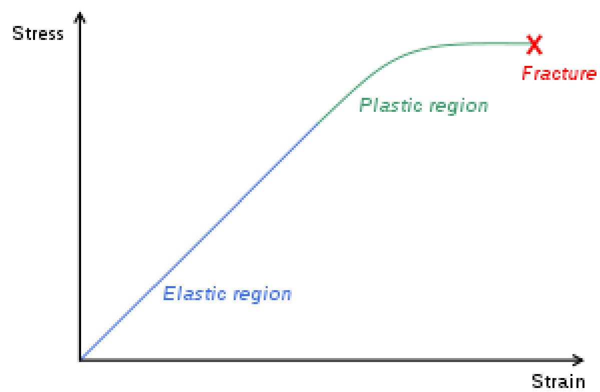
MATERIAL TECHNOLOGY (SPR1201)

UNIT – V (Mechanical Properties and Testing)

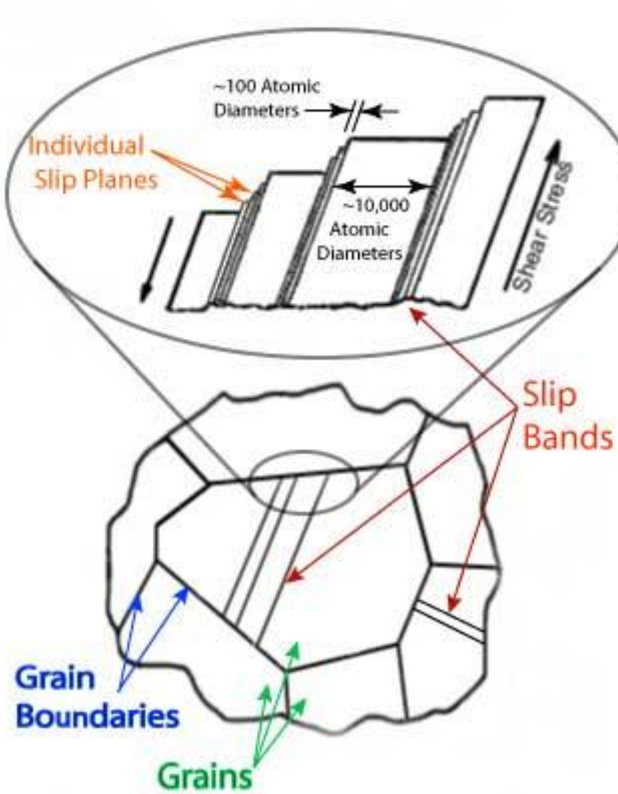
Elastic/Plastic Deformation: When a sufficient load is applied to a metal or other structural material, it will cause the material to change shape. This change in shape is called deformation. A temporary shape change that is self-reversing after the force is removed, so that the object returns to its original shape, is called elastic deformation. In other words, elastic deformation is a change in shape of a material at low stress that is recoverable after the stress is removed. This type of deformation involves stretching of the bonds, but the atoms do not slip past each other. When the stress is sufficient to permanently deform the metal, it is called plastic deformation.



However, an object in the plastic deformation range will first have undergone elastic deformation, which is reversible, so the object will return part way to its original shape.

Fracture: This type of deformation is also irreversible. A break occurs after the material has reached the end of the elastic, and then plastic, deformation ranges. At this point forces accumulate until they are sufficient to cause a fracture. All materials will eventually fracture, if sufficient forces are applied.

Deformation by slip: When the stress is sufficient to permanently deform the metal, it is called plastic deformation. The plastic deformation involves the breaking of a limited number of atomic bonds by the movement of dislocations. The force needed to break the bonds of all the atoms in a crystal plane all at once is very great. However, the movement of dislocations allows atoms in crystal planes to slip past one another at a much lower stress levels. Since the energy required to move is lowest along the densest planes of atoms, dislocations have a preferred direction of travel within a grain of the material. This results in slip that occurs along parallel planes within the grain. These parallel slip planes group together to form slip bands, which can be seen with an optical microscope. A slip band appears as a single line under the microscope, but it is in fact made up of closely spaced parallel slip planes as shown in the image.



Fatigue: Another deformation mechanism is fatigue, which occurs primarily in ductile metals. It was originally thought that a material deformed only within the elastic range returned completely to its original state once the forces were removed. However, faults are introduced at the molecular level with each deformation. After many deformations, cracks will begin to appear, followed soon after by a fracture, with no apparent plastic deformation in between. Fatigue has been a major cause of aircraft failure, especially before the process was well understood . There are two ways to determine when a part is in danger of metal fatigue; either predict when failure will occur due to the material/force/shape/iteration combination, and replace the vulnerable materials before this occurs, or perform inspections to detect the microscopic cracks and perform replacement once they occur. Selection of materials not likely to suffer from metal fatigue during the life of the product is the best solution, but not always possible. Avoiding shapes with sharp corners limits metal fatigue by reducing stress concentrations, but does not eliminate it.

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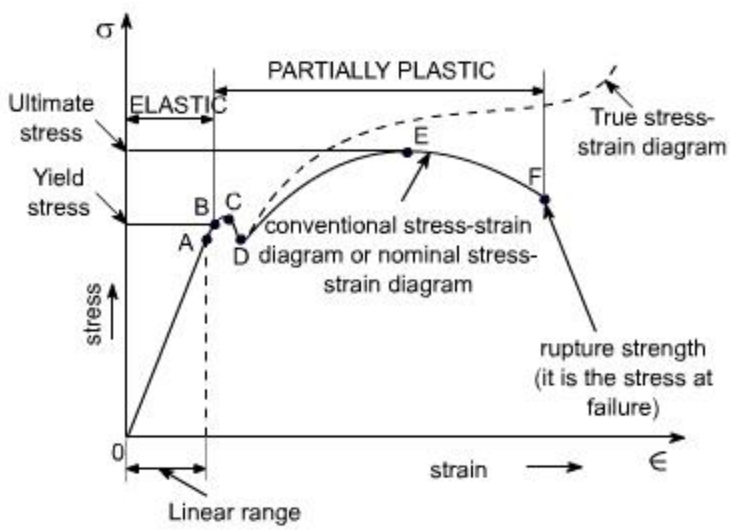
[For application where a force comes on and off the structure a number of times, the material cannot withstand the ultimate stress of a static tool. In such cases the ultimate strength depends on no. of times the force is applied as the material works at a particular stress level. Experiments one conducted 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 fatque tests]

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

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.

