Gopalan College of Engineering and Management
(ISO 9001:2015)
Approved by All India Council for Technical Education (AICTE), New Delhi
Affiliated to Visvesvaraya Technological University (VTU), Belagavi, Karnataka
Recognised by Govt. of Karnataka
Address: 181/1, 182/1, Sonnenahalli, Hoodi, K.R.Puram, Whitefield, Bangalore, Karnataka - 560 048
Phone No: (080) - 42229748 **Email:** gcem@gopalancolleges.com **Website:** www.gopalancolleges.com/gcem

MODULE-WISE SOLUTIONS

Year / Semester	II / IV
Course Code	21AE44
Course Name	Mechanics of Materials

Module 5: Mechanical Properties of Materials

1. **Define fracture. Explain types of fracture in materials. (10 Marks) Aug./Sept.2020, 18AE34**

Fracture is the separation or fragmentation of a solid body into two or more parts under the action of load. During fracture atomic bonds are broken and new surfaces are formed.

TYPES OF FRACTURE

Fractures are broadly classified into

(i) Ductile or Type I fracture

(ii) Brittle or Type II fracture

(iii) Shear or Type III fracture

i) Ductile fracture or Type I fracture

It is characterised by an appreciable amount of plastic deformation. The fracture proceeds relatively slowly and the fracture surface is dull in appearance. Ductile fracture is of two types:

(a) Highly ductile fracture.

(b) Moderately ductile fracture or Cup and Cone Fracture.

(a) Highly ductile fracture : In this the material necks down to a point fracture and yields to 100% reduction in cross sectional area.

Eg : soft metals like pure gold, lead etc.,

Fig. 1.41 : Highly ductile fracture

(B) CUP AND CONE FRACTURE - STAGES

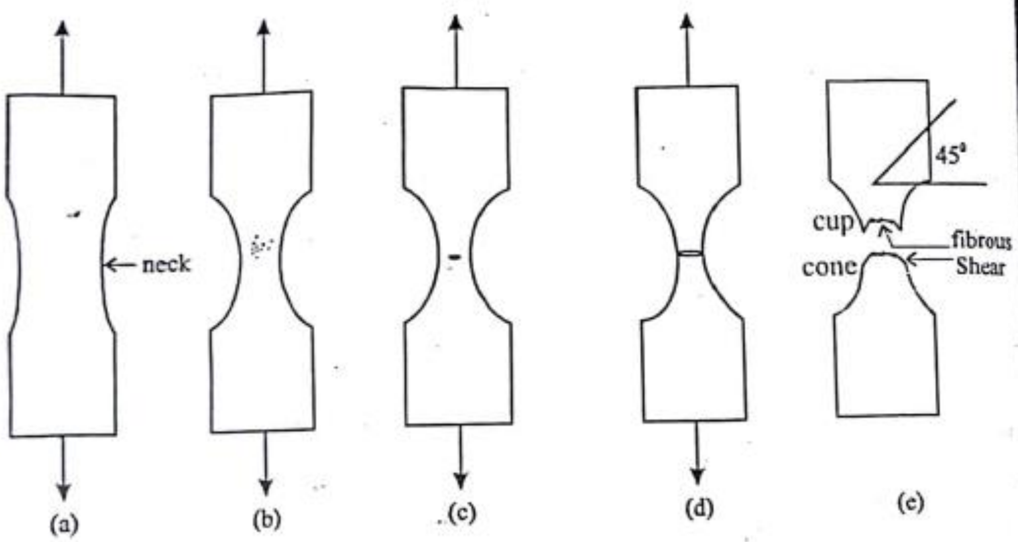

Fig. 1.42 : Stages of Cup and cone fracture

Stage (a) - Initial necking or reduction in cross - sectional area takes place.

(b) - Small cavities or voids form in the interior of the cross section.

(c) - As load is increased these minute cavities join together (co-alesce) to form an elliptical crack which has its long axis perpendicular to the direction of load.

(d) - The crack continues to grow in a direction parallel to its major axis.

(e) - Finally, fracture results due to rapid propagation of the crack.

The fracture surface has two portions. One is the outer perimeter of the neck where fracture takes place by shear deformation at an angle of 45° approximately to the tensile load because this is the angle at which the shear stress is maximum. The other portion is the interior which has an irregular or fibrous appearance while the sheared portion will have a shiny surface.

ii) Brittle fracture or Type II fracture

Like in ductile fracture, here also small cavities join together to form a crack and this crack propagates. But all these stages happen instantly and the material failure takes place suddenly.

