rectified currents.

3.2.4 Magnetic Field Orientation

For optimum flaw detection, the major axis of the discontinuity should be perpendicular to the direction of the magnetic flux. However, the magnetic flux may be regarded as effective in detecting discontinuities up to 45° from the optimum direction (see Fig. 13.10).

Note: Full coverage may be achieved by magnetising the surface in two perpendicular directions.

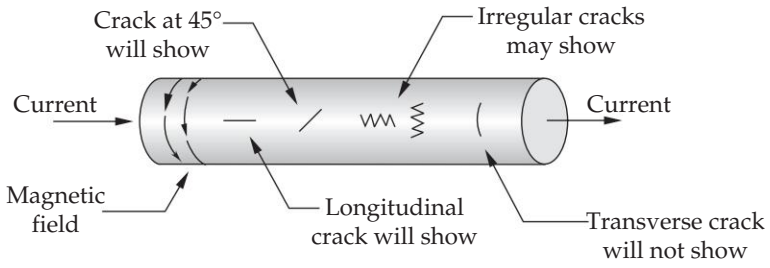


Fig. 13.10 *Optimum orientation of discontinuities with respect to direction of magnetic field (Courtesy of Iowa State University — NDT Resource Centre)*

3.3 Application of Detection Media

The surface of the part to be inspected should be adequately and uniformly coated with magnetic particles. The coating may be applied by immersion, flooding or spraying (for liquid developers) and dusting (for dry powders). The magnetizing current should be applied at least twice, either by the continuous residual methods, and sufficient time should be allowed for indications to build-up.

Dry powder, when used, should be applied in a manner that minimizes disturbance of the indications.

During application of magnetic inks, the detection media should be allowed to flow onto the surface with very little pressure so that the particles are allowed to form an indication without being washed off.

In the continuous method, the detecting media should be applied immediately prior to and during magnetization. The application should cease before magnetization is terminated.

In the residual method, the detecting media should be applied immediately after the part has been magnetized. The effectiveness of this method, which depends on the retentivity of the material and the magnetizing force, should only be used in those cases where the continuous method cannot be employed.

3.4 Viewing Conditions

The inspection should be carried out with the naked eye or at a maximum magnification of 3×.

When using coloured detection media, the area under test should be evenly illuminated to a level of not less than 500 lx, daylight or artificial light. Strong reflections from the surface should be avoided.

Note: 500 lx is equivalent to bright daylight or to artificial light from a fluorescent tube of 80 W at a distance of about 1 m, or from a tungsten filament lamp of 100 W at a distance of 0.2 m.

When using fluorescent detection media, the room or area where the inspection is to be carried out should be darkened, to a maximum white light level of 20 lx. The test surface should be illuminated with UV-A radiation. The UV-A irradiance at the test surface should not be less than 10 W/ m^2.

Prior to viewing, sufficient time (usually at least 5 min) should be allowed for the operator's eyes to become adapted to the reduced ambient lighting.

The UV-A source should be switched on at least 10 min prior to use in order to guarantee the correct radiation level.

4 TEST PROCEDURE

Carefully clean the surface of the part to be inspected. Unless otherwise specified, magnetize the part in two mutually perpendicular directions. Uniformly coat the entire surface by spraying (for liquid developers) or dusting (for dry powders).

Note: In order to restrict the deterioration of the part on contact with the electrode, the following precautions should be taken:

1) Do not switch on the current when the contacts are not in complete contact with the surface and only remove the contacts when the current has been switched off.
2) Use completely clean and suitable contacts.

Examine the test surface under suitable lighting conditions. Record the discontinuities, if any. Discontinuities will appear as spots or lines. Retest any area with questionable or doubtful indications to verify whether actual indications are present.

After inspection, demagnetize the part and clean the surface.

5 REFERENCES

1. IS 3703:1980, *Code of Practice for Magnetic Particle Flaw Detection*.
2. ASTM E 709:2001, *Standard Guide for Magnetic Particle Examination*.
3. ASTM E 1444:2001, *Standard Practice for Magnetic Particle Examination*.
4. ISO 4986:1992, *Steel Casting—Magnetic Particle Inspection*.
5. ISO 9934–1:2001, *Non-Destructive Testing—Magnetic Particle Testing—Part 1: General Principles*.
6. ISO 9934-2:2002, *Non-Destructive Testing—Magnetic Particle Testing—Part 2: Detection Media*.
7. ISO 9934–3:2002, *Non-Destructive Testing—Magnetic Particle Testing—Part 3: Equipment*.

14

Liquid Penetrant Inspection

1 PRINCIPLE

Liquid penetrant inspection (LPI) is a non-destructive testing method, which is used for detecting surface discontinuities, such as cracks, seams, laps, cold shuts, laminations, isolated porosity and through leaks, in non-porous materials. The test consists of the following sequence of operations:

1) Preparation of the surface to be inspected;
2) Application of the penetrant to the prepared surface;
3) Removal of the excess penetrant;
4) Application of a developer; and
5) Visual examination and assessment under appropriate viewing conditions.

2 DEFINITIONS

2.1 Penetrant Materials

Cleaners, penetrants, removers and developers used in penetrant testing.

2.2 Penetrant

Liquid which when applied to a component is designed to find its way into surface discontinuities and to remain there in detectable amounts during subsequent removal of excess penetrant from the surface.

2.2.1 Colour Contrast Penetrant

Penetrant that is a solution of dyes (typically red) in a liquid base.

2.2.2 Dual Purpose Penetrant

Penetrant that gives indications which are capable of being viewed either under visible light or UV-A radiation.

2.2.3 Fluorescent Penetrant

Penetrants that fluoresces under UV-A radiation.

2.3 Excess Penetrant Removal

Means employed to remove excess penetrant from the test surface, without removing any penetrant from the discontinuities.

2.4 Developer

Substance which has the property of withdrawing penetrant from discontinuities to make them more easily visible.

2.5 Reference Block

Test piece with known discontinuities, either natural or artificial, used to determine and/ or compare the sensitivity of penetrant processes and to check their reproducibility.

3 PENETRANT MATERIALS

3.1 Penetrants

Penetrants are classified as
1) Fluorescent penetrants;
2) Color contrast penetrants; or
3) Dual purpose penetrants.

3.2 Excess Penetrant Removers

Penetrant removal operations involve the use of:
1) Water only;
2) Oil-based or water-based emulsifiers; or
3) Solvent in liquid form.

3.3 Developers

Developers may be:

1) Dry powders;
2) Suspension of powder in water or solution of powder in water; or
3) Suspension of powder in volatile, non-aqueous solvents that are either non-inflammable or flammable.

4 TEST CONDITIONS

4.1 Compatibility of Materials

All penetrant inspection materials should be compatible with the material to be examined, particularly with regard to long-term corrosion effects.

4.2 Precleaning and Surface Preparation

The surface of the part to be inspected should be free from scale, dirt, oil, grease, water, coatings and other contaminants, which may prevent the penetrant from entering into the discontinuities. For removal of protective finishes, for example, paint, an agreed chemical method that avoids ingress of the products into any surface discontinuities, should be used.

4.3 Test Temperature

The temperature of the test surface and of the penetrant materials should be between 10 °C and 50 °C. In special cases temperatures as low as 5 °C may be used.

4.4 Viewing Conditions

The inspection should be carried out with the naked eye or at a maximum magnification of 3×.

When using colour contrast penetrants, the area under test should be evenly illuminated to a level of not less than 500 lx, daylight or artificial light. Strong reflections from the surface should be avoided.

Note: 500 lx is equivalent to bright daylight or to artificial light from a fluorescent tube of 80 W at a distance of about 1m, or from a tungsten filament lamp of 100 W at a distance of 0.2 m.

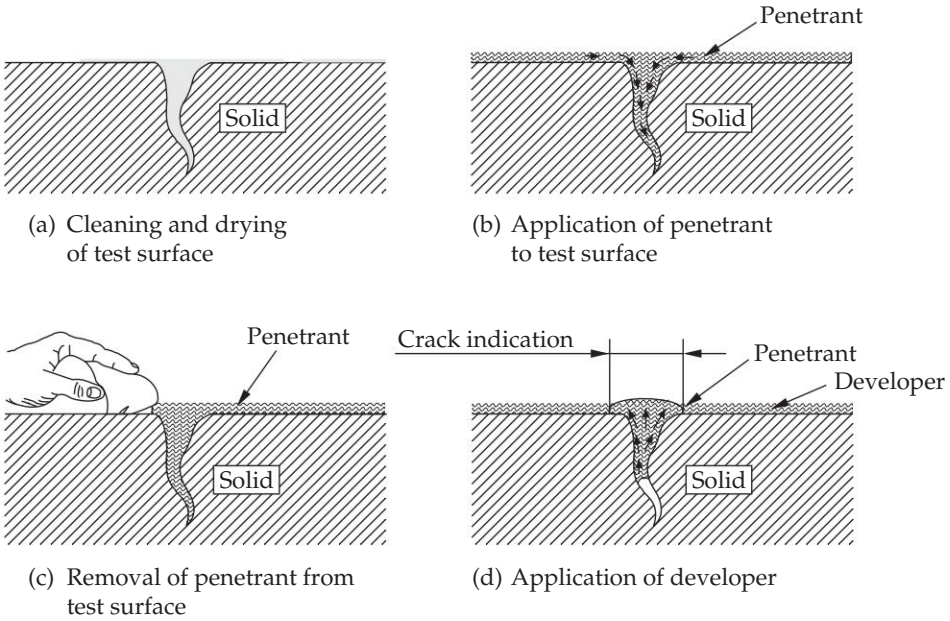
When using fluorescent detection media, the room or area where the inspection is to be carried out should be darkened, to a maximum white light level of 20 lx. The test surface should be illuminated with UV-A radiation. The UV-A irradiance at the test surface should not be less than 10 W/ m^2.

Prior to viewing, sufficient time (usually at least 5 min) should be allowed for the operator's eyes to become adapted to the reduced ambient lighting.

The UV-A source should be switched on at least 10 min prior to use in order to guarantee the correct radiation level.

5 TEST PROCEDURE

Apply the penetrant to the prepared surface with a brush, with a spray can, by electrostatic spraying, by flooding, or by immersion, and leave for a sufficient period of time (usually 5 min to 60 min) to allow the penetrant to enter any discontinuity open to the surface [see Fig. 14.1(b)]. The penetration time depends upon the properties of the penetrant, the test temperature, the test material and specific defects. In no case should the penetrant be allowed to dry during the penetration time. The time during which the surface remains completely wetted should not be less than that recommended by the manufacturer of the penetrant.



(a) Cleaning and drying of test surface

(b) Application of penetrant to test surface

(c) Removal of penetrant from test surface

(d) Application of developer

Fig. 14.1 *Four essential operations for liquid penetrant inspection (Courtesy of Iowa State University — NDT Resource Centre)*

Remove the excess penetrant with a clean, dry, absorbent lint-free cloth or with paper towels [see Fig. 14.1(c)], in such a manner as to ensure the retention of penetrant in the discontinuities. Insufficient removal of the penetrant will leave a background which will interfere with the subsequent indication of discontinuities and possibly give rise to erroneous indications. For fluorescent penetrant inspection, check the cleaning under ultraviolet radiation. For visible dye penetrant inspection, continue the cleaning until no visible evidence of the coloured dye remains on the surface.

Uniformly apply a developer, compatible with the penetrant, to the test surface within the period recommended by the manufacturer, in order to draw the penetrant from the discontinuity to the surface, and thereby give an enhanced indication to the discontinuity. The developer may be applied by spraying, electrostatic spraying, by a flow-on technique, or by immersion, as recommended by the manufacturer. After application of the developer on the test surface, ensure that the surface presents a uniform appearance, with no remaining agglomerated masses or powder.

After applying the developer, allow the part to stand for a sufficient time (usually 10 min to 30 min) for any indications to appear [see Fig. 14.1(d)]. This time will depend upon the testing media being used, the material examined and the nature of the defects present. In general, the development time will be of the order of 50 % of the penetration time up to the full penetration time for fine discontinuities. Excessively long development times may cause penetrant in large, deep discontinuities to bleed back, thereby producing broad smudged indications.

When the development time has elapsed, examine the test surface with the naked eye and assess it under appropriate viewing conditions.

Record the presence of discontinuities, if any. Discontinuities will appear as spots or lines (see Fig. 14.2, Plate 9). Retest any area with questionable or doubtful indications to verify whether actual indications are present.

After inspection, clean the surface and, if necessary, apply a corrosion preventative.

6 REFERENCES

1. IS 3658:1999, *Code of Practice for Liquid Penetrant Flaw Detection.*
2. ASTM E 165:2002, *Test Method for Liquid Penetrant Examination.*
3. ASTM E 1417:1999, *Standard Practice for Liquid Penetrant Examination.*
4. DIN EN 571-1:1997, *Non-Destructive Testing — Penetrant Testig — Part 1: General Principles.*
5. ISO 3452:1984, *Non-Destructive Testing — Penetrant Inspection — General Principles.*
6. SAE J426:1991, *Liquid Penetrant Test Methods.*

15

End-Quench Hardenability Test (Jominy Test)

1 PRINCIPLE

The end-quench hardenability test (Jominy test) consists of austenitizing a steel test piece and then quenching it by spraying water on one of its ends. The hardenability of the steel is determined by measuring the hardness at one or more points situated at specified distances from the quenched end of the test piece.

2 APPARATUS

2.1 Laboratory Furnace

2.2 Tongs

2.3 Quenching Device

The quenching device (see Fig. 15.1) should consist of a means of suddenly inducing the water jet to impinge on the end of the test piece to be quenched. This can be achieved by a quick action tap and a system to adjust the flow rate of the water. The quenching device may also incorporate a disc which will allow the water jet to be released and cut off rapidly.

The test piece support (see Fig. 15.1) should facilitate precise centring of the test piece above the end of the water supply pipe and allow it to be held in position during spraying.

(Dimensions in millimetres)

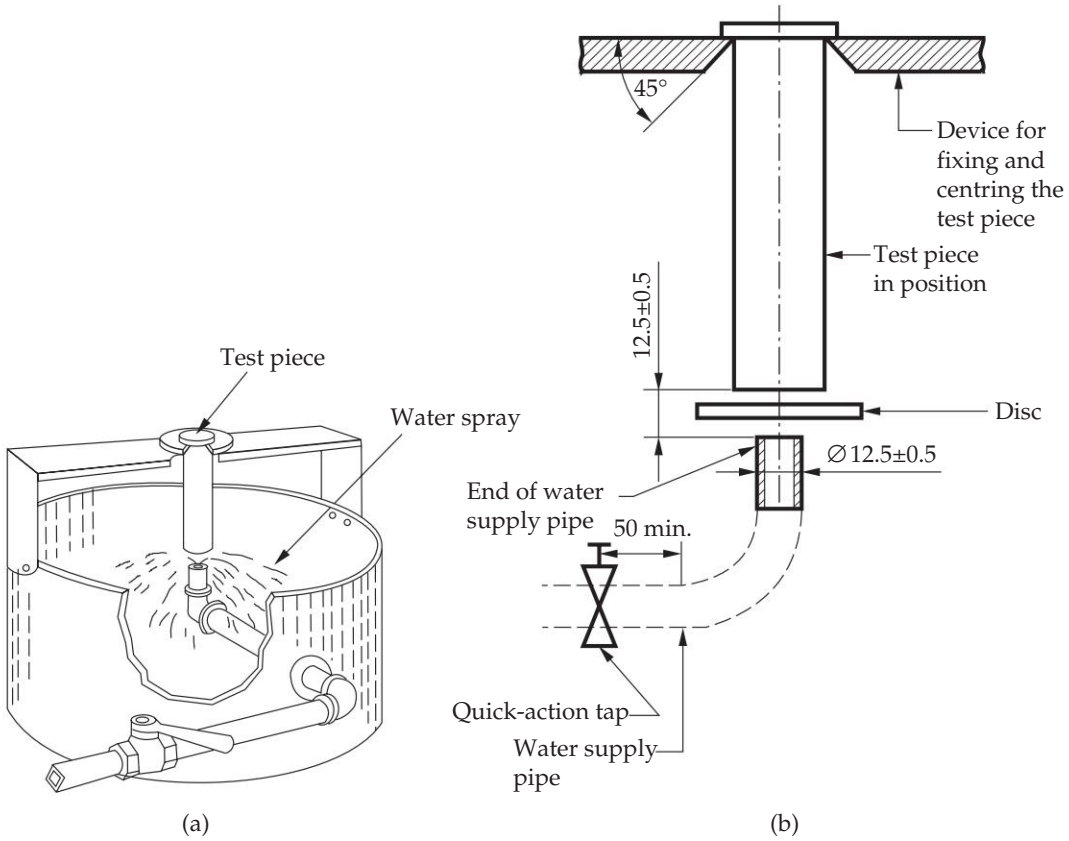


Fig. 15.1 *Quenching device* (*Source:* Ref. 4)

2.4 Rockwell Hardness Testing Machine

2.5 Fixture for Positioning the Test Piece for Hardness Indentations

3 TEST CONDITIONS

3.1 Test Piece

3.1.1 Sampling

The test piece should be prepared from forged or rolled bars, as follows:

1) For diameters ≤ 40 mm, the test piece should be produced by machining;
2) For diameters > 40 mm and ≤ 150 mm, the test piece should be produced by first forging the bar to a diameter of 40 mm and then machining it; and
3) For diameters > 150 mm, the test piece should be taken so that its axis is 20 mm to 25 mm below the surface of the product.

Note: The longitudinal flats specified in Section 4.3 should have their axes at approximately the same distance from the surface of the product.

3.1.2 Heat Treatment

The forged or rolled test bar should be normalized before final machining. The normalizing treatment should be carried out at the average temperature within the range specified for the steel in the material standard. The holding time at the normalizing temperature should be between 30 min and 35 min.

3.1.3 Machining

The cylindrical surface of the test piece should be machined by fine turning. The surface of the test piece end to be quenched should have a fine finish, preferably obtained by grinding, and should be free from burrs.

3.1.4 Dimensions

The dimensions of the test piece should be as shown in Fig. 15.2.

Note: The finish-machined test piece should be free from decarburization.

3.2 Quenching Medium

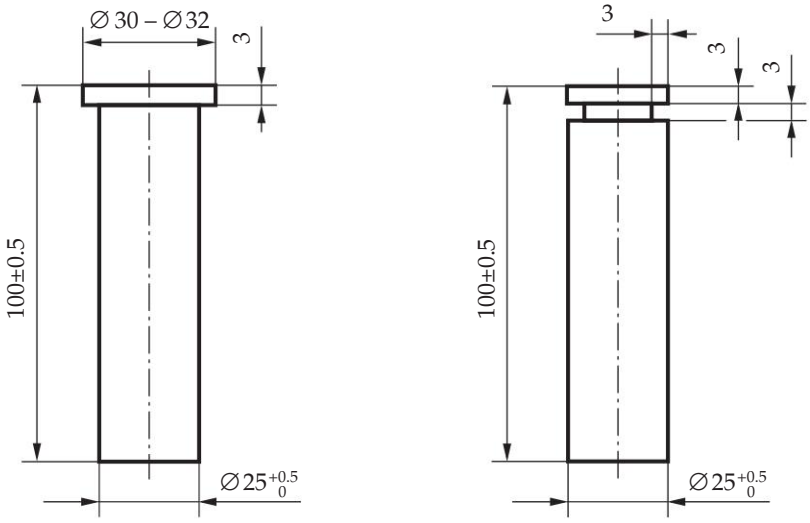
The temperature of cooling water should lie between 15 °C and 25 °C.

4 TEST PROCEDURE

4.1 Heating of Test Piece

Heat the test piece uniformly to the quenching temperature specified in the material standard for the steel being tested for at least 20 min, and then maintain it at that temperature for 30 min to 35 min.

(Dimensions in millimetres)



(a) Test piece with flange (b) Test piece with undercut

Fig. 15.2 *Dimensions of test piece* (*Source:* Ref. 4)

Take precautions to minimize decarburization or carburization of the test piece, and to avoid any marked oxidation with formation of scale. This may be achieved either by using a controlled atmosphere, or by placing the test piece in a vertical position in a suitable container (see Fig. 15.3) whose bottom is covered either with graphite granules or with cast iron chips on which the test piece will rest.

4.2 Quenching of Test Piece

Prior to quenching the test piece, open the quick action tap and adjust the water jet to a height of 65±10 mm above the end of the water supply pipe. Note the valve setting, and then close the tap. Alternatively, keep the water flowing but block the water column with a disc so that there is no contact between the water jet and the test piece when the test piece is initially placed in the fixture.

Ensure that the test fixture is dry at the beginning of each test. Remove the test piece from the furnace with tongs and place it in the test fixture. Immediately open the quick action tap, or alternatively swivel the disc out of position so that the water impinges on the bottom of the test piece without wetting the sides of the test piece. The time lag between removal of the test piece from the furnace and the start of spraying should not exceed 5 s. Throughout the quenching process protect the test piece from air draughts and water splashes.

Allow the test piece to remain in the test fixture for at least 10 min, and then turn off the water. After this time, cool the test piece to room temperature by immersing it in cold water.

(Dimensions in millimetres)

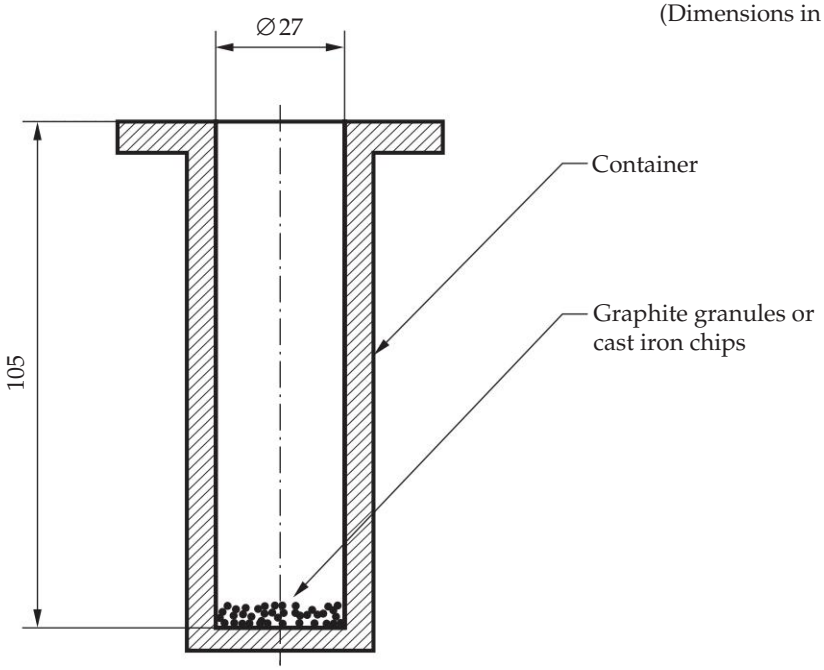


Fig. 15.3 *Example of a low carbon, unalloyed steel container for heating the test piece* (*Source:* Ref. 4)

4.3 Preparation for, and Measurements of Hardness, after Quenching

Grind two flats 180° apart to a depth of 0.4 mm to 0.5 mm along the entire length of the test piece. Grind these flats using a fine grinding wheel and an abundant supply of coolant to avoid any heating which is likely to modify the microstructure of the test piece. Verify that no softening has been caused by grinding, by immersing the test piece in a 5% nitric acid solution in water until it is completely blackened. The colour obtained should be uniform. If there are any stains, indicating the presence of soft spots, grind two new flats at 90° and repeat the etching.

