Chapter No. four: Tests **Time: 10 Hours**

The tensile test

The tensile test is the most important of the mechanical tests used to obtain data on the properties of materials. The test is usually performed by slowly and steadily applying a tensile load to standardize test specimen shown in Fig. below. After the sample has been loaded in tension and broken, the two halves are held firmly together and the distance between the marks is again measured.

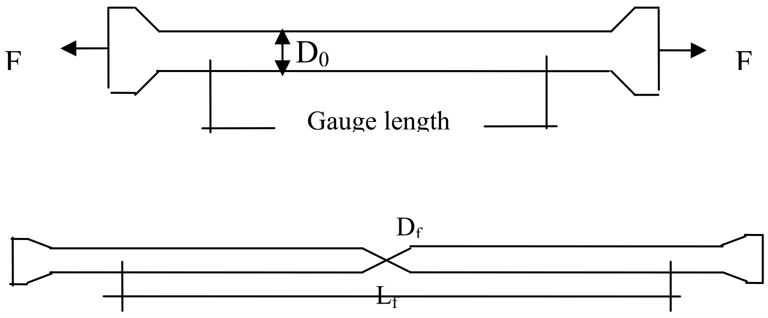
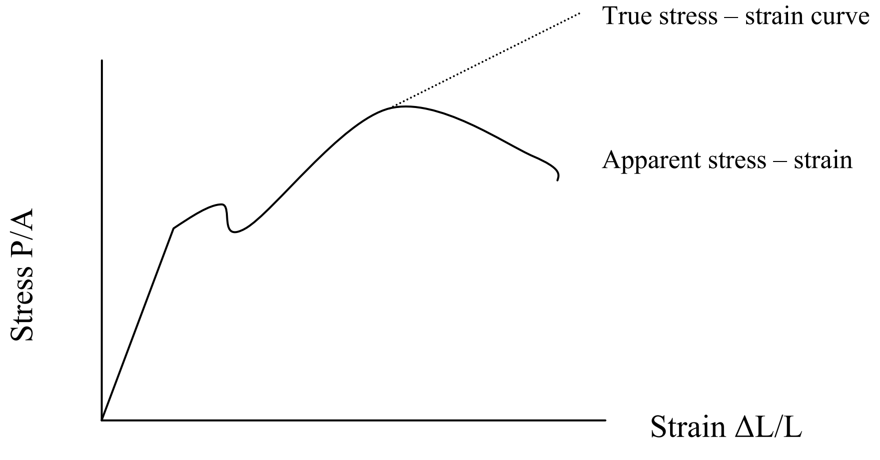


Fig.1

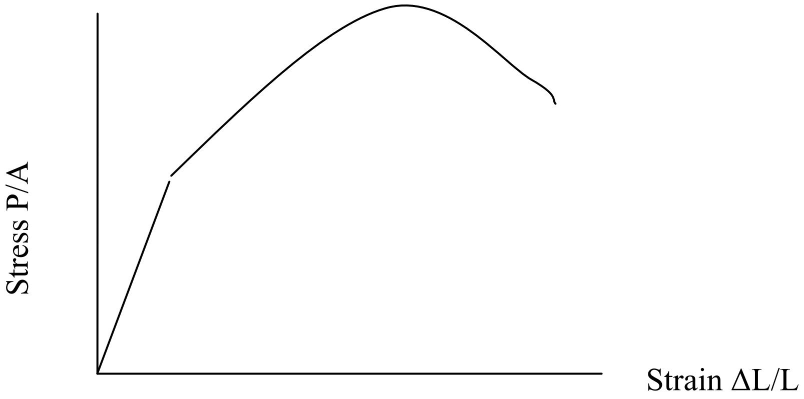
The stress – Strain curve in tension

After testing the specimen, it is necessary to represent the data in the form of stress – strain diagram. The stress is defined as the load divided by the cross sectional area of the specimen at the start of the test. As the test proceeds, the actual cross sectional area decreases. The stress based upon the initial area is not the true stress, but it is generally used. The strain used is the elongation of a unit length of the test specimen taken over the gauge length. Typical stress – strain diagram are shown in Fig. below:



Stress – Strain curve for low carbon steel

Stress – Strain curve for non ductile material –
Cast iron (no plastic deformation)

