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Indian Standard

GLOSSARY OF TERMS RELATING TO METHODS OF MECHANICAL TESTING OF METALS

(*First Revision*)

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INDIAN STANDARDS INSTITUTION
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

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Indian Standard

GLOSSARY OF TERMS RELATING TO METHODS OF MECHANICAL TESTING OF METALS

(First Revision)

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Indian Standard

GLOSSARY OF TERMS RELATING TO METHODS OF MECHANICAL TESTING OF METALS

(First Revision)

0. FOREWORD

0.1 This Indian Standard (First Revision) was adopted by the Indian Standards Institution on 18 April 1982, after the draft finalized by the Methods of Physical Tests Sectional Committee had been approved by the Structural and Metals Division Council.

0.2 This standard was first published in 1969. In this revision, SI units have been adopted and definitions of a number of new terms incorporated.

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1. SCOPE

1.1 This standard defines the various terms commonly used in the methods of mechanical testing of metals.

1.1.1 The terms covered relate to tension, compression, shear, torsion, bend, hardness, impact, cupping, fatigue, creep and fracture toughness testing of metallic materials.

2. GENERAL

2.1 Calibration — The process of determining the characteristic relationship between the values of the physical quantity applied to the instrument and the corresponding positions of the index.

2.2 Ductility — The ability of a material to deform plastically before fracture. It is usually evaluated by (a) comparing values of the elongation and/or the reduction of area of the specimen in tensile tests; (b) the depth of cup in the cupping tests; or (c) the internal diameter and angle of bend in the bend tests.

2.3 Elasticity — The property of the material by virtue of which it tends to recover its original size and shape on removal of applied stress, not exceeding its elastic limit.

2.4 Elasticity (Elastic) Limits — The greatest stress which a material is capable of sustaining without any permanent strain remaining upon complete release of the stress.

2.5 Flexural Strength — Flexural strength is the resistance of a material to bending.

2.6 Flexural Test — A test performed on a test piece from a material by subjecting it to a transverse loading under a given condition in a testing machine and noting the deflection produced at any desired point on the test piece and the corresponding load.

2.7 Flexure — The bending characteristic of a material subjected to transverse load is called flexure.

2.8 Hooke's Law — This law states that stress is proportional to strain. The law holds good up to the proportional limit.

2.9 Malleability — The property of metals and alloys to plastically deform under compression (pressing, hammering, rolling etc) without rupture.

2.10 Mechanical Properties — The properties of a material that reveal its elastic and inelastic behaviours when force is applied, thereby indicating its suitability for mechanical applications. For example, modulus of elasticity, tensile strength, hardness, fatigue limit etc.

2.11 Mechanical Testing — The procedure followed for determining the mechanical properties.

2.12 Nil Ductility Transition Temperature — The maximum temperature where a standard drop weight specimen breaks into two pieces.

2.13 Proportional Limit — The stress at which the strain just ceases to be proportional to the applied stress.

2.14 R-ratio (Plastic strain ratio) — It is the ratio of the true strain that has occurred in a width direction ' w ' perpendicular to the direction of applied stress and in the plane of the sheet, to the concomitant true strain in the thickness direction ' t ',

2.15 Resilience — The amount of energy per unit volume released upon unloading.

2.16 Strain — A measure of change in size or shape of a body with reference to its original shape or size, as a result of the applied force. Strain is a non-dimensional quantity frequently expressed in centimetres per centimetre.

NOTE 1 — Strain may be either linear (tensile strain or compressive strain) or angular (shear strain).

NOTE 2 — Linear thermal expansion per unit length, sometimes called ' thermal strain ' is not considered as strain in mechanical testing.

2.16.1 *Elastic Strain* — The change per unit dimension due to stress within the elastic range, with recovery of the original dimensions upon release of load, given the time.

2.16.2 *Linear Strain* — The change per unit length of a linear dimension due to the force applied.

2.16.2.1 *Axial strain* — The linear strain parallel to the longitudinal axis of the specimen.

2.16.2.2 *Transverse strain* — The linear strain in transverse (perpendicular) to the axis of the specimen.

2.16.3 *Plastic Strain or Permanent Strain* — The change per unit dimension due to applied stress that does not disappear or will remain after removal of applied stress.

2.16.4 *Shear or Angular Strain* — The tangent of the angle of rotation of lines originally drawn perpendicular to two parallel lines on the body, under the action of a force.

For small strains, this angle in radian and its tangent may be taken as equal.

The aforementioned definition is made clear from Fig. 1.

$$\text{Shear strain} = \tan\theta = \frac{a}{h}$$

where

θ = shear angle,

a = linear displacement under shear force, and

h = distance between the parallel lines drawn originally on the body.

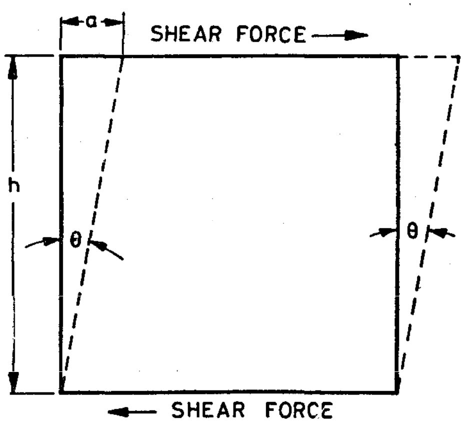


FIG. 1 SHEAR OR ANGULAR STRAIN

2.16.5 *Total True, Strain (True, Natural or Logarithmic Strain)* — The natural logarithm of the ratio of length at the moment of observation to the original gauge length.

