Fracture :

Fracture is the separation of a specimen into two or more parts by an applied stress. Fracture can occur under all service conditions. Materials subjected to extended cyclic loading may result in fatigue fracture (delayed fracture). Also under the influence of a constant applied stress many materials continue to deform indefinitely. This process is called creep. It is an important consideration in high temperature applications. Prevention of failure during service is one of the most important problems faced by the engineers.

Brittle fracture ;

Brittle fracture is the failure of a material without apparent plastic deformation. since this occurs without any indication, this is most dangerous and produces worst consequences. If we join together the broken pieces of a brittle fracture, we get back the original shape and dimensions of the specimen.

In an ideal material, brittle fracture occurs due to the pulling apart and breaking of the inter atomic bonds across two neighbouring atomic planes. The calculated theoretical tensile stress required to break the inter atomic bonds across two adjacent atomic planes is of the order of E/6, where E is the Young's modulus of the material. But since often brittle fracture occurs by the rapid propagation of a crack under applied stresses, brittle materials break at much lower stresses, which are several orders of magnitude lower than the theoretical stress values. Amorphous materials such as glass are completely brittle but crystalline solids usually exhibit some plastic deformation.

Mechanism of Brittle fracture :

Griffith's theory :

The explanation of the fracture of amorphous materials such as glass was first proposed by Griffith. He assumed that in a brittle materials there are many fine cracks. These cracks concentrate the applied stress at their tips. when the stress at the tips of a crack exceeds theoretical stress values the crack expands and fracture occurs. If σ_f is the critical fracture stress, then

$$\sigma_1 = \left(\frac{2yE}{\pi c}\right)^{1/2}$$

Which is called Griffith equation.

where y = surface energy per unit area of the material.

From the above equation it is clear that the stress necessary to cause brittle fracture varies inversely as the square root of the crack length. Hence the tensile strength of a completely brittle material depends on the length of the largest crack existing in the material.

The Griffith equation is not only valid for a surface crack but also for a crack inside the material.

In all materials cracks are distributed throughout when the applied stress is increased, the longest crack with favourable orientation causes fracture first when similar test is carried out on one of the broken pieces, the tensile strength required is usually higher. This is because the most effective crack opened first.

The measured fracture strengths for most brittle materials are significantly lower than those predicted by theoretical calculations based on atomic bonding energies. This discrepancy is due to the presence of very small, microscopic flaws or cracks existing on the surface as well as with in the interior of a body of material.

The applied stress may be amplified or concentrated at the crack tip. The magnitude of the amplification depends on crack orientation and geometry. Because of their ability to amplify an applied stress in their locale, these flaws are sometimes called stress raisers. Thus cracks are a detriment to fracture strength.

$\sigma_1 = 2\sigma\left(\frac{C}{P}\right)^{1/2}$

where σ is the longitudinal tensile stress applied.

σ_m = maximum stress at is tip.

P = radius of curvature at the tip.

The ratio $\frac{\sigma_m}{\sigma}$ = stress concentration factor, K.

$K = \frac{\sigma_m}{\sigma} = 2\left(\frac{C}{P}\right)^{1/2}$

This is a measure of the degree to which an external stress is amplified at the tip of a small crack.

For many brittle crystalline materials, crack propagation on the atomic level corresponds to the successive and repeated breaking of atomic bonds along specific crystallographic planes.

This type of fracture is said to be intragranular (transgranular) fracture because fracture cracks pass through grains. The fractured surface looks grading or granular. In some alloys, crack propagation along grain boundaries is also possible this is termed intragranular fracture. This yields a relatively shiny and smooth fracture surface the main characteristics of brittle fracture are

1. The separation occurs normal to the tensile axis.

2. There is no gross deformation or very little mass deformation.
3. There is no plastic deformation.
4. Rate of crack propagation is rapid with minimum energy absorption.
5. Common b.c.c metals and polycrystalline h.c.p metals are brittle while many f.c.c metals remain ductile.