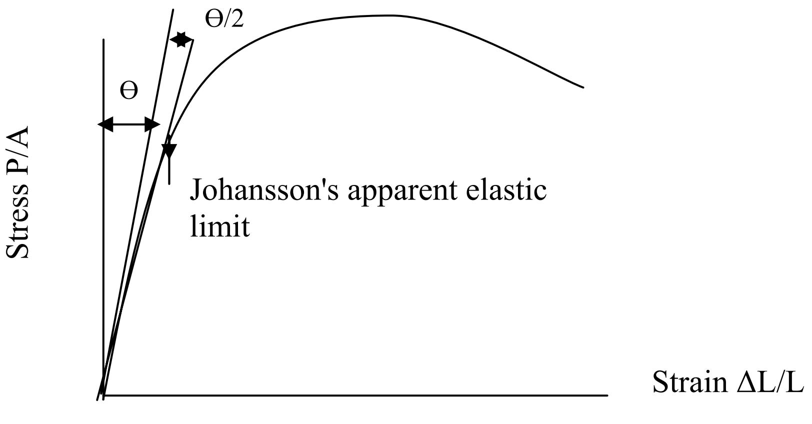


Stress – Strain curve for Aluminum –
Ductile material

Proportional limit

It is the greatest stress that the material is capable of developing without deviation from Hook's law of stress – strain proportionality.

In order to determine the proportional limit, it is necessary to use very sensitive extensometer to detect the slightest deviation from a straight line in the tensile test diagram. Certain materials such as concretes and copper do not have the straight line portion of the stress – strain curve that steel does. For these materials a value known as Johansson's apparent elastic limit. Johansson's apparent elastic limit is defined as that stress at which rate of deformation is 50% greater than the initial rate of deformation as shown for concrete.



Modulus of elasticity

It is a measure of the stiffness of the ductile material. The slope of the initial straight portion of stress – strain diagram represents the modulus of elasticity or Young's modulus.

$$\boxed{E = \tan \Theta = \text{Stress}/\text{strain}}$$

When no straight portion is present in the stress – strain curve, as in the case of concrete material, the modulus of elasticity can be obtained by one of the following methods:

1. Initial tangent modulus:

It is the tangent to the curve at the original, but it is little practical importance.

2. Tangent modulus

It is the tangent at any point on the stress – strain curve, but this modulus applies only to very small changes in load above or below the load at which the tangent modulus is considered.

3. Secant modulus

It is the slop of the line drawn from the origin to any point on the stress – strain curve. There is no standard method of determining the secant modulus, in some laboratories; it is measured at stress ranging from 3 to 14 N/mm^2, in others at stresses representing 15, 25, 33 or 50% of the ultimate strength.

Yield strength

Yield point is defined as the stress at which a marked increase in strain occurs without a concurrent increase in applied stress.

Many materials do not exhibit well defined yield points and the yield points and the yield strength is defined as the stress at which the material exhibits a specified limiting permanent set of 0.2 % (0.002 strain). The yield strength is therefore the stress corresponding to the intersection of a line parallel to the straight line portion of the stress – strain curve.

Ultimate strength

It is obtained by dividing the maximum load reach before the specimen breaks by the initial cross sectional area of the specimen. It is commonly used as basic for established working stresses for a material.

$$\boxed{\begin{array}{l}\text{Ult. Str. For apparent stress – strain curve} = \text{max. Load}/A_0 \\ \text{Ult. Str. For true stress – strain curve} = \text{max. Load}/A_f\end{array}}$$

Elongation

Percentage of elongation is the measure of the ability of a material to undergo deformation without rupture. It is a measure of the ductility of material.

$$\boxed{\%\ \text{Elongation} = (L_f - L_0) / L_0 * 100}$$

Where:

L_f – Final length

L_0 – Initial length

Breaking Strength (Rupture strength, fracture strength)

$$\boxed{\text{Breaking strength} = \text{Load at time of failure} / A_0}$$

The breaking strength on this basis is less than the ultimate stress of the data based on true area. While the true stress of failure is the maximum stress on the material. For the test interval between the ultimate stress and the breaking stress, the specimen continues to elongate even though the resisting stress based on the original area decrease.

