http://nptel.ac.in/courses/Webcourse-contents/IIT-ROORKEE/strength%20of%20materials/lects%20&%20picts/image/lect11/lecture11.htm

MECHANICAL PROPERTIES

LECTURE 1

Mechanical Properties:

In the course of operation or use, all the articles and structures are subjected to the action of external forces, which create stresses that inevitably cause deformation. To keep these stresses, and, consequently deformation within permissible limits it is necessary to select suitable materials for the Components of various designs and to apply the most effective heat treatment. i.e. a Comprehensive knowledge of the chief character tics of the semi-finished metal products & finished metal articles (such as strength, ductility, toughness etc) are essential for the purpose.

For this reason the specification of metals, used in the manufacture of various products and structure, are based on the results of mechanical tests or we say that the mechanical tests conducted on the specially prepared specimens (test pieces) of standard form and size on special machines to obtained the strength, ductility and toughness characteristics of the metal.

The conditions under which the mechanical test are conducted are of three types

(1) **Static:** When the load is increased slowly and gradually and the metal is loaded by tension, compression, torsion or bending.

(2) **Dynamic:** when the load increases rapidly as in impact

(3) **Repeated or Fatigue:** (both static and impact type) . i.e. when the load repeatedly varies in the course of test either in value or both in value and direction Now let us consider the uniaxial tension test.

[For application where a force comes on and off the structure a number of times, the material cannot withstand the ultimate stress of a static tool. In such cases the ultimate strength depends on no. of times the force is applied as the material works at a particular stress level. Experiments one conducted to compute the number of cycles requires to break to specimen at a particular stress when fatigue or fluctuating load is acting. Such tests are known as fatigue tests]

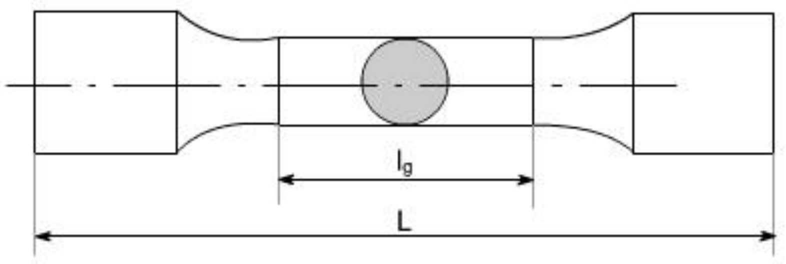
Uniaxial Tension Test: This test is of static type i.e. the load is increased comparatively slowly from zero to a certain value.

Standard specimen's are used for the tension test.

There are two types of standard specimen's which are generally used for this purpose, which have been shown below:

Specimen I:

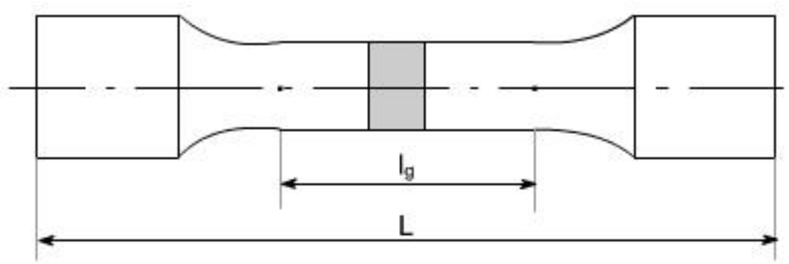
This specimen utilizes a circular X-section.



[specimen with circular X-section]

Specimen II:

This specimen utilizes a rectangular X-section.



[specimen with rectangular X-section]

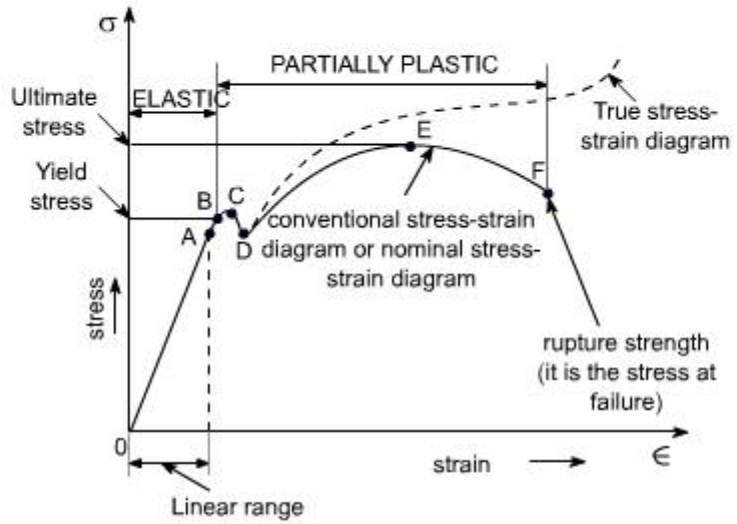
l_g = gauge length i.e. length of the specimen on which we want to determine the mechanical properties.The uniaxial tension test is carried out on tensile testing machine and the following steps are performed to conduct this test.