Fracture surface is granular and almost normal to the direction of the tensile load. There is successive and repeated breaking of the bonds at the atomic level, along specific crystallographic planes called cleavage planes (for example (0001) basal plane in HCP zinc).

Tendency for brittle fracture is increased with (a) decreasing temperature (b) increasing strain rate or rate of loading (c) tri-axial stress conditions usually produced by a notch.

Intergranular fracture : In this the crack propagates along the grain boundaries and fracture occurs.

Intragranular Fracture : In this the fracture crack passes through the grains and the fractures surface looks granular. This is also known as *Transgranular fracture*.

Fig. 1.43 (a) : Brittle fracture

iii) Shear Fracture or Type III fracture

This type of fracture is found in ductile single crystals. This is promoted by shear stresses and occurs as a result of extensive slip on the active slip plane. Fracture surfaces are normally at 45^0 to the direction of tensile load and appear shiny owing to extensive slip between surfaces before fracture.

Note to students : *To understand the different types of fracture, take chalk pieces and try to break it by (i) pulling it apart (ii) crushing (iii) twisting holding both ends.*

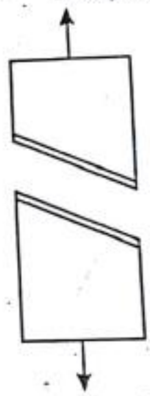

Fig. 1.43 (b) : Shear fracture

2. What is creep? Explain the stages of creep deformation. (10 Marks) Aug./Sept.2020, 18AE34

CREEP

Description of the Phenomenon

When materials under several service conditions are required to sustain steady loads for long periods of time, they undergo a time dependent deformation. This is known as **creep** and can also be defined as '*the slow and progressive deformation of a material with time at constant stress*'. In other words, creep deformation refers to that permanent deformation which occurs in materials that are exposed to lower values of stress (< elastic limit) but for a prolonged length of time.

THREE STAGES OF CREEP - THROUGH CREEP CURVE

The creep curve is obtained by applying a constant tensile load below the yield point to a specimen maintained at constant temperature. The strain or the elongation of the specimen is then determined as a function of time.

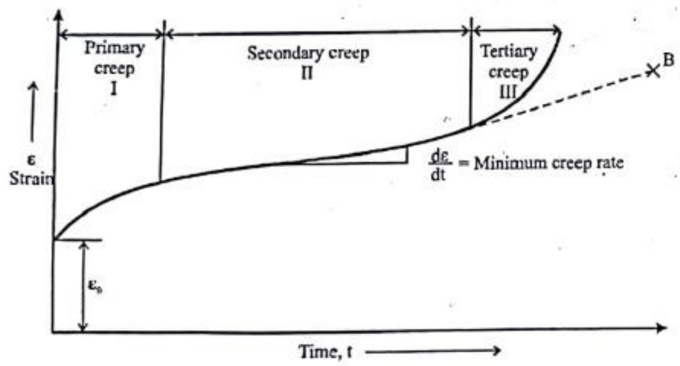

Fig. 1.53 : Three stages of Creep Deformation

(i) Primary Creep :

This is the first stage of the creep which represents a region of decreasing creep rate. In this region the rate at which the material deforms decreases with time until it reaches a constant value. The creep rate goes on reducing because as the metal deforms it undergoes *strain hardening* and offers more and more resistance to further elongation. Primary creep is predominantly a period of transient creep. Primary Creep is important for those materials which undergo creep at room temperature.

(ii) Secondary Creep :

This stage is a period of nearly constant creep rate. The creep rate is constant because *'strain-hardening'* and *'recovery'* effects balance each other. The average value of the creep rate during secondary creep is called the minimum creep rate. This is an important part of the curve because most of the working components will be in this state. Secondary creep is also known as *steady state creep*. Creep in this region takes place by the viscous flow in the materials.

(iii) Tertiary Creep :

This stage is a period of increasing strain rate. Tertiary creep occurs when there is an effective reduction in cross-sectional area due to necking or internal void formation. So the stress at that cross-section increases and consequently the value of strain also increases at a faster rate before the occurrence of fracture.

