1

PROPERTIES OF MATERIALS

There are hundreds of engineering materials used in manufacturing processes. The engineering materials are available with a wide range of useful properties and charecteristics. The brief knowledge of properties of commonly used materials is essential to every engineer.

1.1. CLASSIFICATION OF ENGINEERING MATERIALS

The engineering materials are broadly classified as metallic and non-metallic materials:

1.1.1 Metallic Materials

The metallic materials include iron, copper, aluminium, magnesium, nickel, titatnium, lead, tin, and zinc as well as the alloys of these materials, such as steel, brass and bronze etc. These materials possess the properties of luster, high thermal conductivity, and high electrical conductivity. They are relatively ductile and some have good magnetic properties.

The metallic materials are further classified as ferrous and non-ferrous materials.

(*i*) *Ferrous metals* :

These are the metals which have iron as their main constituent, such as cast iron, mild steel, wrought iron, and steels etc.

(*ii*) *Non-ferrous metals*

These metals do not contain iron as their main constituent such as copper, aluminium and their alloys, tin, zinc, etc.

1.1.2. Non-metallic Materials

The non-metals or non-metallic materials do not contain metals in their composition. They are less ductile, weaker, and less dense than metals and have poor thermal and electrical conductivities. Some common non-metals are wood, concrete, asbestos, glass, rubber, plastic etc.

1.2. SELECTION OF MATERIAL FOR ENGINEERING PROCESS

The selection of material for an element depends upon the following factors :

(*i*) Easy availability of material.

(*ii*) Suitability of material for working condition in service.

(*iii*) Cost of material

During selection of a material, its physical, chemical, and mechanical properties are considered.

1.2.1. Physical Properties of Metals

The physical properties of metal include lustre, colour, size and shape, density, electrical and thermal conductivity, melting point, specific heat and coefficient of thermal expansion.

1.2.2. Mechanical Properties of Metals

The mechanical properties of the metal are those, which are associated with the behaviour of material under the action of external forces, called loads. These mechanical properties include strength, stiffness, elasticity, plasticity, ductility, brittleness, malleability, toughness, resistance, creep and hardness. These are discussed in brief below :

1. Strength

It is the ability of material to withstand the external forces without destruction or breaking. A stronger material can withstand greater load. The internal resistance offered by material against an external force is called **stress**. The strength of material varies according to type of loading *i.e.*, tensile strength, compressive strength, shearing or torsional strength.

2. Stiffness

It is the ability of material to resist the deformation under the action of external force. The modulus of elasticly is the measure of stiffness.

3. Elasticity

The elasticity of material is a property by virtue of which deformation caused by applied load is disappeared and material regains its original shape after removal of load. In other words, the elasticity of material is its power to regain its original shape after deformation, when load is removed, just like rubber. The elasticity is a tensile property.

4. Plasticity

The plasticity of material is a property, by virtue of which it retains the deformation permanently even after removal of external force causing the deformation action of external forces. The plastic deformation takes place beyond the elastic range and it is necessary for forging, stamping, and cold working processes.

5. Ductility

The ductility is the property of material, which allows bending, elongation and change of cross-section of metals under the action of external loads. A ductile material must be strong and plastic, thus material can be drawn into the wire. Mild steel, copper, aluminium, nickel, zinc and tin are some ductile materials.

6. Brittleness

It is the property of material, which is completely opposite to ductility. A brittle material cannot undergo elastic or plastic deformation, it breaks or fails under the action of external loads. Glass, cast iron are best examples of brittle material.

7. Malleability

It is special case of ductility which permits the materials to be flatten into the sheets without any crack, under the action of hot or cold working. A malleable material may be plastic but it is not necessary to be ductile. For an example, the lead can easily be rolled and hammered into their sheets, but cannot be drawn into wire, thus lead is malleable not ductile. The some other malleable materials are soft steel, wrought iron, copper and aluminium.

8. Toughness

It is the property of material to resist the fracture due to high impact loads like hammer below. It is measured in terms of amount of energy that a material can absorb before actual fracture takes place. For example, under the impact load the mild steel absorbs much more energy, before undergoing any fracture while a glass piece immediately undegoes the fracture. Thus mild steel is tougher metal.

9. Resilence

It is the property of material to absorb energy elastically and to resist impact loads and shocks. On removal of load, the energy stored is given off exactly as in a spring, when the load is removed.

10. Hardness

It is fundamental property of material and closely related with strength. It is defined as ability of material which resists scratching, cutting, abrasion, penentration, wear, and machining etc. The hardness is also the ability of material to cut another metal.

11. Machinability

The machinability is the property of material by virture of which the material can undergo various machining process. A soft material has good machinability. The copper, aluminium and mild steel have good machinability, while hard materials like white cast iron is very less machinable.