Secure the test piece in a suitable holder (see Fig. 15.4) which is firmly attached to the elevating screw of the hardness testing machine. Ensure that the test piece is well supported and rigidly held during hardness testing. The device for moving the test piece on the hardness testing machine should allow accurate centring of the flat and spacing of the indentations to within ± 0.1 mm.

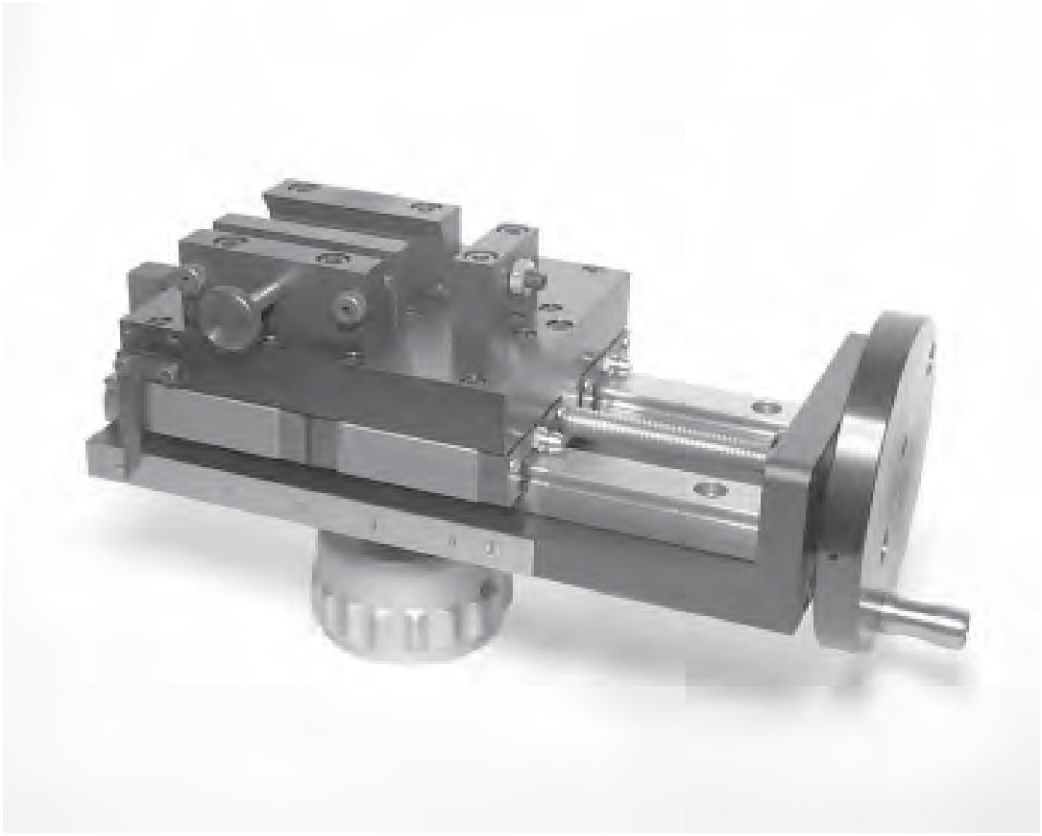


Fig. 15.4 *Fixture for positioning the test piece for hardness indentations (Courtesy of Newage Testing Instruments, Inc.)*

Measure the Rockwell C hardness along the axis of the flats at the following distances from the quenched end:

1) ***For low alloy steels and high manganese carbon steels:*** At 1.5, 3, 5, 7, 9, 11, 13, 15, 20, 25, 30, 35, 40, 45 and 50 mm.
2) ***For plain carbon steels:*** At 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 15, 20, 25 and 30 mm.

Do not record hardness values below 20 HRC. Before measuring the hardness on the second flat, remove any raised edges of hardness indentations on the first flat by grinding. The difference in the hardness values on the two flats at the same distance from the quenched end should not exceed 3 HRC. If this value is exceeded, repeat the hardness test on new flats, 90° from the first two flats.

Note: By agreement, the Rockwell C hardness measurements may be replaced by measurements of Vickers hardness (HV 30).

At each distance from the quenched end, calculate the arithmetic mean of the hardness measurements made at this distance on each of the two flats. Plot these hardness values as a function of the distance from the quenched end (see Fig. 15.5).

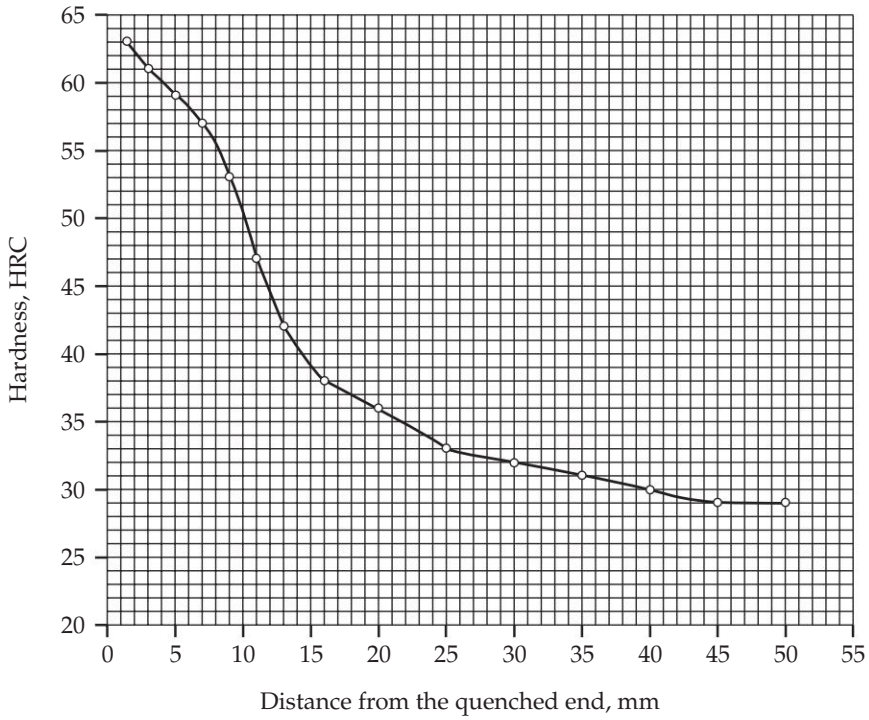


Fig. 15.5 *Typical end-quench hardenability curve (Jominy curve)*

Note: With the aid of computer facilities, calculation models by treatment of numerical data have been developed to determine the Jominy curve from the chemical composition (see "SAE EA 406, Hardenability Prediction Calculator").

5 REFERENCES

1. ASTM A 255:2002, *Test Method for End-Quench Test for Hardenability of Steel.*
2. IS 1501:2002, *Method for Vickers Hardness Test for Metallic Materials.*
3. IS 1586:2000, *Method for Rockwell Hardness Test for Metallic Materials (Scales A, B, C, D, E, F,* G, H, K, 15N, 30N, 45N, 15T, 30T and 45T).
4. IS 3848:1981, *Method for End-Quench Test for Hardenability of Steel.*
5. ISO 642:1999, *Steel — Hardenability Test by End-Quenching (Jominy Test).*

16

Micrographic Method for the Determination of Grain Size of Steels

1 PRINCIPLE

The micrographic method for the determination of the ferritic or austenitic grain size in steels consists of examining the polished surface of a specimen which has been appropriately treated to reveal the grain boundaries and estimating the grain size by comparison or measurement method.

2 DEFINITIONS

2.1 Grain

A closed polygonal shape with more or less curved sides which can be revealed on a flat cross-section of the sample, polished and prepared for micrographic examination.

2.1.1 Austenitic Grain

Crystal with a face-centered cubic crystal structure which may, or may not, contain annealing twins.

2.1.2 Ferritic Grain

Crystal with a body-centered cubic crystal structure which never contains annealing twins.

Note: Ferrite grain size is generally estimated for unalloyed steels with a carbon content of 0.25 % or less. If pearlite islands of dimensions identical to those of the ferrite grains are present, the islands are then counted as ferrite grains.

3 APPARATUS

3.1 Laboratory Furnace

3.2 Metallographic Sample Preparation Equipment

3.3 Etching Reagent

3.4 Metallurgical Microscope

4 SPECIMEN

Unless otherwise specified, the polished face of the specimen should be parallel to the principal axis of deformation in wrought products. The finish of the test surface should be such that the grains are clearly revealed during microscopic examination.

Note: Ensure that the test surface is free from artifacts which can give misleading results.

5 TEST PROCEDURE

5.1 Revealing the Grains Boundaries

5.1.1 Revealing the Ferritic Grain Boundaries

Reveal the ferrite grains by etching either with nital (nitric acid ethanol solution), or with picral (picric acid ethanol solution), or with an appropriate etchant.

5.1.2 Revealing the Austenitic Grain Goundaries

In the case of steels having a single-phase or two-phase austenitic structure at ambient temperature, reveal the austenitic grains by etching with an appropriate reagent.

For other steels, use one of the methods specified below depending upon the information required:

1) "Bechet-Beaujard" method by etching with aqueous saturated picric acid solution;
2) "Kohn" method by controlled oxidation;
3) "McQuaid-Ehn" method by carburization; or
4) If need be, other methods specially agreed upon when ordering.

5.1.2.1 "Bechet-Beaujard" Method by Etching with Aqueous Saturated Picric Acid Solution

Field of application: This method reveals austenitic grains formed during heat treatment of the specimen. It is applicable to specimens which have a fine martensitic or bainitic structure.

Preparation: If the sample does not have a fine martensitic or bainitic structure, heat treat the unalloyed and low alloy steels as follows:

1) Austenitize at 850±10 °C for 1.5 h for steels whose carbon content is greater than 0.35 %, and
2) Austenitize at 880±10 °C for 1.5 h for steels whose carbon content is less than or equal to 0.35 %.

After this treatment, cool the specimen by quenching in water or oil to produce a fine bainitic or martensitic structure.

Polishing and etching: Polish a flat surface of the specimen for micrographic examination. Etch the sample using an aqueous solution saturated with picric acid together with at least 0.5 % sodium alkysulfonate or another appropriate wetting agent.

Notes:

1) The period of etching may vary from a few minutes to more than one hour. Slight re-heating of the solution to 60 °C, for example, may improve the etching action and reduce the period of etching.
2) Several successive etching and polishing operations are sometimes necessary to ensure a sufficient contrast between the grain boundaries and the general base of the sample.

Result: The boundaries of the prior-austenite grain boundaries appear directly in the micrographic examination.

5.1.2.2 "Kohn" Method by Controlled Oxidation

Field of application: This method is suitable for most types of steels and shows up the austenitic grain pattern formed by preferential oxidation of the boundaries during austenitization at the temperature of a given heat treatment.

Preparation: Polish a flat surface of the specimen for micrographic examination. Ensure that the rest of its surface does not show any traces of oxide. Place the specimen in a laboratory furnace having an inert atmosphere (for example, high purity argon or a vacuum of 1 Pa). Austenitize the sample under conditions of temperature and time specified in the material standard.

At the end of the specified heating period, introduce air into the furnace for a period of 10 s to 15 s. Cool the test piece by quenching in oil or water.

Polishing and etching: Examine the polished surface through the microscope. If there is heavy oxidation of the sample, remove the oxide adhering to the previously polished surface by lightly polishing with a fine abrasive, taking care that the oxide network which has formed at the grain boundaries is retained. Complete the polishing. Etch the test piece using Vilella's reagent or Benedick's reagent.

Result: The preferential oxidation of the boundaries shows up the pattern of austenitic grains.

5.1.2.3 "McQuaid-Ehn" Method by Carburization

Field of application: This method is primarily intended for case hardening steels having carbon contents up to 0.25%, but is also used for other grades of up to 0.60%. The method shows up austenitic grain boundaries formed during carburization of these steels. It is not usually suitable for determining grains actually formed during other heat treatments. The grain boundaries of the carburized layer are revealed as a network of proeutectoid cementite.

Preparation: Ensure that the specimen is free from any trace of decarburization or of surface oxidation.

Note: Any prior treatment, either cold, hot, mechanical, etc., may have an effect on the shape of the grain obtained.

Space the specimens conveniently in a carburizing chamber fitted with a lid and fill the chamber with dry and active carburizing compound, consisting of about 60 % charcoal grains and 40 % barium carbonate ($BaCO_3$). Ensure that the volume of carburizing compound is at least 30 times the volume of the specimens to be carburized.

Carburize the specimens by maintaining the carburizing chamber at 925±10 °C for 8 h. Cool the specimens to a temperature lower than the critical temperature (Ar_1) at a sufficiently slow rate, e.g. furnace cool, to ensure that the cementite is precipitated at the grain boundaries of the hypereutectoid zone of the carburized layer.

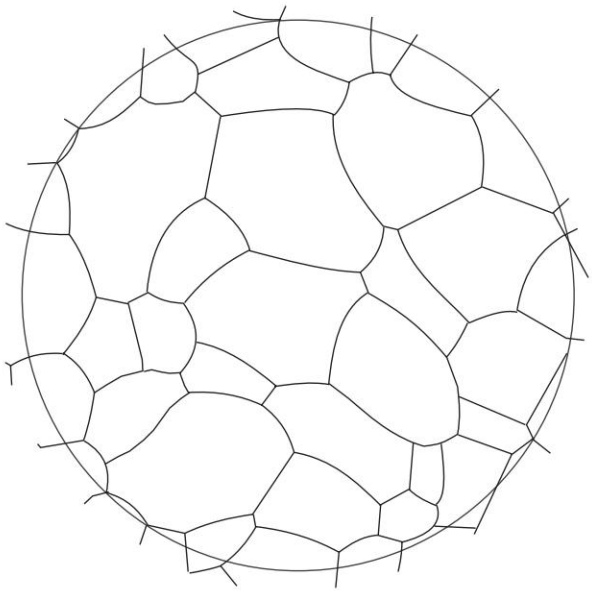
Note: Use a fresh carburizing compound for each test.

Polishing and etching: Section the carburized specimen at right angles to the surface and polish the cut surface for micrographic examination. Etch the specimen with nital or "Le Chatelier and Igevski" reagent (alkaline sodium picrate). The latter reagent should be used in the boiling state.

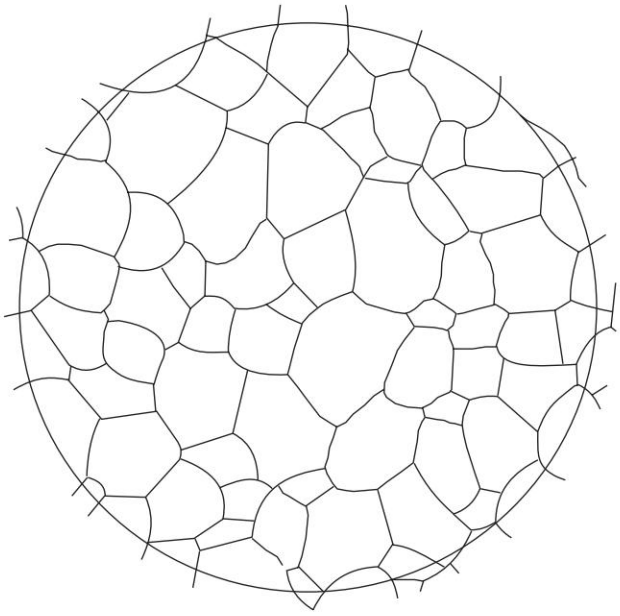
Result: The grain boundaries of the carburized layer, which is approximately 1 mm thick, should be revealed as a network of proeutectoid cementite.

5.2 Determination of Grain Size

Examine the entire etched polished surface under a microscope at a magnification of 100×. Estimate the grain size by comparing the fields of view with the reference diagrams given in Fig. 16.1.

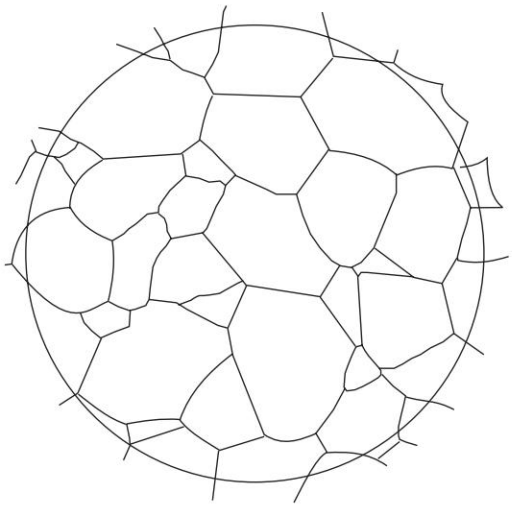


No. I



No. II

Fig. 16.1 *Reference diagrams for grain size (magnification 100×)— ASTM grain size Nos. I to VIII* (*Source:* Ref. 1)



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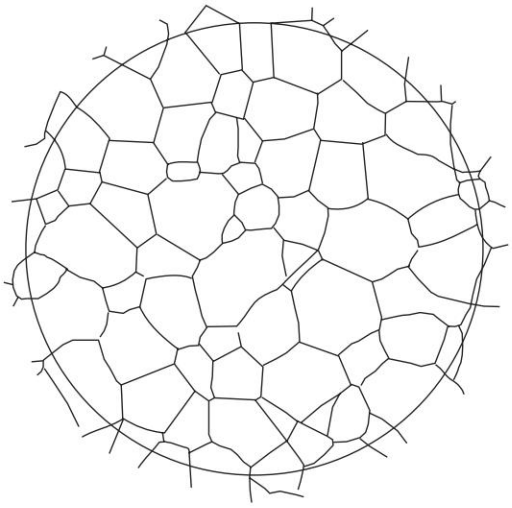


No. IV

Fig. 16.1 *contd.*

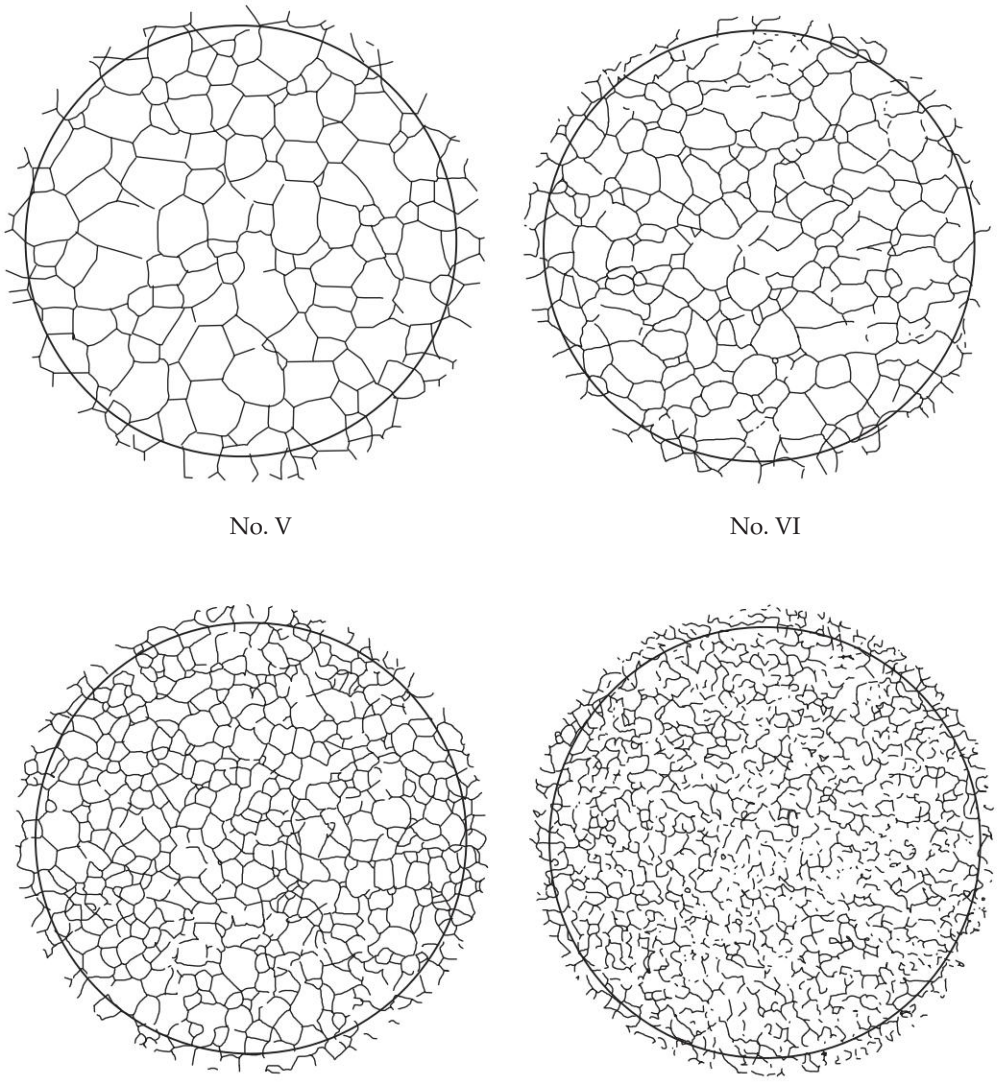


Fig. 16.1

6 REFERENCES

1. IS 4748:1988, *Methods for Estimating Average Grain Size of Metals.*
2. ASTM E 112:1996e3, *Standard Test Methods for Determining Average Grain Size.*
3. BS 4490:1989, *Methods for Micrographic Determination of the Grain Size of Steel.*
4. ISO 643:2003, *Steels— Micrographic Determination of the Apparent Grain Size.*

17

Micrographic Method for the Determination of Nonmetallic Inclusions in Wrought Steels

1 PRINCIPLE

The micrographic method for the determination of nonmetallic inclusions in wrought steel products consists of comparing, for each type of inclusion, the observed fields with the standard diagrams (see Fig. 17.1 or 17.2) and allocating them the same classification as that of the diagrams that resemble them most closely.

These diagrams correspond to circular or square fields of view, each with an area of 0.50 mm^2, and observed at a magnification of 100×. According to the shape and distribution of the inclusions, the standard diagrams are divided into the following four main groups:

1) *Group A (sulphide type):* Highly malleable, individual grey particles with a wide range of aspect ratios (length/ width) and generally rounded ends;
2) *Group B (aluminate type):* Numerous non-deformable, angular, low aspect ratio (generally < 3), black or bluish particles (at least three) aligned in the deformation direction;
3) *Group C (silicate type):* Highly malleable, individual black or dark grey particles with a wide range of aspect ratios (generally ≥ 3) and generally sharp ends; and
4) *Group D (globular oxide type):* Non-deformable, angular or circular, low aspect ratio (generally < 3), black or bluish, randomly distributed particles.