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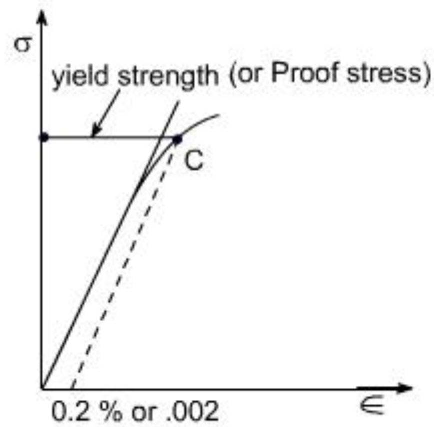


(E) A further increase in the load will cause marked deformation in the whole volume of the metal. The maximum load which the specimen can with stand without failure is called the load at the ultimate strength.

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

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

s_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]

Percentage Elongation: ' d ':

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.

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

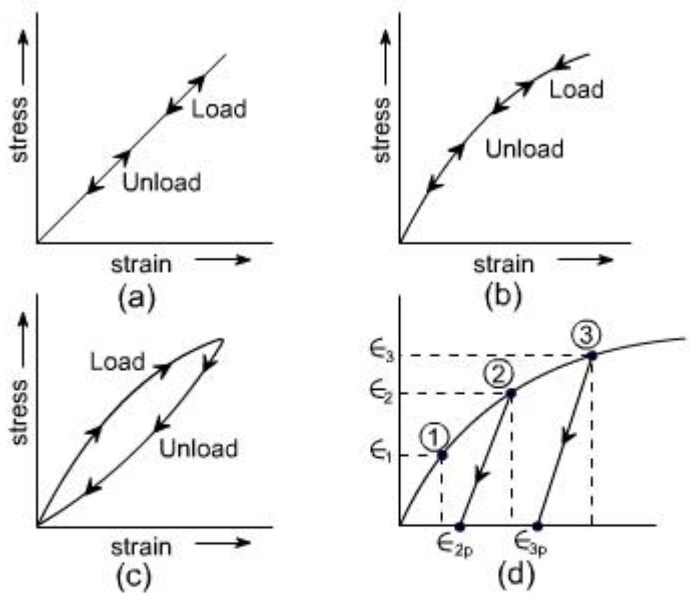
l_I = gauge length of specimen after fracture(or the distance between the gage marks at fracture)

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

For 50 mm gage length, steel may here a % elongation d 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 s vs Î is not single valued since the strain corresponding to any particular ‘ s ' 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 (Î$_2$ - Î$_{2p}$), where Î$_{2p}$ is the plastic strain remaining after the load is removed. Similarly for level (3) the plastic strain will be Î$_{3p}$.

Ductile and Brittle Materials:

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

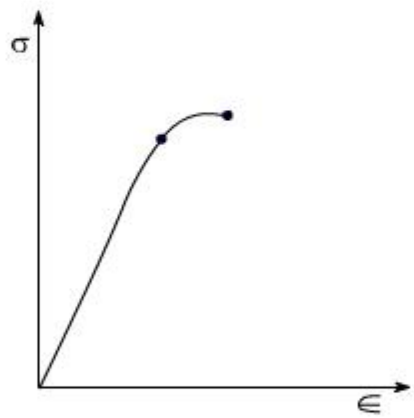
Ductile Materials:

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.

<u>Brittle Materials:</u>

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.

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.

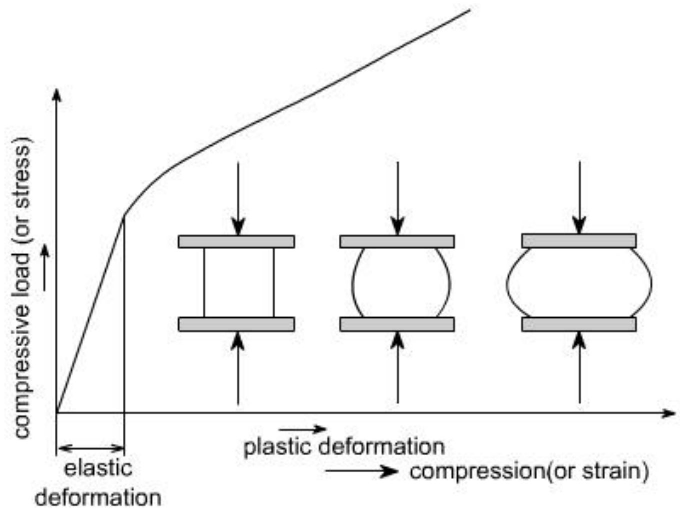
Shape of the specimen: The shape of the machine to be used for the different materials are as follows:

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

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

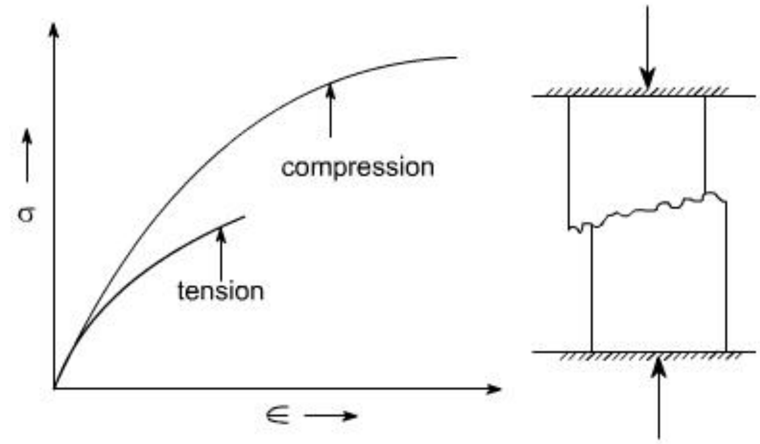
(3) In tension test, a specimen is being stretched, necking may occur, and ultimately fracture fakes place. On the other hand when a small specimen of the ductile material is compressed, it begins to bulge on sides and becomes barrel shaped as shown in the figure above. With increasing load, the specimen 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 tem ‘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