12. Formability

The formability is the property of material by virture of which the material can undergo various plastic deformation processes.

13. Weldability

It is defined as the capacity of metals to be welded into an inseparable joint to form a homogeneous structure after immiscibility of material. Welding procedure changes metallurgical, chemical, physical and thermal properties of parent metals.

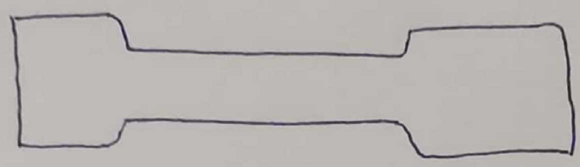
14. Creep

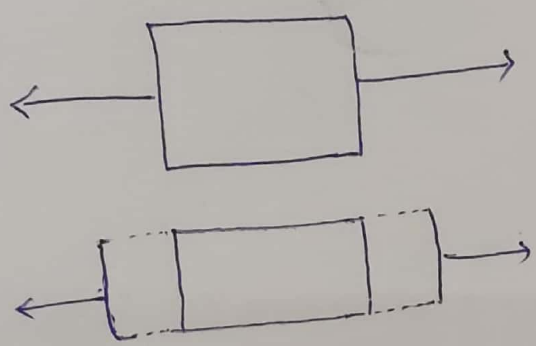
The creep is progressive permanent deformation with time under the action of constant stresses at high temperature. This property is very important for parts used in I.C. engines, turbines and boilers.

15. Fatigue

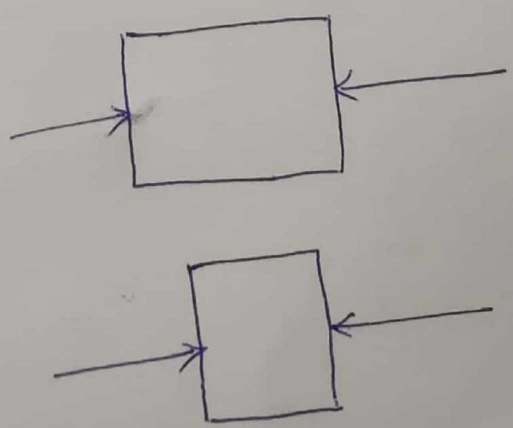
The Fatigue is failure of material, when it is subjected to cyclic loads, in which the maximum stress is developed in each cycle, which is well within elastic limit. This phenomenon of material failure under the cycle loading is known as fatigue. The stress at which the material fails due to fatigue is called as fatigue strength. The fatigue failure always shows a brittle fracture with no appreciable deformation of material in the vicinity of fracture.

For all materials, there is a well-defined value of stress below which material does not fail due to fatigue, even it is under cyclic loading, this value of stress is known as the fatigue limit or endurance limit of the material.



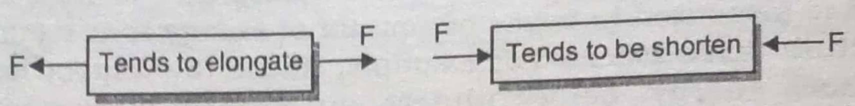


Tensile



Compressive

the load and properties of the material. Fig 1.1 shows the nature of tensile and compressive forces.



(a) Rod under tensile force (b) Rod under compression

Fig. 1.1.

The rod tends to be elongate under the tensile force, thus its cross-sectional area will decrease. While under the action of compressive force, the rod tends to be shorten and its cross-sectional area will be thicken. Whatever the type of loading, it is the natural tendency of material to resist the deformation.

1.3.1 Stress

It is the internal reactive resistance (Opposite force) of material per unit area against the action of the applied force. The internal reactive resistance is equal and opposite to applied force, therefore, in simple words, *the stress can be defined as force per unit area.* It is designated as σ and measured in N/m^2. Thus

$$\sigma = \frac{\text{Load applied}}{\text{Cross-sectional area}} = \frac{F(\text{Newton})}{A(m^2)}\ (N/m^2) \qquad \text{... (1.1)}$$

1.3.2 Strain

Strain is defined as the deformation caused per unit length of the component, i.e., change in length per unit length of component. It is designated as *e* and it is a unitless quantity.

$$e = \frac{\text{Change in length}}{\text{Original length}} = \frac{\Delta L}{L} \qquad \text{... (1.2)}$$

The deformation in the material due to applied force is not necessarily along the length only. It can be in length, volume or both, which ultimately leads to a change in shape of the body. When the deformation along the length, then strain is called longitudinal strain, if in volume, then volumetric strain and when in transverse direction, then shear or transverse strain.

1.3.3 Engineering Stress and Strain

If the stress is calculated on the basis of original cross- sectional area of the specimen, then the stress is called **nominal or engineering stress**. Similarly, if the strain is calculated on the basis of original length of the specimen, then it is called **nominal** or **engineering strain**.