Each main group on the chart consists of two sub-groups, each made up of five diagrams representing increasing inclusion content. This division into sub-groups is merely intended to facilitate examples of different thicknesses of nonmetallic particles.

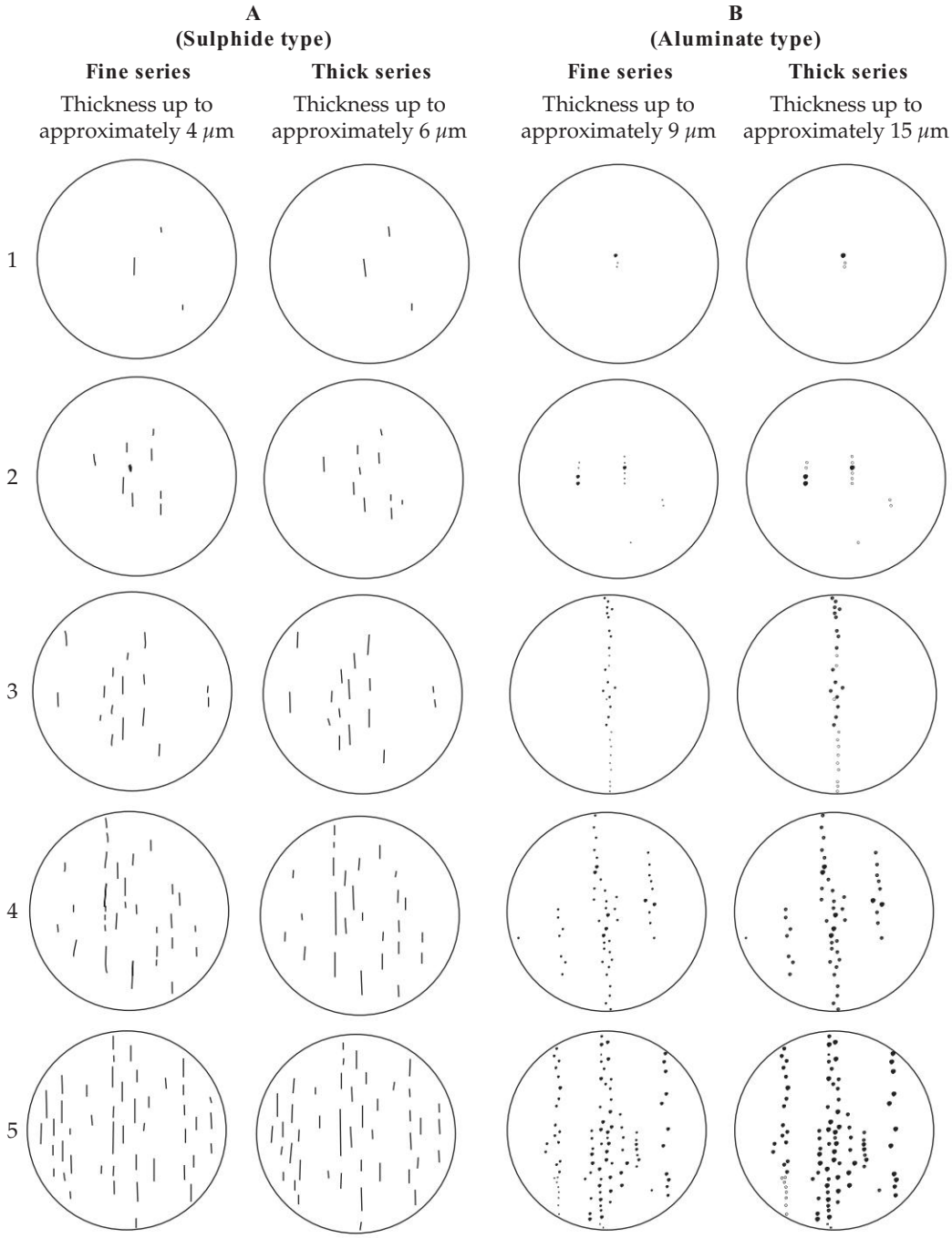


Fig. 17.1 *Jernkontoret standard diagrams* (*Source:* Ref. 1)

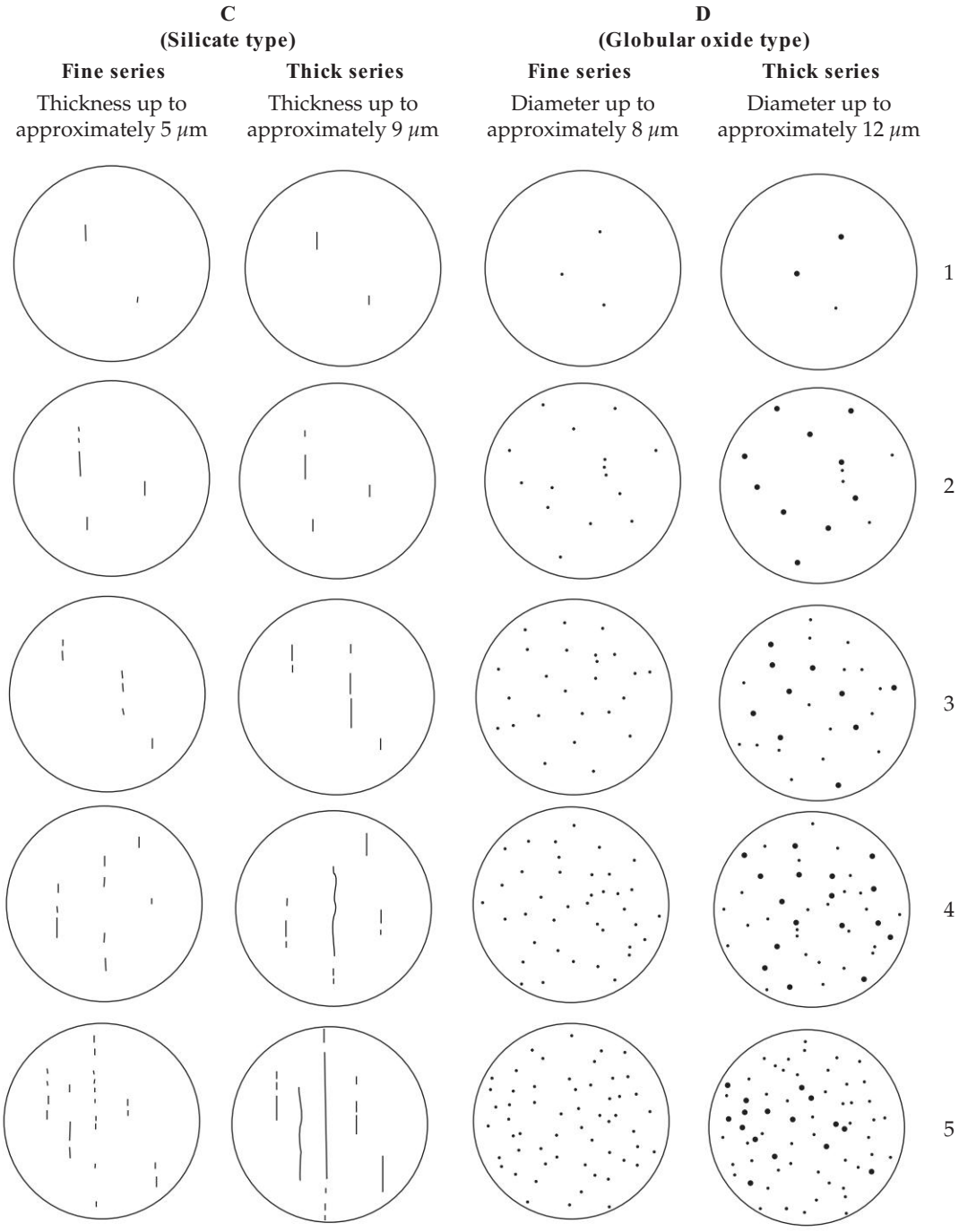


Fig. 17.1

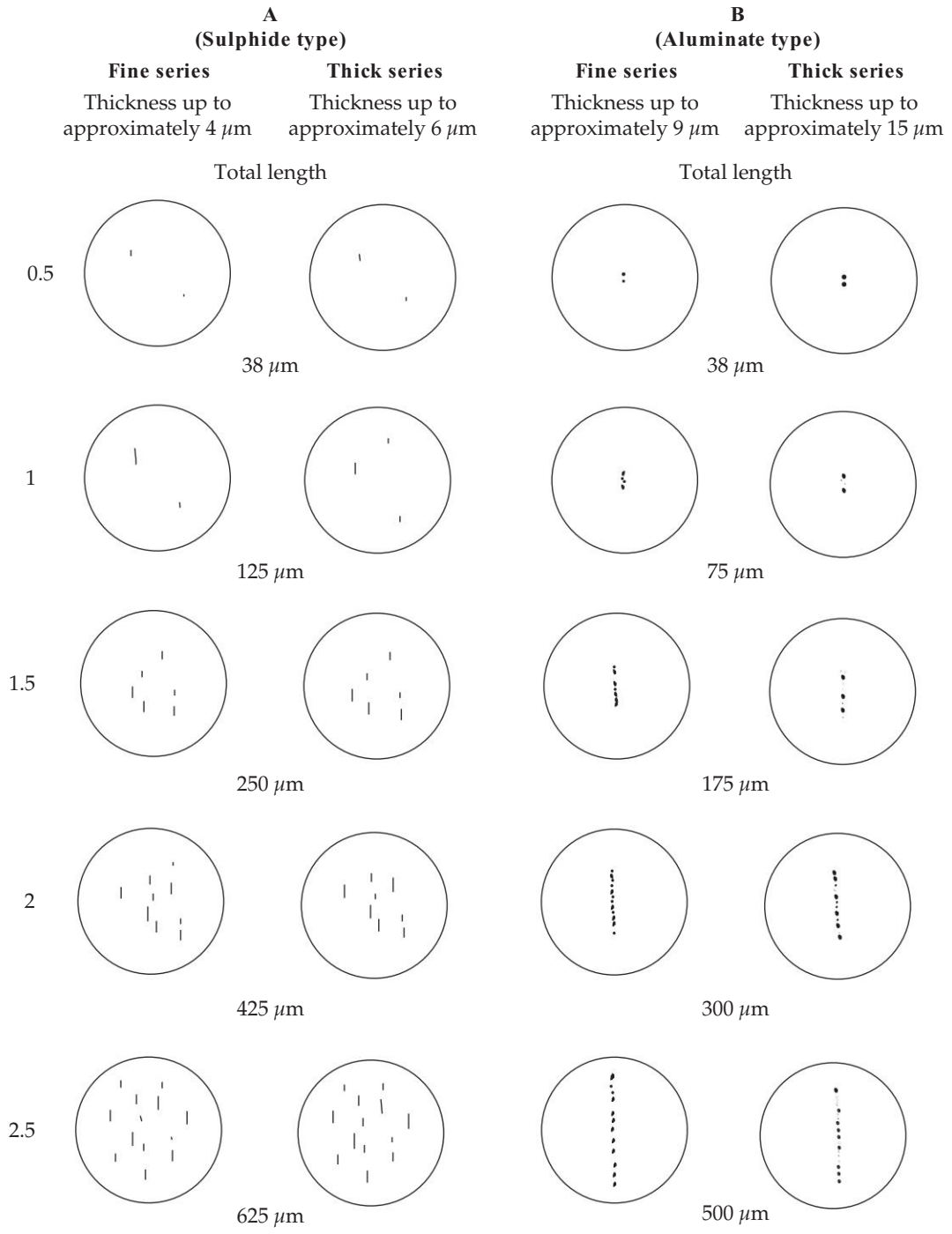


Fig. 17.2 *ASTM standard diagrams* (*Source:* Ref. 1)

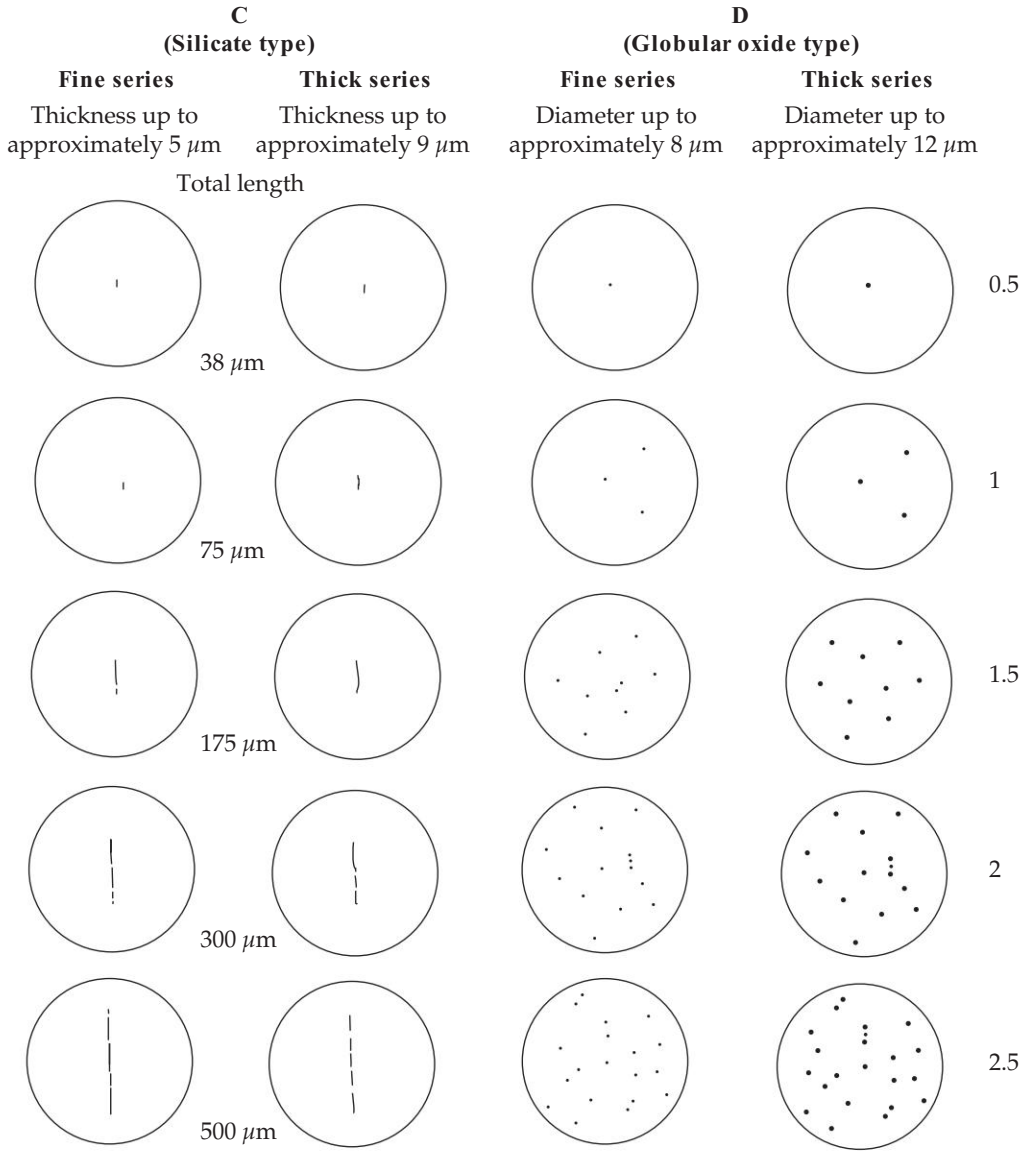


Fig. 17.2

2 APPARATUS

2.1 Metallographic Sample Preparation Equipment

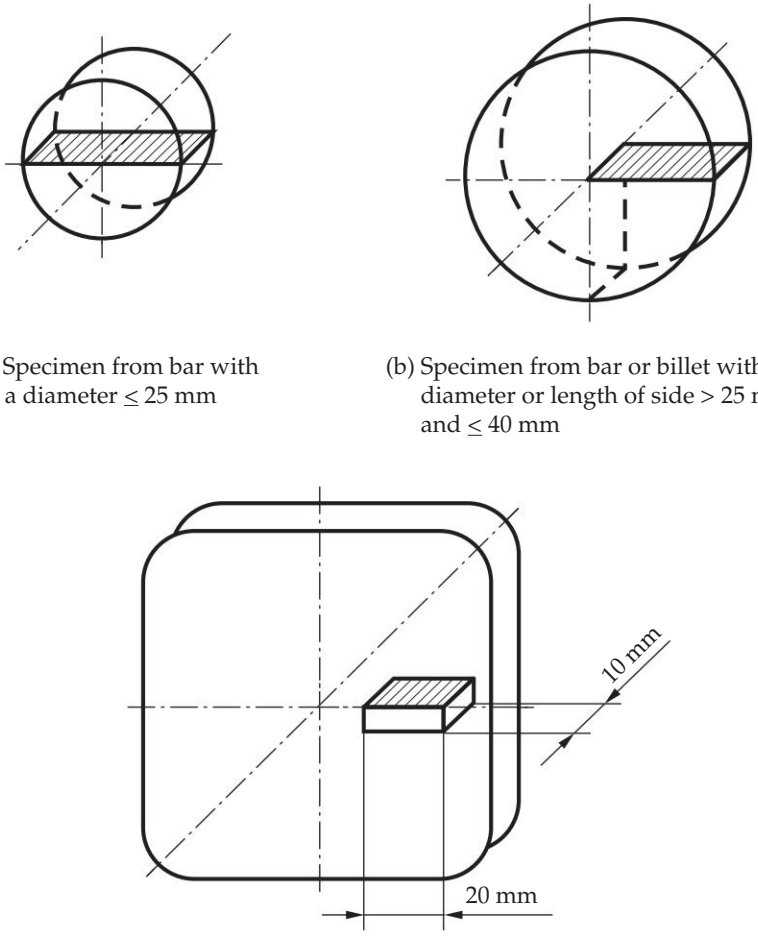
2.2 Metallurgical Microscope

3 SPECIMEN

3.1 Sampling

Unless otherwise specified, the specimens should be taken as shown in Fig. 17.3. The number of specimens to be taken should be as specified in the product standard.

The polished surface of the specimen used to determine the content of inclusions should be approximately 200 mm^2 (20 mm × 10 mm). It should be parallel to the longitudinal axis of the product.



(a) Specimen from bar with a diameter ≤ 25 mm

(b) Specimen from bar or billet with a diameter or length of side > 25 mm and ≤ 40 mm

(c) Specimen from bar or billet with a diameter or length of side > 40 mm

Fig. 17.3 *Location of specimens in bars and billets* (*Source:* Ref. 1)

3.2 Preparation

The specimen should be cut so as to obtain a flat surface for examination. In order to avoid rounding the edges of the specimen when polishing, the specimen may be held mechanically or may be mounted.

When polishing the specimens, prevent any tearing out or deformation of the inclusions, or contamination of the polished surface, so that the surface is as clean as possible. If this condition cannot be met in the as-received condition, the specimen should be heat treated to the maximum attainable hardness before polishing.

Note: It is advisable to use diamond paste for polishing.

4 TEST PROCEDURE

Examine the entire unetched, polished surface under a microscope at a magnification of 100×, either by projecting it on to a ground glass or by observing with the help of an eyepiece. Ensure that the area of the field of view is 0.50 mm^2. Compare each field of view with the standard diagrams given in Fig. 17.1 or Fig. 17.2. Unless otherwise agreed, examine at least 100 fields.

Notes:

1) Inclusions which are longer than the diameter of the field or field width should be noted separately; the same is true of inclusions thicker than those of the standard diagrams.
2) If a field of inclusions falls between two standard diagrams, rate according to the lower diagram.

4.1 Method A

For each type of inclusion record the reference number corresponding to the worst field examined, in the fine and thick series.

Example

A2, B1e, C3, D1 indicates the symbol for the type of inclusion followed by the reference number of the worst field, the presence of thick inclusions being indicated by the letter *e*.

4.2 Method B

Alternatively, for each field of view, record the reference number corresponding to each type of inclusion, in the fine and thick series. Calculate the arithmetic mean for each type of inclusion in the fine and thick series.

Example

For type A inclusions (fine series) take:

n_1 as the number of fields of index 0.5
n_2 as the number of fields of index 1
n_3 as the number of fields of index 1.5
n_4 as the number of fields of index 2
n_5 as the number of fields of index 2.5

Total index = $(n_1 \times 0.5) + (n_2 \times 1) + (n_3 \times 1.5) + (n_4 \times 2) + (n_5 \times 2.5)$

$$\text{Mean index} = \frac{\text{Total index}}{N}$$

where N is the total number of fields observed.

5 REFERENCES

1. IS 4163:1982, *Method for Determination of Inclusion Content in Steel by Microscopic Method.*
2. ISO 4967:1998, *Steel— Determination of Content of Nonmetallic Inclusions— Micrographic Method Using Standard Diagrams.*
3. ASTM E 45:1997, *Standard Test Methods for Determining the Inclusion Content of Steel.*

e

18

Macroscopic Methods for Assessing the Content of Nonmetallic Inclusions in Wrought Steels — Blue Fracture Test Method

1 PRINCIPLE

The blue fracture test method for assessing the content of nonmetallic inclusions in wrought steel products consists of determining the total number and distribution of nonmetallic inclusions visible on the surface of a fracture which has undergone blue tempering. This fracture is in the longitudinal direction of the product and the inclusions normally appear as white stringers (see Fig. 18.1).

Note: In general, the blue fracture test is carried out on semi-finished products.

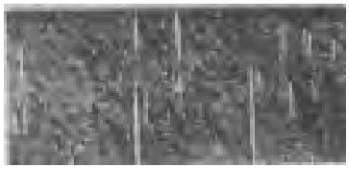


Fig. 18.1 *Blue-tempered fracture surface showing macro-inclusions as white stringers* (*Source:* Ref. 3)

2 DEFINITIONS

2.1 Macro-Inclusions

Nonmetallic inclusions visible to the naked eye or with the aid of a magnifying glass with a magnification of not more than 10×. Only inclusions greater than 1 mm long are taken into consideration.

2.2 Blue Tempering

Operation carried out in an oxidizing medium at a temperature such that the surface of the ferrous product is covered with a thin, continuous, adherent film of blue coloured oxide.

3 APPARATUS

3.1 Laboratory Furnace

3.2 Tongs

3.3 Press for Fracturing the Test Piece

3.4 Magnifying Glass

4 TEST PIECE

4.1 Sampling

The test piece (see Fig. 18.2) should consist of a slice whose thickness is measured parallel to the longitudinal direction, and the slice being taken by hot or cold sawing or by flame cutting.

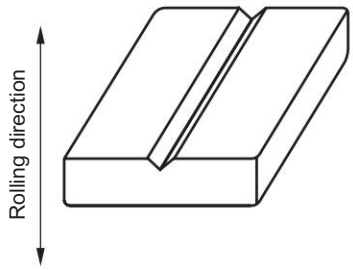


Fig. 18.2 *Test piece for the blue fracture test*

When flame cutting is used, care should be taken to ensure that the fracture takes place outside the heat-affected zone.

The number and position of the test pieces should be as specified in the product standard. In general, five samples from each cast or lot are taken.