(i) The ends of the specimen's are secured in the grips of the testing machine.

(ii) There is a unit for applying a load to the specimen with a hydraulic or mechanical drive.

(iii) There must be a some recording device by which you should be able to measure the final output in the form of Load or stress. So the testing machines are often equipped with the pendulum type lever, pressure gauge and hydraulic capsule and the stress Vs strain diagram is plotted which has the following shape.

A typical tensile test curve for the mild steel has been shown below



Nominal stress – Strain OR Conventional Stress – Strain diagrams:

Stresses are usually computed on the basis of the original area of the specimen; such stresses are often referred to as conventional or nominal stresses.

True stress – Strain Diagram:

Since when a material is subjected to a uniaxial load, some contraction or expansion always takes place. Thus, dividing the applied force by the corresponding actual area of the specimen at the same instant gives the so called true stress.

SALIENT POINTS OF THE GRAPH:

(A) So it is evident form the graph that the strain is proportional to strain or elongation is proportional to the load giving a st.line relationship. This law of proportionality is valid upto a point A.

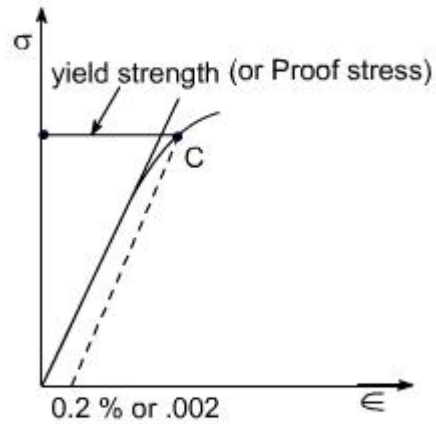
or we can say that point A is some ultimate point when the linear nature of the graph ceases or there is a deviation from the linear nature. This point is known as **the limit of proportionality or the proportionality limit**.

(B) For a short period beyond the point A, the material may still be elastic in the sense that the deformations are completely recovered when the load is removed. The limiting point B is termed as **Elastic Limit** .

(C) and (D) - Beyond the elastic limit plastic deformation occurs and strains are not totally recoverable. There will be thus permanent deformation or permanent set when load is removed. These two points are termed as upper and lower yield points respectively. The stress at the yield point is called the yield strength.

A study a stress – strain diagrams shows that the yield point is so near the proportional limit that for most purpose the two may be taken as one. However, it is much easier to locate the former. For material which do not posses a well define yield points, In order to find the yield point or yield strength, an offset method is applied.

In this method a line is drawn parallel to the straight line portion of initial stress diagram by off setting this by an amount equal to 0.2% of the strain as shown as below and this happens especially for the low carbon steel.



(E) A further increase in the load will cause marked deformation in the whole volume of the metal. The maximum load which the specimen can with stand without failure is called the load at the ultimate strength.

The highest point 'E' of the diagram corresponds to the ultimate strength of a material.

σ_u = Stress which the specimen can with stand without failure & is known as Ultimate Strength or Tensile Strength.

σ_u is equal to load at E divided by the original cross-sectional area of the bar.

(F) Beyond point E, the bar begins to forms neck. The load falling from the maximum until fracture occurs at F.

[Beyond point E, the cross-sectional area of the specimen begins to reduce rapidly over a relatively small length of bar and the bar is said to form a neck. This necking takes place whilst the load reduces, and fracture of the bar finally occurs at point F]

Note: Owing to large reduction in area produced by the necking process the actual stress at fracture is often greater than the above value. Since the designers are interested in maximum loads which can be carried by the complete cross section, hence the stress at fracture is seldom of any practical value.