1.3.4 True Stress and Strain

If the specimen is loaded beyond elastic limit, cross-section changes. If the stress and strain are determine on the basis of actual cross-sectional area, and actual length of the specimen, then corresponding stress is called true stress and strain is called true strain.

1.3.5 Hooke's Law

It states that within the elastic limit, the stress is directly proportional to the strain *i.e.*, ratio of stress to strain is constant. This constant is known as *Young's* **modulus of elasticity** and is designated by letter *'E'* Mathematically.

$$E = \frac{\sigma}{e} = \text{Constant} \quad ...(1.3)$$

1.3.6 Modulus of Elasticity

The modulus of elasticity or coefficient of elasticity is an inherent property of materials. It is a measure of material stiffness, an ability of material to resist deflection of stretching under the load.

1.4 STRESS-STRAIN RELATIONSHIP

For the ductile materials such as mild steel, copper, aluminium etc., the relationship between stress and strain can be better understood with the help of stress- strain curve as shown in Fig. 1.2 This curve is drawn by plotting a graph between different values of stresses and corresponding strains obtained during tensile test of material specimen. The stress values are taken along y-axis and corresponding strain values along x-axis.

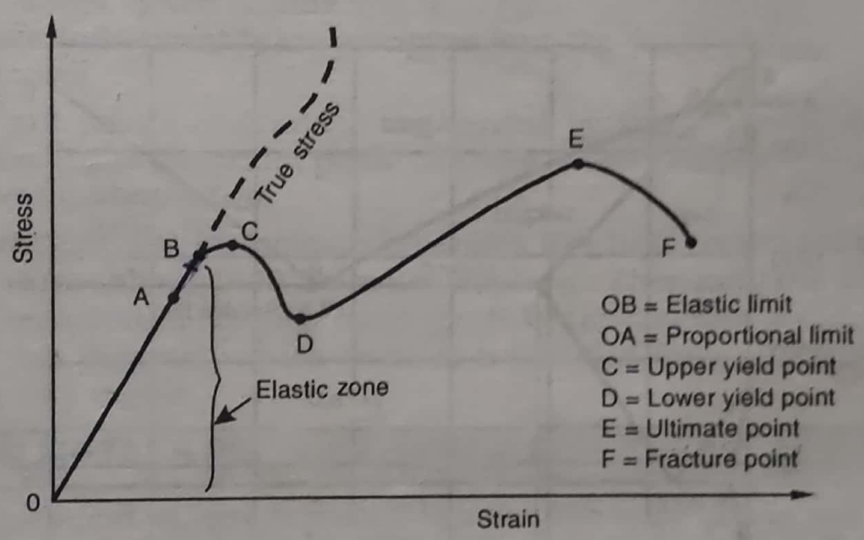


Fig. 1.2. Stress-strain curve for ductile material (such as mild steel).

The careful study of curve reveals that the material elongates elastically in the beginning of test. In portion OA, the strain increases in direct proportion to the applied stress. It means, if load is removed from the material during this portion of curve, the material will automatically return to its original length *i.e.*, Hooke's law is perfectly obeyed. This portion OA of curve is called **proportional limit**.

If the material is loaded beyond this limit, another point B on the curve reaches, it is called **elastic limit** of the material. It is the point corresponding to maximum stress value upto which material will exhibit true elastic behaviour. If the material stress is less than this value, the material will regain its original shape. However, Hooke's law does not obey in the portion AB, even though it is within elastic limit.

If the material is loaded beyond the elastic limit (Point B), the applied stresses cause plastic (Permanent) deformation and material fails to regain its original shape and size even after removal of load. In the plastic range, the strain increases more rapidly than the corresponding stress. This process continues till a point C is reached, where the strain increases even without any further increase in the stress. At point C, the material stretches suddenly. The point C corresponding to maximum stress is called **upper yield point**. The point D reaches due to stretching flow of material without any

1.6. FERROUS METALS

The main constituent of ferrous metals is iron. The pure iron is soft metal and it is called **ferrite**. The pure iron is very less in practical use because it has poor machinability, poor finish and highly ductile. It is also difficult to get the pure iron from iron ore like hemetite, limonite, magnetite etc. The iron obtained from its ore exists in several forms such as pig iron, wrought iron, cast iron, steel etc.

The ferrous materials have been the backbone of civilization and numerous varieties have been developed over the years to meet the specific need of industries.

1.6.1. Pig Iron

The pig iron is the very first product obtained from the process of converting iron ore into useful metal. It consists of 3 to 4% carbon, 1 to 3% silicon, 0.1 to 1% phosphorus and small percentage of manganese, sulphur etc.

The pig iron is used as raw material for other processes to obtain better iron products.

