UNIT – 5: MECHANICAL DEFORMATION AND TESTING

PLASTIC DEFORMATION:

- The plastic deformation in metals occurs due to **permanent displacement of atoms or molecules from their original position in the lattice** and they do not return to their original position after the removal of load.
- The plastic deformation of single crystal metals takes place by the process of slip and twinning.
- Both slip and twinning occurs by pure shearing stress.

Explain mechanism of PLASTIC DEFORMATION BY SLIP:

Slip is a process or mechanism by which plastic deformation produced as the result of dislocation motion.

The plane over which the dislocations move is called slip plane and the direction of movement of dislocation is called slip direction. The combination of the slip plane and the slip direction is termed as **slip system**.

The following figure illustrates the classical picture of slip.

In figure (a), a shear stress is applied to a metal cube with a top polished surface. Slip occurs when the shear stress exceeds a critical value called **Critical Resolved Shear Stress (CRSS).** The atoms move an integral number of atomic distances along the sip plane, and a step is produced in the polished surface (see figure (b)). When we view the polished surface from above with a microscope, the step shows up as a line and we call it as a slip line.

When the load is further increased, blocks again divided and relative displacement takes place (shown in figure (c)). Slip can be imagined to a pack of playing cards when they are shuffled.

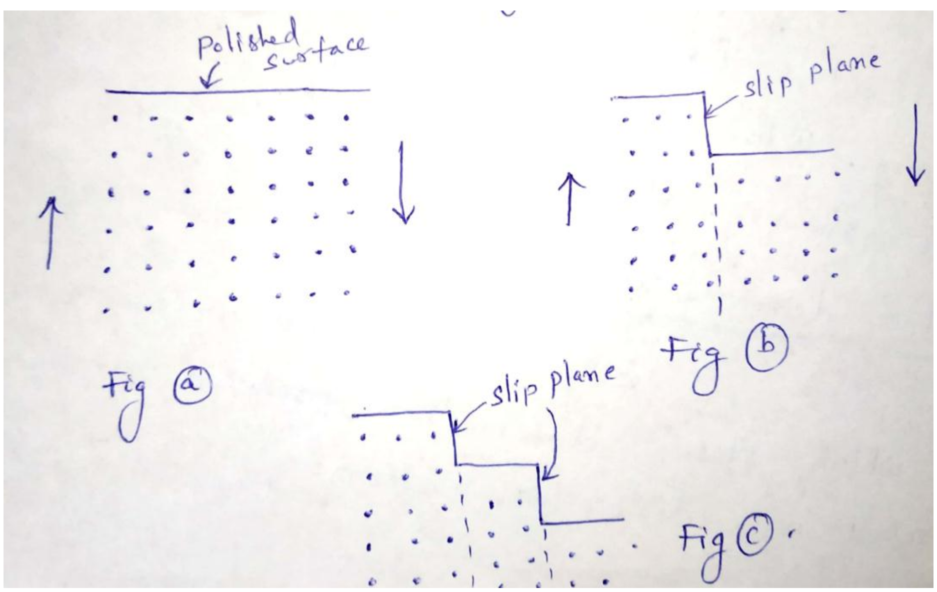


Figure: Schematic representation of slip

Explain mechanism of PLASTIC DEFORMATION BY TWINNING:

Twinning is a prominent mechanism of plastic deformation in some metallic materials. It is a shear force that can produce atomic displacements.

Twinning is a process in which the atoms in a part of the crystal subjected to stress rearrange themselves so that the orientation of the part changes in such a way that the distorted part becomes a mirror image of the other part.

In twinning, each plane of atoms moves through a definite distance and in the same direction. The extent of movement of each plane is proportional to its distance from the twinning plane as shown in figure below. The distanced moved by each successive atomic plane is greater than the previous plane by a few atomic spacings.