4.2 Preparation

The test piece should contain a groove in the middle of one of the principal sides (i.e. perpendicular to the longitudinal axis of the product). Its shape is variable and its depth should be such that the thickness of the remaining slice is 10–20 mm. The purpose of this groove is to facilitate the fracture of the test piece.

Note: Macro-inclusions appear clearly for a particular hardness range. Hence, in certain cases, the test piece, may be hardened, possibly followed by tempering, prior to testing.

5 TEST PROCEDURE

Heat the test piece in air to the blue brittleness temperature (300 °C to 350 °C) and fracture, or alternatively fracture the test piece at the ambient temperature and then subsequently heat to blue the fracture.

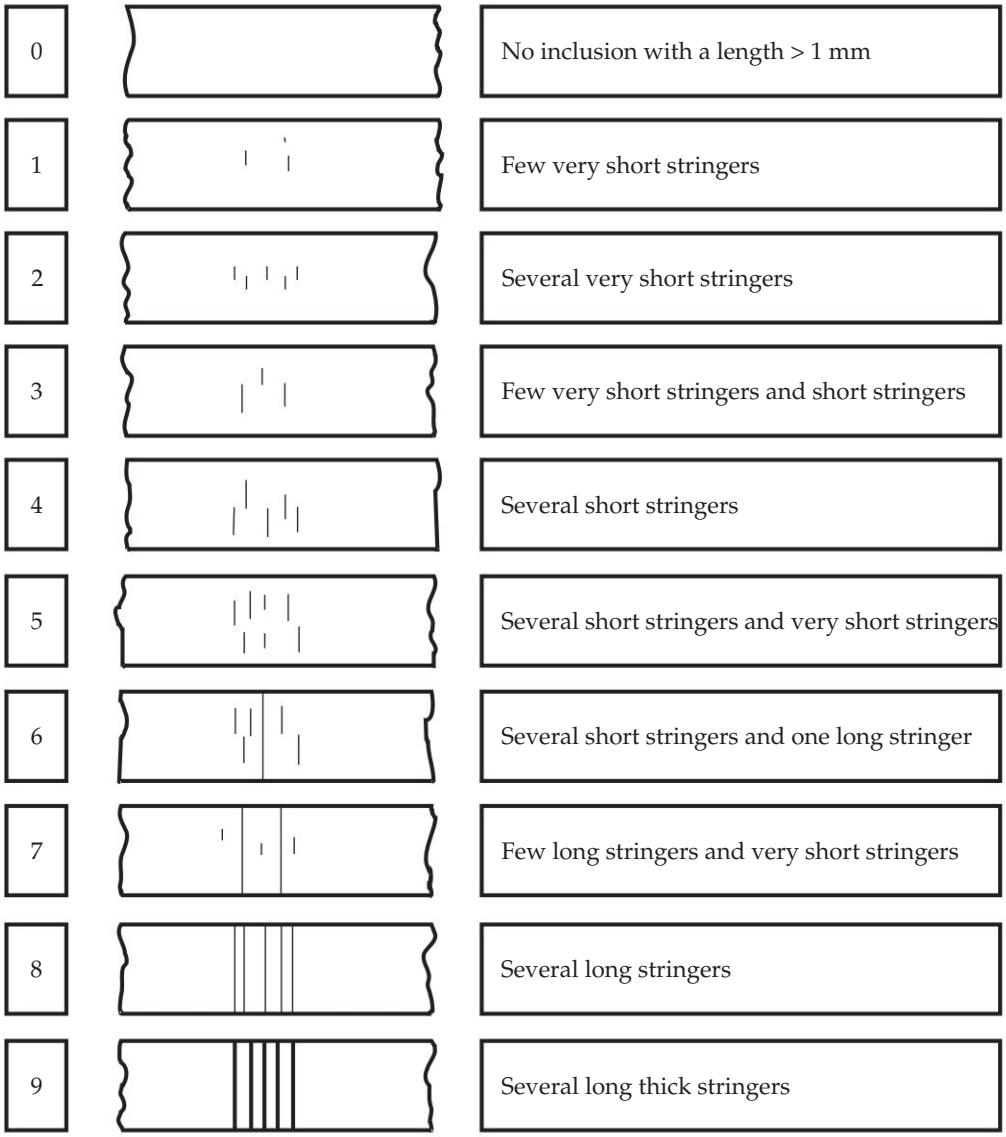
Examine the fracture surfaces with the naked eye or at a magnification of less than or equal to 10×, and compare with the series of ten reference diagrams given in Fig. 18.3.

Alternatively, count the length and/ or thickness of the inclusions (see Tables 18.1 and 18.2).

The acceptance limit should be as specified in the product standard.

Notes:

1) Comparative tests should be carried out on products which have undergone similar hot-working reductions.
2) Care should be taken during examination of steels with ferrite lines or carbide stringers, as these may be confused with inclusion stringers.



Explanation of terms

Very short stringers	: ≥ 1 mm ≤ 2.5 mm	Few	: ≤ 3
Short stringers	: > 2.5 mm ≤ 5 mm	Several	: > 3
Long stringers	: > 5 mm	Thick	: > 0.5 mm

Fig. 18.3 *Standard diagrams for the blue fracture test method*

Table 18.1 *Inclusion Distribution Based on Length*

Symbol	Length mm
L_o	No macroscopic inclusion
L_1	≥ 1.0 ≤ 2.5
L_2	> 2.5 ≤ 5.0
L_3	> 5.0 ≤ 10
L_4	> 10
Source: Ref. 1	

Table 18.2 *Inclusion Distribution Based on Thickness*

Symbol	Thickness mm
T_o	No macroscopic inclusion
T_1	≥ 0.10 ≤ 0.25
T_2	> 0.25 ≤ 0.50
T_3	> 0.50 ≤ 1.00
T_4	> 1.00
Source: Ref. 1	

6 REFERENCES

1. IS 10138-1:1992, *Macroscopic Methods for Determination of Non-Metallic Inclusion Content in Wrought Steels—Part 1: Blue Fracture Test Method.*
2. IS 3763:1976, *Wrought Steels — Macroscopic Methods for Assessing the Content of Non-Metallic Inclusions.*
3. K.E. Thelning, *Steel and Its Heat Treatment,* 2nd Edition, Butterworths, London, UK, 1984.

19

Macrographic Examination of Steel by Sulphur Printing (Baumann Method)

1 PRINCIPLE

The Baumann method for the macrographic examination of steel by sulphur printing is a qualitative test which is employed to detect the distribution of sulphur in steel and certain physical irregularities, such as cracks and porosity, by printing on photo-sensitive paper previously soaked in sulphuric acid solution.

2 APPARATUS

2.1 Container

A shallow container, such as a photographic tray, is required to contain the sulphuric acid solution. The container should be large enough to soak the photographic paper without excessive folding of the paper. A similar tray is also required to hold the photographic fixing solution.

2.2 Timing Device

A timing device is necessary for timing the contact printing time, and the washing and fixing periods.

2.3 Photographic Paper

A thin, matte type, photographic bromide paper should be used.

2.4 3% Solution of Sulphuric Acid in Water

2.5 Photographic Fixing Solution

A commercial fixing solution or a 15% to 20% solution of sodium thiosulphate in water may be used.

2.6 Hair Drier

3 TEST CONDITIONS

3.1 Test Piece

3.1.1 Sampling

The test may be made on the product or on a test piece cut from the product. In general, this consists of a section perpendicular or parallel to the direction of rolling for products such as bars, billets and rounds.

The test surface should be located away from the cut faces when cutting has been carried out by hot shearing or flame cutting.

3.1.2 Preparation

The test surface should be flat and smooth. A surface finish with a R_a of at least 3.2 μm should be obtained after machining. The test surface should also be free from foreign matter, such as dirt and oil.

Notes:

1) The test surface should be free from pronounced cutting tool marks.
2) A very smooth finish (mirror type finish) will cause the paper to slip on the test piece, resulting in a blurred image.

3.2 Test Temperature

The test should be carried out at ambient temperature.

4 TEST PROCEDURE

Immerse the photographic paper of appropriate size for about 3 to 4 min in a sufficient volume of sulphuric acid solution. Remove the paper from the acid solution and allow the excess acid solution to drain off.

Note: Soaking time in excess of 5 min may cause swelling of the emulsion.

Apply the sensitive side of the paper, still damp, to the surface to be examined. Alternatively, if the test piece is small, apply the test surface to the photographic paper which has been impregnated beforehand. To ensure good contact, eliminate air bubbles and drops of liquid between the surface of the test piece and the sheet of paper, for example, by means of a rubber roller. Do this carefully so that the paper does not slip. Allow the photographic paper to remain in contact with the test surface for 30 s to 10 min, depending upon the concentraion of the acid solution and the sulphur content of the steel.

Carefully peel off the print and wash it in clear running water for about 10 min.

Immerse the print for at least 10 min in fixing solution, then wash it in clear running water for at least 30 min and dry.

Examine the print (see Fig. 19.1). The presence of sulphides is revealed on the print by the brown colouration produced by silver sulphide (Ag_2S). The greater the sulphur content of the steel, the darker is the image. Localized sulphur segregation is revealed on the print as a concentration of darker spots. Dark spots or lines may also be formed at cracks, voids or holes. White spots are usually due to entrapped air between the paper and the test piece.

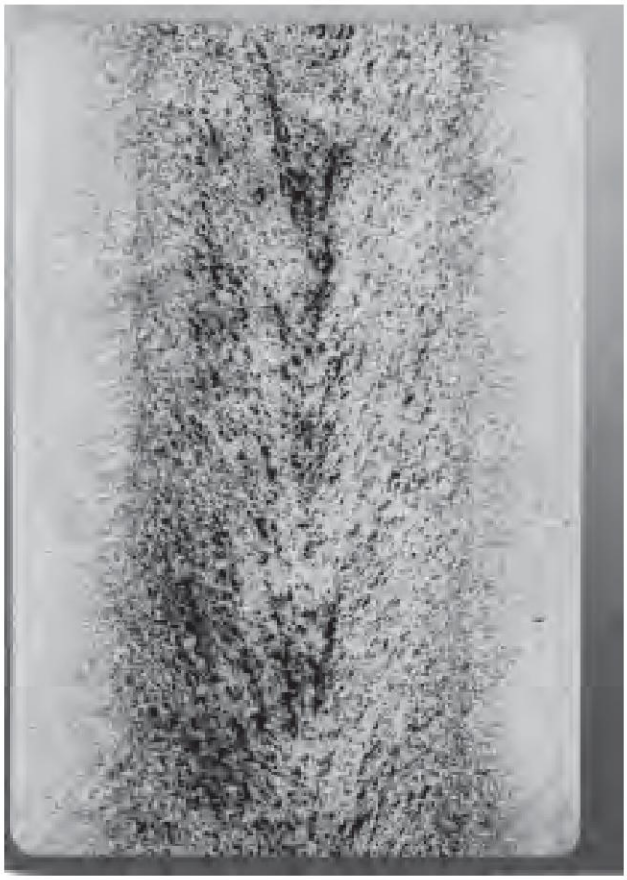


Fig. 19.1 *Typical sulphur print of a continuously cast billet*

5 REFERENCES

1. IS 12037:1987, *Specification for Macrographic Examination of Steel by Sulphur Print (Baumann Method)*.
2. BS 6285:1982, *Method for the Macrographic Examination of Steel by Sulphur Print (Baumann Method)*.
3. ISO 4968:1979, *Steel — Macrographic Examination by Sulphur Print (Baumann Method)*.
4. G.L. Kehl, *The Principles of Metallographic Practice*, 3rd Edition, McGraw-Hill, New York, USA, 1949.
5. ASTM E 1180:2003e1, *Standard Practice for Preparing Sulphur Prints for Macrostructural Examination*.

20

Determination of the Effective Case Depth of Carburized or Carbonitrided, and Hardened Cases in Steels

1 PRINCIPLE

The effective case depth of carburized or carbonitrided, and hardened cases in steels is determined from the gradient of hardness on a cross-section normal to the surface. It is estimated graphically from a curve representing the variation in hardness as a function of the distance from the surface of the part.

2 DEFINITION

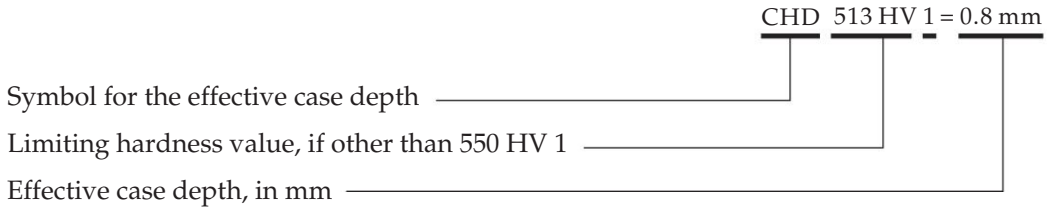
2.1 Effective Case Depth of a Carburized or Carbonitrided, and Hardened Case

The perpendicular distance between the surface of a carburized or carbonitrided and hardened ferrous product and the point at which the Vickers hardness is 550 HV, when measured using an applied test force of 9.807 N (1 kgf).

Notes:

1) By agreement, test forces other than the reference test force of 9.807 N (1 kgf), between 0.9807 N (0.1 kgf) and 9.807 N (1 kgf), may be used.
2) By agreement, a limiting hardness value other than 550 HV, for example 513 HV (50 HRC) may also be used (see Ref. 6).

3 DESIGNATION OF EFFECTIVE CASE DEPTH



4 APPARATUS

4.1 Metallographic Sample Preparation Equipment

4.2 Hardness Testing Machine

The Vickers hardness testing machine should comply with the requirements given in IS 1754. It should be capable of applying test forces between 0.9807 N (0.1 kgf) and 9.807 N (1 kgf).

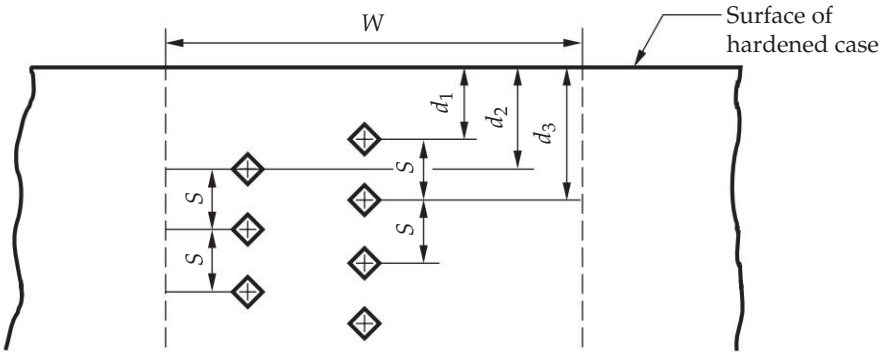
The measuring device should be capable of measuring the diagonals of the indentation to an accuracy of ± 0.5 μm.

5 TEST PROCEDURE

Cut the carburized or carbonitrided, and hardened part at right angles to the hardened case in an area chosen by agreement between the supplier and the user. Grind and polish the surface on which the measurement is to be made. Take all precautions to avoid rounding the edges of the surface and over-heating of the part.

Note: In order to avoid rounding the edges, mount the sample in a plastic material or hold it in a clamp.

Make the hardness indentations, using an applied test force of 9.807 N (1 kgf), along one or more parallel lines normal to the surface and within a band (W) of width 1.5 mm (see Fig. 20.1).



Key:

d_1, d_2, d_3 = Distances between the surface of the hardened case and the 1st, 2nd and 3rd hardness indentations, respectively
S = Distance between the centres of two adjacent indentations
W = Band width

Fig. 20.1 *Position of hardness indentations* (*Source:* Ref. 1)

Note: If the thickness of the case hardened layer is not compatible with the size of the hardness indentation, use an appropriate test force in the range of 0.9807 N (0.1 kgf) to 9.807 N (1 kgf).

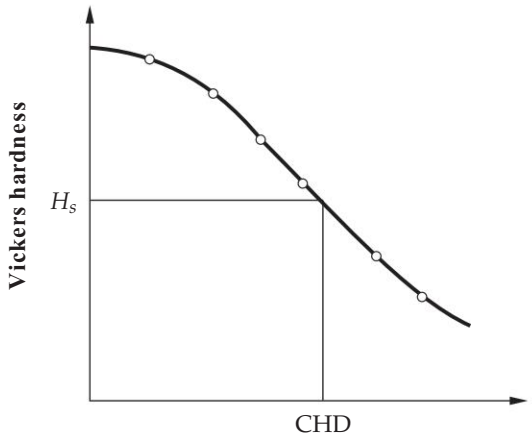
Ensure that the distance between the surface and the centre of the first indentation from the surface is at least two-and-a-half times the mean diagonal of the indentation, and that the distance between the centres of two adjacent indentations is at least three times the mean diagonal of the indentation (see Fig. 20.1). The difference between the successive distances of each indentation from the surface (e.g. $d_2 - d_1$) should also not exceed 0.1 mm.

Make the hardness indentations on the surface in two bands. Measure the size of the hardness indentations using an optical device giving a minimum magnification of 400×.

Calculate the hardness value at each depth and plot the results in order to obtain curves representing the variation in hardness as a function of distance from the surface.

From the two curves plotted, determine for each band, the distance from the surface to the point at which the hardness is equal to 550 HV (see Note 2 in Section 2.1).

If the difference between these two values is less than or equal to 0.1 mm, take the mean of these two distances as the effective case depth. However, if the difference between these two values is greater than 0.1 mm, repeat the test.



Key:

H_S = Limiting hardness value for the determination of effective case depth
CHD = Effective case depth

Fig. 20.2 *Typical curve representing the variation in hardness as a function of distance from the surface of a carburized and hardened steel part* (*Source:* Ref. 5)

6 REFERENCES

1. IS 6416:1988, *Methods for Measuring Case Depth of Steel.*
2. IS 1501:2002, *Method for Vickers Hardness Test for Metallic Materials.*
3. IS 1754:2002, *Method for Verification of Vickers Hardness Testing Machines.*
4. BS 6479:1984, *Method for Determination and Verification of the Effective Depth of Carburized and Hardened Cases in Steels.*
5. ISO 2639:2002, *Steels—Determination and Verification of the Depth of Carburized and Hardened Cases.*
6. SAE J423:1998, *Methods of Measuring the Case Depth of Steel.*
7. K.E. Thelning, *Steel and Its Heat Treatment*, 2nd Edition., Butterworths, London, UK, 1984.

21

Determination of the Effective Case Depth of Flame or Induction Hardened Cases in Steels

1 PRINCIPLE

The effective case depth of flame or induction hardened cases in steels is determined from the gradient of hardness on a cross-section normal to the surface. It is estimated graphically from a curve representing the variation in hardness as a function of the distance from the surface of the part.

2 DEFINITION

2.1 Effective Case Depth of a Flame or Induction Hardened Case

The perpendicular distance between the surface of a flame or induction hardened ferrous product and the point at which the Vickers hardness is equal to 80 % of the minimum surface hardness, when measured using an applied test force of 9.807 N (1 kgf).

Notes:

1) By agreement, test forces other than the reference test force of 9.807 N (1 kgf), between 4.903 N (0.5 kgf) and 49.03 N (5 kgf), may be used.
2) By agreement, other values of the hardness limit (see Table 21.1) may also be used.

Table 21.1 *Hardness Limits for the Determination of Effective Case Depth of Flame or Induction Hardened Cases in Steels*

Carbon content in steel[1] % (m/m)	Hardness limit for determination of effective case depth	
	HV	HRC
0.28–0.32	350	35
0.33–0.42	400	40
0.43–0.52	450	45
≥ 0.53	500	50

[1] The "carbon content in steel" refers to the specified mean carbon content of the steel grade to be tested.

Source: Ref. 1

3 APPARATUS

3.1 Metallographic Sample Preparation Equipment

3.2 Hardness Testing Machine

The Vickers hardness testing machine should comply with the requirements given in IS 1754. It should be capable of applying test forces between 4.903 N (0.5 kgf) and 49.03 N (5 kgf).

The measuring device should be capable of measuring the diagonals of the indentation to an accuracy of ± 0.5 μm.

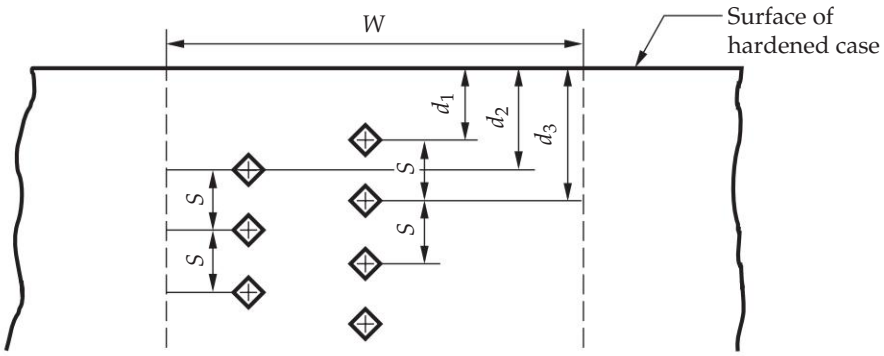
4 TEST PROCEDURE

Cut the flame or induction hardened part at right angles to the hardened case in an area chosen by agreement between the supplier and the user. Grind and polish the surface on which the measurement is to be made. Take all precautions to avoid rounding the edges of the surface and over-heating of the part.

Note: In order to avoid rounding the edges, mount the sample in a plastic material or hold it in a clamp.

Make the hardness indentations, using an applied test force of 9.807 N (1 kgf), along one or more parallel lines normal to the hardened case and within a band (W) of width 1.5 mm (see Fig. 21.1). Make the first indentation at a distance of 0.15 mm from the surface (d_1). Space the subsequent indentations at 0.1 mm (e.g. $d_2 - d_1$) intervals. In the case of a large depth of surface hardening, the distance between the indentations can be greater, but

maintain the distance of 0.1 mm between the indentations in the immediate vicinity of the presumed hardness limit zone. Ensure that the distance between the surface and the centre of the first indentation from the surface is at least two-and-a-half times the mean diagonal of the indentation, and that the distance between the centres of two adjacent indentations (S) is at least three times the mean diagonal of the indentation (see Fig. 21.1).



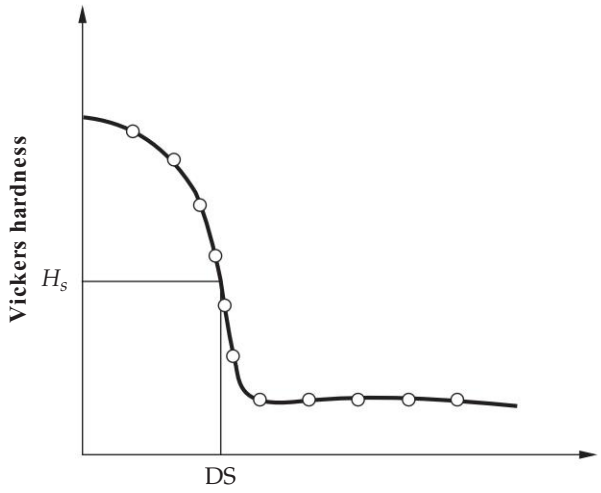
Key:

d_1, d_2, d_3 = Distances between the surface of the hardened case and the 1st, 2nd and 3rd hardness indentations, respectively
S = Distance between the centres of two adjacent indentations
W = Band width

Fig. 21.1 *Position of hardness indentations* (*Source:* Ref. 1)

Make the hardness indentations on the polished surface in one or two bands. Measure the size of the hardness indentations using an optical device giving a minimum magnification of 400×. Calculate the hardness value at each depth and plot the results in order to obtain curves(s) representing the variations in hardness as a function of distance from the surface (see Fig. 21.2).