2.16.6 *True Strain* — The ratio of increase in length to the instantaneous length at the beginning of the deformation.

2.17 Stress — Expressed as force per unit area.

2.17.1 *Fracture Stress* — The true normal stress on the minimum cross sectional area at the beginning of fracture. It usually applies to the tension test of un-notched specimens.

2.17.2 *Nominal Stress* — The stress computed by simple elasticity formula ignoring stress-raisers and disregarding plastic flow.

2.17.3 *Normal Stress* — The stress or the component of stress acting perpendicular to a given plane. Normal stress may either be a tensile stress or a compressive stress depending on the direction of the force.

2.17.4 *Principal Stresses* — The normal stresses on three mutually perpendicular planes on which there are no shear stresses.

2.17.5 *Residual Stress* — The stress present in a body that is free from external force or thermal gradient.

2.17.6 *Shear Stress* — The stress component tangential to the plane on which the forces act.

2.17.7 *Torsional Stress* — The shear stress of a transverse cross-section resulting from twisting.

2.17.8 *True Stress* — The axial stress in tension or compression calculated on the basis of the instantaneous cross-sectional area instead of the original area.

2.18 Stress-Strain Diagram — A diagram similar to the load-extension curve but plotted with corresponding value of stress, as ordinate and strain, as abscissa.

2.19 Transverse Test — A test generally applied to brittle materials like cast iron, by subjecting a suitable test piece of the material to transverse loads when held between two horizontal supports (mandrels) in a testing machine.

2.20 Verification — The process of testing an instrument for the purpose of assessing the errors of pointer indications. The assessment is to determine whether an instrument conforms to the stipulations laid down.

3. TENSION, COMPRESSION, SHEAR AND TORSION TESTING

3.1 Breaking Load or Final Load — The load at which the specimen fractures (*see* Fig. 2).

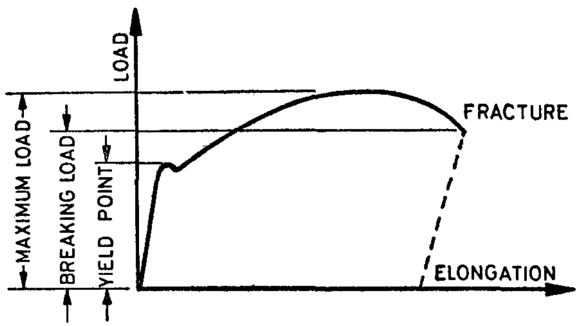


FIG. 2 LOAD-ELONGATION DIAGRAM

3.2 Cohesive Strength — The hypothetical stress in an un-notched bar causing tensile fracture without plastic deformation

3.3 Compression Strength — The maximum compressive stress that a material is capable of developing, based on original area of cross-section.

NOTE — In the case of materials which fail in compression by a shattering fracture, the compressive strength has a definite value. In the case of materials which do not fail in compression by shattering fracture, the value obtained for compressive strength is an arbitrary one based on the degree of distortion that is regarded as indicating complete failure of the material.

3.4 Elastic Constants — Modulus of elasticity either in tension or compression (E) or in shear (G); bulk modulus (K); and Poisson's ratio (σ). These are related by:

a) $1 + \sigma = \dfrac{E}{2G}$, and

b) $E = 3K(1 - 2\sigma)$.

3.5 Elongation — The increase in gauge length measured after fracture of the specimen within the gauge length. It is usually expressed as a percentage of the original gauge length.

3.5.1 *Percentage of Permanent Elongation* — The permanent variation in the gauge length of a tensile test piece after removal of the prescribed stress expressed as a percentage of the original gauge length.

3.5.2 *Uniform Elongation* — The elongation which occurs between the upper yield point and the tensile strength.

3.5.3 *Yield Point Elongation* — Beyond the upper yield point, the appreciable elongation which occurs before the load again resumes a steady increase.

3.6 Extensometer — A device for measuring the extension or linear strain.

3.7 Extensometer Gauge Length — The length of the parallel portion of the test piece used for the measurement of extension using an extensometer. This gauge length may differ from the original gauge length of the specimen.

3.8 Gauge Length — The prescribed part of the cylindrical or prismatic portion of the test piece on which elongation is measured at any moment during the test. Following distinction is made between original and final gauge lengths:

a) Original gauge length is the gauge length before the test piece is strained.

b) Final gauge length is the gauge length after the test piece has fractured and the fractured parts are carefully fitted together as nearly as a single piece.

3.9 Maximum Load — The maximum load which the test piece has withstood during the test (*see* Fig. 2).

3.10 Modulus of Elasticity — The ratio of stress to corresponding strain below the proportional limit:

a) Young's modulus (E) is the modulus in tension or compression.

b) Rigidity modulus or modulus of transverse elasticity or shear modulus (G) is the modulus corresponding to shear strain resulting from shear stress.

c) Bulk modulus (K) is the modulus corresponding to the volumetric strain resulting from three mutually perpendicular and equal direct stresses.