1.6.2. Wrought Iron

It is the purest of all forms of iron. It contains iron upto 99.9% and at least 99.2%. It is obtained by burning away carbon from molten iron and subjecting the product to hammering and rolling. It is malleable, ductile and easily bend without any crack. It can easily be forge-welded. It is used for chains, crane hooks, railway couplings, rivets, steam and water pipes, boiler tubes etc.

Iron and its Alloy

Pure iron is a soft material and its limited use in engineering application. Iron is used to mfg steel. which is basically alloy of iron and carbon. ~~The~~

The Pig iron as tapped from blast furnance is still the crude form of row material and is not suitable for making casting without some degree of refining. The Pig iron is refined in cupola, which is small form of blast furnace.

The refined Pig iron tapped from cupola is called cast Iron.

P.T.O

Cast iron is basically an iron Carbon alloy modified by Presence of Silicon phosphorous, sulphur and maganese in varying amounts. Cast iron Contain high Carbon Content from 2 to 4 % both in the Combined or graphite form. Wraught iron is obtain by removing Carbon from Pig Iron by burning it in molten State followed by hammering & rolling. It is purest form of iron and Contain iron range 99.5 to 99.9 %. Wtraugh iron is malleable and ductile.

1.5 IRON-CARBON EQUILIBRIUM DIAGRAM

The steel is mainly composed of iron and carbon and it is the most important engineering metal. The iron carbon equilibrium diagram shown in Fig. 1.3. is the graphically representation of the effects of temperature and presence of carbon on all phases in steel.

This diagram is constructed by plotting the temperatures along the ordinate and the carbon percentages along the abscissa. Apart from indicating the temperature ranges and percentage carbon in the alloy it also indicates the boundaries at which the phase changes take place. It also helps in understanding the basis and principles of heat treatment.

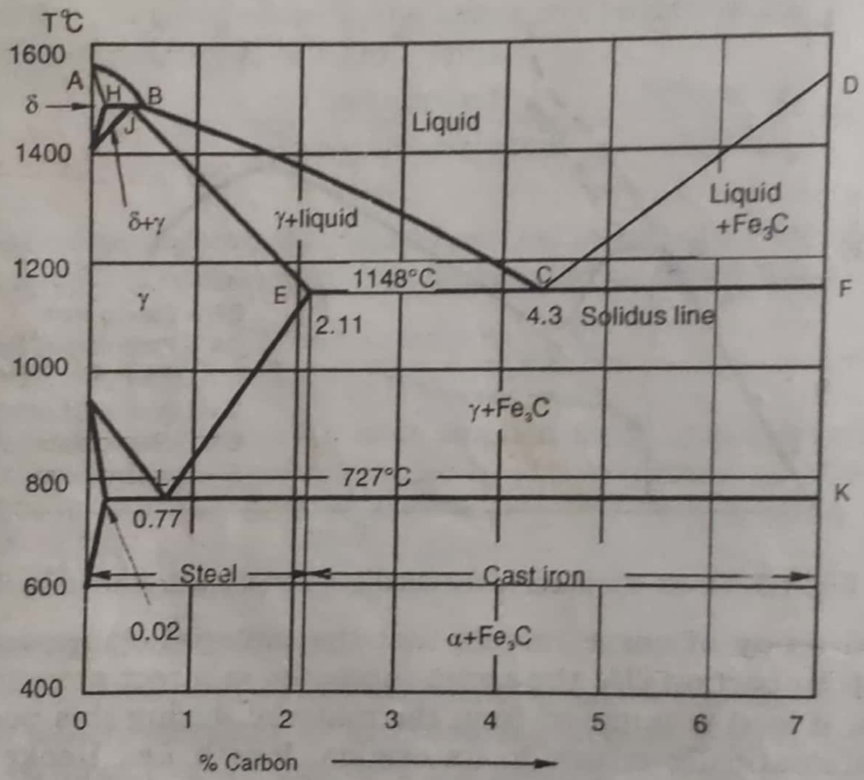


Fig.1.3 Iron- carbon equilibrium diagram

There are four single phases of steel in within the diagram. Three of these, δ - iron, austenite (γ-iron), ferrite (α -iron) occur in pure iron and fourth is the carbide intermetallic compound called **cementite.**

1. The δ-iron is also known as δ-*ferrite* is phase of steel, which presents at extreme high temperature (@ 1400°C) and therefore, it is of little engineering importance.

2. γ-iron or *austenite* is face centered cubic structure phase of iron and it has high solubility of carbon upto 2.11%. It is chemically uniform and highly ductile at elevated temperature. Therefore, most of heat treatment of steel begins with austenite structure.

3. α-iron or *ferrite* is the stable form of iron at temperature below 912°C. It has only 0.02 % carbon in its solid solution. It forces creation of two phase mixture in most steels.