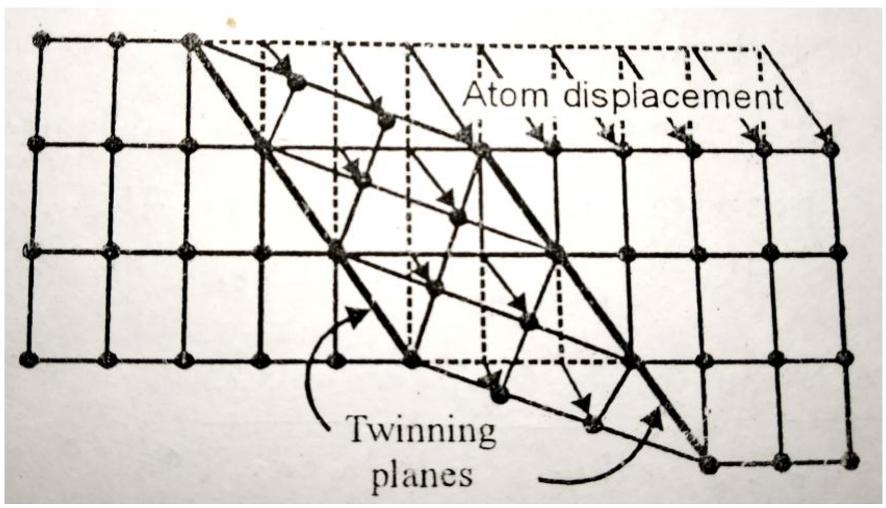


Figure: Schematic representation of twinning

The twinning plane is perpendicular to the paper. When shear stress is applied, the crystal will twin about the twinning plane in such a way that the region to the left to the left of the twinning plane is not deformed whereas the region to the right is deformed. The atomic arrangement on either side of the twinned plane is in such a way that they are mirror reflections of each other.

Twins are known as Annealing twins when they are produced during annealing heat treatment and mechanical twins when they are produced during mechanical deformation of metals.

Write the Differences between slip and twinning:

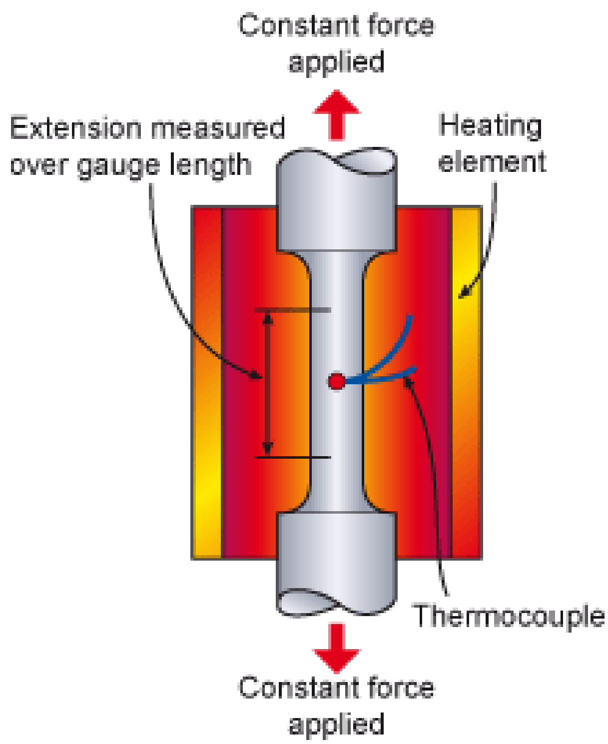
Factor	Slip	Twinning
Amount of movement	Atoms are moved by discrete number of inter atomic distances relative to their initial position. i.e., one inter atomic distance or two inter atomic distances etc.	Movement of atoms is proportional to the distance from twinned planes. Atoms move only interms of fractions of inter atomic distances. i.e.,1/3 or 3/5 inter atomic distances, etc.
Cryatallographic orientation (or) lattice orientation	The slipped crystal lattice has the same orientation.	The twinned crystal lattice is the mirror image of the original lattice.
Microscopic appearance	Surface of deformed crystal can be seen as thin lines when viewed under microscope.	Twinning can be seen as broad lines when viewed under microscope.
Stress required	The stress required to produce slip is comparatively lower than twinning. Or (the stress required for slip is comparatively low)	The stress required for twinning is comparatively higher than slip. Or (the stress required for twinning is comparatively more)
	The stress necessary to propagate slip is usually higher than the stress required to start slip.	The stress necessary to propagate twinning is lesser than that required starting it.
	For slipping to occur, a threshold value of stress called critical resolved shear stress is required.	For twinning to occur, no such threshold value of stress is required.
Number	Slip lines may be present in even or odd numbers.	Twin lines always occur in pairs.
Time	Slip takes several million seconds to occur, i.e. there is a delay time of several million seconds prior to forming of one slip band.	Twins can form in a few micro-seconds only.
	Crystal slip is a line defect.	Twinning is a surface defect or grain boundary defect.
	Slip is commonly observed in Body Centered Cubic (BCC) and Face Centered Cubic (FCC) metals.	Twinning is commonly observed in Hexagonal Close Packing (HCP) metals.
	After the slip, the crystal axis remains the same.	After twinning, the crystal axis is deformed.