NOTE — The stress-strain relationship of many metals does not conform to Hooke's law throughout the elastic range and deviates from it even at stresses well below the elastic limit. For such metals the slope of either the tangent to the stress-strain curve at specified point, the secant drawn from the origin to any specified point on the stress-strain curve or the chord connecting any two specified points on the stress-strain curve is usually taken to be the modulus of elasticity. In these cases, the modulus is correspondingly designated as tangent, secant, or chord modulus with the indication of stress or stresses.

3.11 Modulus of Rupture — The nominal stress at fracture in bend or torsion tests.

3.11.1 *Modulus of Rupture in Bending* (S_b) — The bending moment at the fracture divided by the section modulus:

$$S_b = \frac{Mc}{I}$$

where

M = The maximum bending moment computed from maximum load and original moment arm,

c = the initial distance from the neutral axis to the extreme fibre where the failure occurs, and

I = the initial moment of inertia of cross-section about the neutral axis.

3.11.2 *Modulus of Rupture in Torsion* (S_s) — The torque at the fracture divided by the polar section modulus:

$$S_s = \frac{Tr}{J}$$

where

T = the maximum twisting moment,

r = the original outer radius, and

J = the polar moment of inertia of the original cross-section.

NOTE — When the proportional limit in tension or compression or shear is exceeded the modulus of rupture in bending or torsion is greater than the corresponding actual maximum tensile or compressive or shear stress in the extreme fibre, independent of the effect of stress concentration near the points of application of load or torque.

3.12 N-Value (Work Hardening Exponent/Strain Hardening Coefficient) — The n-value approximates to a measure of the stretch forming capability of material.

3.13 Necking or Waisting — A form or shape of the localized reduction in cross-section occurring in a ductile metal under tension before fracture.

3.14 Notch — A slot or groove of specified characteristics intentionally cut in a test piece to break it at the desired section.

3.15 Notch Rupture Ductility (Notch Ductility) — Notch rupture ductility of a notched tensile test is the percentage reduction in area of the specimen in the plane of failure at the root of the notch.

3.16 Notch Sensitiveness — A measure of reduction in strength of the metal caused by the presence of notch resulting in stress concentration. The strength may be tensile, impact or cyclic (dynamic)

3.17 Notch Sharpness — A term used to describe the severity of the notch used on the tensile test specimen. It is expressed as the ratio of the diameter of the specimen at the notch to twice the notch root radius.

3.18 Notch Strength Ratio — The ratio of nominal stress required to fracture a notched specimen, to that required to fracture an un-notched specimen.

3.19 Notch Tensile (or Creep) Testing — A test for determining the influence of a surface notch upon the properties of a material. It may be conducted as a tensile or as creep test.

3.20 Percentage Reduction of Area — The ratio of the maximum change in the area of cross-section during test to the original area of cross-section, expressed as a percentage.

The smallest cross-section may be measured at or after fracture as specified. The term, percentage reduction of area, generally, refers to that after fracture.

3.21 Permanent Set — The plastic deformation which persists after the removal of the applied load (*see* Fig. 3).

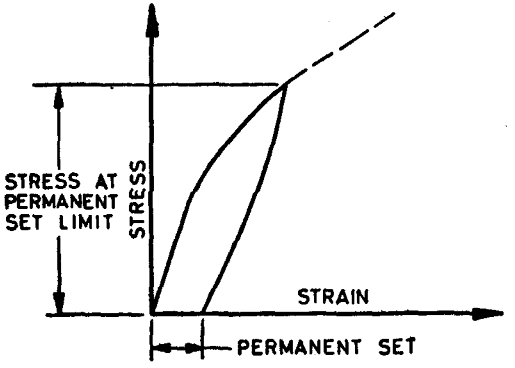


FIG. 3 PERMANENT SET MEASUREMENT

3.22 Poisson's Ratio (σ) — The absolute value of the ratio of the transverse strain to the corresponding axial strain in a body subjected to uniaxial stress, usually within the elastic range.

3.23 Proof Stress (Non-proportional Elongation) (R_p) – The stress at which the non-proportional elongation amounts to a specified percentage of original gauge length. The proof stress which refers to the stress for a non-proportional elongation or a permanent set is usually specified by 0·1 or 0·2 or 0·5 percent of original gauge length. It is conventionally indicated by R_p 0·1 or R_p 0·2 or R_p 0·5. The proof stress in the case of non-proportional elongation is derived from the stress-strain diagram (*see* Fig. 4).

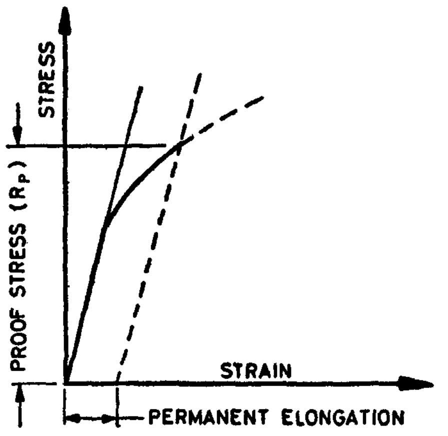


FIG. 4 PROOF STRESS BY NON-PROPORTIONAL ELONGATION

3.24 Proof Stress (Total Elongation) or Proof Stress Underload (R_t) — The stress corresponding to a specified percentage of the original gauge length which is a made-up of the combined elastic and inelastic elongations (*see* Fig. 5). (Usually indicated by the symbol R_t with total elongation suffixed, for example, R_t 0·5).