From the curve(s) plotted, determine for each band, the distance from the surface to the point where the hardness is equal to the specified hardness limit (see Section 2.1). This distance represents the effective case depth of a flame or induction hardened case.



Key:

H_S = Limiting hardness value for the determination of effective case depth

DS = Effective case depth

Fig 21.2 *Typical curve representing the variation in hardness as a function of distance from the surface of a flame or induction hardened steel part* (*Source*: Ref. 7)

5 REFERENCES

1. IS 6416:1988, *Methods for Measuring Case Depth of Steel.*
2. IS 1501:2002, *Method for Vickers Hardness Test for Metallic Materials.*
3. IS 1754:2002, *Method for Verification of Vickers Hardness Testing Machines.*
4. BS 6481:1984, *Method for Determination of Effective Depth of Hardening of Steel after Flame or Induction Hardening.*
5. ISO 3754:1976, *Steel—Determination of Effective Depth of Hardening after Flame or Induction Hardening.*
6. SAE J423:1998, *Methods of Measuring Case Depth.*
7. K.E. Thelning, *Steel and Its Heat Treatment*, 2nd Edition, Butterworths, London, UK, 1984.

22

Determination of the Depth of Decarburization in Steels

1 PRINCIPLE

The depth of decarburization in unalloyed and low alloy steels is usually determined by the micrographic method or by the microhardness survey method.

The microscopic method consists in determining by optical microscopy the variation in microstructure associated with the change in carbon content. This technique is especially valid for steels exhibiting an annealed or normalized (ferrite-pearlite) microstructure.

The microhardness survey method consists in determining the gradient of the microhardness on a cross-section of the product along a line perpendicular to the surface. This technique applies only to hypoeutectoied steels in the hardened, condition, and to decarburized zones that are within a hardened zone. This method becomes inaccurate for low-carbon steels.

2 DEFINITIONS

2.1 Decarburization

Loss of carbon from the surface layer of the steel as a result of heating during processing. This loss may be either partial, or complete.

2.2 Partial Decarburization

Loss of carbon to a level less than that of the unaffected core but greater than the room temperature solubility limit of carbon in ferrite.

2.3 Complete Decarburization

Loss of carbon to a level below the solubility limit of carbon in ferrite so that only ferrite is present. When present, complete decarburization exists adjacent to the surface and normally a layer of partial decarburization is present between it and the unaffected core.

2.4 Depth of Total Decarburization

The perpendicular distance between the surface of the product and the point at which the carbon content is that of the unaffected core. It comprises both partial, and wherever present, complete decarburization.

3 APPARATUS

3.1 Metallographic sample preparation equipment

3.2 Metallurgical microscope (for the micrographic method)

3.3 Hardness Testing Machine (for the microhandness survey method)

The testing machine should comply with the requirements of IS 1754 (for the Vickers hardness test) and/ or IS 7095 (for the Knoop hardness test).

4 TEST PROCEDURE

4.1 Preparation of Sample

Cut the part at right angles to the surface in an area chosen by agreement between the supplier and the user. Grind and polish the surface on which the measurement is to be made. Take all precautions to avoid rounding the edges of the surface and over-heating of the part.

Note: To avoid rounding the edges, mount the sample in a plastic material or hold it in a clamp. If necessary, protect the surface of the part by a metallic deposit suitably applied before cutting to minimize rounding at the edges.

4.2 Micrographic Method

Etch the sample in a solution of 2 % to 4 % nitric acid in ethanol (nital) or 2 % to 5 % picric acid in ethanol (picral) to reveal the microstructure of the steel.

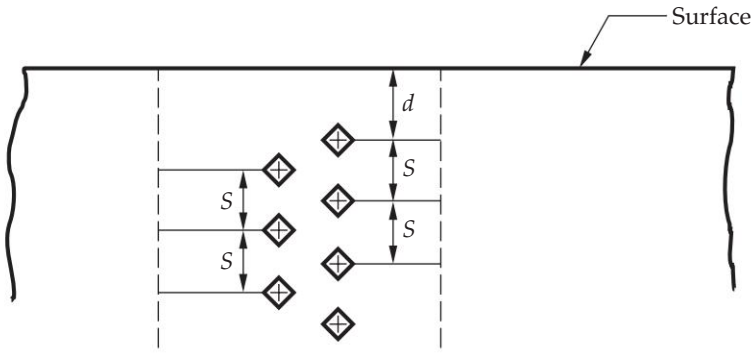
Note: Some steels may be slow to etch or may require etching solutions different from the nital or picral solutions.

Measure the distance from the surface to the specified decarburization limit (see Section 2 and Fig. 22.1, Plate 10) at a magnification of 100×, either with the aid of a measuring eyepiece, or directly on the screen of the microscope, or on a photomicrograph.

For each sample, make a minimum of five measurements in the deepest uniformly decarburized zone. The mean of these measurements is the depth of decarburization.

4.3 Microhardness Survey Method

Make a series of hardness indentations, along one or more parallel lines perpendicular to the surface (see Fig. 22.2) using an applied test force between 0.4903 N (0.05 kgf) and 4.903 N (0.5 kgf) for the Vickers hardness test or an appropriate test force for the Knoop hardness test. Ensure that the distance between the surface of the test piece and the first indentation from the surface is at least two-and-a-half times the diagonal of the indentation, and that the distance between two adjacent indentations (S) is at least three times the diagonal of the indentation (see Chapters 9 and 10 for the Vickers and Knoop hardness test, respectively.



Key:

d = Distances between the surface and the 1st hardness indentation

S = Distance between two adjacent indentations

Fig. 22.2 *Position of hardness indentations* (*Source:* Ref. 6)

Measure the size of the indentations using an optical device giving a minimum magnification of 400×. Convert the measurements into hardness values and plot the results in order to obtain a curve representing the variation in hardness as a function of distance from the surface. Read off the distance from the surface to the point at which the hardness corresponds to the decarburization criterion selected.

Make at least two series of measurements in locations as remote as possible from each other. The mean of the two measurements is the depth of decarburization.

5 REFERENCES

1. IS 6396:2000, *Methods of Measuring Decarburized Depth of Steel.*
2. IS 1501:2002, *Method for Vickers Hardness Test for Metallic Materials.*
3. IS 1754:2002, *Method for Verification of Vickers Hardness Testing Machines.*
4. IS 6885:1973, *Method for Knoop Hardness Testing of Metals.*
5. IS 7095:1973, *Method for Verification of Knoop Hardness Testing Machines.*
6. BS 6617-1:1985*, Determination of Decarburization in Steel— Part 1: Methods for Determining Decarburization by Microscopic and Microhardness Techniques.*
7. ISO 3887:2003, *Steels— Determination of Depth of Decarburization.*
8. ASTM E 1077:2001e1, *Standard Test Methods for Estimating the Depth of Decarburization of Steel Specimens.*

23

Evaluation of the Microstructure of Graphite in Cast Iron

1 PRINCIPLE

The micrographic method for the determination of the form, distribution and size of graphite in cast iron consists of comparing the observed fields with the three series of reference diagrams and allocating them the same classification as that of the diagrams that resemble them most closely. These reference diagrams correspond to circular fields of view of 0.8 mm diameter, observed at a magnification of 100×.

2 DESIGNATION OF THE MICROSTRUCTURE OF GRAPHITE IN CAST IRON

The graphite occurring in cast iron is designated by its:

1) Form (designated by Roman numerals I to VI, see Fig. 23.1);
2) Distribution (designated by capital letters A to E, see Fig. 23.2); and
3) Size (designated by Arabic numerals 1 to 8, see Figs. 23.3 to 23.6 and Table 23.1).

Examples

1. **I A 4** indicates graphite particles of form I, distribution A and size 4.
2. **60 % I A 4 + 40 % I D 7** indicates 60 % graphite of form I, distribution A and size 4, and 40 % graphite of form I, distribution D and size 7.

3 APPARATUS

3.1 Metallographic Sample Preparation Equipment

3.2 Metallurgical Microscope

4 SPECIMEN

4.1 Sampling

The number of specimens and their location, should be as specified in the product standard.

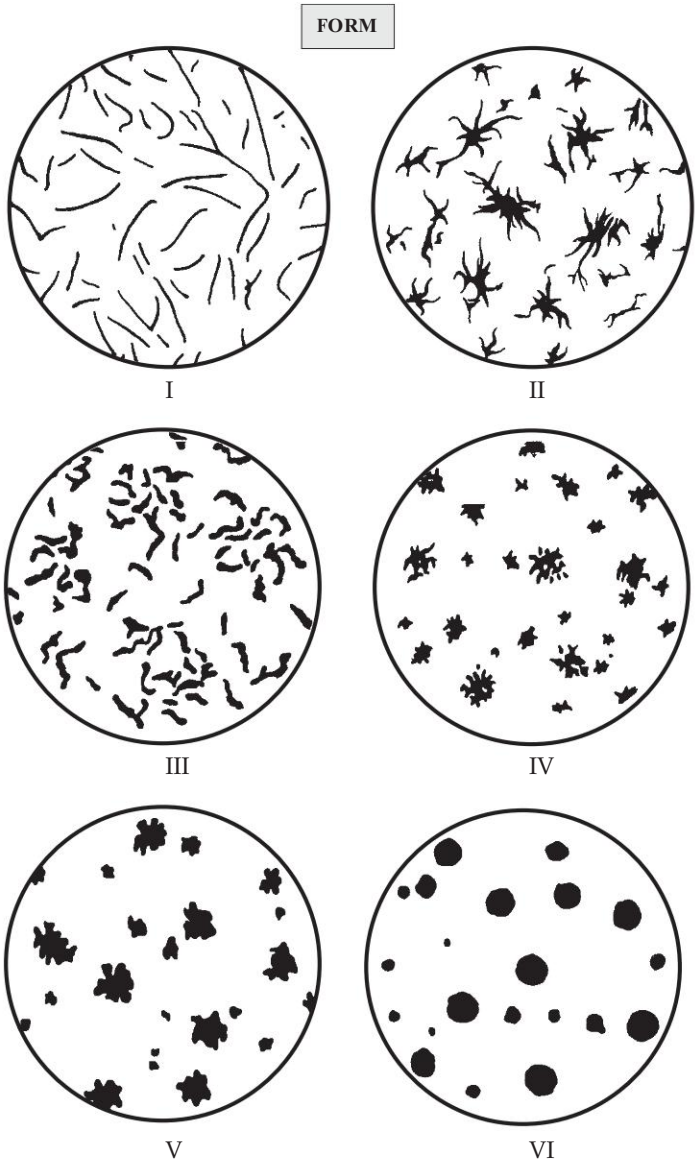


Fig. 23.1 *Reference diagrams for graphite form (distribution A)* (*Source:* Ref. 1)

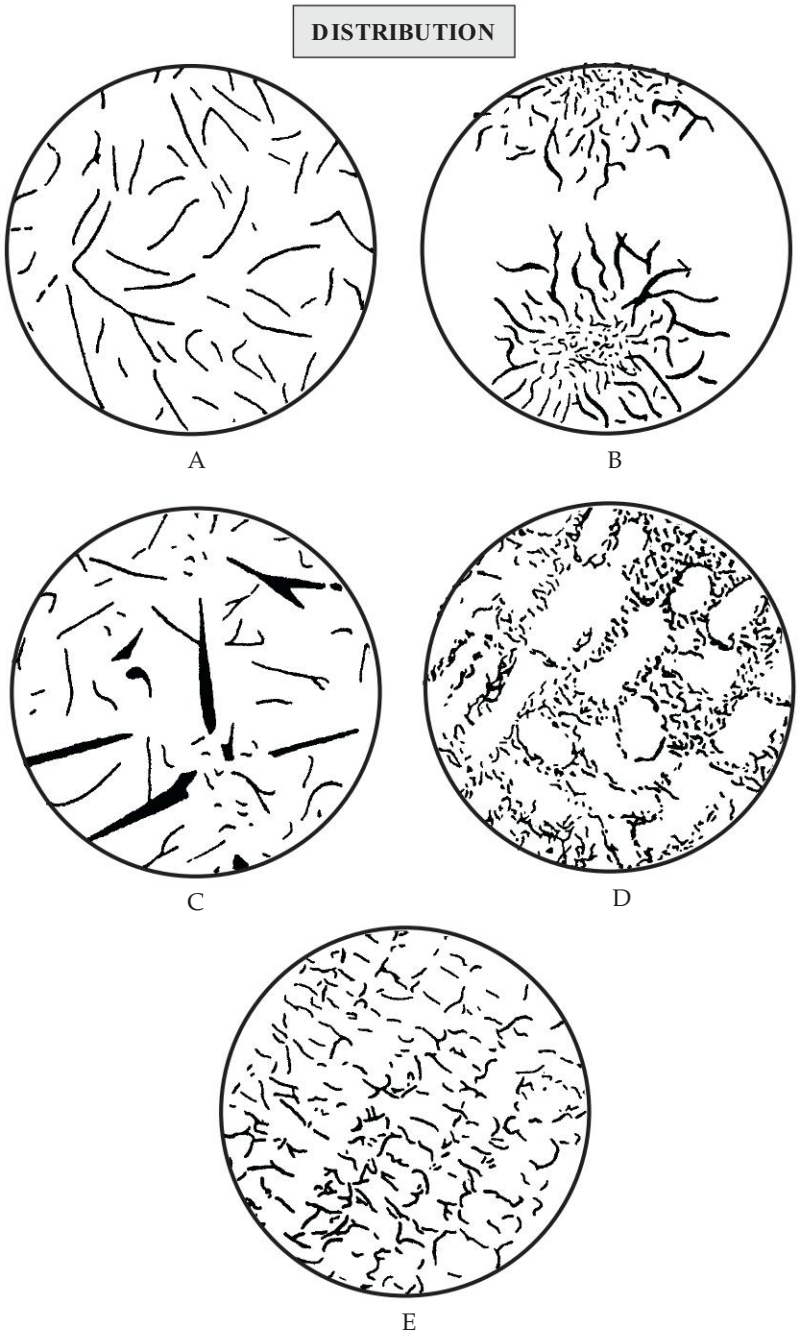


Fig. 23.2 *Reference diagrams for graphite distribution (form I)* (*Source:* Ref. 1)

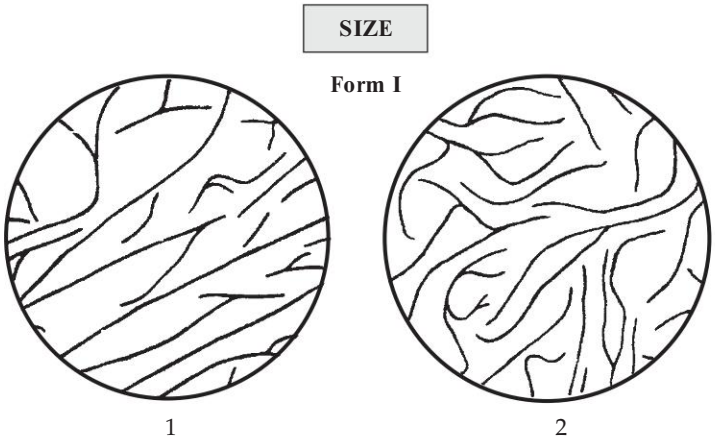


Fig. 23.3 *Reference diagrams for graphite size (form I and distribution A) (magnification 100×) — Reference Nos. 1 and 2 (Source:* Ref. 1*)*

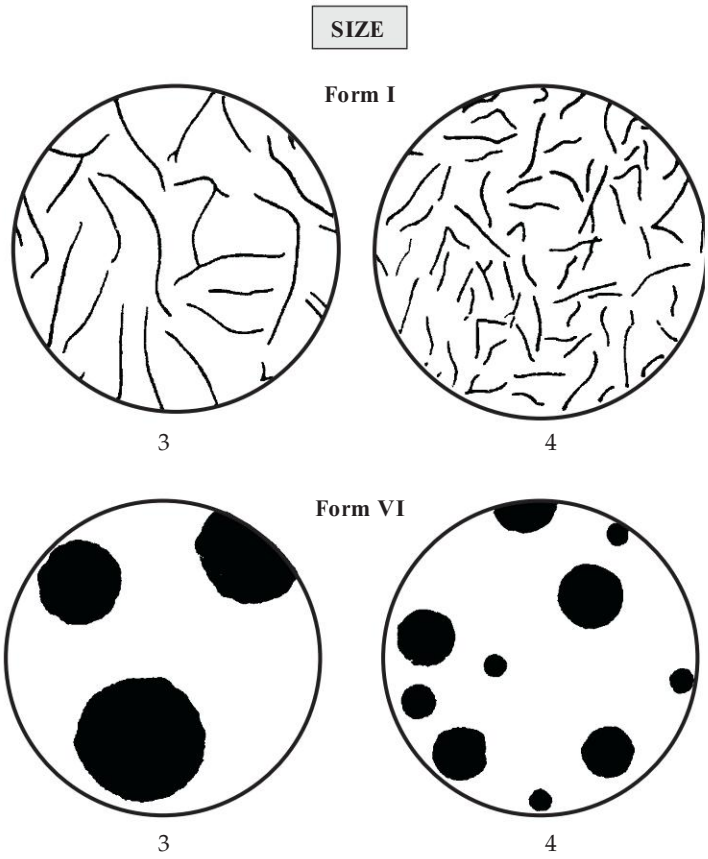


Fig. 23.4 *Reference diagrams for graphite size (forms I and VI, and distribution A) (magnification 100×) — Reference Nos. 3 and 4* (*Source:* Ref. 1)

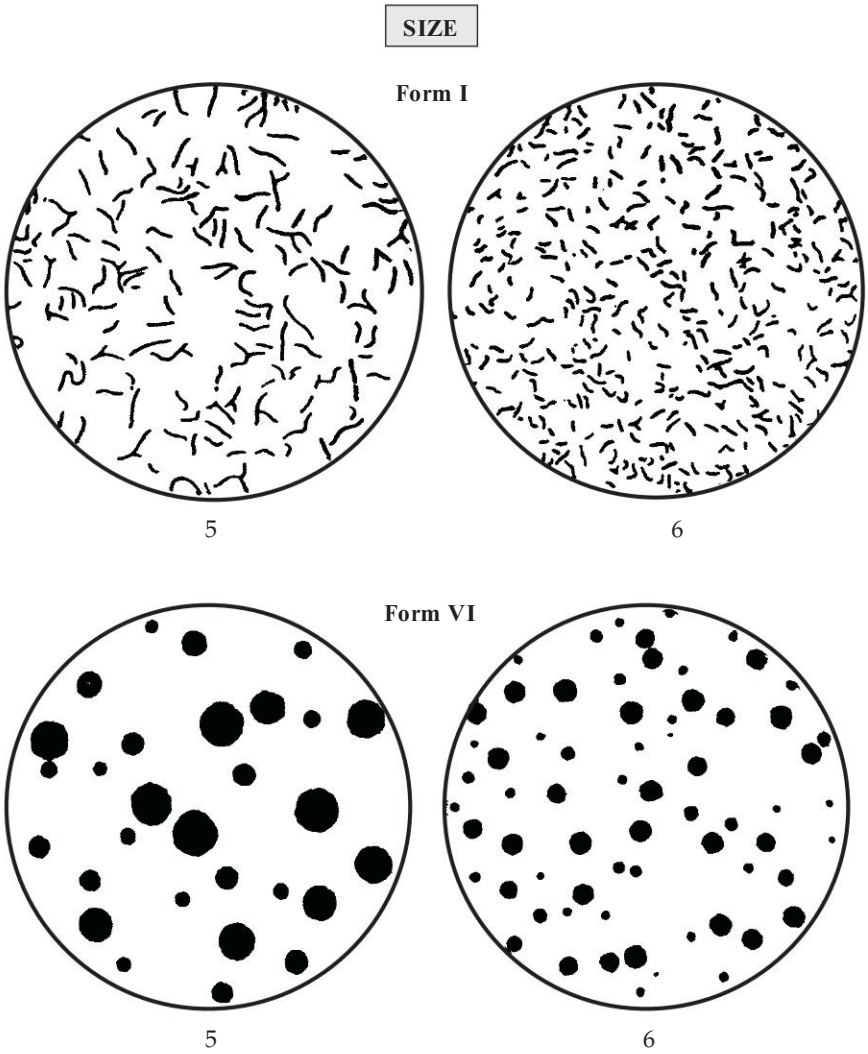


Fig. 23.5 *Reference diagrams for graphite size (forms I and VI, and distribution A) (magnification 100×) — Reference Nos. 5 and 6* (*Source:* Ref. 1)

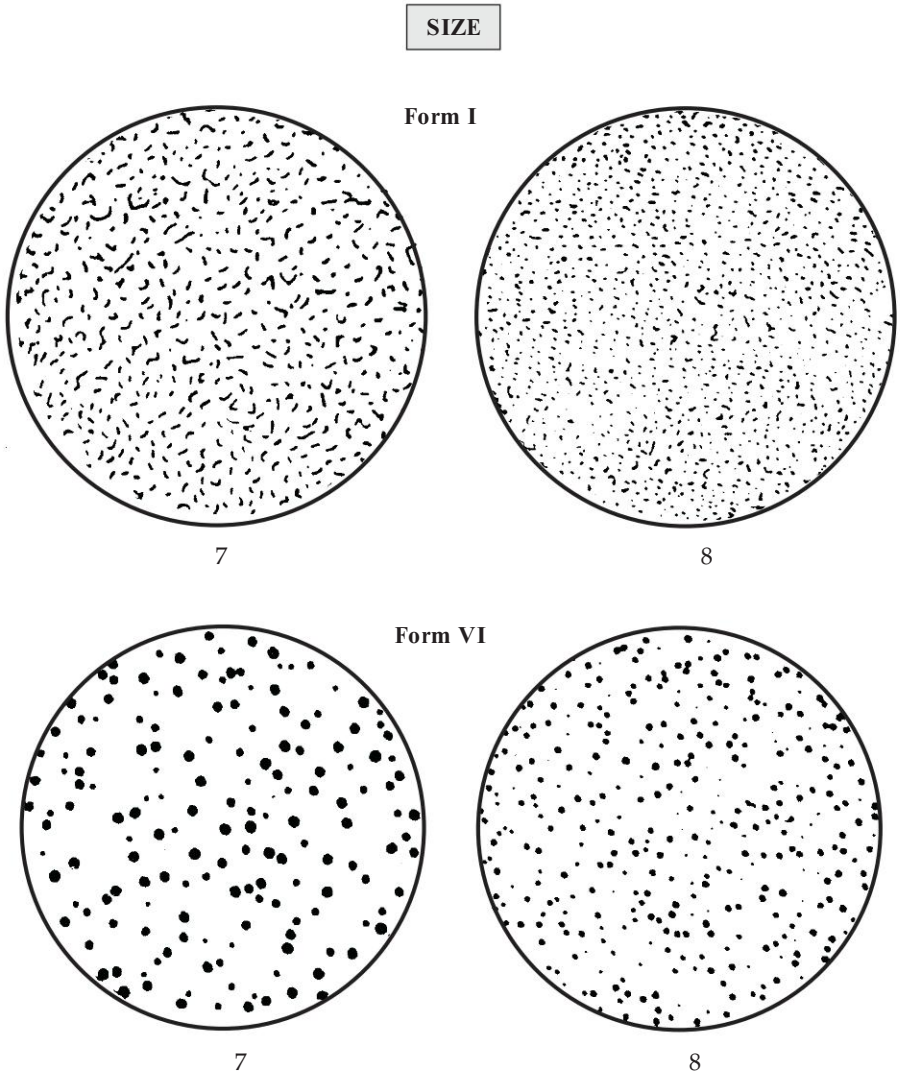


Fig. 23.6 *Reference diagrams for graphite size (forms I and VI, and distribution A) (magnification 100×) — Reference Nos. 7 and 8* (*Source:* Ref. 1)

Table 23.1 *Dimension of the Graphite Particles — Forms I to VI*

Reference number	Dimension of the particles observed at a magnification of 100× mm	True dimension mm
1	> 100	> 1
2	50 to 100	0.50 to 1
3	25 to 50	0.25 to 0.50
4	12 to 25	0.12 to 0.25
5	6 to 12	0.06 to 0.12
6	3 to 6	0.03 to 0.06
7	1.5 to 3	0.015 to 0.03
8	< 1.5	< 0.015

Source: Ref. 1

4.2 Preparation

The specimen should be cut so as to obtain a flat surface for examination. In order to avoid rounding the edges of the specimen when polishing, the specimen may be held mechanically or may be mounted. When polishing the specimen, prevent any tearing out or deformation of the graphite particles, or contamination of the polished surface, so that the surface is as clean as possible.