CREEP:

- Creep is defined as the time dependent strain or plastic deformation of materials when subjected to a constant load at elevated temperature.
- Slow and progressive deformation is called creep

Creep test:

- A creep test is simply a tension test run at constant load and constant temperature and is shown in figure below.



Creep test

- Initially, gage length on the specimen is marked and noted down.
- In this test, the specimen is subjected to constant load and constant temperature. These two parameters are kept constant till the completion of the test.
- The extension or change in the gage length is noted from time to time.
- The strain of the specimen is determined from time to time.
- Strain verses time graph is plotted and is called creep curve.
- The time required to complete this test may take several months or years.
- A typical creep curve is shown in figure

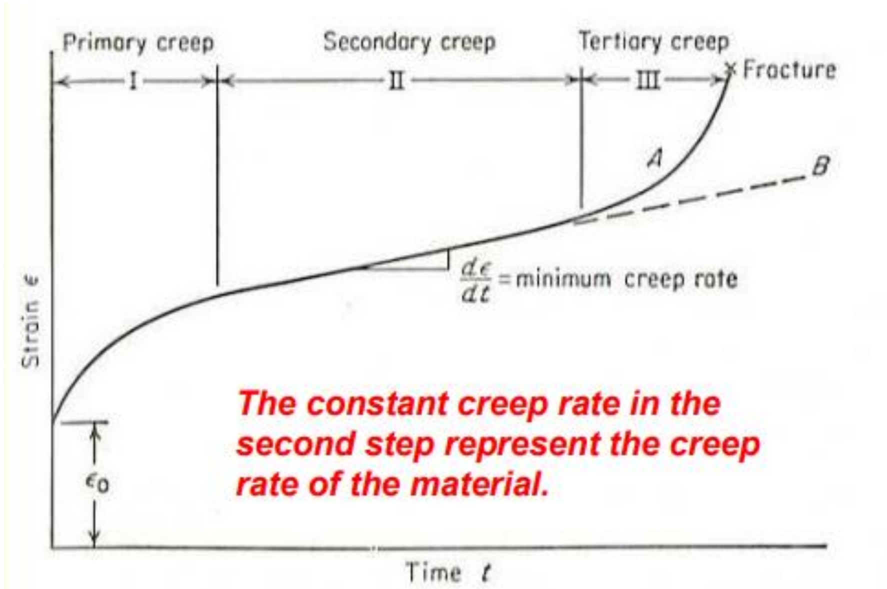


Figure: Typical creep curve

Whenever we apply a load on a material, there is a instantaneous strain or deformation (ε_0) and is indicated in the creep curve. It is elastic strain.

Creep curve consisting of three regions or stage namely Primary creep or transient creep, secondary creep or steady state creep and tertiary creep.

Primary creep:

In this region **the creep rate decreases with time** i.e **the slope of the curve diminishes with time** because of strain or work hardening process. Because of strain hardening, the material resists the plastic deformation that is why the first region of creep curve slope diminishes with time.

Secondary creep:

During this secondary or steady state creep (also called minimum creep rate), the deformation continues at an approximately constant rate.

Tertiary creep:

After the secondary creep, **the creep rate increases rapidly with time** until fracture occurs.

Fatigue test:

Fatigue:

- Failure of a material under dynamic loads or repeated cyclic loads is called fatigue.
- The structures which experiences cyclic loads are bridges, planes, machine parts etc.