The value obtained by total elongation method would only be equivalent to R_p if suitable allowance is made for the measurement of elastic extension.

3.25 Shear Force — A type of force which causes or tends to cause two contiguous parts of the body to slide relative to each other in a direction parallel to their plane of contact.

3.26 Shear Fracture — A mode of fracture in crystalline materials resulting from the movement along cleavage planes which are preferentially oriented in the direction of the shear stress.

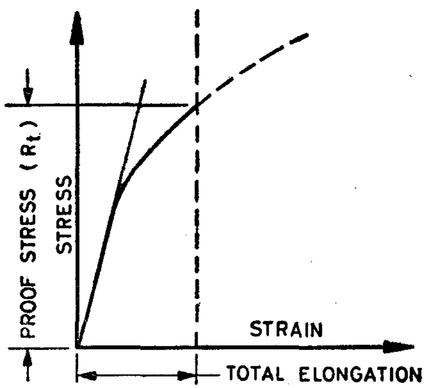


FIG. 5 PROOF STRESS BY TOTAL ELONGATION

3.27 Shear Strength — The stress required to produce fracture in the plane of cross-section, acted on by the shear force.

3.28 Tensile Strength — The stress corresponding to maximum load in a tension test (*see* Fig. 2).

3.29 Torque — The product of force and the perpendicular distance from its line of application to the axis about which it acts.

3.30 Torsional Movement — The algebraic sum of the couples or the moments of the external forces about the axis of twist or both.

3.31 Yield Point — The first stress in a material, usually less than the maximum attainable stress, at which an increase in strain results without an increase in stress (*see* Fig. 2). If there is a decrease in the stress after yielding a distinction is made between upper and lower yield points.

3.31.1 *Apparent Yield Stress* — In tests where a stress-strain diagram is not obtained, the value of stress determined from the load at which a lag/hesitation or drop of the pointer is first observed. The load taken is the maximum, usually recorded by the slave pointer during yield extension.

3.31.2 *Lower Yield Stress* (R_eL) — In tests where a stress-strain diagram is obtained, the lowest value of stress measured during plastic deformation at yield, ignoring any initial transient effects occurring.

3.31.3 *Upper Yield Stress* (R_eH) — In tests where a stress-strain diagram is obtained, the value of stress measured at the commencement of plastic deformation at yield, or the value of stress measured at the first peak obtained during yielding even when that peak is equal to or less than any subsequent peaks observed during plastic deformation at yield.

4. HARDNESS TESTING

4.1 Brinell Hardness Test — An indentation hardness test using calibrated machines to force a hard steel ball, under specified conditions of load and time, into the surface of the material under test and to measure the diameter of the resulting impression after release of the load.

4.1.1 *Brinell Hardness Number* (*HB*) — A number related to the area of the permanent impression made by ball indenter of the specified size pressed into the surface of the material under a specified load. The surface area of the impression is determined from the mean diameter of the rim of the impression and the ball diameter. Brinell hardness number is calculated from the formula:

$$HB = \frac{0{\cdot}102 \times F}{\pi \frac{D}{2} \left(D - \sqrt{D^2 - d^2} \right)}$$

where

F = test load in Newton,

D = diameter of ball in millimetres, and

d = mean diameter of the impression in millimetres.

4.2 Hardness — The resistance of metal to plastic deformation, usually by indentation. However, the term may also refer to stiffness, or temper or to resistance to scratching, abrasion or cutting. Indentation hardness may be measured by various hardness tests, such as Brinell, Rockwell and Vickers.

4.3 Indentation Hardness — A number related to the area or to the depth of the impression made by an indenter of fixed geometry under a known static load.

The term 'indentation hardness' has no quantitative meaning, except in terms of a particular test in which the area and shape of the indenter, the identing load and other conditions of test are specified.

4.4 Knoop Hardness Test — An indentation hardness test using calibrated machines to force into the surface of the material under test, a rhombic based diamond pyramid indenter of specified edge angles, under stipulated conditions and to measure the long diagonal after removal of the load.

4.4.1 *Knoop Hardness Number* (*HK*) — A number related to the applied load and to the projected area of the permanent impression made by a rhombic based diamond pyramid indenter (of included edge angles of 172°30′ and 130°0′) derived from the formula:

$$HK = \frac{0{\cdot}102\ P}{0{\cdot}070\ 28\ d^2}$$

where

P = applied load in Newton, and

d = long diagonal of the impression in millimetres.

In reporting Knoop hardness numbers, the test load should always be stated.

4.5 Micro Hardness Tests — These tests are usually conducted using metallurgical microscopes or special purpose instruments under loads less than 1 kg normally in the range of 15 to 500 g, indenter being the standard Vicker's diamond pyramid or the Knoop indenter. Advantage of this method is that the hardness of individual constituents of a microstructure may be measured.