Iron – Carbon diag

ⓐ <u>Eutectoid Reaction</u> :→ Austenite decompose in

Austenite $\xrightarrow[727°C]{0.77\%C}$ Ferrite + Cementite
(γ) (α) (Fe_3C)

Product of eutectid reaction is called Pearlite

ⓑ ~~Eutectoid~~ Reaction :→
Eutectic

Liquid $\xrightarrow[1130°C]{4.3\%C}$ Austenite + Cementite

Liquid alloy transfer into ↗

ⓒ Peritectic Reaction :→

Liquid (0.53% C) + Delta iron ~~Detra~~ (0.09% C) $\xrightarrow{1493°C}$ Austenite (0.17% C)

TYPES OF CAST IRON :-

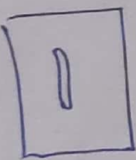
① Grey Cast Iron :-

(i) presence of graphite gives a gray shade to the Surface
(ii) All Carbon in the form of graphite
(iii) Graphite is in the form of flakes.
(iv) Carbon % 2.4 to 3.8%. higher carbon reduce the mechanical property of C.I.
(v) other elements are ~~Stiff~~ silicon, maganese, Sulphur, phophorous.

(vi) Good machinability, weldability Corrosion resistance
(vii) used for Low load application.
(viii) ferrite and pearlite composition. with medium course It has graphite flakes.
(ix) bearing, Guide way, piston ring, Cylinder block, gear, flywheel Compressor pump.

② White Cast Iron:-

(i) presence of cementite gives shiny light Coloured.
(ii) obtain by rapid Cooling of molten alloy.
(iii) Called Chilled C.I.



(iv) hard and brittle 400 to 500 BHN.
(v) Unmachinable m/ching by grinder
(vi) similar elements with grey C.I.
(vii) Abrasive material and good strength. & wear property.
(viii) Railroad wheel, screw, agriculture application.

③ Malleable Cast Iron :-

(i) Not use for making Component Subjected to shock load ~~(ii)~~ for such application malleable cast Iron use.
(ii) obtain by annealing of Casting the white C.I. (prolong heating)
(iii) Long flakes of graphite convert in round nodules.
(iv) high strength and good ductility
(v) Carbon 2.5 to 3% other alloy element similar to Grey C.I.
(vi) Dynamic load, impact load and vibration
(vii) gear box, hooks, coupling, Elongation 2 to 8%. 160-270 BHN
(viii) Tensile strength 350 to 600 N/mm², good machinability

4) Nodular Cast Iron:-

(i) High strength
(ii) obtain by adding small amount of alkali metal to the alloy in liquid state
(iii) Mostly magnesium is used 0.03 to 0.07 %
(iv) maximum Carbon 3.3 %
(v) During solidification process ; magnesium cause the graphite to precipitate in spherical nodular shape
Thus it prevents formation of flakes of graphite
(vi) good machinability, castability, damping property.
(vii) strength is better then Grey C.I.
500-600 N/mm² ← strength
(viii) 10 % elongation.
(ix) crankshaft, cylinder head, pump, valve bodies.
(x) graphite, due to its layered structure, has lubricating effect. Therefore, it reduce friction and gives wear resistance to Cast Iron.

* Cast Iron :- Cast iron has carbon in excess of 2.14%.

Carbon is presence in Cast iron in the form of either Cementite or graphite or both. The classification of Cast iron is based upon the form of graphite and the Condition under which it is formed

Properties => Low tensile high Compressive
good hardness, abrasion resistance
Low ductile & high brittleness
Low melting point, Can casting easily
Can't forged and rolled

*. Effect of Alloying element on Cast Iron:-

4 % ← ① Silicon:- Promotes formation of graphite, Reduction in cooling rate
Magnese :- 1.25 to 1.4 %. for chilled & white cast Iron.
Sulfer :- Increse the size of graphite flakes, Keep limited quantity 0.12 %.
Phosphorous :- Improve fluidity but increase brittleness 0.2 %. only

Stress and Strain :→ When an external load is applied to an object, its molecule generate an internal resistive force, which oppose the externally applied load. This resistive per unit area called stress.

$$\text{Stress} = \frac{\text{force}}{\text{area}} \quad N/m^2$$

The external force also causes the object to deform. The deformation per unit length called strain

$$\text{strain} = \frac{\text{Change in length}}{\text{original length}}$$

Types of ~~toa~~ stress :→ stress can be classify according to the type and nature of external applied force.