Reduction of area

As the load on the test material is increased, the original cross sectional area decrease until it is a minimum at the instant of fracture. It is usual to express this reduction in area as the ratio of the change in area to the original specimen cross sectional area expressed as a percentage.

$$\boxed{\%\ \text{reduction in area} = \{(A_0 - A_f)/ A_0\} * 100}$$

Where - A_f– Final cross sectional at the point of failure
A_0– Original cross sectional

Ductility

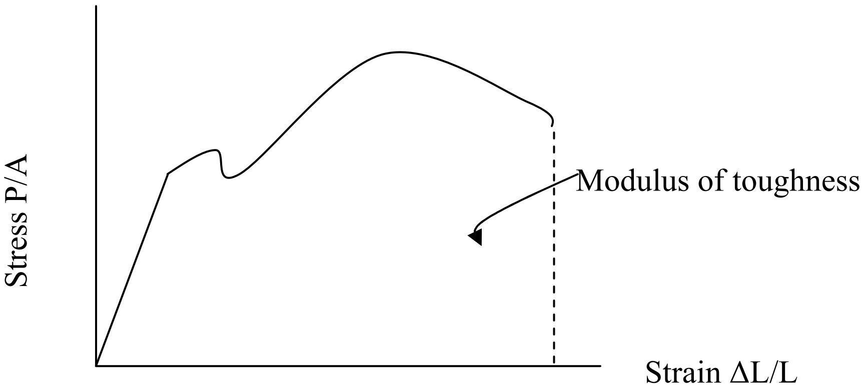
Is the property of a material of being deformed by stretching without recovery of shape upon removed of stretching force. Ductility of metals is ordinarily determined by measuring the elongation and reduction of cross sectional area of a tensile strength test specimen.

Toughness

The resistance to impact. Toughness is also considered to mean resistance to fracture when the material is deformed above the elastic limit.

It is a measure of the work required to cause fracture to occur. The area under stress – strain curve represent modulus of toughness.

$$\boxed{\text{Modulus of toughness} \simeq 2/3\ (€_f\ *\ б_f)}$$



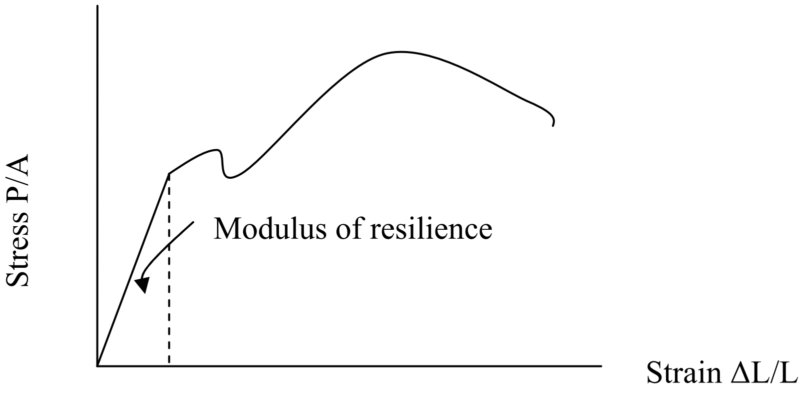
Brittleness

Is the opposite of toughness and ductility and refers to small resistance to sudden blow. A brittle meta breaks suddenly without appreciable permanent deformation or warning of approaching failure.

Resilience

Is that property of an elastic body by which energy can be stored up in the body by loads applied to it and given up in recovering it\s original shape when the loads are removed. The area under the straight portion of stress - strain curve represent the modulus of resilience.

$$\boxed{\text{Modulus of resilience} = 1/2\ (€_{P.L.}\ *\ б_{P.L.})}$$



Plasticity

Is the property by which a body, when deformed by the application of forces, remains in the deformed shape without recovering the original shape, when the force is removed.

H.W.:

The following data where obtained during the tensile test of mild steel circular bar 12.75 mm diameter and 203.2 mm gauge length. Determine the following:

1) The apparent stress at each point
2) Strain at each point
3) True stress at each point (Assume D at failure is 8,51 mm and D at max. load is 11.15 mm)
4) Draw stress – strain curved based on:
    a) Original cross sectional area
    b) True cross sectional area
5) Proportional limit
6) Modulus of elasticity
7) Upper and lower yield point
8) Ultimate strength
9) Breaking strength based on the original cross sectional area and on true cross sectional area
10) Percentage of elongation
11) Percentage of reduction in cross sectional area.
12) Ductility
13) Resilience and toughness

Load (N)	4393	16902	29357	33360	33627	35584	41366	48839	52709	55378	56356	43768
Deformation (mm)	0.0254	0.127	0.228	0.305	0.356	3.81	6.35	11.68	16.76	26.92	43768	42.42

Compressive strength

Compressive strength should be determined on cylinders with a height equal to about two times the diameter. The ends of the cylinders should be carefully prepared to be parallel and plane surfaces.

For steels it is possible to determine the ultimate compressive strength only for brittle steels, since all ductile steel are greatly deformed under load and show no well defined fracture.