4.6 Poldi Hardness Tester — A portable hardness tester consisting of a holder, carrying a 10 mm diameter steel ball fitted to alide along a square steel bar of known hardness. The ball is placed on the surface of the component to be tested and the bracket carrying the bar and ball is given a smart hammer blow, which makes a simultaneous indentation of the ball on both the standard bar and the work-piece, by virture of the ball strapped between the two. A comparison of the diameters of the indentations as per the following relationship gives a measure of the hardness, *HB*, of the component:

$$HB\ (\text{ component }) = HB\ (\text{ standard bar }) \times \frac{D - \sqrt{D^2 - d_b^2}}{D - \sqrt{D^2 - d_c^2}}$$

where

D = diameter of ball indenter (usually 10 mm);

d_b = diameter of the impression on standard bar used; and

d_c = diameter of the impression on the component.

4.7 Rockwell Hardness Test — An indentation hardness test using calibrated machines to force a diamond cone indenter or a hard steel ball under specified conditions into the surface of the material under test in two operations (preliminary and total loads) and to measure the difference in depth of the impression under the specified load condition.

4.7.1 *Rockwell Hardness Number* (*HR*) — A number derived from the net increase in the depth of impression as the load on an indenter is increased from fixed preliminary load to total load and then returned to the preliminary load.

Indenters for the Rockwell test include steel balls of several specified diameters and a diamond cone indenter having an included angle of 120° with a spherical tip of a radius of 0·200 mm. Rockwell hardness numbers are always quoted for a scale symbol representing the indenter, the load and the dial used.

4.8 Rockwell Superficial Hardness Test — This test is made on a machine similar to that used for Rockwell hardness tests but differs as to preliminary load and total load. One point of hardness of regular Rockwell corresponds to 2 microns, while in superficial, it corresponds to 1 micron.

4.8.1 *Rockwell Superficial Hardness Number* — A number derived from the net increase in the depth of impression as the load on an indenter is increased from the fixed preliminary load to a total load and then returned to the preliminary load.

Identers of the Rockwell superficial test include steel balls of several specified diameters and the diamond cone indenter of an included angle of 120° with a spherical tip of 0 200 mm radius. Rockwell superficial hardness numbers are always quoted with a scale number representing the indenter, the load and the dial used.

4.9 Scleroscope Test — A hardness test, wherein the loss of kinetic energy of a falling ‘ tup ’, resulting from the indentation caused by the impact of the ‘ tup ’ on the metal sample, is indicated by the height of rebound.

4.10 Vickers Hardness Test — An indentation hardness test using calibrated machines to force a square based diamond pyramid indenter having specified face angles into the surface of the specimen under a predetermined load and to measure the diagonals of the resulting impression after release of the load.

4.10.1 *Vickers Hardness Number* (*HV*) — The Vickers Hardness Number is proportional to the quotient of the load in Newtons applied to a square based diamond pyramid indenter of included face angles of 136°, by the surface area of the impression in square millimetres calculated from the measured diagonals of the impression. Vickers hardness number is calculated from the formula:

$$HV = \frac{0{\cdot}102 \times 2F \sin \frac{136^\circ}{2}}{d^2} \simeq 0{\cdot}1891\, F/d^2$$

where

F = applied load in Newtons, and

d = arithmetic mean of the diagonals of the impression in millimetres.

5. BEND TESTING

5.1 Angle of Bend — The angle through which the specimen is bent.

5.2 Bend Test — A test performed to indicate the ductility and soudness of metallic materials by bending a standard test piece over a specified angle, a round a pin or mandrel of a specified diameter in a testing machine and noting the behaviour of the material during and after bending process.

The ductility is judged by non-cracking (or otherwise) of the material under the conditions of test.

The following four general types of bend tests are the recognized methods used for bending:

a) *Free Bend* — The Bend obtained by applying force at the ends of a specimen without any application of force at the point of maximum bending.

b) *Guided Bend* — The bend obtained by using a plunger to force the specimen into a die in order to produce the desired contour of the outside and inside surfaces of the specimen.

c) *Semi-guided Bend* — The bend obtained by applying a force directly to the specimen in the portion specified. In order to obtain this, the specimen is either held at one end or forced around a pin or around an edge. When the specimen is supported at the ends, it is bent by a force applied in the middle. In certain cases, the bend may be started in this manner and finished in the manner of a free bend.

d) *Wrap-around Bend* — The bend obtained when a specimen is wrapped around a cylindrical mandrel in a closed helix.

5.3 Bending Moment — At any section of a member subjected to bending, is the algebraic sum of couples or moments of all external forces, or both, acting on one side.

5.4 Mandrel or Pin — The plunger or tool used in making guided, semi-guided or wrap-around bend tests by the application of bending force in the inner surface of the bend.

5.5 Radius of Bend — The minimum radius of the inside surface of the bend specimen.

6. CREEP TESTING

6.1 Creep — The time dependent part of strain of a metal or alloy when stressed below its yield point or proportional limit. Its effect is more marked at elevated temperatures, and therefore, is important in the case of metals and alloys for high temperature uses.

6.1.1 *Primary Creep* — The exhaustion stage of creep at a diminishing rate (*see* Fig. 6).

6.1.2 *Secondary Creep* — The stable stage of creep at a constant rate.

6.1.3 *Tertiary Creep* — The final stage of creep at an accelerating rate, preceding fracture (*see* Fig. 6).