<u>Brinell Hardness test:</u>

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

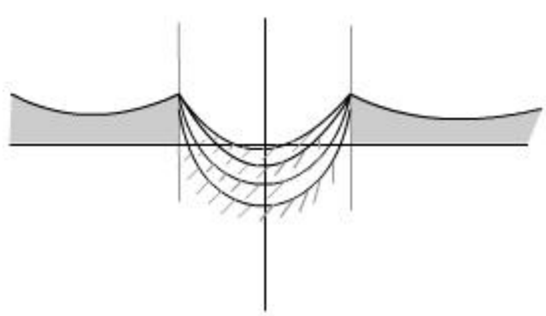
It may be shown that $A = \frac{1}{2}\pi D\left[D - \sqrt{D^2 - d^2}\right]$

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:

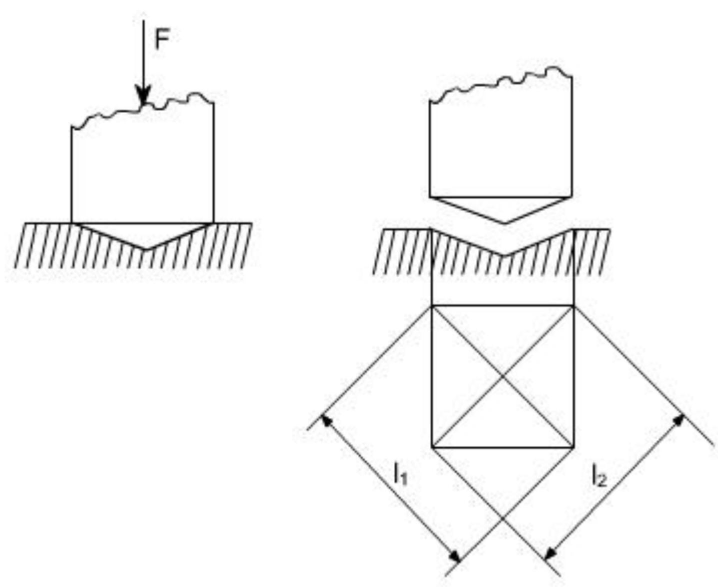
The Vicker's Hardness test follows a procedure exactly a identical with that of Brinell test, but uses a different indenter. The steel ball is replaced by a diamond, having the from of a square – based pyramid with an angle of 136^0 between opposite faces. This is pressed into the flat surface of the 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.

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

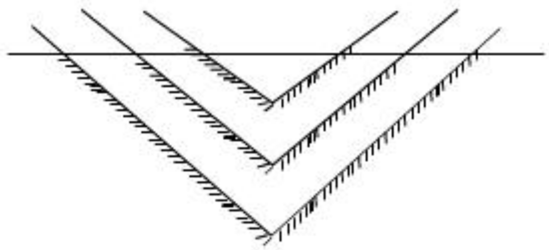
$$= \frac{l^2}{.854 v_x} \Rightarrow H_V = \frac{F}{\frac{l^2}{.854}}$$

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

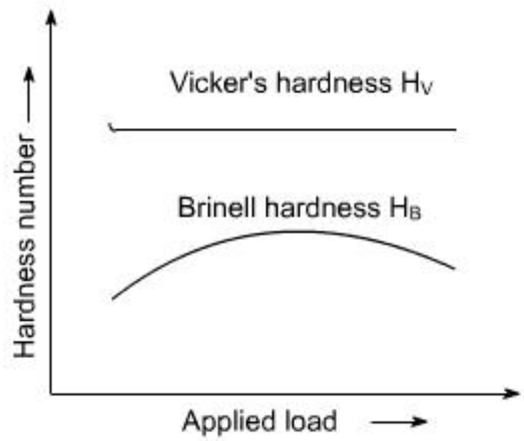
It may be shown that where l is the average lengthof the diagonal is $l = \frac{1}{2}(l_1 + l_2)$



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.



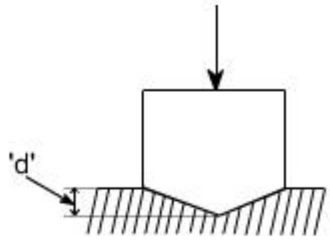
Advantage: Apart from the convenience the vicker's test has certain advantages over the Brinell test.

(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.

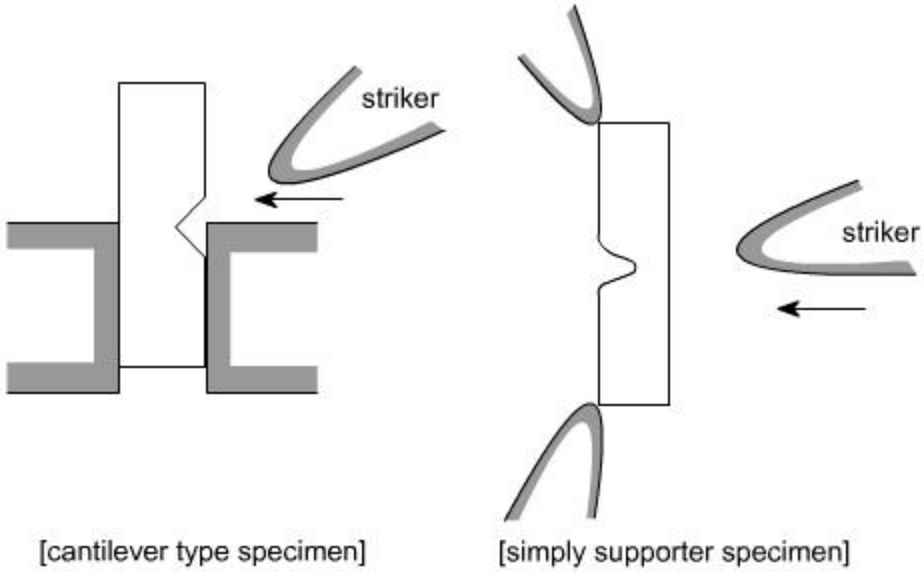
Impact testing:

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.