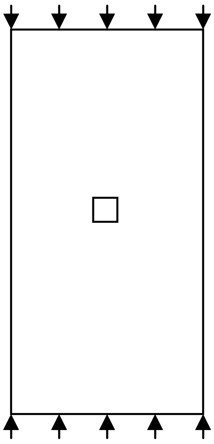
Ductile metal under the test

$$\boxed{\text{Compressive strength} = P/A}$$

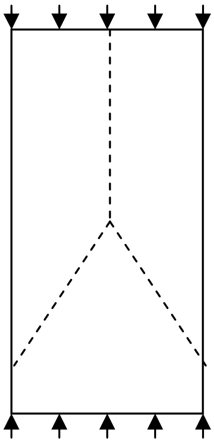
Where P- Load at failure

A- Cross sectional area normal to load

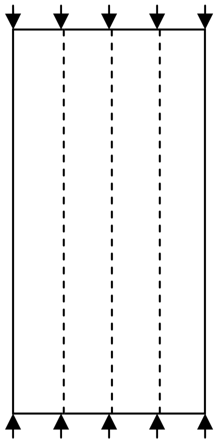
Brittle material such as concrete is much weaker in tension and in shear than in compression, and failures of concrete specimens under compressive load are essentially shear failures on oblique planes. When the strength of concrete is high and lateral expansion at the end bearing surfaces is relatively unrestrained, the specimen may separate into columnar fragments what is known as a splitting fracture. Often failure occurs through a combination of shear and splitting.



Shear Failure



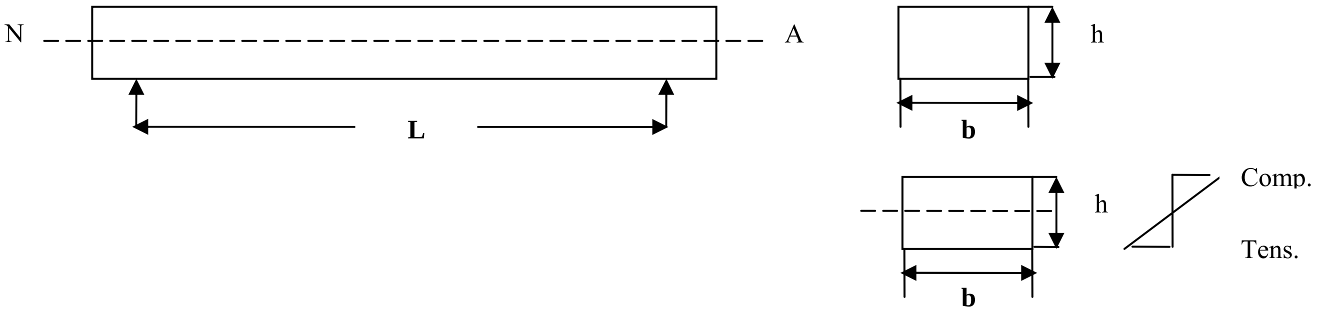
Combination shear Failure and splitting failure



Splitting Failure

Flexural strength

In flexural test, the beam may be tested on simple supports. When a materials is subjected to being tensile and compressive stresses and in may cases direct shear stresses are developed.



Flexural strength is expressed in term of " modulus of rupture " which is the maximum tensile (or compressive) stress at rupture computed from the following formula :

$$\boxed{S_b = MC/I}$$

Where S_b – Stress in the fiber farthest from the neutral axis
M- Bending moment at the section
I- Moment of inertia of the cross section
C- Distance from neutral axis farthest fiber

The modulus of rupture is a good index for comparing different grades and glasses of materials. The beam test in flexural in a given series of tests should be of the same shape and size so that the modulus of rupture values can compared directly.

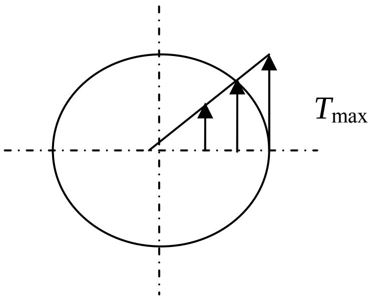
The flexural strength of a metal directly depends upon the tensile and compressive properties of that metal. If the section is symmetrical, the failure will occur on the tension side if the metal is not ductile and on the compression side if it is ductile.