Percentage Elongation: 'δ ':

The ductility of a material in tension can be characterized by its elongation and by the reduction in area at the cross section where fracture occurs.

It is the ratio of the extension in length of the specimen after fracture to its initial gauge length, expressed in percent.

$$\delta = \frac{(l_1 - l_g)}{l_1} \times 100$$

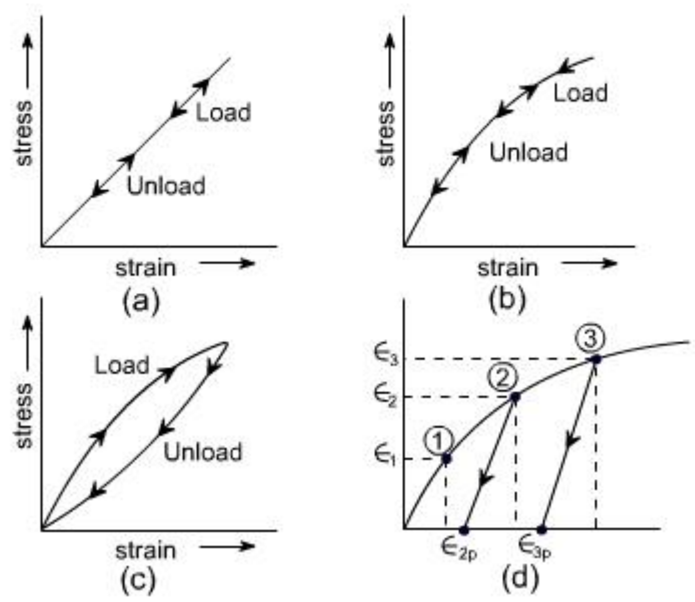
l_l = gauge length of specimen after fracture(or the distance between the gage marks at fracture)

l_g= gauge length before fracture(i.e. initial gauge length)

For 50 mm gage length, steel may here a % elongation δ of the order of 10% to 40%.

Elastic Action:

The elastic is an adjective meaning capable of recovering size and shape after deformation. Elastic range is the range of stress below the elastic limit.



Many engineering materials behave as indicated in Fig(a) however, some behaves as shown in figures in (b) and (c) while in elastic range. When a material behaves as in (c), the σ vs ∈ is not single valued since the strain corresponding to any particular ' σ ' will depend upon loading history.

Fig (d): It illustrates the idea of elastic and plastic strain. If a material is stressed to level (1) and then relased the strain will return to zero beyond this plastic deformation remains.

If a material is stressed to level (2) and then released, the material will recover the amount ($\in_2 - \in_{2p}$), where $\in_{2p}$ is the plastic strain remaining after the load is removed. Similarly for level (3) the plastic strain will be $\in_{3p}$.

Ductile and Brittle Materials:

Based on this behaviour, the materials may be classified as ductile or brittle materials

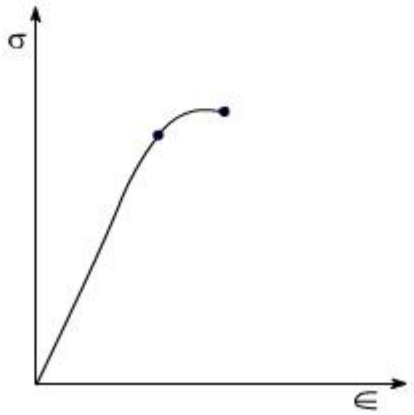
Ductile Materials:

It we just examine the earlier tension curve one can notice that the extension of the materials over the plastic range is considerably in excess of that associated with elastic loading. The Capacity of materials to allow these large deformations or large extensions without failure is termed as ductility. The materials with high ductility are termed as ductile materials.

Brittle Materials:

A brittle material is one which exhibits a relatively small extensions or deformations to fracture, so that the partially plastic region of the tensile test graph is much reduced.

This type of graph is shown by the cast iron or steels with high carbon contents or concrete.



Conditions Affecting Mechanical Properties:

The Mechanical properties depend on the test conditions

(1) It has been established that lowering the temperature or increasing the rate of deformation considerably increases the resistance to plastic deformation. Thus, at low temperature (or higher rates of deformation), metals and alloys, which are ductile at normal room temperature may fail with brittle fracture.