Ductile fracture :

Ductile fracture is the rupture of a material after a considerable amount of plastic deformation.

When a common ductile materials is subjected to tensile stress the fracture process can be distinguished by three stages.

a) the specimen begins necking and minute cavities form in the reached region.

b) the cavities join and form a minute crack in the centre of the specimen; and

c) the crack spreads outwards to the surface of the specimen in a direction at 45° to the tensile axis. This results in cup and cone fracture surfaces.

Fully ductile materials will continue to neck down to an infinitesimally thin edge or a point. when the cross section at the neck becomes so small that it cannot bear the load any longer ductile fracture occurs.

Ductile cracks are often found to nucleate at brittle particles. The brittle particles may be naturally there in multiphase materials such as cementite in steel or they may be present as foreign inclusion such as oxide inclusion in copper.

The engineer requires both strength and ductility for his structural materials. Ductility increases the strength of the material and also avoids unpredictable brittle fractures.

Difference between brittle and ductile fractures:

Brittle fracture	Ductile fracture
1. Occurs with minimum deformation	Occurs with large plastic deformation
2. Occurs suddenly without any warning	Occurs with slow tearing of the metal with absorption on of energy.
3. Occurs at the point where micro crack is largest.	Occurs in some localised region where the deformation is very large.
4. Movement of crack involves very little plastic deformation adjacent to the crack	Crack propagates as a result of highly localised plastic deformation of metal
5. Metals fail by cleavage after relatively large macroscopic strain.	Metals fail with negligible macroscopic strain.
6. Fractured surface shows sharp planar facets.	Fractured surface is dirty with rough contour.

Fracture toughness :

A material's inherent resistance to fracture when a crack is present is termed its fracture toughness. It is defined by the critical value of a parameter G_c. $\sigma_f \pi c \sqrt{E}$

$G_c = \sigma f \pi \sqrt{E}$

also $G_c = 2\gamma$

Another parameter more commonly used to describe the fracture toughness of a material is critical stress intensity factor K_c. For a sharp crack, when the applied tensile stress is perpendicular to the crack faces, the critical stress intensity factor is given by

$Kc = \sigma_f \sqrt{\pi c}$

Facture initiates in a material as soon as K_c is reached.

Fatigue failure ;

Ductile materials may also fracture when subjected to cyclic stresses. The cyclic stresses are considerably lower than the static fracture stress such a delayed fracture resulting from extended service is called fatigue.

A fatigue failure can occur well below the yield stress of a material. For example for mild steel, the yield strength is 220 MNM^{-2} but it fails at a stress of 140 MNM^{-2} when subjected to large number of cyclic stresses i.e. stress reversals.

Fatigue limit ;

Fatigue limit or the endurance limit can be defined as the stress that would cause failure after a specified number of stress reversals.

Note :

When the applied stress is below the fatigue limit, the material withstands any number of stress reversals.

Prevention of fracture :

a) Good design avoiding the sharp corners and there by eliminating the stress concentration increaser the fatigue life.

b) Removal of surface irregularities which may initiate a crack by polishing the surface of the component is yet another method of increasing the fatigue resistance.

c) One also harden the surface either by carburizing or nitriding to increase the resistance to the crack initiation at the surface.

Creep ;

One may be under the assumption that stress and strain occur simultaneously but in the case of many materials this is not entirely true. Under the influence of a constant applied stress the material may continue to deform indefinitely. This process is called creep.

Creep can be defined as the permanent deformation of a material under load as a function of time, particularly at elevated temperatures.

Creep is influenced by minor variations in metallurgical conditions. some of these affecting variables are

i) Grain Size
ii) Prior Strain
iii) Formation of solid solutions &
iv) Precipitation & Dispersion hardening

The Characteristics of a creep resistance materials.

i) Instantaneous extension produced as soon as the test load is applied.
ii) Primary or transient creep stage during which further work hardening occurs.
iii) A steady state or secondary creep during which the work-hardening effect of plastic deformation is balanced by recovery.
iv) A period of accelerating or tertiary creep leading to eventual fracture.