Torsion test

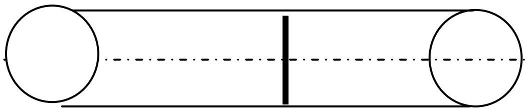
The torsion test is conducted by twisting a solid cylinder specimen. The torque and the angle of twist are measured. The intensity of the shearing stress due to torsion on any section of a cylinder shaft varies directly as the distance from the axis of the shaft and the maximum intensity of shearing stress is found at circumference. The mathematical expression for the maximum shearing stress in the extreme fiber of circular shaft is :

$$\boxed{T_{\text{max.}} = 2T/\pi\, r^3}$$

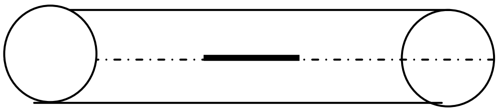
Where T – is the torque
r- the radius of the section



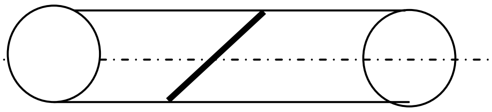
The cracking was developed in the direction parallel to the shear plane. This plane may be parallel or perpendicular to the longitudinal axis of the specimen. It is probable that failure occurs in the plane making an angle with longitudinal axis as shown in Fig. below:



Shear plane perpendicular
to the longitudinal axis



Shear plane parallel
to the longitudinal axis



Shear plane making an angle
with longitudinal axis

<u>H.W. :</u>

1. Differentiate between the behavior of ductile and brittle metal during compressive test?
2. Explain this sentences "The flexural strength of a metal directly depends upon the tensile and compressive properties"?
3. Determine the property of the metal that torsion test results depend upon?

Impact test

Impact tests may be performed for two purposes:

1. to determine the ability of the material to resist impact under service conditions.
2. to determine weather a metal has resistance to failure due to brittleness under service conditions in a machine or structure.

Impact tests may be classified into two groups:

1. <u>Utility impact tests:</u>

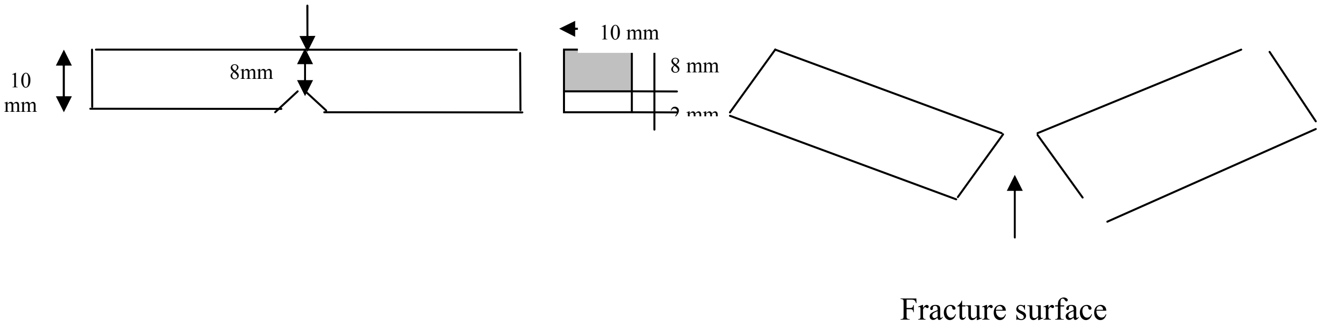
Utility impact tests for detecting the presence of brittleness or determining the comparative toughness of material are applied to steel rails, pipes, as well as to non-metal materials such as concrete, stone, wood …etc.

2. <u>Standard impact tests:</u>

The charpy and Izod impact testing machines are the two most common machines for conducting standard impact tests on metals. These machines determine the amount of work necessary to fracture a small test specimen by impact. They consist essentially of a weighted pendulum, suitable holders or supports for the specimen, and a device for recording the angular swing of the pendulum.