The area of the polished surface of the specimen used to determine the graphite form, distribution and size should be about 100 mm^2.

5 TEST PROCEDURE

Examine the entire unetched polished surface under a microscope at a magnification of 100×, either by projecting it on to a ground glass or by observing with the help of an eyepiece. Ensure that the diameter of the field of view is 0.8 mm. Compare each field of view with the reference diagrams given in Figs. 23.1 to 23.6 and Table 23.1. Record the form, distribution and size of the graphite particles.

6 REFERENCES

1. IS 7754:1975, *Method for Designation of the Microstructure of Graphite in Cast Iron*.
2. ISO 945:1975, *Cast Iron — Designation of Microstructure of Graphite*.
3. ASTM A 247:1967, *Standard Method for Evaluating the Microstructure of Graphite in Iron Castings*.

Annexure A

EQUIVALENT NATIONAL AND INTERNATIONAL STANDARDS ON TESTING OF METALS

A.1 Equivalent National and International Standards on Mechanical Testing of Metals

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
1	***Samples and test pieces***							
1.1	Location and preparation of samples and test pieces for mechanical testing of wrought steel products	3711:1990	–	EN ISO 377:1997	EN ISO 377:1997	377:1997	G 0416:1999	–
1.2	Designation of test piece axes in wrought steel products	8632:1977	–	EN ISO 3785:1995	EN ISO 3785:1995	3785:1976	–	–
2	***Creep tests***							
2.1	Test method							
2.1.1	Uninterrupted uniaxial creep testing in tension	3407-1:1983	E 139:2000e1	EN 10291:2000	EN 10291:2001	204:1997	Z 2271:1999	–
2.2	Verification of tension creep testing machines	1828-2:2002	E 4:2003	EN ISO 7500-2:1999	EN ISO 7500-2:1999	7500-2:1996	–	–
2.3	Calibration of force-proving instruments used for the verification of uniaxial testing machines	–	E 74:2002	EN ISO 376:2004	EN ISO 376:2005	376:2004	B 7728:2002	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
2	***Creep tests (Contd.)***							
2.4	Calibration of extensometers	12872:1990	E 83:2002	EN ISO 9513:2002	EN ISO 9513:2003	9513:1999	B 7741:1999	–
2.5	Calibration of thermocouples	–	–	–	–	–	C 1602:1995	–
3	***Ductility tests***							
3.1	Bars, rods and sections							
3.1.1	Bend test	1599:1985	E290:1997a	EN ISO 7438:2000	EN ISO 7438:2000	7438:1985	Z 2248:1996	–
3.2	Flat products							
3.2.1	Bend test	1599:1985	E 290:1997a	EN ISO 7438:2000	EN ISO 7438:2000	7438:1985	Z 2248:1996	–
3.2.2	Guidelines for the determination of forming-limit diagrams	–	E 2218:2002	–	–	12004;1997, TR 14936:1998	–	–
3.2.3	Erichsen cupping test	10175-1:1993	F 643:1984	EN ISO 20482:2003	EN ISO 20482:2003	20482:2003	Z 2247:1998	–
3.2.4	Reverse bend test	1403-1:1993	–	EN ISO 7799:2000	EN ISO 7799:2000	7799:1985	–	–
3.3	Tubes	–	–	–	–	–		
3.3.1	Bend test	2329:1985	–	EN ISO 8491:2004	EN ISO 8491:2004	8491:1998	–	–
3.3.2	Drift expanding test	2335:1985	–	EN ISO 8493:2004	EN ISO 8493:2004	8493:1998	–	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
3	***Ductility tests (Contd.)***							
3.3.3	Flanging test	2330:1986	–	EN ISO 8494:2004	EN ISO 8494:2004	8494:1998	–	–
3.3.4	Flattening test	2328:1983	–	EN ISO 8492:2004	EN ISO 8492:2004	8492:1998	–	–
3.3.5	Ring expanding test	12260:1987	–	EN ISO 8495:2004	EN ISO 8495:2004	8495:1998	–	–
3.3.6	Ring tensile test	12278:1988	–	EN ISO 8496:2004	EN ISO 8496:2004	8496:1998	–	–
3.4	Wires	–	–	–	–	–	–	–
3.4.1	Reverse bend test	1716:1985	–	EN 10218-1:1994	EN 10218-1:1994, 51211:1978	7801:1984	–	–
3.4.2	Reverse torsion test	12261:1987	–	EN 10218-1:1994	EN 10218-1:1994	9649:1990	–	–
3.4.3	Simple torsion test	1717:1985	A 938:2004	EN 10218-1:1994	EN 10218-1:1994, 51212:1978	7800:2003	–	–
3.4.4	Wrapping test	1755:1983	–	EN 10218-1:1994	EN 10218-1:1994, 51215:1975	7802:1983	–	–
4	***Fatigue tests***							
4.1	Test method							
4.1.1	Axial load fatigue test	5074:1969	E 466:1996e1	3518-3:1963	–	1099:1975	–	–
4.1.2	Rotating bar bending fatigue test	5075:1985	–	3518-2:1962	50113:1982	1143:1975	Z 2274:1978	–
4.1.3	Torsional stress fatigue test	12514:1988	–	–	–	1352:1977	–	–
4.2	Dynamic force calibration of axial load fatigue testing machines	6886:1973	E 467:1998a	DD2:1971	–	4965:1979	–	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
5	***Fracture toughness tests***							
5.1	Test method							
5.1.1	Determination of plane-strain fracture toughness K_{Ic}	10180:1982	E 399:1990	EN ISO 12737:1999	EN ISO 12737:1999	12737:1996	G 0564:1999	–
5.1.2	Determination of crack tip opening displacement (CTOD)	–	E 1290:2002	7448-2:1997	–	–	–	–
5.1.3	Determination of fracture resistance curves — *R*-curves	–	E 561:1998	7448-4:1997	–	–	–	–
		–						
6	***Hardness tests***							
6.1	Brinell hardness test							
6.1.1	Test method	1500:1983	E 10:2001e1	EN ISO 6506-1:1999	EN ISO 6506-1:1999	6506-1:1999	Z 2243:1998	–
6.1.2	Verification of testing machines	2281:1983	E 10:2001e1	EN ISO 6506-2:1999	EN ISO 6506-2:1999	6506-2:1999	B 7724:1999	–
6.1.3	Calibration of reference blocks	4132:1984	E 10:2001e1	EN ISO 6506-3:1999	EN ISO 6506-3:1999	6506-3:1999	B 7736:1999	–
6.1.4	Tables of Brinell hardness values for use in tests made on flat surfaces	10588:1983	E 10:2001e1	EN ISO 6506-1:1999	EN ISO 6506-1:1999	6506-1:1999	–	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
6	***Hardness tests* (*Contd.*)**							
6.2	Knoop hardness test							
6.2.1	Test method	6885:1973	E 384:1999e1	–	–	4545:1993	Z 2251:1998	–
6.2.2	Verification of testing machines	7095:1993	E 384:1999e1	–	–	4546:1993	B 7734:1997	–
6.2.3	Calibration of reference blocks	7097:1973	E 384:1999e1	–	–	4547:1993	–	–
6.2.4	Tables of Knoop hardness values for use in tests made on flat surfaces	6885:1973	E 384:1999e1	–	–	10250:1994	–	–
6.3	Rockwell and Rockwell superficial hardness test (scales A, B, C, D, E, F, G, H, K, 15N, 30N, 45N, 15T, 30T and 45T)							
6.3.1	Test method	1586:2000	E 18:2003e1	EN ISO 6508-1:1999	EN ISO 6508-1:1999	6508-1:1999	Z 2245:1998	–
6.3.2	Verification of testing machines	1586.2000	E 18:2003e1	EN ISO 6508-2:1999	EN ISO 6508-2:1999	6508-2:1999	B 7726:1997	–
6.3.3	Calibration of reference blocks	1586:2000	E 18:2003e1	EN ISO 6508-3:1999	EN ISO 6508-3:1999	6508-3:1999	B 7730:1997	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
6	***Hardness tests (Contd.)***							
6.4	Scleroscope hardness test							
6.4.1	Test method	7096:1981	E 448:1982e1	–	–	–	Z 2246:2000	–
6.4.2	Verification of testing machines	7172:1984	E 448:1982e1	–	–	–	B 7727:2000	–
6.4.3	Calibration of reference blocks	10166:1982	E 448:1982e1	–	–	–	B 7731:2000	–
6.5	Vickers hardness test							
6.5.1	Test Method	1501:2002	E 92:1982e2, E 384: 1999e1	EN ISO 6507-1:1998	EN ISO 6507-1:1998	6507-1:1997	Z 2244:2003	–
6.5.2	Verification of testing machines	1754:2002	E 92:1982e2, E 384:1999e1	EN ISO 6507-2: 1998	EN ISO 6507-2:1998	6507-2:1997	B 7725:1997	–
6.5.3	Calibration of reference blocks	4133:2002	E 92:1982e2, E 384:1999e1	EN ISO 6507-3:1998	EN ISO 6507-3:1998	6507-3:1997	B 7735:1997	–
6.5.4	Tables of Vickers hardness values for use in tests made on flat surfaces	10927-1:1984, 10927-2:1984, 10927-3:1991	E 92:1982e2, E 384:1999e1	EN ISO 6507-1:1998	EN ISO 6507-1:1998	6507-1:1997	–	–
6.6	Hardness conversion tables	4258:1982	E 140:2002e1	EN ISO 18265:2003	EN ISO 18265:2004	18265:2003	–	J417:1983
7	***Impact tests***							
7.1	Charpy impact test							
7.1.1	Test method							
	(a) Charpy impact test (U-notch)	1499:1977	E 23:2004	EN 10045-1:1990	EN 10045-1:1991	83:1976	Z 2242:1998	–
	(b) Charpy impact test (V-notch)	1757:1988	E 23:2004	EN 10045-1:1990	EN 10045-1:1991	148:1983	Z 2242:1998	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
7	***Impact tests (Contd.)***							
7.1.2	Verification of testing machines	3766:1977	E 23:2004	EN 10045-2:1993	EN 10045-2:1993	148-2:1998	B 7722:1999	–
7.1.3	Preparation and characterization of Charpy V reference test pieces for verification of testing machines	15420:2003	–	–	–	148-3:1998	B 7740:1999	–
7.2	Izod impact test							
7.2.1	Test method	1598:1977	E 23:2004	131-1:1961	–	–	Z 2242:1998	–
7.2.2	Verification of testing machines	3766:1977	E 23:2004	131-4:1972	–	–	–	–
8	***Tensile test***							
8.1	Test method							
	(a) Tensile test at ambient temperature	1608:1995	E 8M:2004	EN 10002-1:2001	EN 10002-1:2001	6892:1998	Z 2241:1998	–
	(b) Tensile test at elevated temperature	–	E 21:2003a	EN 10002-5:1992	EN 10002-5:1992	783:1999	G 0567:1998	–
	(c) Tensile test at low temperature	–	–	–	ISO 15579:2002	15579:2000	–	–
	(d) Determination of plastic strain ratio (r) of sheet and strip	11999:1987	E 517:2000	–	–	10113:1991	Z 2254:1996	–
	(e) Determination of tensile strain hardening exponent (n) of sheet and strip	–	E 646:2000	–	–	10275:1993	Z 2253:1996	–

A.1 Equivalent National and International Standards on Mechanical Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
8	***Tensile test* (*Contd.*)**							
8.2	Verification of tension/ compression testing machines	1828-1:1991	E 4:2003	EN ISO 7500-1:2004	EN ISO 7500-1:2004	7500-1:2004	B 7721:2002	–
8.3	Calibration of force-proving instruments used for the verification of uniaxial testing machines	4169-1988	E 74:2002	EN ISO 376:2004	EN ISO 376:2005	376:2004	B 7728:2002	–
8.4	Calibration of extensometers	12872:1990	E 83:2002	EN ISO 9513:2002	EN ISO 9513:2003	9513:1999	B 7741:1999	–
8.5	Calibration of thermocouples	–	–	–	–	–	C 1602:1995	–
8.6	Conversion of elongation values							
	(a) Carbon and low alloy steels	3803-1:1989	–	EN ISO 2566-1:1999	EN ISO 2566-1:1999	2566-1:1984	–	–
	(b) Austenitic steels	3803-2:1989	–	EN ISO 2566-2: 2001	EN ISO 2566-2:1999	2566-2:1984	–	–

A.2 Equivalent National and International Standards on Non-Destructive Testing of Metals

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
1	Liquid penetrant inspection — General Principles	3658:1999	E 165:2002, E 1417: 1999	EN 571-1:1997	EN 571-1:1997	3452:1984	Z 2343-1:2001	J426:1991
2	Magnetic particle inspection — General Principles	3703:1980	E 709:2001, E 1444:2001	EN ISO 9934-1:2001 PD 6513:1985	EN ISO 9934-1:2002	9934-1:2001	–	J420:1991

A.3 Equivalent National and International Standards on Metallographic and Other Methods of Testing of Metals

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
1	Determination of case depth in steel							
1.1	Determination and verification of the effective depth of carburized and hardened cases	6416:1988	–	EN ISO 2639:2002	EN ISO 2639:2003	2639:2002	G 0557:1996	J423:1998
1.2	Determination of the effective depth of hardening after flame or induction hardening	6416:1988	–	6481:1984	50190-2:1979	3754:1976	G 0559:1996	J423:1998
1.3	Determination of nitrided case depth	6416:1988	–	–	50190-3:1979	–	G 0562:1993	–
1.4	Determination of total or effective thickness of thin surface-hardened layers	13691:1993	–	6286:1982	–	4970:1979	–	–
2	Determination of content of non-metallic inclusions in wrought steels							
2.1	Macroscopic methods							
2.1.1	Blue fracture test method	10138-1:1992	–	5710:1979	–	3763:1976	–	–
2.1.2	Magnetic particle inspection method	10138-3:1983	–	5710:1979	–	3763:1976	–	–
2.1.3	Step machined test method	10138-2:1983	–	5710:1979	–	3763:1976	G 0556:1998	–
2.2	Micrographic method using standard diagrams	4163:2004	E 45:1997	–	50602:1985	4967:1998	G 0555:2003	J422:1983
3	Determination of depth of decarburization in steels	6396:2000	E 1077:2001e1	EN ISO 3887:2003	EN ISO 3887:2003	3887:2003	G 0558:1998	J419:1983
4	Hardenability test of steel by end quenching (Jominy test)	3848:1981	A 255:2002	EN ISO 642:1999	EN ISO 642:2000	642:1999	G 0561:1998	J406:1998

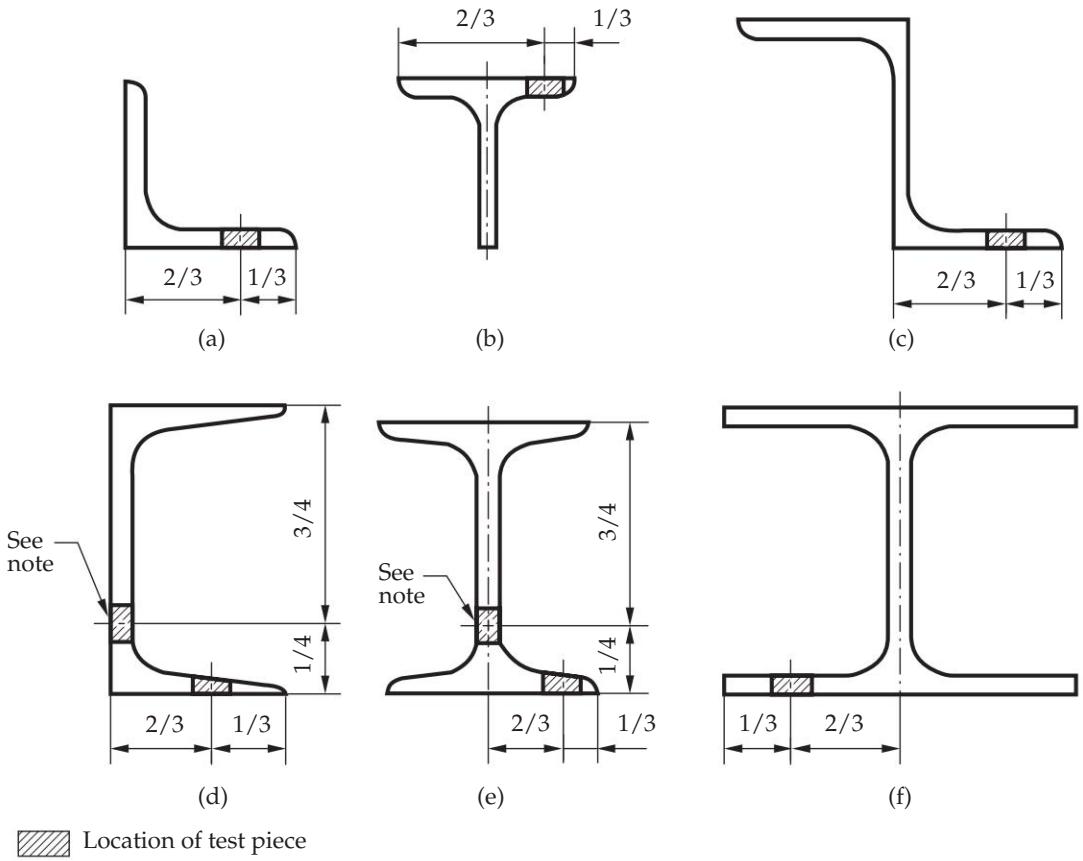
A.3 Equivalent National and International Standards on Metallographic and Other Methods of Testing of Metals (Contd.)

S. No.	Type of test	IS	ASTM	BS	DIN	ISO	JIS	SAE
5	Macrographic examination of steel by sulphur print (Baumann method)	12037:1987	E 1180:2003e1	6285:1982	–	4968:1979	G0560:1998	–
6	Macroscopic examination of metals	11371:1985, 12573:1988, 13015:1991, 13484:1992, 13605:1992	E 340:2000e1, E 381:2001	6533:1984	–	4969:1980	G 0553:1996	–
7	Manual point counting method for statistically estimating the volume fraction of a constituent with a point grid		E 562:2002	7590:1992, 7590A:1992	–	9042:1988	–	–
8	Micrographic determination of apparent grain size of steels	4748:1988	E 112:1996	EN ISO 643:2003	EN ISO 643:2003	643:2003	G 0551:2005, G 0552:2005	–
9	Micrographic method for assessing the distribution of carbides in tool steels and bearing steels using reference photo-micrographs	12211:1987	A 892:1988	–	–	5949:1983	–	–

Annexure B

LOCATION OF TENSILE AND IMPACT TEST PIECES IN WROUGHT STEEL PRODUCTS

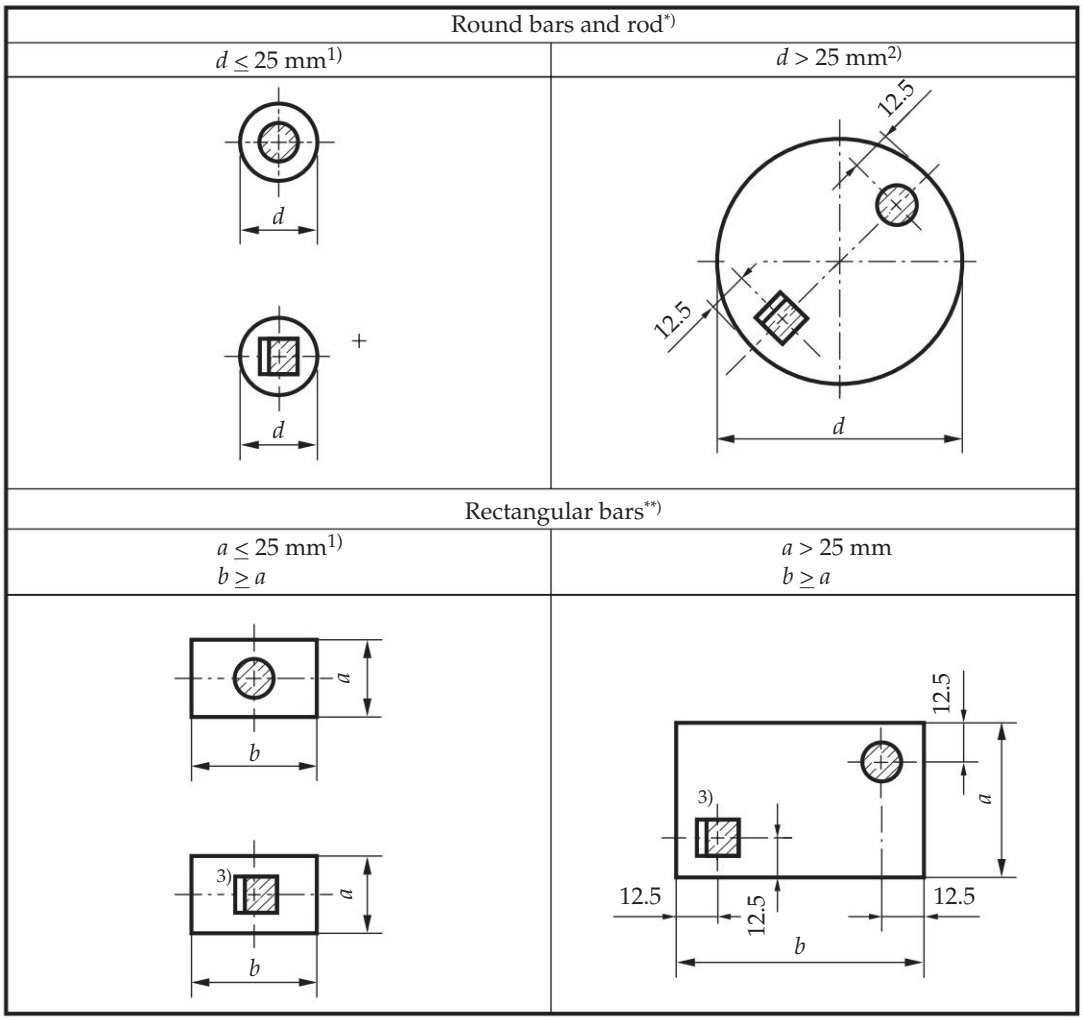
B.1 Location of Tensile and Impact Test Pieces in Sections



Note: By agreement, the sample can be taken from the web, at a quarter of the total height. For sections with inclined flanges, machining of the inclined surface is permitted in order to make it parallel to the other surface.