① Normal Stress — ⓐ Tensile, ⓑ Compressive

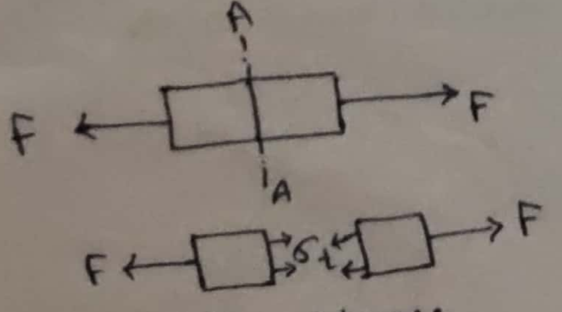
② Tangential stress — Shear stress { Direct Shear, Torsional Shear

Normal Stress :- (Tensile and Compresive)

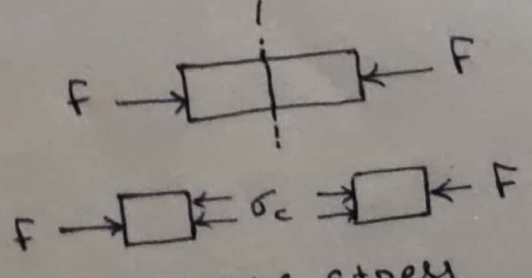
When the external applied load is perpendicular to the area on which stress is consider is called Normal stress.

When the applied load increase the length of object it is tensile stress.

When the applied load decrease the length of body it is called compressive stress.



Tensile Stress

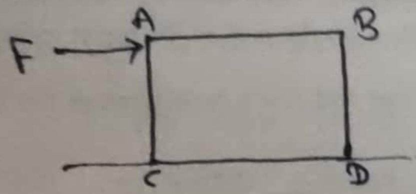


Compressive Stress

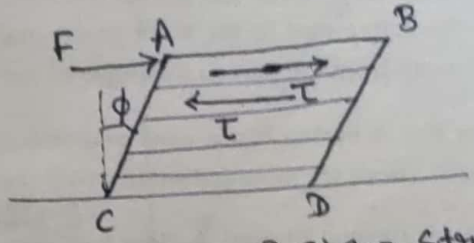
Tangential Stress :→ (Direct and Torsional shear)

Consider a rectangular body ABCD fixed at its lower sufface CD. A Force F act along its top surface AB. Considered the ABCD is manufacture of No. of layers. When the external force F is applied on a body. It causes the different layer to slide relative to each other. Each layer applied equal and opposite force above and below layer. This stress is called shear stress. $\tau = F/a$

where a is the area of the layer in the direction Perpendicular to the Paper



Body with Shear Load



Concept of Shear Stress.

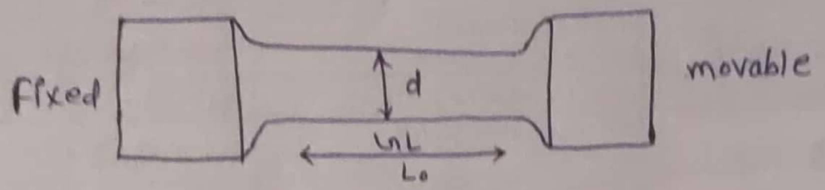
The Shear strain is defined as the angular deformation of the face AC. It is equal to angle ϕ

TESTING OF MATERIAL

The mechanical Properties of Material are determine by Some different test.

① **Tensile Test** :→ The object of tensile test is to ~~calculate~~ obtain the ultimate tensile strength, yield strength, Percentage elongation and percentage reduction in cross sectional area.

Use Speciment with circular cross section area having shape like dumb-bell.



Load is increased gradually. The load measured and displayed continuously on a dial gauge or digital display. The elongation is also measured continuously using extensometer, mechanical arrangement with graph paper. The stress can be determine by using the data

Load at yield Point and area gives yield strength

Load at ultimate point and area gives ultimate strength

* Determination of % elongation :-

After the specimen break, the two piece are put together tightly and elongated gauge length is measured

$$\% \text{ elongation} = \frac{\text{change in length}}{\text{original length}} \times 100$$

L_o = gauge length.