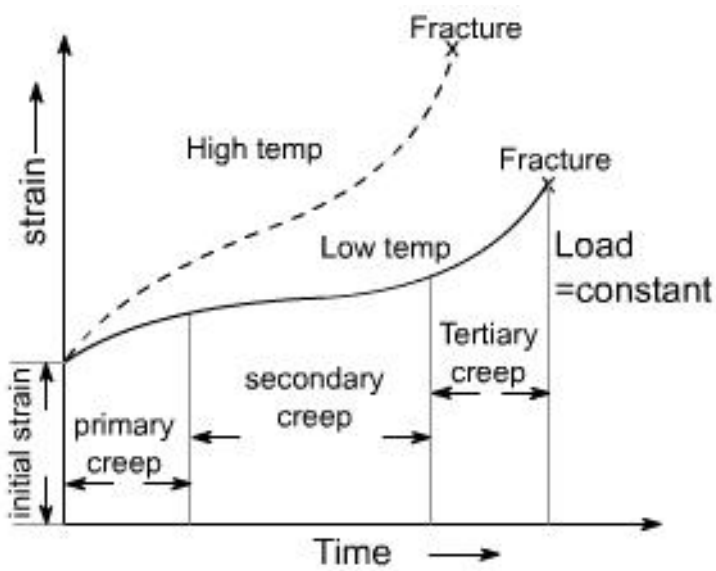
The specimen may be of circular or square cross – section arranged either as a cantilever or a simply supported beam.

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 reactors, 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 Î 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.

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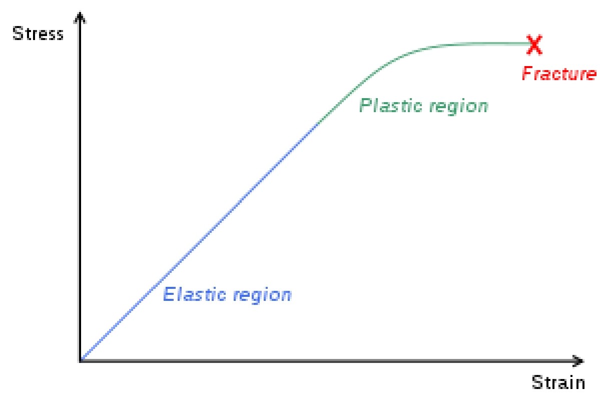

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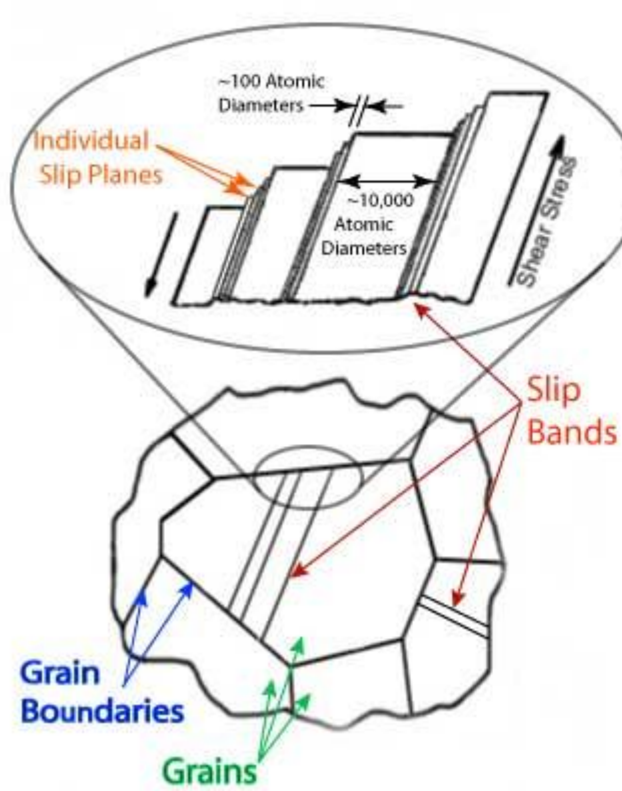

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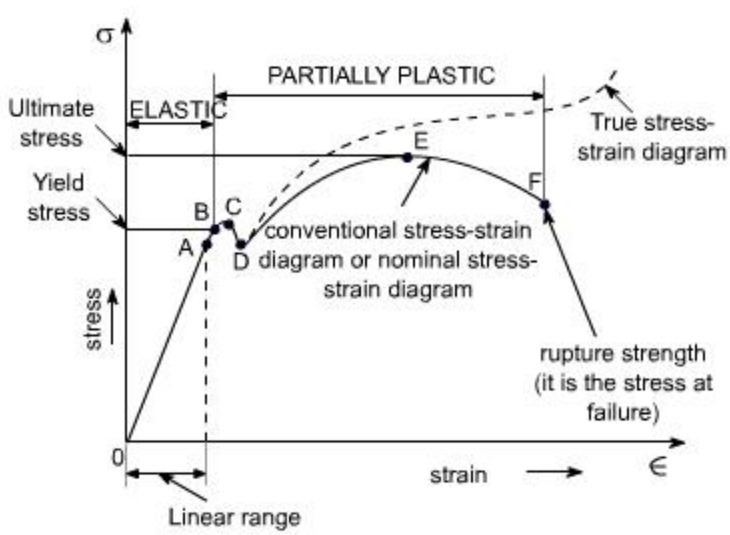