(2) Notches i.e. sharp charges in cross sections have a great effect on the mechanical properties of the metals. A Notch will cause a non – uniform distribution of stresses. They will always contribute lowering the ductility of the materials. A notch reduces the ultimate strength of the high strength materials. Because of the non – uniform distribution of the stress or due to stress concentration.

(3) Grain Size: The grain size also affects the mechanical properties.

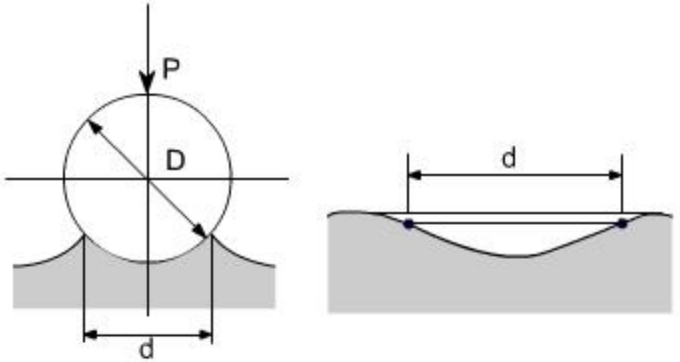
Hardness:

Hardness is the resistance of a metal to the penetration of another harder body which does not receive a permanent set.

Hardness Tests consists in measuring the resistance to plastic deformation of layers of metals near the surface of the specimen i.e. there are Ball indentation Tests.

Ball indentation Tests:

iThis method consists in pressing a hardened steel ball under a constant load P into a specially prepared flat surface on the test specimen as indicated in the figures below :



After removing the load an indentation remains on the surface of the test specimen. If area of the spherical surface in the indentation is denoted as F sq. mm. Brinell Hardness number is defined as :

Bhn = P / F

F is expressed in terms of D and d

D = ball diameter

d = diametric of indentation and Brinell Hardness number is given by

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

Then is there is also **Vicker's Hardness Number** in which the ball is of conical shape.

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LECTURE 2

Compression Test: Machines used for compression testing are basically similar to those used for tensile testing often the same machine can be used to perform both tests.

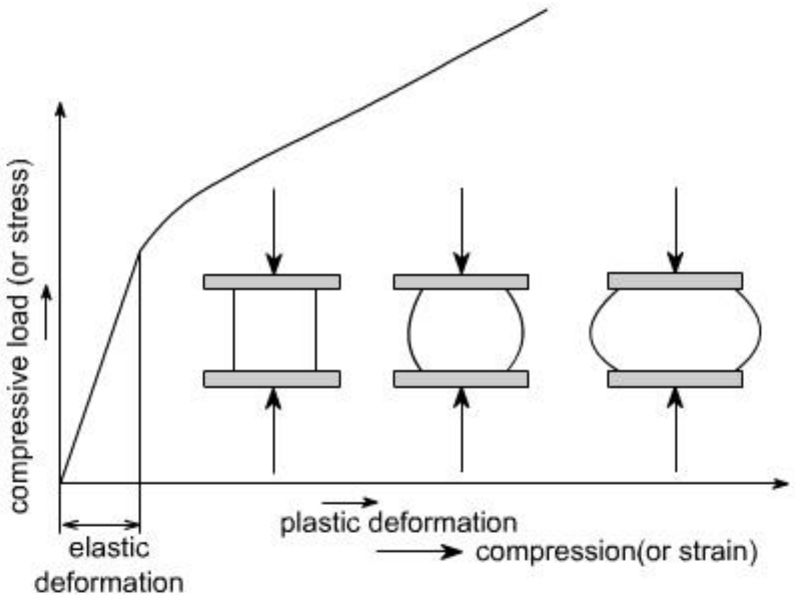
Shape of the specimen: The shapes of the specimen to be used for the different materials are as follows:

(i) For metals and certain plastics: The specimen may be in the form of a cylinder

(ii) For building materials: Such as concrete or stone the shape of the specimen may be in the form of a cube.

Shape of stress stain diagram

(a) Ductile materials: For ductile material such as mild steel, the load Vs compression diagram would be as follows



(1) The ductile materials such as steel, Aluminum, and copper have stress – strain diagrams similar to ones which we have for tensile test, there would be an elastic range which is then followed by a plastic region.

(2) The ductile materials (steel, Aluminum, copper) proportional limits in compression test are very much close to those in tension.