$$= \frac{L - L_o}{L_o} \times 100$$

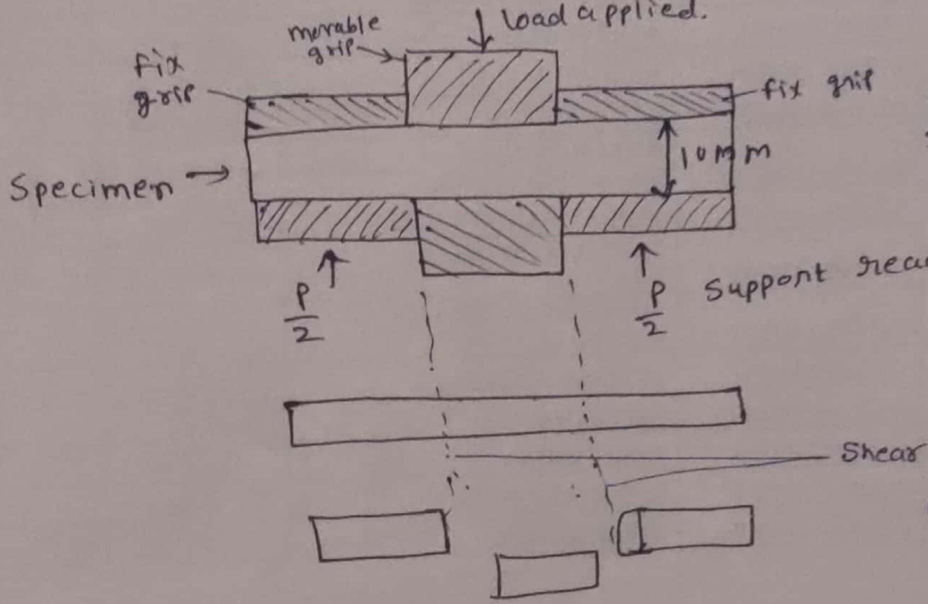
* Ductile material % elongation more then 15%.
* Brittle material show less then 5% elongation.

Scanned by CamScanner

Cross - Shear Test :→

This test is perform to Calculate the shear stress of materia cylindrical bar of 10mm dia is used. The specimen is loaded such that direct shear stress is induced on its cross section. The mode of loading is in double shear. Two cross section are loaded simultaneously by direct shear load. If the load applied is P, the two supporting grips apply reaction load of P/2 each.

$$\text{Average Shear stress } \tau = \frac{\text{Load}}{\text{Area}} = \frac{P}{2A}$$



① Cross shear Test specimen and setup for Holding

② specimen is in double shear

③ specimen failed

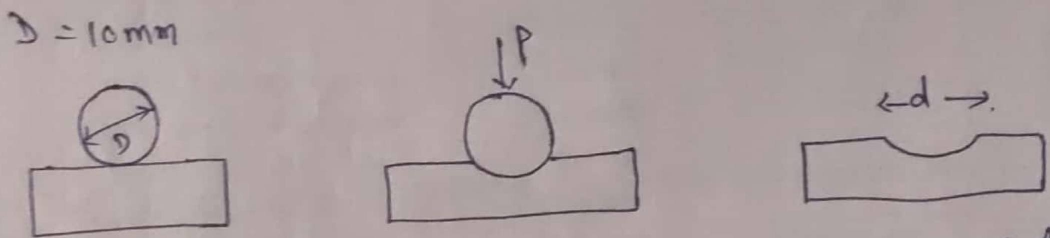
HARDNESS TEST :→

There are no. of method used for determining the hardness of material. The most Common used method is Brinell test, Rockwell test and vickers test. In all of these method, an indenter is pressed against smooth and polished surface of the material. By applying specific load. The indenter penetrates into the surface of the material. The mark produced by such penetration is called indentation. The dimension of the indentation, along with the magnitude of applied load, are used to Calculate the hardness of the material. The value of hardness obtain by these test is denoted by a numbers.

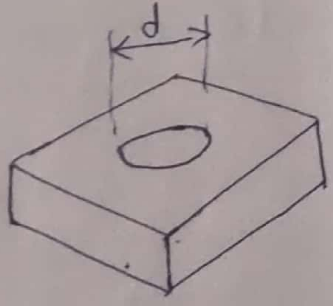
Brinell Hardness Test

- Most fundamental method
- Indenter is a hard spherical ball, made of tungsten carbide
- Dia of ball 10 mm., These ball is pressed on Plane and polished surface of the material
- Magnitude of applied load. 3000 kgf for steel & cast Iron
  1000 kgf for ~~Cast Iron~~ copper & alloy
  250 kgf for soft material (alluminium)
- The dia of the indentation is measured

$$BHN = \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$



Ball indenter   Load application   Indentation



Limitation of Brinell Hardness Test :→

- Not use for the material Having hardness above 450BHN
- Not use for the object having small depth.
- Depth of the object should be more then 10 times of the depth of indentation.
- Due to the indetation on the ~~[illegible]~~ Product, ~~[illegible]~~ So the tested Product may not be further usable.

Rockwell Hardness Test

It is one of the Common test use in industry
For different type of application there are different standard (or Standard) in this test. They are identified as A, B, C and so on. In this test (A and C) the indenter is a diamond cone, known as Brale. The apex angle of the cone is 120°. In Rockwell B test, the indenter is a hardened steel ball having dia of 1.5875 mm.

Rockwell Hardness numbers are denoted by R_A, R_B, R_C.

The load is applied in two step.