Fig. B.1 *Location of tensile and impact test pieces in sections* (*Source:* Ref. 1)

B.2 Location of Tensile and Impact Test Pieces in Bars and Rod



*) The distance of the test cross-section from the end of the product should be at least equal to the distance from the surface of the product.

**) If b does not exceed 25 mm, the centre line of the test piece should be at $\frac{b}{2}$.

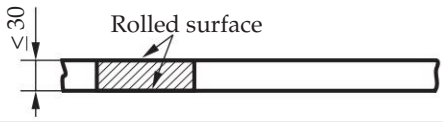
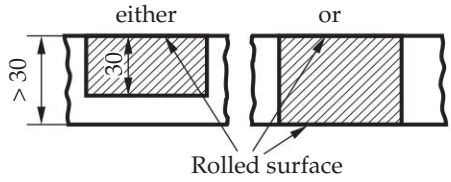
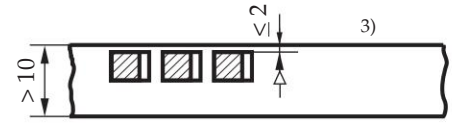
1) For small products (d or b < 25 mm), the test piece should, if possible, consist of an unmachined part of the bar.

2) For round bars, the notch axis should be about parallel to the direction of a diameter.

3) For rectangular bars, the notch axis should be perpendicular to the wider rolling surface

Fig. B.2 *Location of tensile and impact test pieces in bars and rod* (*Source:* Ref. 3)

B.3 Location of Tensile and Impact Test Pieces in Flat Products

Type of test	Thickness of product	Orientation of test piece[1] for product widths		Location of test piece relative to the rolled surface
	mm	< 600 mm	≥ 600 mm	mm
Tensile test[1]	≤ 30	Longitudinal	Transverse	
	> 30			
Impact test[2]	> 10[3]	Longitudinal	Transverse	

Location of test piece

1) Orientation of the longitudinal axis of the test piece with reference to the principal rolling direction.

2) The notch axis should be perpendicular to the rolled surface.

3) For products of thickness greater than 30 mm, the impact test piece may be taken at one-fourth the thickness from the rolled surface.

For products of thickness between 5 mm and 10 mm, the width of the impact test piece, is generally, equal to the thickness of the product, the height remaining fixed at 10 mm. In case of dispute on impact test results from such subsize test pieces, test pieces having a cross-section of 10 mm × 7.5 mm or 10 mm × 5 mm should be used.

Fig. B.3 *Location of tensile and impact test pieces in flat products.*

B.4 REFERENCES

1. IS 2062:1999, *Steel for General Structural Purposes — Specification*.
2. IS 3711:1990, *Wrought Steel — Selection and Preparation of Samples and Test Pieces for Mechanical Tests.*
3. IS 5517:1993, *Steels for Hardening and Tempering — Specification*.
4. ISO 377:1997, *Steel and Steel Products — Location and Preparation of Samples and Test Pieces for Mechanical Testing.*

Annexure C

Hardness Conversion Tables for Metals

C.1 Steels and Cast Iron

Table C.1 *Conversion of hardness-to-hardness or hardness-to-tensile strength values for unalloyed steels, low alloy steels and cast iron*

Tensile strength MPa	Vickers hardness HV 10	Brinell hardness HBS (HBW)[1)]	Rockwell hardness							
			HRB	HRF	HRC	HRA	HRD	HR15N	HR30N	HR45N
255	80	76.0								
270	85	80.7	41.0							
285	90	85.5	48.0	82.6						
305	95	90.2	52.0							
320	100	95.0	56.2	87.0						
335	105	99.8								
350	110	105	62.3	90.5						
370	115	109								
385	120	114	66.7	93.6						
400	125	119								
415	130	124	71.2	96.4						
430	135	128								
450	140	133	75.0	99.0						

(*Contd.*)

Table C.1 *(Contd.)*

Tensile strength MPa	Vickers hardness HV 10	Brinell hardness HBS (HBW)[1)]	Rockwell hardness							
			HRB	HRF	HRC	HRA	HRD	HR15N	HR30N	HR45N
465	145	138								
480	150	143	78.7	(101.4)						
495	155	147								
510	160	152	81.7	(103.6)						
530	165	156								
545	170	162	85.0	(105.5)						
560	175	166								
575	180	171	87.1	(107.2)						
595	185	176								
610	190	181	89.5	(108.7)						
625	195	185								
640	200	190	91.5	(110.1)						
660	205	195	92.5							
675	210	199	93.5	(111.3)						
690	215	204	94.0							
705	220	209	95.0	(112.4)						
720	225	214	96.0							
740	230	219	96.7	(113.4)						
755	235	223								
770	240	228	98.1	(114.3)	20.3	60.7	40.3	(69.6)	(41.7)	(19.9)
785	245	233			21.3	61.2	41.1	70.1	42.5	21.1

(Contd.)

Table C.1 *(Contd.)*

Tensile strength MPa	Vickers hardness HV 10	Brinell hardness HBS (HBW)[1)]	Rockwell hardness							
			HRB	HRF	HRC	HRA	HRD	HR15N	HR30N	HR45N
800	250	238	99.5	(115.1)	22.2	61.6	41.7	70.6	43.4	22.2
820	255	242			23.1	62.0	42.2	71.1	44.2	23.2
835	260	247	(101)		24.0	62.4	43.1	71.6	45.0	24.3
850	265	252			24.8	62.7	43.7	72.1	45.7	25.2
865	270	257	(102)		25.6	63.1	44.3	72.6	46.4	26.2
880	275	261			26.4	63.5	44.9	73.0	47.2	27.1
900	280	266	(104)		27.1	63.8	45.3	73.4	47.8	27.9
915	285	271			27.8	64.2	46.0	73.8	48.4	28.7
930	290	276	(105)		28.5	64.5	46.5	74.2	49.0	29.5
950	295	280			29.2	64.8	47.1	74.6	49.7	30.4
965	300	285			29.8	65.2	47.5	74.9	50.2	31.1
995	310	295			31.0	65.8	48.4	75.6	51.3	32.5
1030	320	304			32.2	66.4	49.4	76.2	52.3	33.9
1060	330	314			33.3	67.0	50.2	76.8	53.6	35.2
1095	340	323			34.4	67.6	51.1	77.4	54.4	36.5
1125	350	333			35.5	68.1	51.9	78.0	55.4	37.8
1155	360	342			36.6	68.7	52.8	78.6	56.4	39.1
1190	370	352			37.7	69.2	53.6	79.2	57.4	40.4
1220	380	361			38.8	69.8	54.4	79.8	58.4	41.7
1255	390	371			39.8	70.3	55.3	80.3	59.3	42.9
1290	400	380			40.8	70.8	56.0	80.8	60.2	44.1
1320	410	390			41.8	71.4	56.8	81.4	61.1	45.3

Table C.1 *(Contd.)*

Tensile strength MPa	Vickers hardness HV 10	Brinell hardness HBS (HBW)[1)]	Rockwell hardness							
			HRB	HRF	HRC	HRA	HRD	HR15N	HR30N	HR45N
1350	420	399			42.7	71.8	57.5	81.8	61.9	46.4
1385	430	409			43.6	72.3	58.2	82.3	62.7	47.4
1420	440	418			44.5	72.8	58.8	82.8	63.5	48.4
1455	450	428			45.3	73.3	59.4	83.2	64.3	49.4
1485	460	437			46.1	73.6	60.1	83.6	64.9	50.4
1520	470	447			46.9	74.1	60.7	83.9	65.7	51.3
1555	480	456			47.7	74.5	61.3	84.3	66.4	52.2
1595	490	466			48.4	74.9	61.6	84.7	67.1	53.1
1630	500	475			49.1	75.3	62.2	85.0	67.7	53.9
1665	510	485			49.8	75.7	62.9	85.4	68.3	54.7
1700	520	494			50.5	76.1	63.5	85.7	69.0	55.6
1740	530	504			51.1	76.4	63.9	86.0	69.5	56.2
1775	540	513			51.7	76.7	64.4	86.3	70.0	57.0
1810	550	523			52.3	77.0	64.8	86.6	70.5	57.8
1845	560	532			53.0	77.4	65.4	86.9	71.2	58.6
1880	570	542			53.6	77.8	65.8	87.2	71.7	59.3
1920	580	551			54.1	78.0	66.2	87.5	72.1	59.9
1955	590	561			54.7	78.4	66.7	87.8	72.7	60.5
1995	600	570			55.2	78.6	67.0	88.0	73.2	61.2
2030	610	580			55.7	78.9	67.5	88.2	73.7	61.7
2070	620	589			56.3	79.2	67.9	88.5	74.2	62.4

(Contd.)

Table C.1 *(Contd.)*

Tensile strength MPa	Vickers hardness HV 10	Brinell hardness HBS (HBW)[1)]	Rockwell hardness							
			HRB	HRF	HRC	HRA	HRD	HR15N	HR30N	HR45N
2105	630	599			56.8	79.5	68.3	88.8	74.6	63.0
2145	640	608			57.3	79.8	68.7	89.0	75.1	63.5
2180	650	618			57.8	80.0	69.0	89.2	75.5	64.1
	660				58.3	80.3	69.4	89.5	75.9	64.7
	670				58.8	80.6	69.8	89.7	76.4	65.3
	680				59.2	80.8	70.1	89.8	76.8	65.7
	690				59.7	81.1	70.5	90.1	77.2	66.2
	700				60.1	81.3	70.8	90.3	77.6	66.7
	720				61.0	81.8	71.5	90.7	78.4	67.7
	740				61.8	82.2	72.1	91.0	79.1	68.6
	760				62.5	82.6	72.6	91.2	79.7	69.4
	780				63.3	83.0	73.3	91.5	80.4	70.2
	800				64.0	83.4	73.8	91.8	81.1	71.0
	820				64.7	83.8	74.3	92.1	81.7	71.8
	840				65.3	84.1	74.8	92.3	82.2	72.2
	860				65.9	84.4	75.3	92.5	82.7	73.1
	880				66.4	84.7	75.7	92.7	83.1	73.6
	900				67.0	85.0	76.1	92.9	83.6	74.2
	920				67.5	85.3	76.5	93.0	84.0	74.8
	940				68.0	85.6	76.9	93.2	84.4	75.4

[1)] Brinell hardness values up to 450 HB were determined using a steel ball indenter, while those above this value were determined with a hardmetal ball.

Note: Values in parentheses are those lying outside the defined range of the standard test method but which may be used as approximate values.

Source: Ref. 1

C.2 Aluminium and Its Alloys

Table C.2 *Conversion of hardness-to-hardness values for wrought aluminium and its alloys*

Brinell hardness HBS 10/500	Vickers hardness HV 15	Rockwell hardness					
		HRB	HRE	HRH	HR15T	HR30T	HR15W
40	44		46	83	59		77
45	50		53	87	62		79
50	56		59	91	64		80
55	62		65	94	67		82
60	68		70	97	70		83
65	74		75	100	72		85
70	80	28	80	102	74	44	86
75	86	34	84	104	76	47	87
80	92	40	88	106	78	50	88
85	98	46	91	107	80	52	89
90	105	51	94	108	81	54	89
95	111	56	96		82	57	90
100	117	60	98		83	59	90
105	123	65	99		84	61	91
110	129	69	100		85	63	91
115	135	72	101		86	65	91
120	141	76			86	67	92
125	147	79			86	68	92
130	153	81			87	70	93
135	159	84			87	71	93
140	165	86			88	73	94
145	171	87			88	74	94
150	177	89			89	75	94
155	183	90			89	76	95
160	189	91			89	77	95

Source: Ref. 2

C.3 Copper and Its Alloys

Table C.3 *Conversion of hardness-to-hardness values for wrought copper*

Vickers hardness		Knoop hardness		Brinell hardness		Rockwell hardness							
HV 1	HV 0.1	HK 1	HK 0.5	HBS 10/500	HBS 2/20	HRB	HRF	HR15T			HR30T		HR45T
				Thickness of strip, mm									
				2.03	1.02	≥ 1.02	≥ 1.02	0.25	0.51	≥ 1.02	0.51	≥ 1.02	≥ 1.02
40	51.3	40.2	42.8				28.0	57.5	48.0	38.5			
42	52.2	43.7	45.2				30.5	58.5	49.5	41.0			
44	53.9	45.9	47.8				33.5	59.5	51.0	43.0			
46	55.8	48.0	50.2		41.0		36.0	60.5	52.0	45.0			
48	57.3	50.3	52.7		42.0		39.0	61.0	53.5	47.5		1.5	
50	58.9	52.8	55.0		44.5		41.5	62.0	55.0	49.5		4.5	
52	60.7	55.0	57.2		46.5		44.0	63.0	56.0	51.5		7.5	
54	62.3	57.4	59.5		48.0		47.0	63.5	57.5	53.0		10.0	
56	64.0	59.8	61.8		49.5		49.0	64.5	58.5	55.0		13.0	
58	65.8	62.0	63.8		51.5		51.5	65.0	60.0	57.0		15.5	
60	67.5	64.6	65.9		53.0		54.0	66.0	61.0	59.0		18.0	
62	69.1	67.0	67.9		55.0		56.0	66.5	62.0	61.0		21.0	
64	70.9	69.5	70.0		57.0		58.0	67.5	63.5	63.5		23.5	
66	72.6	71.9	71.9		58.5		60.0	68.0	64.5	64.5		25.5	
68	74.3	74.1	74.4		60.5	2.0	62.0	69.0	65.5	66.0		28.0	
70	75.8	76.8	76.6		62.0	5.0	64.0	69.5	66.5	67.5		30.0	
72	77.6	78.9	78.7		64.0	8.5	66.0	70.0	67.5	69.0		32.0	
74	79.2	81.1	79.9		66.0	11.5	67.5	71.0	68.5	70.0		34.0	

(Contd.)

Table C.3 *(Contd.)*

Vickers hardness		Knoop hardness		Brinell hardness		Rockwell hardness							
HV 1	HV 0.1	HK 1	HK 0.5	HBS 10/500	HBS 2/20	HRB	HRF	HR15T			HR30T		HR45T
				Thickness of strip, mm									
				2.03	1.02	≥ 1.02	≥ 1.02	0.25	0.51	≥ 1.02	0.51	≥ 1.02	≥ 1.02
76	81.0	83.5	81.9		67.5	14.5	69.0	71.5	69.5	71.5		36.0	2.0
78	82.8	85.7	84.0		69.5	17.0	71.0	72.0	70.0	72.5		37.5	5.0
80	84.5	87.9	86.0		71.5	20.0	73.0	72.5	71.0	73.5		39.5	7.0
82	86.1	90.1	87.9		73.0	23.0	74.5	73.5	72.0	74.5		41.0	9.5
84	87.9	92.3	90.0		75.0	25.5	76.5	74.0	73.0	75.0		43.0	12.0
86	89.7	95.5	92.0		77.0	28.0	78.0	74.5	73.5	76.0		44.0	14.0
88	91.2	96.9	94.0		79.0	30.5	79.5	75.0	74.5	77.0		46.0	16.5
90	93.0	98.9	96.0	74.5	81.0	33.0	81.0	75.5	75.0	78.0		47.5	19.0
92	94.7	101.0	98.0	77.0	83.0	35.5	82.0	76.0	75.5	79.0		49.0	21.0
94	96.4	103.2	100.0	79.5	85.0	38.0	83.0	76.5	76.5	80.0		51.0	23.0
96	98.0	105.3	102.1	82.0	86.5	40.0	84.5	77.0	77.0	80.5		52.0	25.5
98	99.8	107.3	104.0	84.5	88.0	42.0	85.5	77.5	77.5	81.0		53.5	26.5
100	101.5	109.4	106.0	87.0	90.0	44.5	87.0	78.0	78.0	82.0		55.0	28.5
102	103.2	111.5	108.0	89.5	92.0	46.5	87.5	78.5	79.0	82.5		56.0	30.0
104	104.9	113.5	110.1	92.0	94.0	48.0	88.5	79.0	79.5	83.0		57.0	32.0
106	106.6	115.6	112.6	94.5	96.0	50.0	89.5	79.5	80.0			58.0	33.0
108	108.3	117.5	114.5	97.0	98.0	52.0	90.5		80.5	83.5		59.0	34.5
110	109.9	119.5	116.3	99.5	100.0	53.5	91.0	80.0		84.0		60.0	36.0
112	111.8	121.4	118.1	102.0	102.0	55.0	91.5	80.5	81.0			61.0	37.0
114	113.5	123.2	119.9	105.0	103.5	57.0	92.5	81.0	81.5	84.5		62.0	38.5
116	115.0	125.1	121.7	107.0	105.5	58.5	93.0		82.0			63.0	40.0
118	116.8	127.1	123.5	110.0	107.5	59.5	94.0	81.5		85.0		64.0	41.5

(Contd.)

Table C.3 *(Contd.)*

Vickers hardness		Knoop hardness		Brinell hardness		Rockwell hardness							
HV 1	HV 0.1	HK 1	HK 0.5	HBS 10/500	HBS 2/20	HRB	HRF	HR15T			HR30T		HR45T
				Thickness of strip, mm									
				2.03	1.02	≥ 1.02	≥ 1.02	0.25	0.51	≥ 1.02	0.51	≥ 1.02	≥ 1.02
120	118.5	129.0	125.2	112.0	109.0	61.0	95.0	82.0	82.5			65.0	42.5
122	121.1	131.0	127.0	115.0	111.0	62.5	95.5		83.0	85.5		66.0	44.0
124	121.9	133.0	128.7	117.5	113.0	64.0	96.0	82.5	83.5	86.0		66.5	45.0
126	123.6	134.9	130.4	120.0	115.0	65.0	97.0		84.0			67.5	46.5
128	125.2	136.8	132.1		117.5	66.0	98.0	83.0	84.5	87.0		68.5	48.0
130	127.0	138.7	133.8		119.0	67.0	99.0		85.0			69.5	49.0

Source: Ref. 2

Table C.4 *Conversion of hardness-to-hardness values for cartridge brass (CuZn30)*

Vickers hardness	Brinell hardness	Rockwell hardness				
HV	HBS 10/500	HRB	HRF	HR15T	HR30T	HR45T
45	42		40.0			
46	43		43.0			
47	44		45.0			
48	45		47.0	53.5		
49	46		49.0	54.5		
50	47		50.5	55.5		
52	48		53.5	57.0		
54	50		56.5	58.5	12.0	
56	52		58.8	60.0	15.0	
58	53		61.0	61.0	18.0	
60	55	10.0	62.5	62.5		
62	57	12.5	65.0	63.5	23.0	
64	59	15.5	66.8	65.0	25.5	
66	61	18.5	68.5	66.0	28.0	
68	62	21.5	70.0	67.0	30.0	
70	63	24.5	71.8	68.0	32.0	
72	64	27.5	73.2	69.0	34.0	
74	66	30.0	74.8	70.0	36.0	1.0
76	68	32.5	76.0	70.5	38.0	4.5
78	70	35.0	77.4	71.5	39.5	7.5
80	72	37.5	78.6	72.0	41.0	10.0
82	74	40.0	80.0	73.0	43.0	12.5
84	76	42.0	81.2	73.5	44.0	14.5
86	77	44.0	82.3	74.5	45.5	17.0
88	79	46.0	83.5	75.0	47.0	19.0
90	80	47.5	84.4	75.5	48.0	21.0
92	82	49.5	85.4	76.5	49.0	23.0
94	83	51.0	86.3	77.0	50.5	24.5
96	85	53.0	87.2	77.5	51.5	26.5

(Contd.)

Table C.4 *(Contd.)*

Vickers hardness	Brinell hardness	Rockwell hardness				
HV	HBS 10/500	HRB	HRF	HR15T	HR30T	HR45T
98	86	54.0	88.0	78.0	52.5	28.0
100	88	56.0	89.0	78.5	53.5	29.5
102	90	57.0	89.8	79.0	54.5	30.5
104	92	58.0	90.5	79.5	55.0	32.0
106	94	59.5	91.2	80.0	56.0	33.0
108	95	61.0	92.0		57.0	34.5
110	97	62.0	92.6	80.5	58.0	35.5
112	99	63.0	93.0	81.0	58.5	37.0
114	101	64.0	94.0	81.5	59.5	38.0
116	103	65.0	94.5	82.0	60.0	39.0
118	105	66.0	95.0	82.5	60.5	40.0
120	106	67.0	95.5		61.0	41.0
122	108	68.0	96.0	83.0	62.0	42.0
124	110	69.0	96.5		62.5	43.0
126	112	70.0	97.0	83.5	63.0	44.0
128	113	71.0	97.5		63.5	45.0
130	114	72.0	98.0	84.0	64.5	45.5
132	116	73.0	98.5	84.5	65.0	46.5
134	118	73.5	99.0		65.5	47.5
136	120	74.5	99.5	85.0	66.0	48.0
138	121	75.0	100.0		66.5	49.0
140	122	76.0	100.5	85.5	67.0	50.0
142	124	77.0	101.0		67.5	51.0
144	126	77.5	101.5	86.0	68.0	51.5
146	128	78.0	102.0		68.5	52.5
148	129	79.0	102.5		69.0	53.0
150	131	80.0		86.5	69.5	53.5
152	133	80.5	103.0			54.0
154	135	81.5	103.5		70.0	54.5

(Contd.)