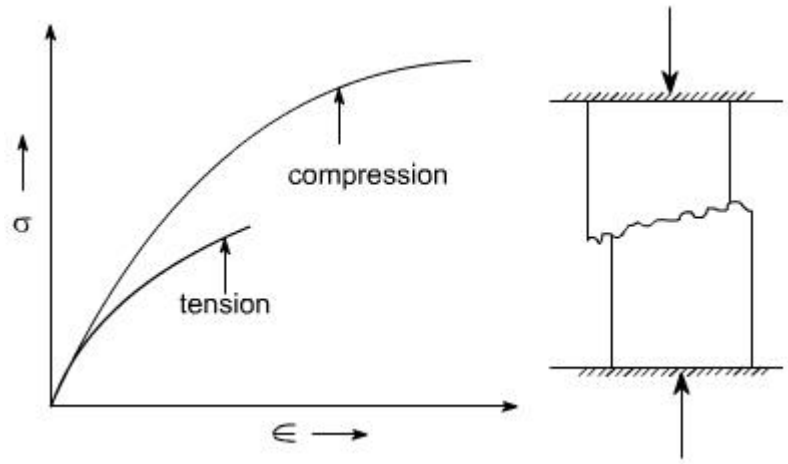
(3) In tension test, a specimen is being stretched, necking may occur, and ultimately fracture fakes place. On the other hand when a small specimen of the ductile material is compressed, it begins to bulge on sides and becomes barrel shaped as shown in the figure above. With increasing load, the specimen is flattened out, thus offering increased resistance to further shortening (which means that the stress – strains curve goes upward) this effect is indicated in the diagram.

Brittle materials (in compression test)

Brittle materials in compression typically have an initial linear region followed by a region in which the shortening increases at a higher rate than does the load. Thus, the compression stress – strain diagram has a shape that is similar to the shape of the tensile diagram.

However, brittle materials usually reach much higher ultimate stresses in compression than in tension.

For cast iron, the shape may be like this



Brittle materials in compression behave elastically up to certain load, and then fail suddenly by splitting or by craking in the way as shown in figure. The brittle fracture is performed by separation and is not accompanied by noticeable plastic deformation.

Hardness Testing:

The term 'hardness' is one having a variety of meanings; a hard material is thought of as one whose surface resists indentation or scratching, and which has the ability to indent or cut other materials.

Hardness test: The hardness test is a comparative test and has been evolved mainly from the need to have some convenient method of measuring the resistance of materials to scratching, wear or in dentation this is also used to give a guide to overall strength of a materials, after as an inspection procedure, and has the advantage of being a non – destructive test, in that only small indentations are lift permanently on the surface of the specimen.

Four hardness tests are customarily used in industry namely

(i) Brinell

(ii) Vickers

(iii) Rockwell

(vi) Shore Scleroscopy

The most widely used are the first two.

In the Brinell test the indenter is a hardened steel ball which is pressed into the surface using a known standard load. The diameter of resulting indentation is than measured using a microscope & scale.

Units:

The units of Brinell Hardness number in S.I Unit would have been N/mm^2 or Mpa

To avoid the confusion which would have been caused of her wise Hardness numbers are quotes as kgf / mm^2

Brinell Hardness test:

In the Brinell hardness test, a hardened steel ball is pressed into the flat surface of a test piece using a specified force. The ball is then removed and the diameter of the resulting indentation is measured using a microscope.

The Brinell Hardness no. (BHN) is defined as

BHN = P / A

Where P = Force applied to the ball.

A = curved area of the indentation

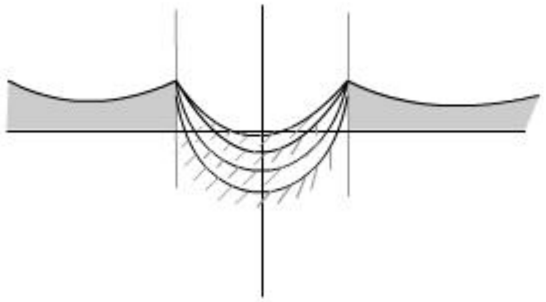
It may be shown that $A = \frac{1}{2}\pi D\left[D - \sqrt{D^2 - d^2}\right]$

D = diameter of the ball,

d = the diameter of the indentation.