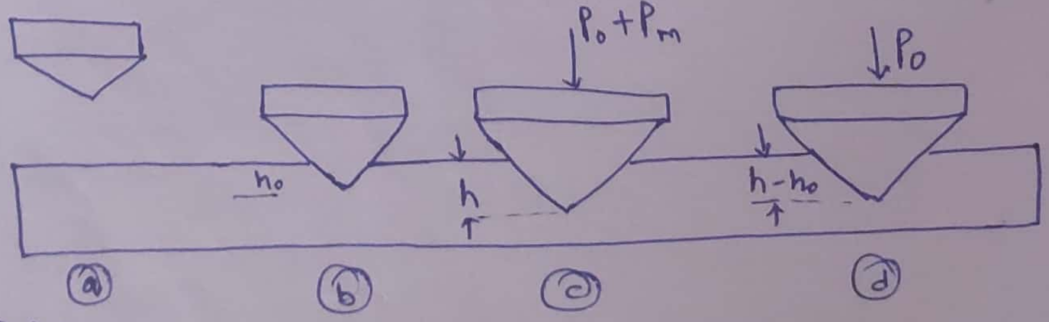
Minor Load $P_0 \rightarrow$ 10 kgf For A, B, C case
Major Load $P_m \rightarrow$ 50 kgf for scale A
90 kgf for scale B
140 kgf for scale C

* The minor load causes a small impression in the specimen which is mostly elastic in nature. The major load enlarges the indentation by plastic deformation.
* The vertical travel of the indenter, after the applicatⁿ of minor load is h_0 and it is h after both the minor and major load have been applied.

The travel of 0.002 mm of brale is considered as one unit.

$$e = \frac{h - h_0}{0.002}$$

$R_A = R_C = 100 - e$
$R_B = 130 - e$



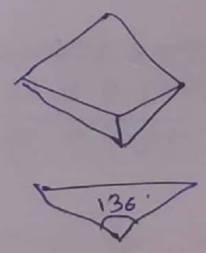
(a) Diamond Cone indenter (b) Indenter position when minor load
(c) With minor and major load (d) Indenter position when the major load is Removed

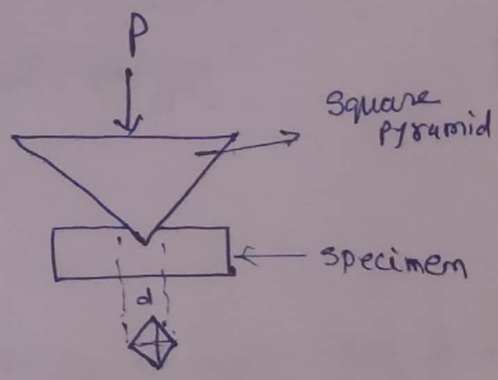
Vickers Hardness Test

- Indenter is a square pyramid
- Diamond Pyramid Hardness or DPH
- The angle b/w the opposite lateral face of Pyramid 136°
- This test is Particularly Suitable for the Component with very small thickness. for small thickness the load applied is also small

5, 10, 20, 30, 100 or 120 kgf

$$DPH = \frac{2P \sin(\alpha/2)}{d^2} = 1.8544 \frac{P}{d^2}$$

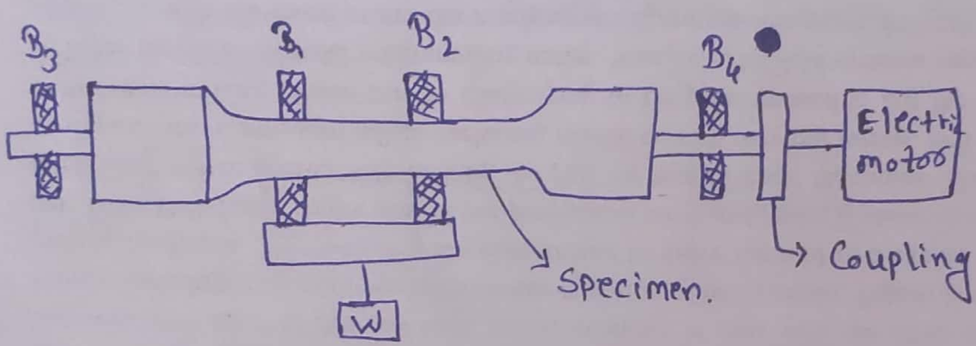




(a) square Pyramid Indenter

Fatigue Test

- In fatigue failure, the life of Component is defined by the no. of cycle it can bear before failur The fatigue life is closely related to the magnitude of load and nature of load.
- For this test a circular cross-section and dumb-bell shape specimen is used.



- The magnitude of stress can be varied by changing the size of the suspended load. The test is carried out for the different values of suspended load. The number of cycle at which the specimen fails, are recorded for the different value of stress. The result is ploted as S-N curve.
- The life of the specimen in term of no. of cycle goes on increasing, as the magnitude of applied stress decreases.
- The S-N curve for ferrous material have a typical Knee shape this indicate that below a certain value of applied stress, the life of the specimen is theoritically infinite. That is, it shall never fail. This limit is called Endurance limit.