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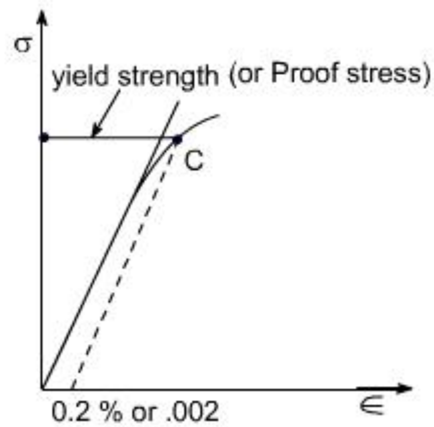
A study a stress – strain diagrams shows that the yield point is so near the proportional limit that for most purpose the two may be taken as one. However, it is much easier to locate the former. For material which do not posses a well define yield points, In order to find the yield point or yield strength,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

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

s_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]

<u>Percentage Elongation: ' d ':</u>

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.

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

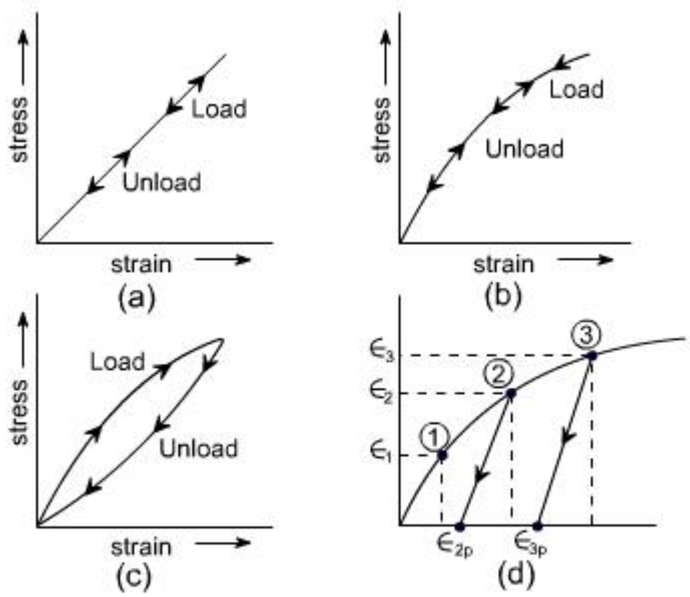
l_I = gauge length of specimen after fracture(or the distance between the gage marks at fracture)

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

For 50 mm gage length, steel may here a % elongation d 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 s vs Î is not single valued since the strain corresponding to any particular ‘ s ' 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 (Î$_{2}$ - Î$_{2p}$), where Î$_{2p}$ is the plastic strain remaining after the load is removed. Similarly for level (3) the plastic strain will be Î$_{3p}$.

<u>**Ductile and Brittle Materials:**</u>

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

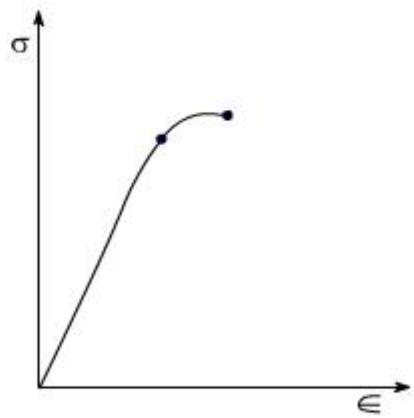
<u>**Ductile Materials:**</u>

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.

<u>**Brittle Materials:**</u>

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.

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.

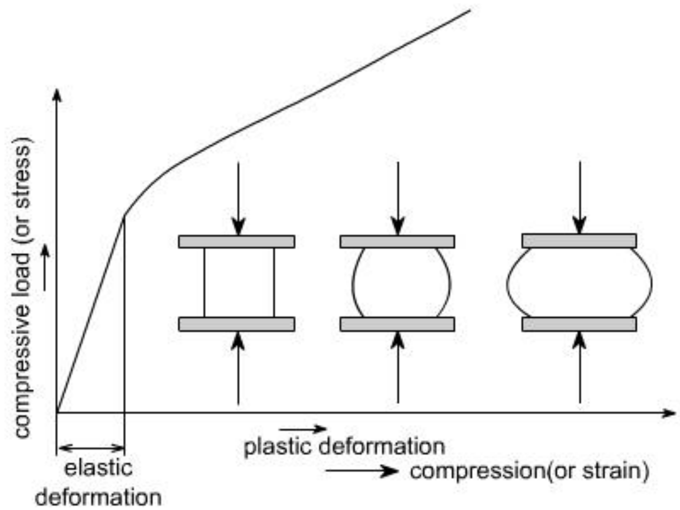
Shape of the specimen: The shape of the machine to be used for the different materials are as follows:

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

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

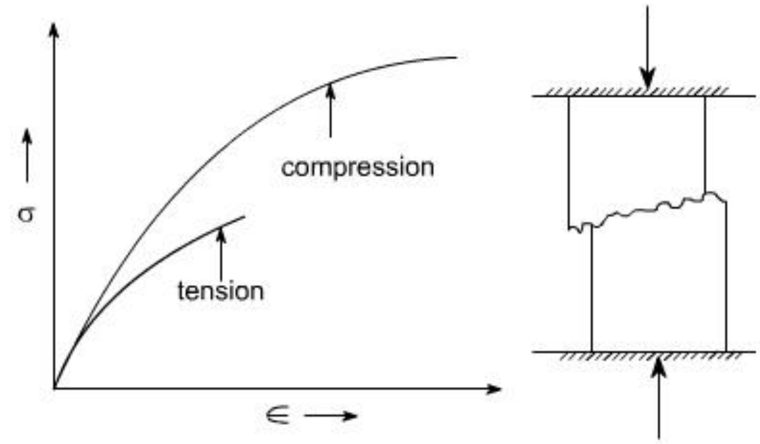
(3) In tension test, a specimen is being stretched, necking may occur, and ultimately fracture fakes place. On the other hand when a small specimen of the ductile material is compressed, it begins to bulge on sides and becomes barrel shaped as shown in the figure above. With increasing load, the specimen 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 tem '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