In the Brinell Test, the ball diameter and applied load are constant and are selected to suit the composition of the metal, its hardness, and selected to suit the composition of the metal, its hardness, the thickness etc. Further, the hardness of the ball should be at least 1.7 times than the test specimen to prevent permanent set in the ball.

Disadvantage of Brinell Hardness Test: The main disadvantage of the Brinell Hardness test is that the Brinell hardness number is not independent of the applied load. This can be realized from. Considering the geometry of indentations for increasing loads. As the ball is pressed into the surface under increasing load the geometry of the indentation charges.



Here what we mean is that the geometry of the impression should not change w.r.t. load, however the size it impression may change.

Vickers Hardness test:

The Vicker's Hardness test follows a procedure exactly a identical with that of Brinell test, but uses a different indenter. The steel ball is replaced by a diamond, having the from of a square – based pyramid with an angle of 136^0 between opposite faces. This is pressed into the flat surface of the test piece using a specified force, and the diagonals of the resulting indentation measured is using a microscope. The Hardness, expressed as a Vicker's pyramid number is defined as the ratio F/A, where F is the force applied to the diamond and A is the surface area of the indentation.

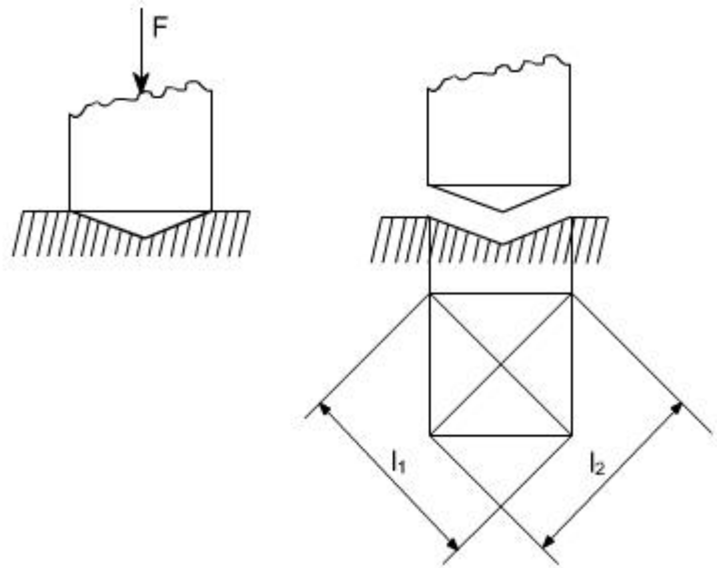
$$A = \frac{\frac{1}{2} l^2}{\sin \frac{1}{2}(136^0)}$$

$$= \frac{l^2}{.854 v_x} \Rightarrow H_V = \frac{F}{\frac{l^2}{.854}}$$

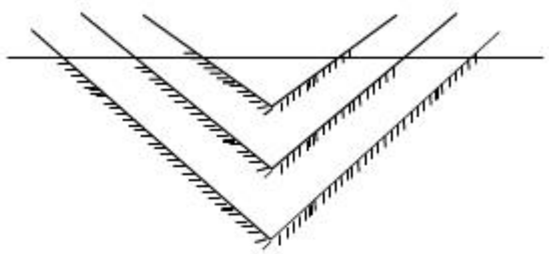
$$H_V = \frac{.854F}{l^2}$$

where l is the average lengthof the diagonal is $l = \frac{1}{2}(l_1 + l_2)$

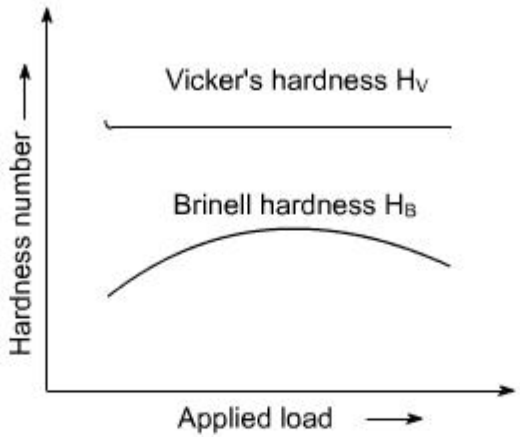
It may be shown that



In the Vicker Test the indenters of pyramidal or conical shape are used & this overcomes the disadvantage which is faced in Brinell test i.e. as the load increases, the geometry of the indentation's does not change



The Variation of Hardness number with load is given below.