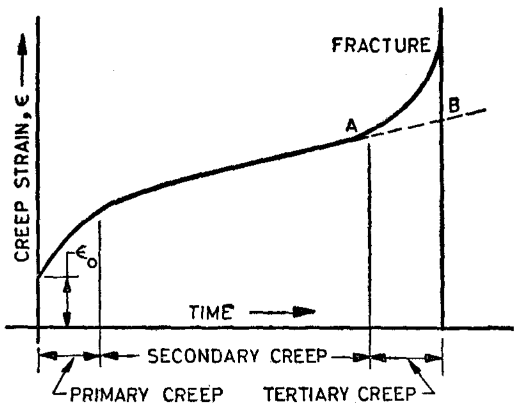


FIG. 6 STAGES OF CREEP

6.2 Creep Ductility — Creep ductility is indicated by the elongation at rupture of a creep specimen.

6.3 Creep Limit — The maximum stress which a metal or an alloy can withstand indefinitely without deforming faster than at a specified strain rate.

6.4 Creep Recovery — The time dependent portion of the decrease in strain following unloading of a creep specimen.

6.5 Creep Rupture or Stress Rupture Strength — The stress that shall cause fracture at a constant temperature in a given time.

6.6 Creep Strength — The constant nominal stress that will bring about a specified quantity of creep in a given time or creep rate at constant temperature.

6.7 Dynamic Creep — Creep that occur under conditions of fluctuating load or fluctuating temperature.

6.8 Initial or Instantaneous Stress — In a relaxation test is the stress enduring at the instant the specimen reaches the desired strain level.

6.9 Instantaneous Recovery — The decrease in strain occurring immediately upon unloading a creep specimen, before any creep recovery takes place.

6.10 Instantaneous Strain — The strain occurring immediately upon loading a creep specimen before the commencement of creep.

6.11 Percentage of Total Plastic Strain — The total plastic extension of the gauge length inclusive of any plastic extension during loading, expressed as a percentage of the original gauge length (*see* Fig. 7).

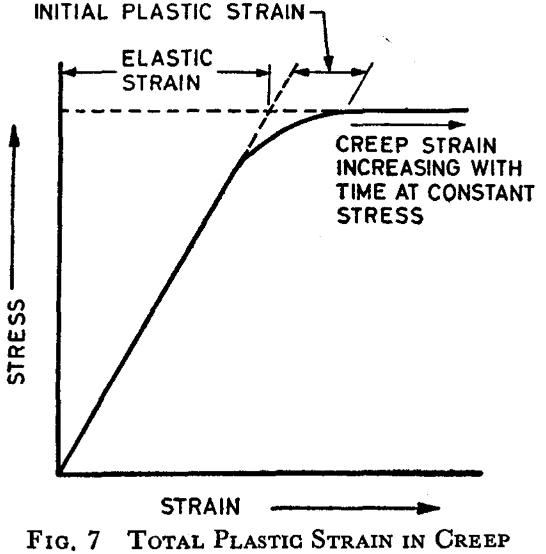


FIG. 7 TOTAL PLASTIC STRAIN IN CREEP

6.12 Rate of Creep — The slope of the creep time curve at a given time.

6.13 Rupture — The complete fracture of the test piece within the parallel length under constant load and constant temperature.

6.14 Stress Relaxation — The time dependent decrease in stress in a member subjected to creep at a constant strain.

6.15 Time to Rupture — The total time elapsed at the test temperature and test load, between the commencement of the test and the rupture of the test piece.

7. FATIGUE TESTING

7.1 Coaxing (or Understressing) — An improvement in the fatigue behaviour of a material as a result of initial cyclic stressing below the normal fatigue limit and then subjected gradually to the desired stress range. Apparently due to strain ageing effects, it may double the number of reversals to failure in the case of steels stressed above their normal fatigue limit.

7.2 Corrosion Fatigue — The fatigue aggravated by corrosion.

7.3 Cumulative Damage Law — In a fatigue test employing various stress ranges and frequencies, sometimes with rest periods between successive application of stress on a single specimen, failure occurs when the sum of damage ratios (cycle ratios) attains unity, that is

$$\sum \frac{n}{N} = 1.$$

where

n = number of cycles at stress S actually performed, and

N = average number of cycles to failure at the stress S.

It is also known as ' linear damage law ' or ' Miner's law '.

7.4 Cycle Ratio — The ratio of the number of cycles (n) of stress applied to a specimen (or structure), to the number of cycles to failure (N) at the same stress, that is, n/N.

7.5 Damage Ratio — An indication of the ' used-up ' life of the material subjected to a number of stress reversals at stress ranges above the fatigue limit. It is, usually, reckoned by the ratio of the difference betweeen the fatigue life (N) of the material at the particular stress stepped-off from the S-N curve and the number of reversals (n) actually endured, to the fatigue life (N), that is, $\frac{N-n}{N}$.

7.6 Damping Capacity — The ability of the material to absorb the energy of vibration or cyclic stressing by internal friction resulting in the conversion of mechanical energy into heat energy.

7.7 Fatigue — A phenomenon leading to fracture under repeated or fluctuating or cyclic stresses below the tensile strength of the material. Fatigue fractures are progressive starting as minute cracks developing under the action of fluctuating stresses.

7.8 Fatigue Life — The number of cycles of stress that can be sustained prior to failure of a specified nature for a stated stress condition.