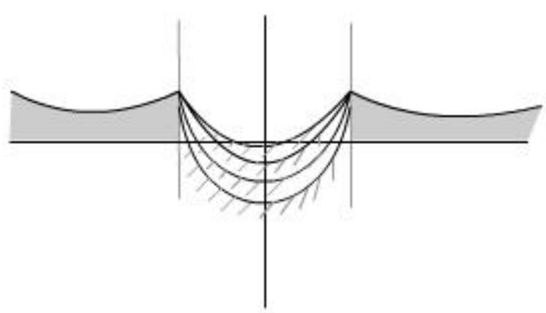
It may be shown that $A = \frac{1}{2}\pi D\left[D - \sqrt{D^2 - d^2}\right]$

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:

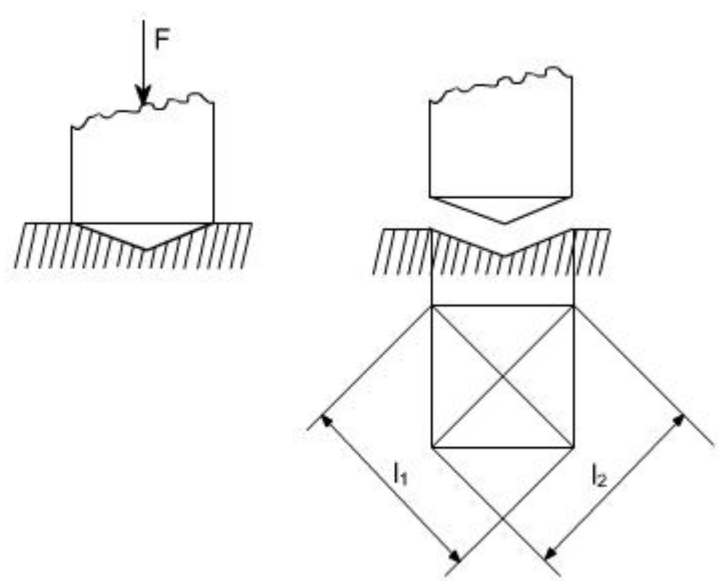
The Vicker's Hardness test follows a procedure exactly a identical with that of Brinell test, but uses a different indenter. The steel ball is replaced by a diamond, having the from of a square – based pyramid with an angle of 136^0 between opposite faces. This is pressed into the flat surface of the 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.

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

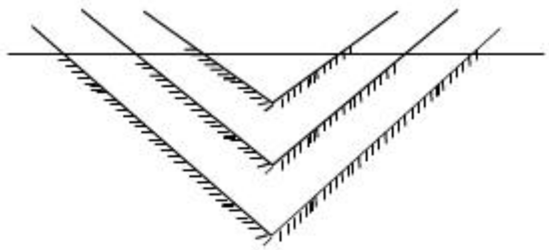
$$= \frac{l^2}{.854 v_x} \Rightarrow H_V = \frac{F}{\frac{l^2}{.854}}$$

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

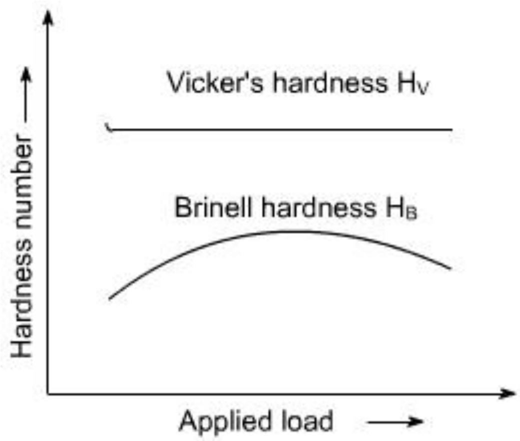
It may be shown that where l is the average lengthof the diagonal is $l = \frac{1}{2}(l_1 + l_2)$



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.



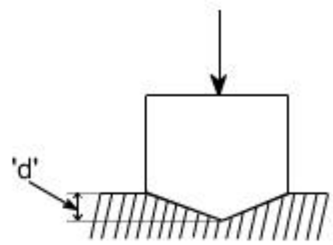
Advantage: Apart from the convenience the vicker's test has certain advantages over the Brinell test.

(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.

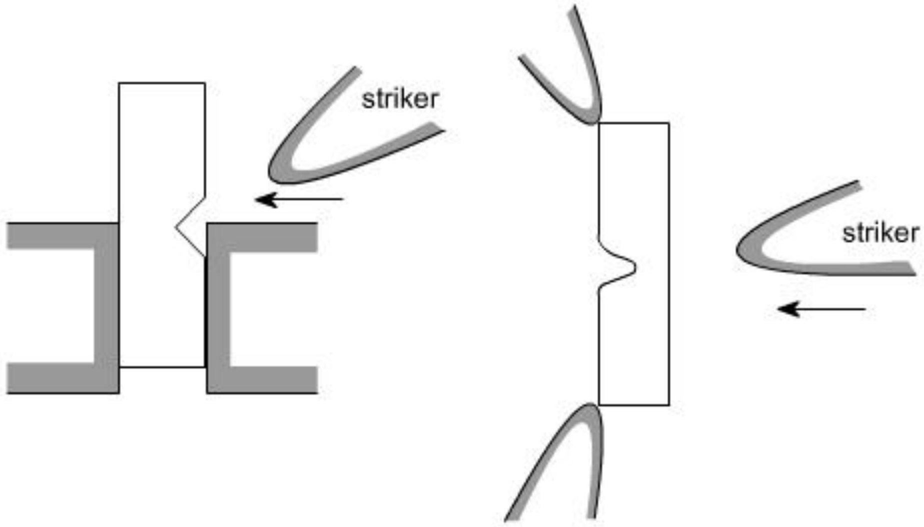
Impact testing:

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]