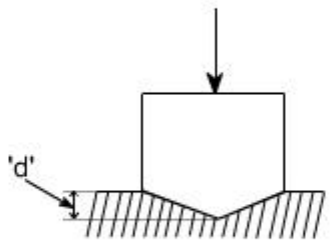
Advantage: Apart from the convenience the vicker's test has certain advantages over the Brinell test.

(i) Harder material can be tested and indentation can be smaller & therefore less obtrusive or damaging.

Upto a 300 kgf /mm^2 both tests give the same hardness number but above too the Brinell test is unreliable.

Rockwell Hardness Test :

The Rockwell Hardness test also uses an indenter when is pressed into the flat surface of the test piece, but differs from the Brinell and Vicker's test in that the measurement of hardness is based on the depth of penetration, not on the surface area of indentation. The indenter may be a conical diamond of 120^0 included angle, with a rounded apex. It is brought into contact with the test piece, and a force F is applied.

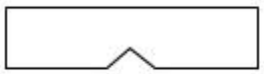


Advantages :

Rockwell tests are widely applied in industry due to rapidity and simplicity with which they may be performed, high accuracy, and due to the small size of the impressions produced on the surface.

IMPACT STRENGTH

Static tension tests of the un-notched specimen's do not always reveal the susceptibility of metal to brittle fracture. This important factor is determined in impact tests. In impact tests we use the notched specimen's.



This specimen is placed on its supports on anvil so that blow of the striker is opposite to the notch the impact strength is defined as the energy A, required to rupture the specimen,

Impact Strength = A / f

Where f = the cross – section area of the specimen in cm^2 at fracture & obviously at notch.

The impact strength is a complex characteristic which takes into account both toughness and strength of a material. The main purpose of notched – bar tests is to study the simultaneous effect of stress concentration and high velocity load application

Impact test are of the severest type and facilitate brittle friction. Impact strength values cannot be as yet is used for design calculations but these tests as rule provided for in specifications for carbon & alloy steels. Further, it may be noted that in impact tests fracture may be either brittle or ductile. In the case of brittle fracture, fracture occurs by separation and is not accompanied by noticeable plastic deformation as occurs in the case of ductile fracture.

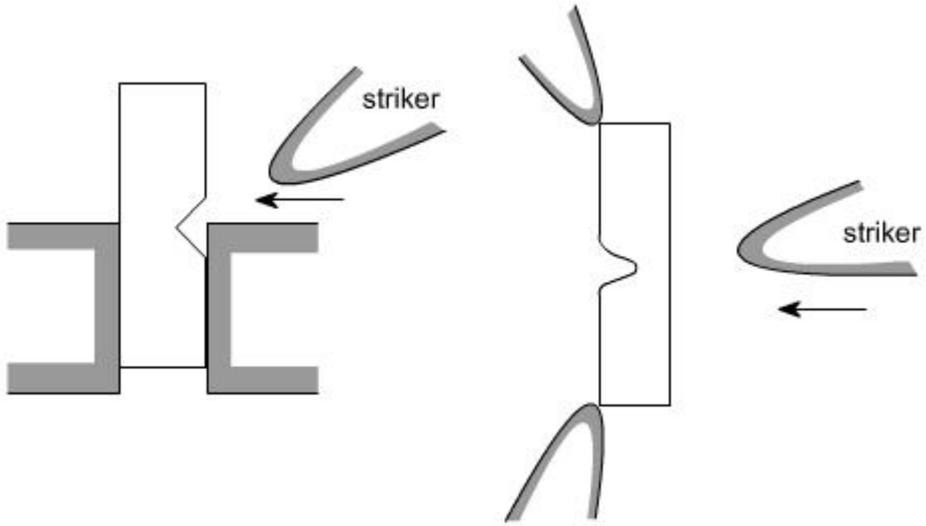
Impact testing:

In an ‘impact test' a notched bar of material, arranged either as a cantilever or as a simply supported beam, is broken by a single blow in such a way that the total energy required to fracture it may be determined.

The energy required to fracture a material is of importance in cases of “shock loading' when a component or structure may be required to absorb the K.E of a moving object.