7.9 Fatigue or Endurance Limit — The maximum stress below which a material can presumably endure an infinite number of stress cycles. If the stress is not completely reversed, the value of the mean stress or the minimum stress, or the stress ratio, should be mentioned (*see* Fig. 8).

7.10 Fatigue or Endurance Ratio — The ratio of the fatigue limit to the tensile strength. For steels, it is of the order of 0·5 (extreme values lying between 0·35 to 0·60 up to 1500 MPa.)

7.11 Fatigue Range or Range of Stress — The algebraic difference between maximum and minimum stress, that is, $S_{max} - S_{min}$

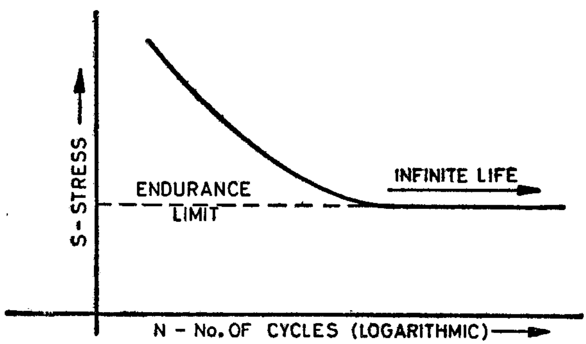


FIG. 8 ENDURANCE LIMIT FROM *S-N* CURVE

7.12 Fatigue Strength — The limiting stress below which a material will withstand a specified number of cycles of stress without fracture.

7.13 Fatigue Testing — The testing of material or component under cyclic stressing (fluctuating or alternating) with its maximum below the ultimate tensile strength of the material.

7.14 Maximum Stress (S_{max}) — The highest algebraic stress value in the stress cycle (tensile stress considered positive and compressive stress negative).

7.15 Mean Stress or Steady Component of Stress (S_m) — The algebraic mean between the maximum and minimum stress in one cycle, that is:

$$S_m = \frac{S_{max} + S_{min}}{2}$$

7.16 Minimum Stress (S_{min}) — The stress having the lowest algebraic value in the cycle (tensile stress considered positive and compressive stress negative).

7.17 Overstressing — The damage to fatigue properties of a material by cycling for a time at a stress above the fatigue limit.

7.18 Scatter of Fatigue Data — The variability of the fatigue life determined at a constant stress amplitude influenced by such causes as surface condition, type of mounting, axiality of stress, the type of testing machine used, the hetrogeneity of the material and the like. It is the general observation that scatter is wider:

a) on smoothly polished specimens rather than on notched specimens:

b) on high-strength materials (such as high tensile steel and age-hardened aluminium alloys and the like) rather than on soft materials (such as mild steel and copper); and

c) at lower stress amplitudes.

7.19 Stress Amplitude (or Variable Component of Stress) (S_a) — One-half of the fatigue range of stress, that is:

$$S_a = \frac{S_{max} - S_{min}}{2}$$

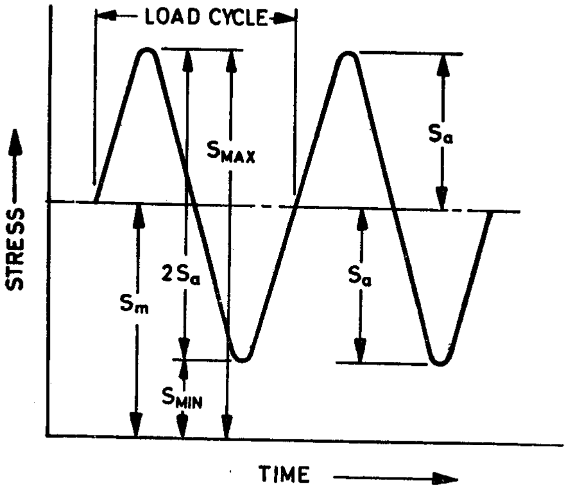
7.20 Stress Cycle — The mode of application of stress (*see* Fig. 9A and 9B) in fatigue testing and may be of:

a) stress alternating between positive and negative limits;

b) stress completely reversed, alternating between equal tension and compression values, with zero as the mean stress; and

c) stress pulsating or fluctuating, that is, regularly varying between zero and a maximum.

7.21 S/N (Wohler) Curve (Stress-Number of Cycles Curve) — The most common, method of representing the fatigue test results by plotting the number of cycles to failure as abscissa and stress amplitude as ordinate, using the logarithmic scale for the number of cycles (*see* Fig. 8).



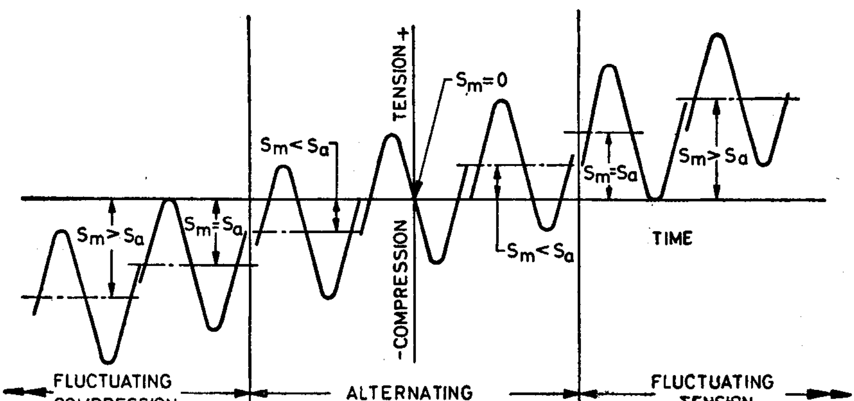
S_m mean stress

S_{Max} maximum stress

S_a stress amplitude

S_{Min} minimum stress

9A Stress-Time Curve to Indicate Various Stresses in Stress Cycles



Alternating stress: Stress varies from positive to negative through zero.