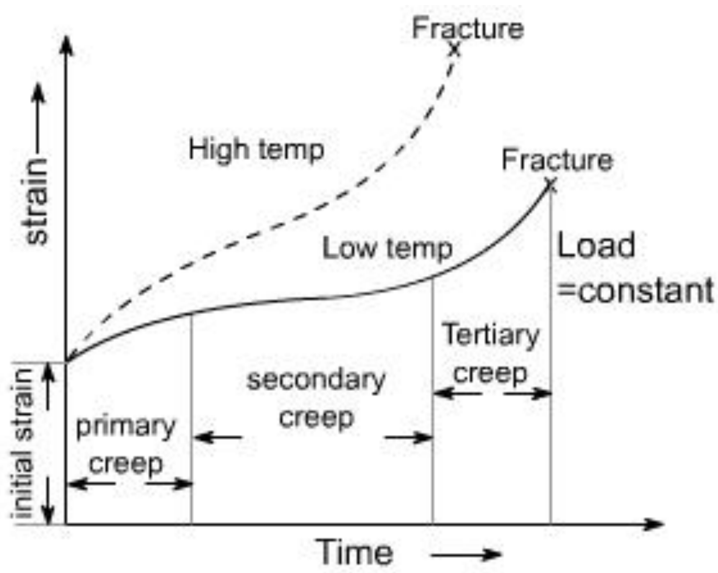
The specimen may be of circular or square cross – section arranged either as a cantilever or a simply supported beam.

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 reactors, 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 Î 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.

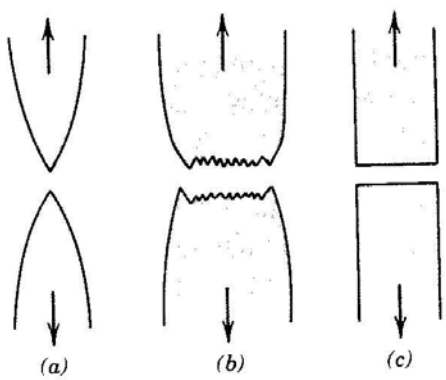
It is obvious that a material which is susceptible to creep effects should only be subjected to stresses which keep it in secondary (st.line) region throughout its service life. This enables the amount of creep extension to be estimated and allowed for in design.

Fracture

Objectives :

- *identify* design parameters limiting fracture and fatigue
- *distinguish* between catastrophic failure vs slow (!) fracture - *leak before break*
- *predict* life of structures based on fatigue and creep phenomena
- *identify* failure mechanisms and parameters controlling them

Ductile vs Brittle ⇔ Fig.8.1 - 8.3



(a) Highly ductile fracture

(b) Moderately ductile fracture

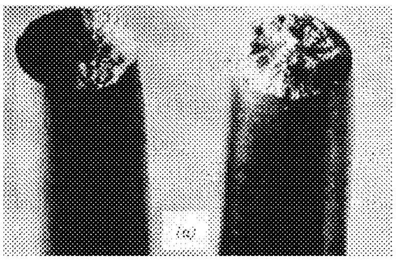
(c) Brittle fracture

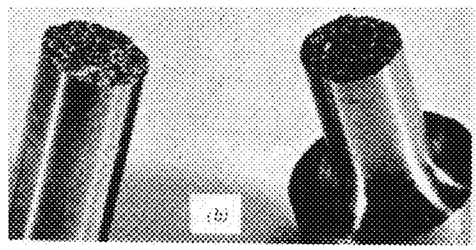
Fracture involves (i) crack initiation and (ii) crack propagation

stable vs *unstable*
(brittle)

Ductile vs Brittle

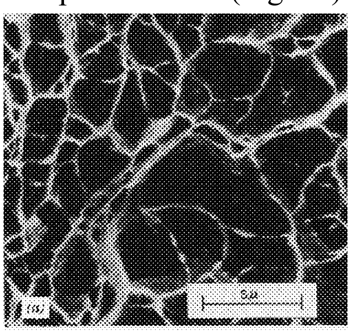
Ductile	Brittle
extensive plastic deformation	little or no plastic deformation
high e_t or RA	very low e_t or RA
dull fracture surface	bright/shiny
stable crack propagation	unstable
(no further crack propagation when $\sigma \rightarrow o$)	(once cracks start propagating, they continue till fracture)
	leads to catastrophic crack propagation & failure
cup-and-cone type fracture	grainy-faceted fracture surfaces





cleavage / transgranular (Fig.8.6a)
or intergranular (Fig. 8.6b)

dimpled fracture (Fig.8.4)



v-shaped *chevron* markings (Fig.8.5)