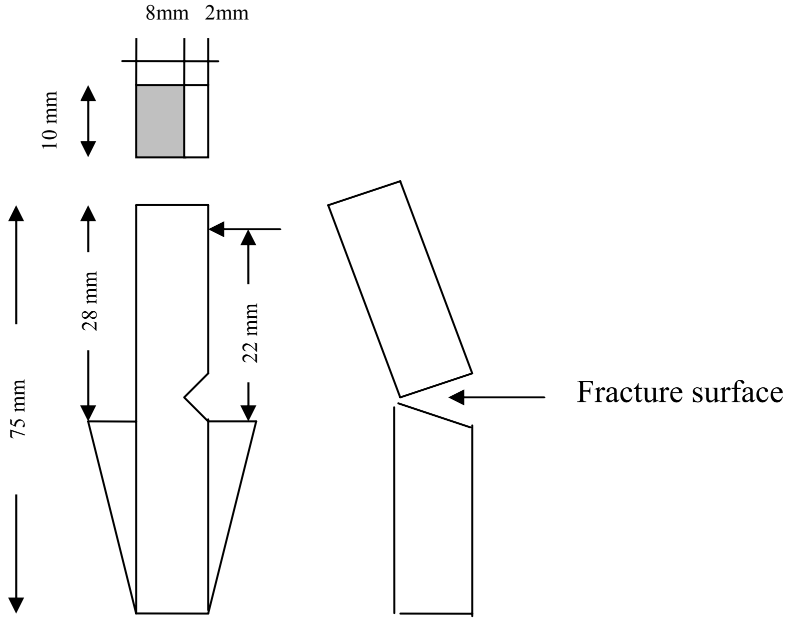
Charpy method

This method is well adapted for examining metals that break with a relatively low absorption of energy. The presence of notch eliminates the influence of surface effects.



Izod method

For tough metals the notched Izod type of specimen tested as a cantilever is used. For extremely brittle metal that test specimen requires no notched, because the first suddenly applied stress causes a brittle failure.



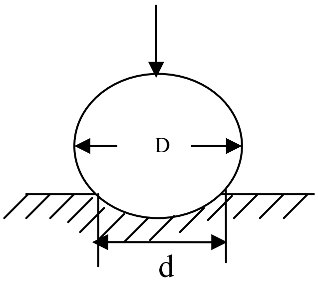
Hardness

Hardness is resistance to plastic deformation. Thus a hard material may have a high elastic limit. Other meanings are given to term, however, such as resistance (1) to abrasion, (2) to scratching, or (3) to indentation of a cone or ball.

Hardness of metals is determined by measuring the resistance to penetration of a ball, cone, or pyramid.

The brinell method is based upon determining the resistance offered to indentation by a hardened sphere that is subjected to a given pressure. The pressure used in testing steel is 3000 kg and a diameter of the ball is 10mm. When softer materials a pressure of 500 kg is used. Brinell numbers can be computed by the formula:

$$\boxed{BHN= 2P/\pi D(D- (D^2 - d^2\ )}$$



Where P- pressure in kg
D- Diameter of the ball
d- Diameter of the impression, mm

The harder the steel, the smaller the indentation under the load and the greater the BHN.

Creep

We have discussed the mechanical properties of materials on room temperature. Many structures, particularly these associated with energy conversion, like turbines, reactors, steam and chemical plant operate at much higher temperature.

As the temperature is raised, materials under loads continuous deformation with time, i.e. start to creep, the strain instead of depending only on the stress, now depends on temperature and time also.

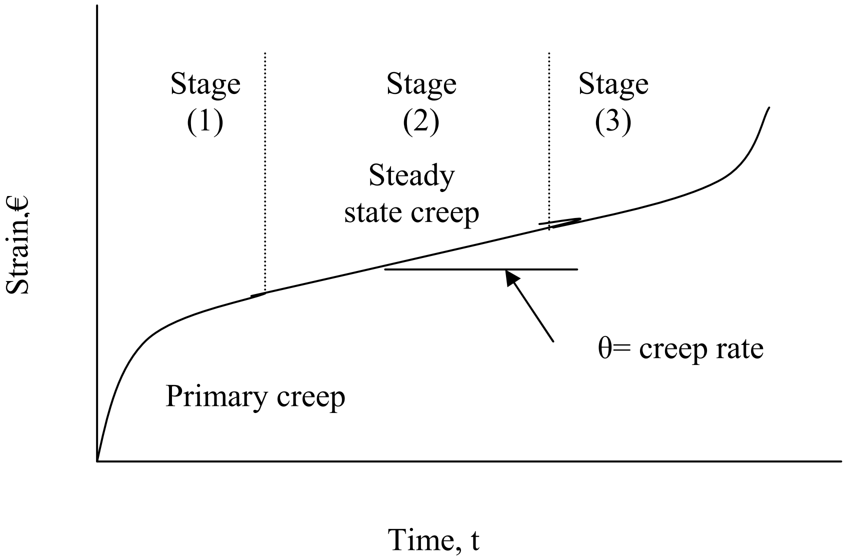
€ = *f* (S,t, T)

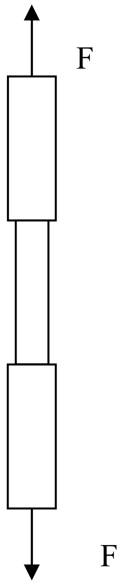
The temperature at which materials start to creep depends on their melting point. As a general rule, it is found that creep starts when:

T > 0.3-0.4 Tm for metals
T > 0.4-0.5 Tm for ceramic
Where Tm – the melting temperature in degree Kelvin

Creep testing and creep curves:

Creep tests require careful temperature control. Typically, a specimen is loaded in tension or compression usually at constant load, inside a furnace which is maintained at a constant temperature, T- The tension is measured as a function of time. Fig. below shows a typical set of results from such a test. Metals polymers, and ceramic, all show creep curves of this general shape.