Table C.4 *(Contd.)*

Vickers hardness	Brinell hardness	Rockwell hardness				
HV	HBS 10/500	HRB	HRF	HR15T	HR30T	HR45T
156	136	82.0	104.0	87.0	70.5	55.5
158	138	83.0	104.5		71.0	56.0
160	139	83.5			71.5	56.5
162	141	84.0	105.0	87.5		57.5
164	142	85.0	105.5		72.0	58.0
166	144	85.5			72.5	58.5
168	146	86.0	106.0	88.0	73.0	59.0
170	147	87.0				59.5
172	149	87.5	106.5		73.5	60.0
174	150	88.0		88.5	74.0	60.5
176	152	88.5	107.0			61.0
178	154	89.0			74.5	61.5
180	156	90.0	107.5		75.0	62.0
182	157	90.5	108.0	89.0		62.5
184	159	91.0			75.5	63.0
186	161	91.5	108.5		76.0	63.5
188	162	92.0		89.5		64.0
190	164	92.5	109.0		76.5	64.5
192	166	93.0			77.0	65.0
194	167		109.5			65.5
196	169	93.5	110.0	90.0	77.5	66.0

Source: Ref. 2

C.4 Reporting of Hardness Values

When reporting converted hardness values, the measured hardness value and hardness scale should be indicated in parentheses as in the following example:

200 HV (190 HBW).

C.5 REFERENCES

1. DIN 50150: 2000, *Conversion of Hardness Values For Metallic Materials.*
2. ASTM E 140:2002, *Standard Hardness Conversion Tables for Metals. Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hard ness, Knoop Hardness and Scleroscope Hardness.*
3. ISO 18265:2003. *Metallic Materials— Conversion of Hardness Values.*

Annexure D

MACROETCHANTS FOR METALS AND ALLOYS

D.1 Selected Macroetchants for Metals and Alloys

Composition	Procedure	Application
Cast irons		
$CuCl_2$ 2.5 g $MgCl_2$ 10 g HCl (conc.) 5 ml Ethanol 250 ml **(Stead's reagent)**[1)]	Immerse specimen in solution at room temperature for up to 3 h. Rinse and dry.	Reveals eutectic cells in grey cast irons.
$(NH_4)_2S_2O_8$ 10 g H_2O 100 ml H_2SO_4 (conc) Few drops	Immerse or swab specimen with solution at room temperature. Rinse and dry.	Reveals carbide and phosphide distribution.
HNO_3 5–10 ml Ethanol 95–90 ml **(Nital)**[1)]	Immerse specimen in solution at room temperature for up to 3 min. Rinse and dry.	Reveals macrostructure in white irons.
Steels		
HCl (conc.) 50 ml H_2O 50 ml	Immerse specimen in solution, heated to 70–80 °C, for 15–60 min. Desmut by vigorous scrubbing with a vegetable fibre brush under running water and dry. For corrosion resistant steels desmut by dipping in warm 20% HNO_3 solution.	Reveals segregation, porosity, hardness penetration, dendrites, flow lines, soft spots, weld structure, etc.
HCl (conc.) 38 ml H_2SO_4 (conc.) 12 ml H_2O 50 ml	Immerse specimen in solution, heated to 70–80 °C, for 30–60 min. Rinse in warm water and dry.	Reveals segregation, porosity, hardness penetration, dendrites, flow lines, soft spots, weld structure, etc.
$(NH_4)_2S_2O_8$ 10 g H_2O 100 ml	Swab specimen with solution at room temperature until the desired etch is obtained. Rinse and dry.	Reveals grain size and weld structure.

(Contd.)

D.1 Selected Macroetchants for Metals and Alloys (Contd.)

Composition	Procedure	Application
Aluminium and aluminium alloys		
NaOH 10 g H_2O 100 ml	Immerse specimen in solution, heated to 60–70 °C, for 5–15 min. Rinse in water, and remove smut in 50% HNO_3 solution. Rinse in water and dry. Repeat etching if necessary.	Reveals macrostructure in all aluminium and aluminium alloys.
HCL (conc.) 75 ml HNO_3 (conc.) 25 ml HF (48%) 5 ml	Immerse or swab specimen with solution at room temperature for 10–15 s. Rinse in warm water and dry.	Reveals grain structure in Al–Mg, Al–Mn, Al-Si and Al–Mg–Si alloys.
HCL (conc.) 45 ml HNO_3 (conc.) 15 ml HF (48%) 15 ml H_2O 25 ml	Immerse specimen in solution at room temperature until desired contrast is obtained. Rinse in warm water and dry.	Reveals macrostructure in pure aluminium, Al-Mg, Al-Mn, Al–Si and Al–Mg–Si alloys.
Copper and copper alloys		
HNO_3 10 ml H_2O 90 ml	Immerse specimen in solution at room temperature for a few minutes. Rinse in water and dry.	Emphasizes grains and cracks in coppers and all brasses.
HNO_3 50 ml H_2O 50 ml	Immerse specimen in solution at room temperature for a few minutes. Rinse in water and dry.	Brings out grain contrast in coppers and all brasses.
$K_2Cr_2O_7$ 2 g NaCl (saturated solution) 4 ml H_2SO_4 8 ml H_2O 100 ml	Immerse specimen in solution at room temperature for 15–30 s and then swab with fresh solution. Rinse in warm water and dry.	Emphasizes grain boundaries and oxide inclusions in coppers, high-copper alloys, phosphor bronzes and tin bronzes.
CrO_3 40 g NH_4Cl 7.5 g HNO_3 (conc.) 50 ml H_2SO_4 (conc.) 8 ml H_2O 100 ml	Immerse specimen in solution at room temperature. Rinse in warm water and dry.	Reveals macrostructure of silicon brass and silicon bronze.

(Contd.)

D.1 Selected Macroetchants for Metals and Alloys (Contd.)

Composition	Procedure	Application
Zinc and zinc alloys		
HCl (conc.) 50 ml H_2O 50 ml	Immerse specimen in solution at room temperature for about 15 s. Remove smut by wiping under running water. Repeat until desired contrast is obtained and then dry.	Reveals grain structure in pure zinc and copper-free zinc alloys.
CrO_3 20 g Na_2SO_4 1.5 g or $Na_2SO_4.10H_2O$ 3.4 g H_2O 100 ml **(Palmerton's reagent)**[1)]	Immerse specimen in solution at room temperature until good contrast is obtained. Rinse in running water and dry. Repeat if necessary.	Reveals structure in zinc alloys containing copper.
[1)] Common name of etching reagents.		

D.2 REFERENCES

1. *ASM Handbook*, Vol. 9, ASM International, Materials Park, Ohio, USA, 1985.
2. G.L. Kehl, *The Principles of Metallographic Laboratory Practice*, 3rd Edition, McGraw-Hill, New York, USA, 1949.
3. ASTM E 340:2000e1, *Standard Test Method for Macroetching Metals and Alloys*.
4. P. Petzow, *Metallographic Etching*, ASM International, Materials Park, Ohio, USA, 1978.

Annexure E

MICROETCHANTS FOR METALS AND ALLOYS

E.1 Selected Microetchants for Metals and Alloys

Composition	Procedure	Application
Cast irons		
HNO_3 1–5 ml Ethanol or methanol 100 ml (95% or absolute) **(Nital)**[1)]	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Structure of general-purpose cast irons. Also used for some special-purpose cast irons.
Picric acid 4 g Ethanol or methanol 100 ml (95% or absolute) **(Picral)**[1)]	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Structure of general-purpose cast irons. Also used for some special-purpose cast irons. Provides better resolution of certain carbide structures than is obtained with nital.
HCl 5 ml Picric acid 1 g Ethanol or methanol 100 ml (95% or absolute) **(Vilella's reagent)**[1)]	Immerse for up to 20 s. Rinse in water and dry.	Structure of high chromium cast irons.
KOH 10 g $K_3Fe(CN)_6$ 10 g **(Murakami's reagent)**[1)]	Immerse for 2–3 min. Rinse in water and dry.	Structure of 30% chromium cast irons.
	Immerse for 10–30 s. Rinse in water and dry.	Structure of high-phosphorous cast irons. Distinguishes between iron phosphide and iron carbide.
Picric acid 2g NaOH 25 g H_2O 100 ml **("Le Chatelier and Igewski" reagent. Also known as alkaline sodium picrate)**[1)]	Immerse for 10 s to 2 min in boiling solution. Rinse in water and dry.	Blackens cementite.

E.1 Selected Microetchants for Metals and Alloys (Contd.)

Composition	Procedure	Application
Steels		
HNO_3 1–5 ml Ethanol or methanol 100 ml (95% or absolute) **(Nital)**[1)]	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry	General structure.
Picric acid 4 g Ethanol or methanol 100 ml (95 % or absolute) **(Picral)**[1)]	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry	General structure.
HCl 5 ml Picric acid 1 g Ethanol or methanol 100 ml (95% or absolute) **(Vilella's reagent)**[1)]	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Prior austenite grain boundaries in martensitic and bainitic steels.
$FeCl_3$ 5 g HCl 50 ml H_2O 100 ml	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Structure of austenitic nickel and stainless steels.
HNO_3 10 ml HCl 20–30 ml Glycerin 30–20 ml	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Structure of iron-chromium alloys, high speed tool steels, and austenitic manganese steels.
HNO_3 10 ml HCl 20 ml Glycerin 20 ml H_2O_2 10 ml	Immerse or swab for a few seconds to a minute or more. Rinse in water and dry.	Structure of iron-chromium-nickel, iron-chromium-manganese, and all other austenitic iron-chromium alloys.
Picric acid 2 g NaOH 25 g H_2O 100 ml **("Le Chatelier and Igewski" reagent. Also known as alkaline sodium picrate)**[1)]	Immerse for 10 s to 2 min in boiling solution. Rinse in water and dry.	Blackens cementite.

E.1 Selected Microetchants for Metals and Alloys (Contd.)

Composition	Procedure	Application
Aluminium and aluminium alloys		
HF (conc.) 1 ml H_2O 200 ml	Swab for about 15 s or immerse for 30–45 s. Rinse in water and dry.	Structure of aluminium and aluminium alloys.
NaOH 1 g H_2O 100 ml	Swab for 5–10 s. Rinse in water and dry.	Structure of aluminium and aluminium alloys, with the exception of aluminium-silicon alloys.
HF (48 %) 2 ml HCl (conc.) 3 ml HNO_3 5 ml H_2O 190 ml **(Keller's reagent)**[1)]	Immerse for 8–15 s. Rinse in warm water and dry.	Structure of aluminium and aluminium alloys.
Copper and copper alloys		
NH_4OH 20 ml H_2O 20 ml H_2O_2 (3 %) 8–20 ml	Immerse or swab for about 1 min. Rinse in water and dry. *Note:* Use freshly prepared reagent.	Structure of most copper and copper alloys.
$K_2Cr_2O_7$ 2 g H_2SO_4 (conc.) 8 ml NaCl (saturated solution) 4 ml H_2O 100 ml	Immerse for 5–60 s. Rinse in water and dry. *Note:* Use freshly prepared reagent.	Structure of coppers; copper-beryllium, copper-manganese, and copper-silicon alloys; nickel silver; and bronzes.
CrO_3 (saturated aqueous solution)	Immerse or swab for 5–30 s. Rinse in water and then dry. *Note:* Use freshly prepared reagent.	Structure of coppers; brasses; bronzes; and nickel silver.
$(NH_4)_2S_2O_8$ 10 g H_2O 90 ml	Immerse in cold or boiling solution.	Structure of coppers; brasses; bronzes; and nickel silver.

E.1 Selected Microetchants for Metals and Alloys

Composition	Procedure	Application
Zinc and zinc alloys		
CrO_3 20 g Na_2SO_4 1.5 g H_2O 100 ml **(Palmerton's reagent)**[1] ***Note:*** For alloys containing copper reduce Na_2SO_4 to 0.75g	Immerse with gentle agitation for 2–3 min. Rinse in a solution of: CrO_3 20 g H_2O 100 ml Thoroughly wash in running water, then dip in alcohol and finally dry with a stream of warm, clean air.	Structure of most zinc and zinc alloys.
CrO_3 10 g Na_2SO_4 1 g H_2O 200 ml **(Dilute Palmerton's reagent)**[1]	Immerse for 2–5 s. Rinse in a solution of: CrO_3 20 g H_2O 100 ml Thoroughly wash in running water, then dip in alcohol and finally dry with a stream of warm, clean air.	Structure of zinc die casting alloys. Also develops contrast between die casting and plated coating.

[1] Common name of etching reagents.

E.2 REFERENCES

1. *ASM Handbook*, Vol. 9, ASM International, Materials Park, Ohio, USA., 1985.
2. G.L. Kehl, *The Principles of Metallographic Laboratory Practice,* 3rd Edition, McGraw-Hill, New York, USA, 1949.
3. G. Petzow, *Metallographic Etching,* ASM International, Materials Park, Ohio, USA, 1978.

Annexure F

DIRECTORY OF SELECTED NATIONAL AND INTERNATIONAL STANDARDS ORGANIZATIONS, AND TECHNICAL ASSOCIATIONS

Europe

- **European Committee for Standardization (CEN)**
  36, rue de Stassart
  1050 Brussels
  Belgium
  Tel. +32 2 550 08 11
  Fax +32 2 550 08 19
  E-mail infodesk@cenorm.be
  Web www.cenorm.be

France

- **Association Francaise de Normalisation (AFNOR)**
  11, avenue Francis de Pressensé
  93571 Saint-Denis La Plaine Cedex
  Tel. +33 1 41 62 80 00
  Fax +33 1 49 17 90 00
  E-mail norminfo@afnor.fr
  Web www.afnor.fr

Germany

- **DIN Deutsches Institut für Normung e.V.**
  Burggrafenstrasse 6
  10787 Berlin
  Postal address
  10772 Berlin
  Tel. +49 30 2601 0
  Fax +49 30 2601 1231
  E-mail postmaster@din.de
  Web www.din.de

India

- **Bureau of Indian Standards (BIS)**
  Manak Bhavan
  9 Bahadur Shah Zafar Marg
  New Delhi 110 002
  Tel. +91 11 2323 0131
  Fax +91 11 2323 9399
  E-mail info@bis.org.in
  Web www.bis.org.in

India *(Contd.)*

- **The Indian Institute of Metals (IIM)**
  "Metal House"
  Plot 13/ 4, Block AQ, Sector V
  Salt Lake City
  Kolkata 700 091
  Tel. +91 33 2367 5004
  Fax +91 33 2367 5335
  E-mail iiom@cal2.vsnl.net.in
  Web www.iim-india.org

International

- **International Organization for Standardization (ISO)**
  1, rue de Varembé
  Case Postale 56
  CH-1211 Geneva 20
  Switzerland
  Tel. +41 22 749 01 11
  Fax +41 22 733 34 30
  Web www.iso.org

Japan

- **Japanese Industrial Standards Committee (JISC)**
  Industrial Science and Technology Policy and Environment Bureau
  Technical Regulation, Standards and Conformity Assessment Policy Unit
  Ministry of Economy, Trade and Industry
  1-3-1 Kasumigaseki, Chiyoda-ku
  Tokyo 100-8901
  Tel. +81 3 35 01 94 71
  Fax +81 3 35 80 86 37
  E-mail jisc@meti.go.jp
  Web www.jisc.go.jp

Russian Federation

- **Federal Agency for Technical Regulation and Metrology (GOST R)**
  Leninsky Prospekt 9
  Moscow, B-49, ГСП-1, 119991
  Tel. +7 095 236 03 00
  Fax +7 095 236 62 31
  E-mail info@gost.ru
  Web www.gost.ru

United Kingdom

- **British Standards Institution (BSI)**
  389 Chiswick High Road
  London W4 4AL
  Tel. +44 (0) 20 8996 9000
  Fax +44 (0) 20 8996 7001
  E-mail cservices@bsiglobal.com
  Web www.bsi-global.com

United Kingdom *(Contd.)*

- **Institute of Materials, Minerals and Mining (IOM^3)**
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  London SW1Y 5DB
  Tel. +44 (0) 20 7451 7300
  Fax +44 (0) 20 7839 1702
  Web www.iom3.org

United States of America

- **American National Standards Institute (ANSI)**
  1819 L Street, NW
  Washington, DC 20036
  Tel. +1 202 293 8020
  Fax +1 202 293 9287
  E-mail info@ansi.org
  Web www.ansi.org
- **American Society for Nondestructive Testing (ASNT)**
  P.O. Box 28518
  1711 Arlingate Lane
  Columbus, OH 43228-0518
  Tel. +1 614 274 6003
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  Web www.asnt.org
- **ASM International**
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  Materials Park, OH 44073-002
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  +1 800 368 9800 (Toll Free–Europe)
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  Web www.asminternational.org
- **ASTM International**
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  E-mail service@astm.org
  Web www.astm.org
- **SAE International**
  400 Commonwealth Drive
  Warrendale, PA 15096-0001
  Tel. +1 724 776 4970
  +1 877 606 7323
  Fax +1 724 776 0790
  E-mail customerservice@sae.org
  Web www.sae.org

Annexure G

DIRECTORY OF SELECTED MATERIAL TEST EQUIPMENT SUPPLIERS

Buehler Ltd.

Address	41 Waukegan Road P.O. Box 1 Lake Bluff, IL 60044 United States of America
Tel.	+1 800 283 4537 (Toll Free – USA only) +1 847 295 6500
Fax	+1 847 295 7979
Web	www.buehler.com
Products	• Hardness testing machines – Knoop – Rockwell and Rockwell superficial – Vickers (HV 0.001 to HV 50) • Image analysis systems • Metallographic sample preparation equipment and consumables • Metallurgical microscopes • Stereomicroscopes

Carl Zeiss, Inc.

Address	One Zeiss Drive Thornwood, NY 10594 United States of America
Tel.	+1 914 747 1800
Fax	+1 914 682 8296
Web	www.zeiss.com
Products	• Image analysis systems • Metallurgical microscopes • Stereomicroscopes

Clemex Technologies Inc.

Address	800 Guimond Longueuil, QC J4G 1T5 Canada
Tel.	+1 450 651 6573 +1 888 651 6573
Fax	+1 450 651 9304 +1 866 651 9304
Web	www.clemex.com
Products	• Hardness testing machines – Knoop – Vickers (HV 0.01 to HV 1) • Image analysis systems

ERICHSEN GmbH & CO. KG

Address	Am Iserbach 14 D-58675 Hemer Germany
Tel.	+49 2372 9683 0
Fax	+49 2372 6430
E-mail	info@erichsen.de
Web	www.erichsen.de
Products	• Erichsen cupping testing machine

Fred V. Fowler Co., Inc.

Address	66 Rowe Street Newton, MA 02466 United States of America
Tel.	+1 617 332 7004 +1 800 788 2353 (Toll Free)
Fax	+1 617 332 4137
E-mail	sales@fvfowler.com
Web	www.fvfowler.com
Products	• Hardness testing machines – Rockwell and Rockwell superficial – Ultrasonic

GE Inspection Technologies, GmbH

Address	Robert Bosch Strasse 3 50354 Huerth Germany
Tel.	+49 2233 601 0
Fax	+49 2233 601 402
E-mail	geinspectiontechnologies@ae.ge.com
Web	www.geinspectiontechnologies.com
Products	• Eddy current inspection equipment • Hardness testing machines – Leeb (Krautkramer) – Ultrasonic (Krautkramer) • Radiographic inspection equipment • Ultrasonic testing equipment (Krautkramer)

Indentec Hardness Testing Machines Ltd.

Address	Lye Valley Industrial Estate Bromley Street Lye Stourbridge DY9 8HX West Midlands United Kingdom
Tel.	+44 (0) 1384 896949
Fax	+44 (0) 1384 424470
E-mail	mail@indentec.demon.co.uk
Web	www.indentec.com
Products	• Hardness testing machines – Brinell – Knoop – Rockwell and Rockwell superficial – Vickers (HV 0.01 to HV 50)

Instron Corporation

Address	100 Royall Street Canton, MA 02021 United States of America
Tel.	+1 781 828 2500 +1 800 564 8378 (Toll Free–USA only)
Fax	+1 781 575 5751
Web	www.instron.com
Products	• Creep testing machines • Fatigue testing machines • Hardness testing machines – Brinell – Knoop – Rockwell and Rockwell superficial – Vickers (HV 0.01 to HV 50) • Impact testing machines • Torsion testing machines • Universal testing machines

LECO Corporation

Address	3000 Lakeview Avenue Saint Joseph, MI 49085 United States of America
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Fax	+1 269 982 8977
E-mail	info@leco.com
Web	www.leco.com
Products	• Hardness testing machines – Brinell – Knoop – Rockwell and Rockwell superficial – Vickers (HV 0.01 to HV 50) • Image analysis systems • Metallographic sample preparation equipment and consumables • Metallurgical microscopes • Stereomicroscopes

Leica Microsystems AG

Address	Ernst-Leitz-Strasse 17-37 Wetzlar 35578 Germany
Tel.	+49 6441 29 0
Fax	+49 6441 29 2590
Web	www.leica-microsystems.com
Products	• Hardness testing machines – Knoop – Vickers (HV 0.001 to HV 2) • Image analysis systems • Metallurgical microscopes • Stereomicroscopes

MAGNAFLUX

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Fax	+1 847 657 5388	+ 44 (0) 1793 490549
E-mail	info@magnaflux.com	info@magnaflux.co.uk
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Products	• Liquid penetrant inspection equipment and accessories • Magnetic particle inspection equipment and accessories	

Mitutoyo America Corporation

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Fax	+1 630 820 2614
E-mail	info@mitutoyo.com
Web	www.mitutoyo.com
Products	• Hardness testing machines – Knoop – Leeb – Rockwell and Rockwell superficial – Vickers (HV 0.0005 to HV 50) • Metallurgical microscopes • Stereomicroscopes

MTS Systems Corporation

Address	14000 Technology Drive Eden Prairie, MN 55344-2290 United States of America
Tel.	+1 800 328 2255 (Toll Free–MTS Helpline–USA only) +1 800 944 1687 (Toll Free–Sales–USA only) +1 952 937 4000
Fax	+1 952 937 4515
E-mail	info@mts.com
Web	www.mts.com
Products	• Creep testing machines • Fatigue testing machines • Universal testing machines

Newage Testing Instruments Inc.

Address	147 James Way Southampton, PA 18966-3817 United States of America
Tel.	+1 215 526 2200 +1 800 806 3924 (Toll Free–USA only)
Fax	+1 215 526 2192
E-mail	info@newage1.com
Web	www.hardnesstesters.com
Products	• Hardness testing machines – Brinell – Knoop – Portable – Rockwell and Rockwell superficial – Vickers (HV 0.01 to HV 30)

Nikon Inc.

Address	1300 Walt Whitman Road Melville, NY 11747-3064 United States of America
Tel.	+1 631 547 8500 +1 800 526 4566 (Toll Free–USA only)
Web	www.nikonusa.com
Products	• Metallurgical microscopes • Stereomicroscopes

Olympus America Inc.

Address	2 Corporate Center Drive P.O. Box 9058 Melville, NY 11747-9058 United States of America
Tel.	+1 631 844 5000 +1 800 446 5967 (Toll Free–USA only) +1 800 645 8160 (Toll Free–USA only)
Fax	+1 516 844 5112
Web	www.olympusamerica.com
Products	• Image analysis systems • Metallurgical microscopes • Stereomicroscopes

Shimadzu Scientific Instruments, Inc.

Address	7102 Riverwood Drive Columbia, MD 21046 United States of America
Tel.	+1 410 381 1227 +1 800 477 1227 (Toll Free–USA only)
Fax	+1 410 381 1222
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