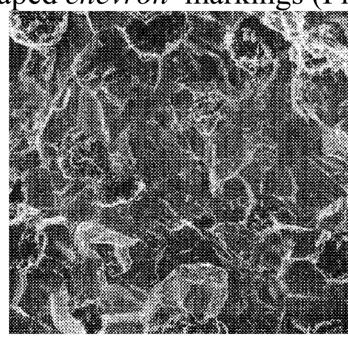


Fig. 8.6a

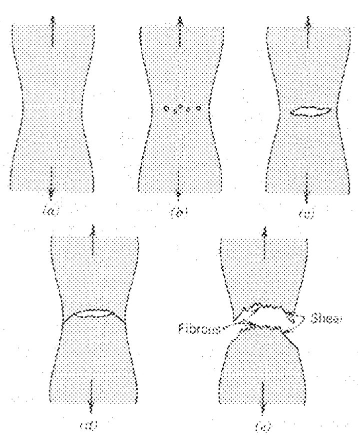


Fig. 8.2

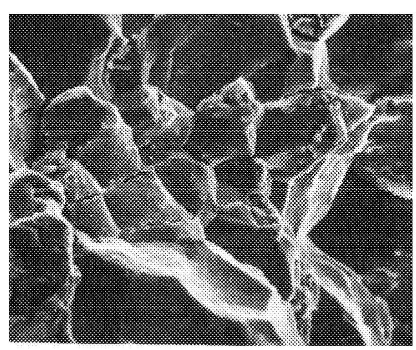
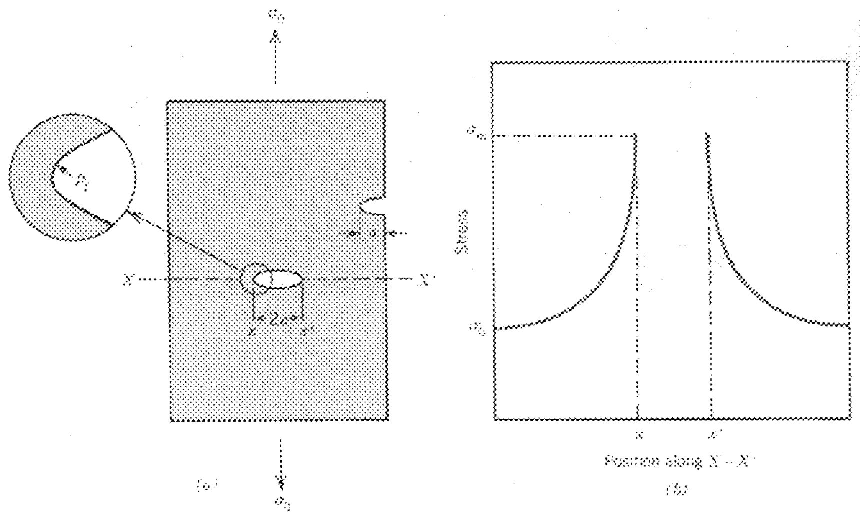


Fig. 8.6b

brittle fracture : crack motion is nearly $\perp$r to the tensile stress axis
- yields a relatively flat fracture surface

Fracture Mechanics

Stress Concentration at crack tips (Fig. 8.7)



$$\sigma_{max}^{crack\text{-}tip} = 2\,\sigma_o \sqrt{\frac{a}{\rho_t}}$$

σ_o is net section stress (nominal applied stress)

$$\kappa = \frac{\sigma_{max}^{crack\text{-}tip}}{\sigma_o} = 2\sqrt{\frac{a}{\rho_t}} \quad \text{(Eq. 8.2)}$$

Griffith theory of brittle fracture :

- fracture occurs when the tensile stress at some crack tip exceeds theoretical cohesive strength of the material

(implies that when there are no cracks at all (!), fracture strength would be equal to the theoretical cohesive strength)

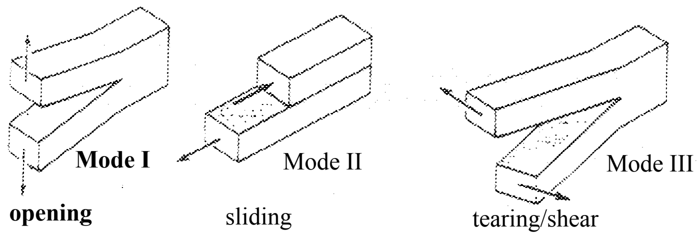
With cracks (real situation) ⇒ elastic strain energy released during crack propagation equals the surface energy increase due to the creation of 2 new surfaces ⇒

Eq. 8.3 : $\sigma_c = \sqrt{\frac{2E\gamma_s}{\pi a}}$ defines the critical stress needed for crack propagation

If there is some plastic deformation (true in majority of cases), add plastic strain energy in Eq. 8.3 (Eq. 8.4) : $\sigma_c = \sqrt{\frac{2E(\gamma_s + \gamma_p)}{\pi a}}$)

Fracture Toughness :

Modes I, II and III



Stress fields around cracks and stress intensity factor (K) : Eqs.8.5 $\sigma_{ij} = \frac{K}{\sqrt{2\pi r}} f_{ij}(\theta)$

r is distance from the crack tip & i,j = x , y ; *K specifies stress distribution at crack tip*

Just like when σ_c is approached, crack propagation can occur ;

define a **critical fracture toughness K_c** $= Y \sigma \sqrt{\pi a}$ (Eq. 8.6) , $Y \approx 1$

K_c depends on the specimen geometry (specifically thickness) and decreases as size increases (Fig. 8.12) and it reaches a minimum value for thick specimens known as **plane strain fracture toughness K_{Ic}**
which is a material parameter {f(T, $\dot{\varepsilon}$, microstructure); $K_{Ic} \Downarrow$ as grain-size $\Uparrow$ }

{condition for plane strain : $B \geq 2.5 \left(\frac{K_{Ic}}{\sigma_y}\right)^2$}

---

i.e. when the applied fracture toughness, $K_I = Y \sigma \sqrt{\pi a}$ reaches K_{Ic},
fracture occurs or crack propagates
[analogous to applied stress vs yield strength]

(units of K_I) $\Leftrightarrow$ large for ductile and low for brittle

Design using Fracture Mechanics

K_{Ic} (material parameter)

Eqs. 8.9 & 8.10 $\Rightarrow$ 3 variables : $\begin{cases} K_{IC} \text{ (material parameter)} \\ \text{applied or imposed stress } (\sigma) \\ \text{flaw size } (a) \end{cases}$

case (i) : if K_{Ic} and *a* are specified $\Rightarrow$ design stress $\sigma_c \leq \frac{K_{Ic}}{Y\sqrt{\pi a}}$

case (ii): if K_{Ic} and σ are specified $\Rightarrow$ maximum allowable flaw size $a_c = \frac{1}{\pi}\left(\frac{K_{Ic}}{\sigma Y}\right)^2$

"a" is measured using various NDT methods (UT, optical, radiography, etc.)

Fracture Testing : C_V etc.

Group Work

Using Griffith's brittle fracture theory, determine the critical crack length for the following examples with the data given in the table.

	σ_c, dyn/cm^2	γ_s, erg/cm^2	E, dyn/cm^2
Iron	9×10^9	1,200	20.5×10^{11}
Zinc	2×10^7	800	3.5×10^{11}
NaCl	2×10^7	150	5.0×10^{11}