If the stress is kept constant instead of the load or if true strain is taken into consideration then the resulting fracture due to creep would be at 'B'.

3. Define fatigue. Explain the stages of fatigue failure. (10 Marks) Aug./Sept.2020, 18AE34

Fatigue is the phenomenon of structural failure due to repeated cyclic loading, causing cracks and material damage over time.

Stages of fatigue failure

Let us consider a ductile material which is subjected to simple alternating tensile and compressive stresses. Failure by fatigue is found to take place in three stages :

(i) Crack nucleation (ii) Crack growth (iii) Fracture

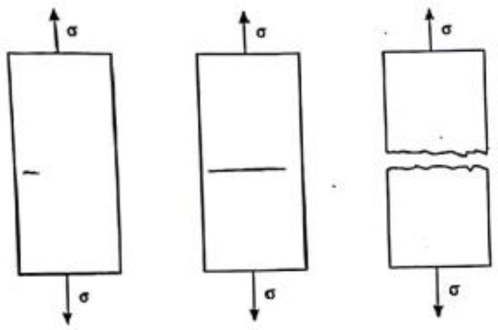

Fig. 1.49 (a) : Crack Nucleation *Fig. 1.49 (b) : Crack growth* *Fig. 1.49 (c) : Fracture*

i) Crack nucleation :

During the first few cycles of loading, localized changes take place in the structure at various places within the material. These changes lead to the formation of submicroscopic cracks. These cracks are usually formed at the surface of the specimen. There are several theories like Orowans theory, Cottrell & Hull theory etc., which explain the mechanism of crack nucleation.

ii) **Crack growth :**

The submicroscopic cracks formed grow as the cycles of loading continue and become microscopic cracks.

iii) **Fracture :**

When critical size is reached, the crack propagates. The area of cross-section supporting the load gets reduced thus increasing the stress value and fracture finally occurs.

Non-propagating cracks

Cracks which do not propagate and result in fracture are known as non-propagating cracks. In any solid, there will always be a number of cracks. Only such cracks which attain the critical size will grow (propagate). According to Griffith's theory a crack will propagate and result in brittle fracture only when there is no net energy change in the system with any increase in crack length .

We know that $$\sigma_f = \sqrt{\frac{2E\gamma_s}{\pi C}}$$

or $$C = \frac{(2E\gamma_s / \pi)^2}{\sigma_f}$$

Where C = half of crack length which results in fracture

4. Write a note on the following: (i) S-N diagram (ii) Factors affecting fatigue (10 Marks) Aug./Sept.2020, 18AE34

S-N DIAGRAMS

The S-N curve which gives information on the fatigue behaviour of a material is a plot of stress (S) against the number of cycles to failure (N). The value of stress that is plotted can be σ_a, σ_{max}, σ_{min}. The values of N are usually taken along a log scale.

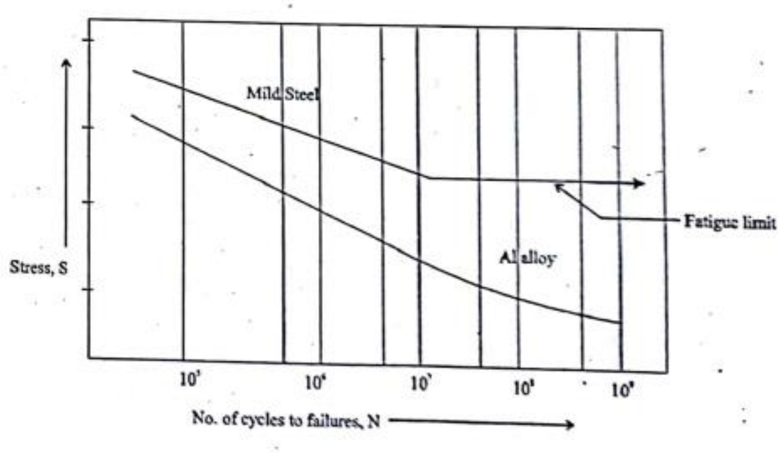

Fig. 1.52 : S-N curves of Mild steel and Alloy

Material Science

The S-N curve is plotted by applying a cyclic load at any particular value of stress and repeated continuously until the specimen fails. The number of cycles required for failure at that stress in plotted. Specimens would fail for different number of cycles when held at different stresses and hence a number of points are obtained. By joining all these points, a S-N curve typical of that material is obtained.