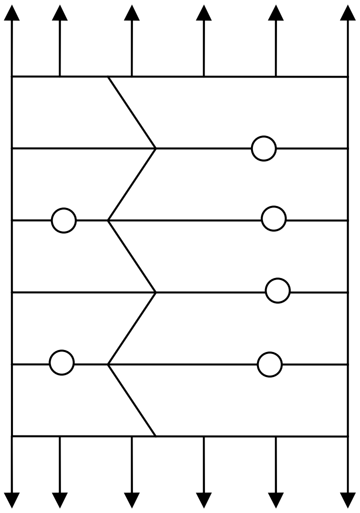


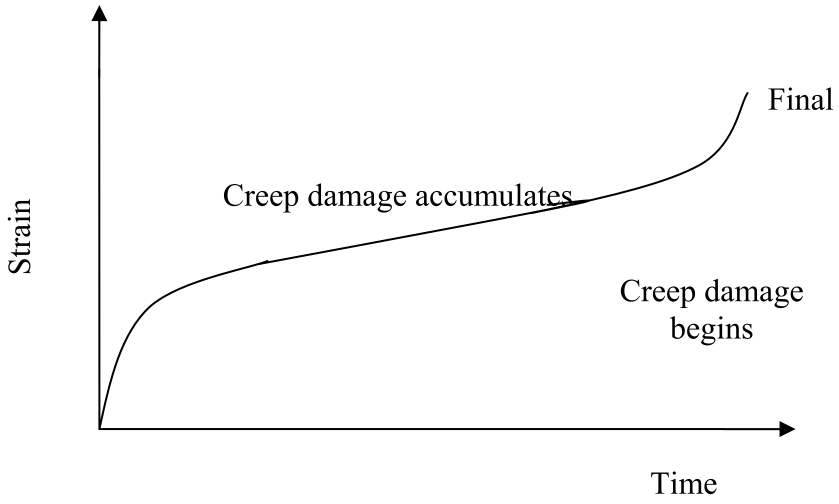


Creep occurs in three stages:
Stage 1 – Primary creep stage
Consist of a short part during which strain increases rapidly
Stage 2 – Secondary creep stage
Consist of a long period where the rate is much slower and constant
Stage 3 – Tertiary creep stage
At this stage the creep rate increases and the material fractures

Creep damage and creep fracture:

During creep, damage, in the form of internal cavities, accumulates. The damage first appears at the start of the tertiary stage of the creep curve reflects this as the holes grows. The section of the sample decreases and (at constant load) the strains goes up and the creep rate goes up even faster than the stress does.





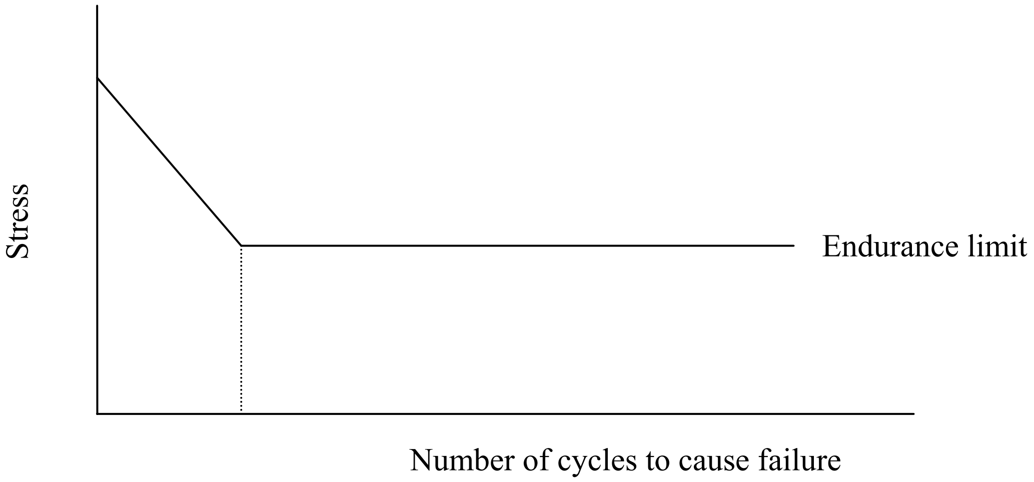
In high temperature design it is important to make sure:

a. That the creep strain during the design life is acceptable.
b. That the creep strain at failure is adequate to cope with the acceptable creep strain.
c. That the time to failure, at the design loads and temperatures is longer (by a suitable factor) than the design life.