Fatigue test:

The most commonly used fatigue testing apparatus is rotating – bending test apparatus. The schematic diagram of this apparatus is shown in figure below.

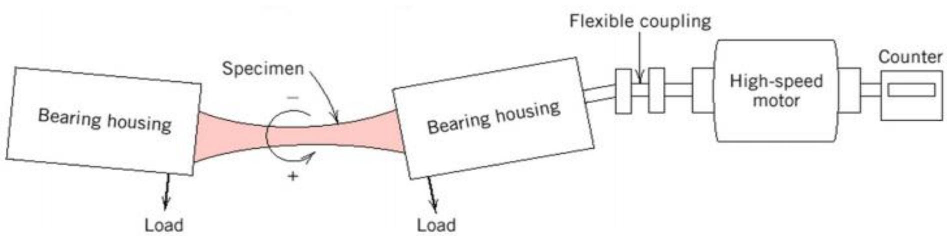


Figure: Fatigue testing apparatus

In this test, the specimen is housed in bearing supports. The test piece or specimen rotates between bearing supports while the load is applied to the specimen. The specimen is subjected to alternative compression and tensile stresses, for every rotation of 180 degrees during testing.

A series of tests are commenced by subjecting a specimen to the stress cycling at relatively large maximum stress amplitude, usually on the order of two thirds of the static tensile strength, the number of cycles to failure is counted. This procedure is repeated on other specimens at progressively decreasing maximum stress amplitudes.

Data are plotted, as stress (S) verses the logarithm of number of cycles to failure (N) for each of the specimens. This curve is called S – N curve.

S – N Curve or diagram:

This is the curve drawn between stress (S) and logarithm of the number of cycles to failure (N).

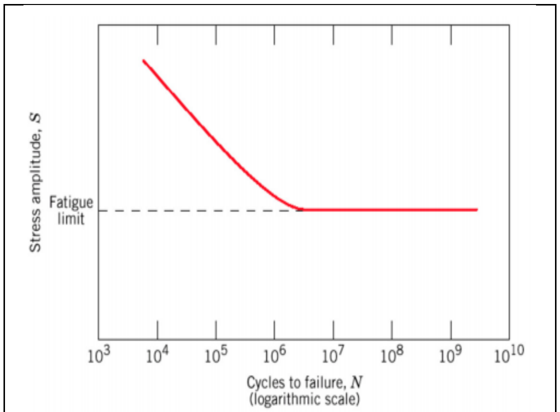


Figure: S-N Curve of Mild steel material

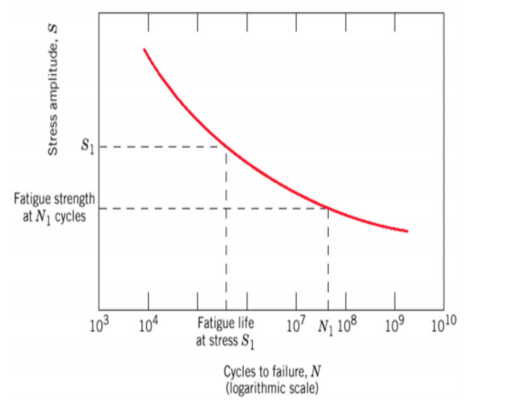


Figure: S-N Curve of Aluminium material

From the above two curves, we can conclude that if S is high N value is less. That means, the higher the magnitude of the stress, the smaller the number of cycles the material is capable of sustain before failure.

Fatigue limit (Endurance Limit)**:**

Stress amplitude below which the material never fails, no matter how large the number of cycles is.

Fatigue strength: Stress at which fracture occurs after specified number of cycles.

Fatigue life: The fatigue life of a member is defined as the number of stress cycles it can stand before failure.

Define fracture. Explain different types of fractures.

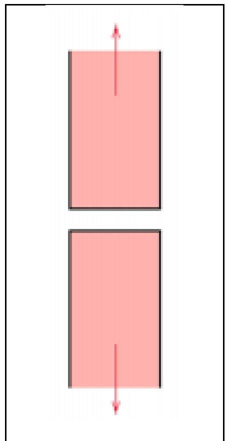
Fracture is the Separation of a body or material in to two or more pieces in response to an imposed stress.