Fluctuating stress: Stress varies from positive to zero or from negative to zero over a range.

9B Types of Cyclic Stresses

FIG. 9 STRESSES

7.22 Stress Ratio — The algebraic ratio of two specified stress values in a stress cycle. The two commonly used ratios are; (a) the ratio of the amplitude of the alternating stress to the mean stress; and (b) the ratio of minimum to maximum stress.

7.23 Thermal Fatigue — The fatigue failure as a result of repeated or fluctuating thermal stresses.

8. IMPACT TESTING

8.1 Brittleness — A tendency to fracture without appreciable deformation. It may be indicated in impact tests by low values or by very low percentage reduction of area in the tensile test.

8.2 Charpy Test — A pendulum type single blow impact test, in which the specimen (usually notched) is supported at both ends, as a simple beam, and broken by a falling pendulum on the face opposite to and immediately behind the notch. The energy absorbed, as determined by the subsequent rise of pendulum, is a measure of impact strength or notch toughness and is expressed in joules.

8.3 Impact Test — The test to determine the behaviour of materials when subjected to high rates of (sudden) loading, usually in bending, tension or torsion. It measures the energy absorbed in breaking the specimen by a single blow or impact.

The results of impact tests have limited application, and only afford an indication of the behaviour of the material with a notch subjected to a sudden blow or impact.

8.4 Impact Strength/Impact Energy — The amount of energy required to fracture a material usually measured by means of an Izod test or Charpy test.

8.5 Izod Impact Test — A pendulum type single blow impact test in which the specimen, usually notched, is fixed at one end and broken by a falling pendulum. The energy absorbed as measured by the subsequent rise of the pendulum in a measure of impact strength or notch toughness. The impact strength is expressed in joules.

8.6 Notch — A slot or groove of specified characteristics intentionally cut in a test piece so as to concentrate the stresses (*see* also **3.14**).

8.7 Notch Brittleness — The susceptibility of a material to a brittle fracture at points of stress concentration. For example, in a notch tensile test if notch strength is less than the tensile strength, it is said to be ' notch brittle ', otherwise ' notch ductile '.

8.8 Notched Bar Test — Bend tests in which a bar, notched on to one side, is bent with the notch in tension. The rate of bending may be slow or rapid (as from a blow) and with many variants. The different tests are Charpy, Izod, Pellini Drop-weight, etc.

8.9 Notch Sensitivity — A notch measure of the reduction in strength of a metal caused by a notch or in effect, stress concentration. Such 'strength' may be in static tensile, bend or (dynamic) fatigue or impact (*see* also **3.19**).

8.10 Notch Toughness — The high resistance of material to fracture under suddenly applied loads at any stress raiser, such as notch.

8.11 Toughness — The ability of a material to absorb energy and deform plastically before fracture. It is usually measured by the energy absorbed in a notched impact test like Izod and Charpy tests. The area under the stress-strain curve in a tensile test is also a measure of the toughness and as such, is proportional to the combined effects of tensile strength and ductility.

8.12 Transition Temperature — Temperature in a range in which the change from ductile to brittle fracture occurs in a notched bar impact test.

9. CUPPING TEST

9.1 Cupping Number — The depth of impression at fracture, in the cupping test, usually expressed in millimetres.

9.2 Cupping Test — A mechanical test used to determine the ductility and drawing properties of sheet metal. It consists in measuring the maximum depth of bulge (or cup) which can be formed before fracture.

9.3 Erichsen Test — A cupping test to measure the suitability of material for deep drawing. A 20-mm diameter ball is forced into a sheet of material through the centre of a pair of 'annuli' used to lightly clamp the sheet. The dome is forced into the sheet. Its height before cracking and the extent of surface roughening as a result of grain coarsening determine the suitability or otherwise of the material for different forming operations.

10. FRACTURE TOUGHNESS TEST

10.1 Crystallographic Cleavage — The separation of a crystal along a plane of fixed orientation, relative to the three dimensional crystal structure, within which separation process causing the newly formed surfaces to move away from one another, in directions containing major components of motion perpendicular to the fixed plane.

10.2 Plane-strain Fracture Toughness (*KIC*) – It is the material toughness property measured in terms of the stress intensity factor and is defined as the resistance to crack propagation in the presence of a notch.

10.3 Stress Intensity Factor (*KI*) — A measure of the stress field intensity near the tip of an ideal crack in a linear elastic medium when deformed so that the crack faces are displaced apart, normal to the crack plane. *KI* is directly proportional to applied load and depends on specimen geometry.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

Quantity	*Unit*	*Symbol*
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

Quantity	*Unit*	*Symbol*
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

Quantity	*Unit*	*Symbol*	*Definition*
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2

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