FACTORS AFFECTING FATIGUE LIFE

1) Effect of stress concentration on fatigue :

Stress concentrations are actually responsible for the majority of fatigue failures occuring in practice. All machine elements contain stress raisers like fillets, key ways, screw threads, porosity etc., Fatigue cracks are nucleated in the region of such geometrical irregularities.

The actual effectiveness of stress concentration is measured by the *fatigue strength reduction factor* (K_f).

It is defined as the ratio of the fatigue strength of a member without any stress concentration (σ_n) to the fatigue strength of the same member with the specified stress concentration (σ'_n).

$$K_f = \frac{\sigma_n}{\sigma_n'}$$

Fatigue failure by stress concentration can be minimized by reducing the avoidable stress - raisers through careful design and the prevention of stress raisers by careful machining and fabrication.

2) Size Effect :

Experiments have shown that fatigue strength of large members is lower than that of small specimens. This may be due to two reasons :

i) The larger member will have a larger distribution of weak points than the smaller one and on an average, fails at a lower stress.

ii) Larger members have larger surface areas. This is important because the imperfections that cause fatigue failure are usually at the surface.

3) Surface Roughness

Practically almost all fatigue cracks nucleate at the surface of the members. Therefore the conditions of the surface such as surface roughness and surface oxidation or corrosion are very important.

Experiments have shown that different surface finishes of the same material can appreciably affect fatigue performance. Smoothly polished specimens have higher fatigue strengths.

4) Surface Residual Stress :

Residual stresses are nothing but locked up stresses which are present in a part even when it is not subjected to an external force. Residual stresses arise during casting or during cold working when the plastic deformation would not be uniform throughout the cross section of the part. Residual stresses can be either tensile or compressive depending on whether it was plastically deformed earlier by tensile or compressive loads respectively.

Those residual stresses at the surface of the members add themselves to the external cyclic stress that is being applied and help in the nucleation of cracks and their further propagation.

5) Effect of Temperature :

(i) **Low temperature :** Fatigue tests on metals carried out at below room temperature shows that fatigue strength increases with decreasing temperature.

(ii) **High temperature :** In general, fatigue strength of metals decreases with increasing temperature above room temperature.

6) Effect of Environment :

Environment also plays an important role in the fatigue behaviour of materials. If fatigue takes place in a metal which is present in a corrosive environment, the rate at which the fatigue crack propagates is greatly increased due to the chemical attack. The combination of corrosion attack and cyclic stresses on a metal is known as corrosion fatigue.

5. **With neat sketch, explain R.R Moore rotating beam test with S.N. diagram for ferrous metals. (10 Marks) July/August 2021, 18AE34**

FATIGUE TESTING - BY R R MOORE REVERSED-BENDING MACHINE

Fatigue failures in engineering materials are observed by conducting the fatigue test which involves the plotting of an S-N diagram. One such test is the R R Moore reversed-bending fatigue testing machine.

Specimens subjected to fatigue test are made to undergo fluctuating or opposite stresses. One such test arrangement is shown in the fig. where the specimen is bent with the help of weights as well as rotated. By this, alternate tensile and compressive stresses are imposed on the various layers of the specimen.

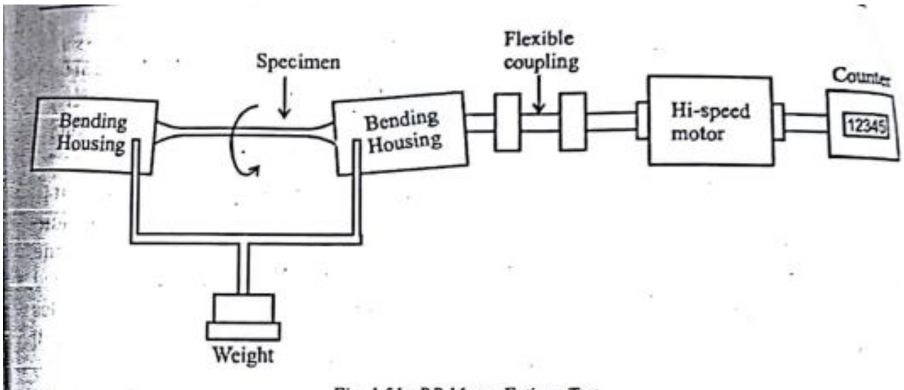

Fig. 1.51 : RR Moore Fatigue Test

A counter coupled to the motor counts the number of cycles to failure. The experiment could be conducted for different loads, and different number of cycles to fractures are noted to draw the S-N diagram.