Types of fractures:

Based on the ability of a material to undergo plastic deformation, fractures are classified into two types: (i) Brittle fracture (ii) Ductile fracture

Brittle fracture:

- It is the failure of a material without apparent (considerable amount of) plastic deformation.
- It occurs suddenly and people cannot identify before its occurrence in order to take any preventive actions.
- Brittle fracture is more dangerous than ductile fracture due the following reasons:
    - Damage to property
    - Damage to people
    - Breakdown in production

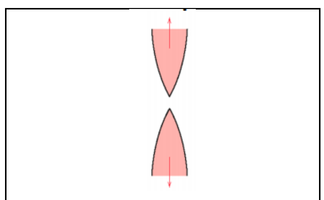


Brittle fracture

Ductile fracture:

- It is the failure of a material with apparent (considerable amount of) plastic deformation.
- It occurs slowly and people can identify before its occurrence. Hence we can take preventive actions.
- There are two types of ductile fractures: (i) Highly ductile fracture (ii) Moderately ductile fracture.

Highly ductile fracture: it can be observed in Lead



highly ductile fracture

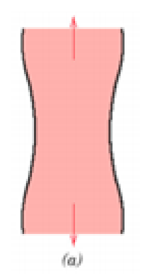
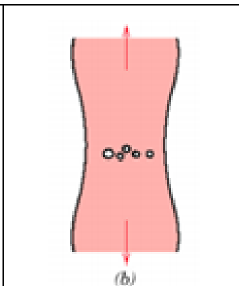
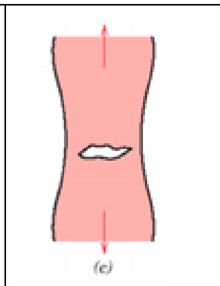
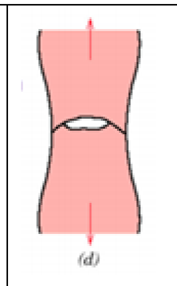
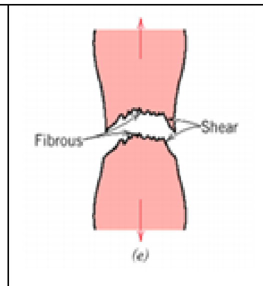
Cup and cone fracture or moderately ductile fracture: it can be observed in Mild steel materials.

Various stages in cup and cone fracture is shown in figure below. Various stages in this cup and cone fracture is as follows.

1. Neck formation: when the applied load reaches the ultimate tensile strength, neck is formed on the material.
2. Formation of voids: when the applied load increased further, void or formation of cavities takes place in the material.

3. Formation of crack: if we increase load further, voids combine together and crack formation takes place inside the material.
4. Crack propagation: crack formed grows towards outer surface by further increase in load.
5. Fracture: the material is going to be failed by increasing the load further.

When we observe the fractured surface, one looks like cup and another one like cone. Hence it is called cup and cone fracture.

				
Necking	void or cavity formation	combination of voids (form of crack)	crack propagation	Fracture

Tensile test:

The standard specimen (ductile material) is fixed in the grips of the Universal Testing Machine (UTM) and a gradually increasing pull is applied. The loads are measured on the main dial of the UTM and the extensions on the elongation scale. The stress-strain diagram is plotted to study the behavior of the material at different loads.

The stress-strain diagram for a mild steel specimen is shown in figure below.