Often a structure must be capable of receiving an accidental ‘shock load' without failing completely, and whether it can do this will be determined not by its strength but by its ability to absorb energy. A combination of strength and ductility will be required, since large amounts of energy can only be absorbed by large amounts of plastic deformation. The ability of a material to absorb a large amount of energy before breaking is often referred as toughness, and the energy absorbed in an impact test is an obvious indication of this property.

Impact tests are carried out on notched specimens, and the notches must not be regarded simply as a local reduction in the cross – sectional area of the specimen, Notches – and , in fact, surface irregularities of many kind – give rise to high local stresses, and are in practice, a potential source of cracks.



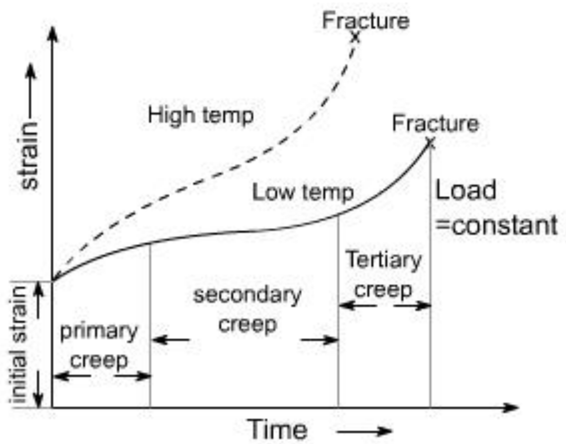
[cantilever type specimen] [simply supporter specimen]

The specimen may be of circular or square cross – section arranged either as a cantilever or a simply supported beam.

Toughness: It is defined as the ability of the material to withstand crack i.e to prevent the transfer or propagation of cracks across its section hence causing failures. Cracks are propagated due to stress concentraction.

Creep: Creep is the gradual increase of plastic strain in a material with time at constant load. Particularly at elevated temperatures some materials are susceptible to this phenomena and even under the constant load, mentioned strains can increase continually until fractures. This form of facture is particularly relevant to the turbines blades, nuclear rectors, furnaces rocket motors etc.

The general from of strain versus time graph or creep curve is shown below.



[Typical creep curve]

The general form of $\in$ Vs t graph or creep curve is shown below for two typical operation conditions, In each case the curve can be considered to exhibit four principal features

(a) An initial strain, due to the initial application of load. In most cases this would be an elastic strain.
(b) A primary creep region, during which he creep rate (slope of the graph) dimensions.
(c) A secondary creep region, when the creep rate is sensibly constant.
(d) A tertiary creep region, during which the creep rate accelerate to final fracture.
It is obvious that a material which is susceptible to creep effects should only be subjected to stresses which keep it in secondary (st.line) region throughout its service life. This enables the amount of creep extension to be estimated and allowed for in design.

Practice Problems:

PROB 1: A standard mild steel tensile test specimen has a diameter of 16 mm and a gauge length of 80 mm such a specimen was tested to destruction, and the following results obtained.
Load at yield point = 87 kN
Extension at yield point = 173 x 16^{-6} m
Ultimate load = 124 kN
Total extension at fracture = 24 mm
Diameter of specimen at fracture = 9.8 mm
Cross - sectional area at fracture = 75.4 mm^2
Cross - sectional Area 'A' = 200 mm^2

Compute the followings:

(i) Modulus of elasticity of steel
(ii) The ultimate tensile stream
(iii) The yield stress
(iv) The percentage elongation
(v) The Percentage reduction in Area.

PROB 2:
A light alloy specimen has a diameter of 16mm and a gauge Length of 80 mm. When tested in tension, the load extension graph proved linear up to a load of 6kN, at which point the extension was 0.034 mm. Determine the limits of proportionality stress and the modulus of elasticity of material.
Note: For a 16mm diameter specimen, the Cross – sectional area A = 200 mm^2
This is according to tables Determine the limit of proportion try stream & the modulus of elasticity for the material.

Ans: 30 MN /m^2 , 70.5 GN /m^2

solution:

$$\text{Limit of proportionaly stress} = \frac{6\ \text{kN}}{200\times10^{-6}}$$

$$= 30\ \text{MN/m}^2$$

$$\text{Young Modulus} \qquad E = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{strain} = \frac{.034}{80}$$

$$E = 30\times10^{6} \Big/ \frac{.034}{80}$$

$$= 70.5\ \text{GN/m}^2$$