6. **Define fatigue loading with examples. (05 Marks) July/August 2021, 18AE34**

Fatigue is the phenomenon of structural failure due to repeated cyclic loading, causing cracks and material damage over time

TYPES OF FATIGUE LOADING WITH EXAMPLES

i) Completely reversed cycle of stress :

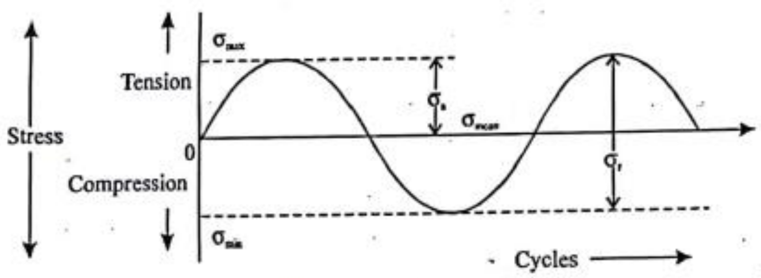

Fig. 1.46 : Alternate tensile and compressive stresses

σ_a = Stress amplitude

σ_r = range of stress

σ_{max} = maximum stress

σ_{min} = minimum stress

σ_{mean} = 0

Fig 1.46 illustrates the type of fatigue loading where a member is subjected to opposite loads alternately with a mean of zero. For example bending of steel wire continuously in either directions leads to alternate tensile and compressive stresses on its surface layers and failure by fatigue.

ii) Repeated stress cycles :

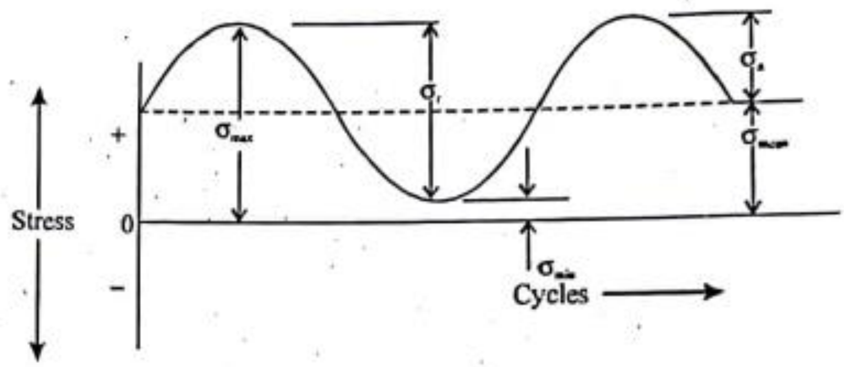

Fig. 1.47 : Various degrees of tension

Fig 1.47 shows the type of fatigue loading where a member is subjected to only tension but to various degrees. A spring subjected to repeated tension as in a toy would lead to fatigue failure.

iii) Irregular or Random stress cycle :

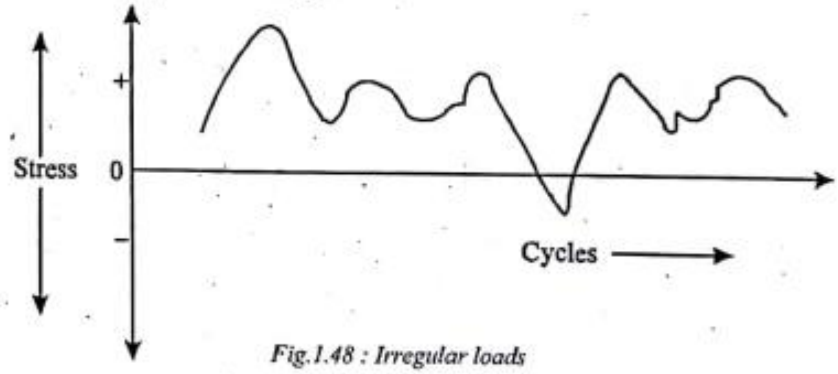

Fig.1.48 : Irregular loads

Fig 1.48 shows a type of fatigue loading where a member could be subjected to irregular loads just as in the case of an aircraft wing subjected to wind loads.