Fatigue strength

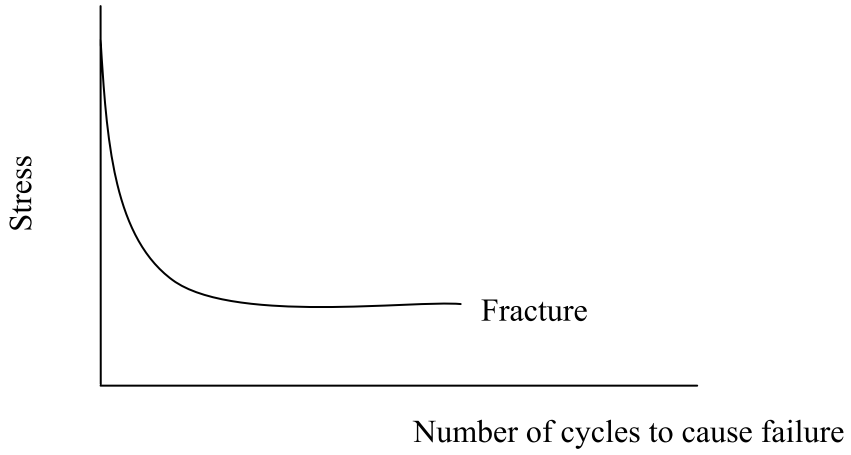
We have considered so far only the strength of material under static loading. In many structures, repeated loading is applied, and when a material fails under a number of repeated loads, each smaller than the ultimate strength, failure in fatigue is said to take place.

The results of fatigue test are represented by a relationship between stress and number of cycles to failure.

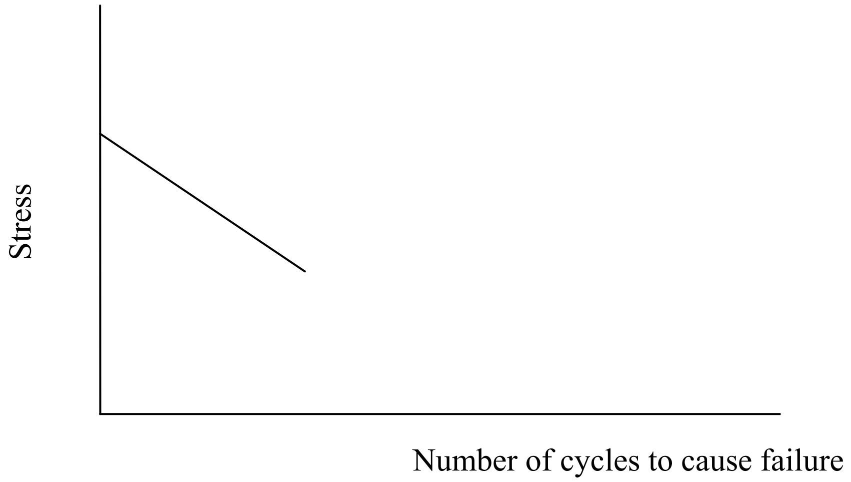


S-N diagram for ferrous metals

At the beginning the stress decreases as the number of cycles increases. After several million cycles the curve becomes horizontal line whose stress value is known as the endurance limit. While almost all ferrous materials exhibit an endurance limit, most nonferrous alloys do not.



S-N diagram for nonferrous metals



S-N diagram for concrete materials

Endurance limit:

The stress below which a material can withstand an indefinitely large number of repetition of stress without failure.

Fatigue strength:

The stress which exceed the endurance limit and at which failure may occur after indefinite number of repeated cycles.

Fatigue failure:

Fatigue failure appears to begin with a crack at a point of weakness in the material, with the crack. Progressing long crystal boundaries. During the stress cycle, these small cracks open and close. The cracks cause highest stress at the base of the crack as compared to the stress if there is no crack. Under this repeated concentration of stress, the cracks will gradually extend a cross the section of the member, finally causing complete failure of the member.