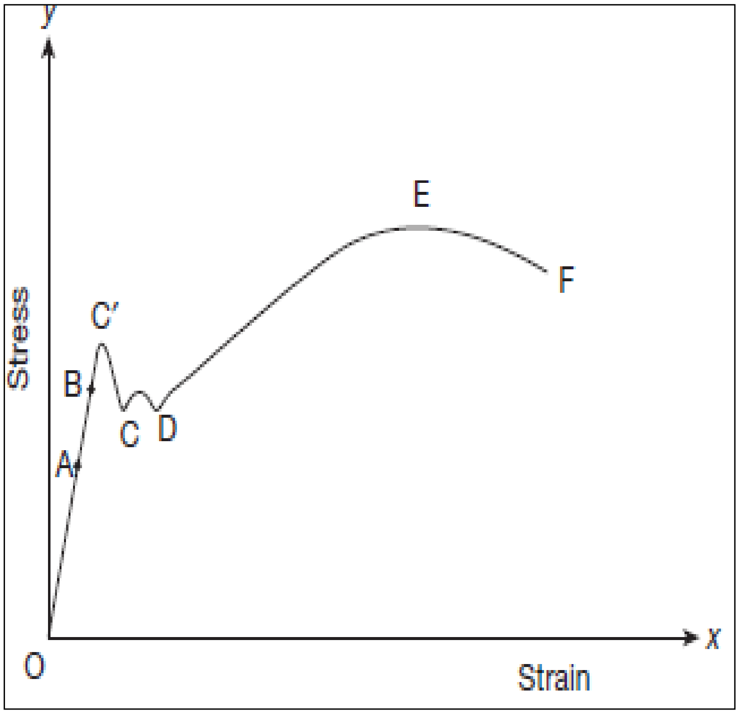
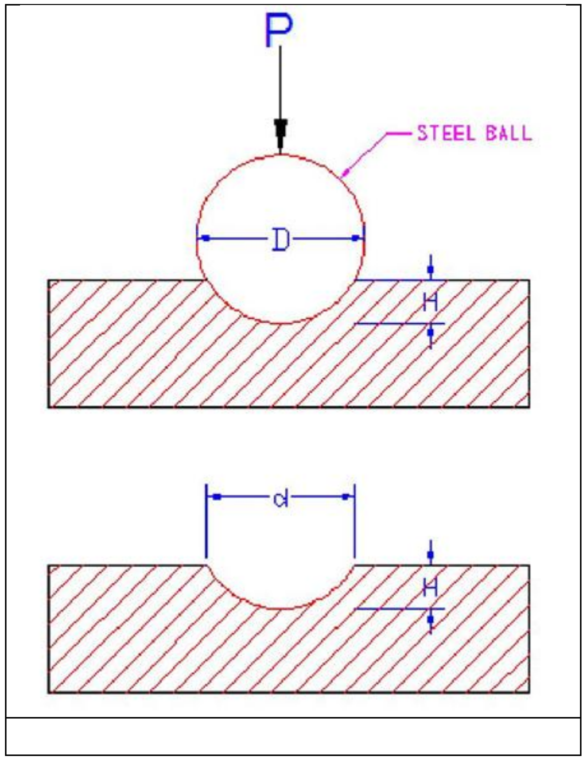


Figure: Stress – strain diagram of a mild steel

The diagram begins with a straight line from O to A, in which stress is directly proportional to strain. Point A shows the limit of proportionality beyond which the curve becomes slightly curved, until point B, this point is the elastic limit of the material. If the load is increased further, it reaches to C` that is yielding point which is called as upper yield point. After that the curve slightly falls down up to C point, which is called as lower yield point. There by the up to point D the graph is horizontal line. This is called Plastic Zone. Point C is the point of sudden large extension, known as yield point. After the yield point stress is reached, the ductile extensions take place, the strains increasing at an accelerating rate as represented by C and D. The material becomes perfectly plastic in this region (C to D), which means that it can deform without an increase in the applied load. If the load is further increased, the steel begins to strain harden. During strain hardening, the material appears to regain some of its strength and offers more resistance, thus requiring increased tensile load for further deformation. The point E is the maximum load or ultimate load up to which the bar extends uniformly over it's parallel length, but if straining is continued, a local deformation (neck formation) starts at E and after considerable local extension, the specimen breaks at F called breaking stress.

Brinell`s Hardness Test:

Brinell hardness test consists in forcing a steel ball of diameter ‘D’ under a load ‘P’ in to the test piece and measuring the mean diameter ‘d’ of the indentation left on the surface after the removal of load. The Brinell hardness is obtained by dividing the test load ‘P’ by the curved surface that is assumed to be a portion of the sphere of diameter ‘D’.



H= depth of indentation = $\frac{D-\sqrt{D^2-d^2}}{2}$

where D = diameter of the indenter; d = mean diameter of indentation.

Brinell Hardness Number = $\frac{2P}{\pi D(D-\sqrt{D^2-d^2}}$