Mechanical Properties

Mechanical Properties

- **TENSILE TEST**
- **FATIGUE TEST**
- **CREEP TEST**
- **HARDNESS TEST**

Tensile Test

INTRODUCTION

- This test is performed to determine mechanical properties like strength, ductility, resilience, toughness and Stiffness of ductile materials.

Tensile Test

- Definition of Stress-Strain
- Testing procedure
- Elastic limit
- Yield stress
- UTS

Tensile Test

- **Resilience**
- **Toughness**
- **Stiffness**
- **Ductility**
- **True Stress- Strain**

Tensile Test

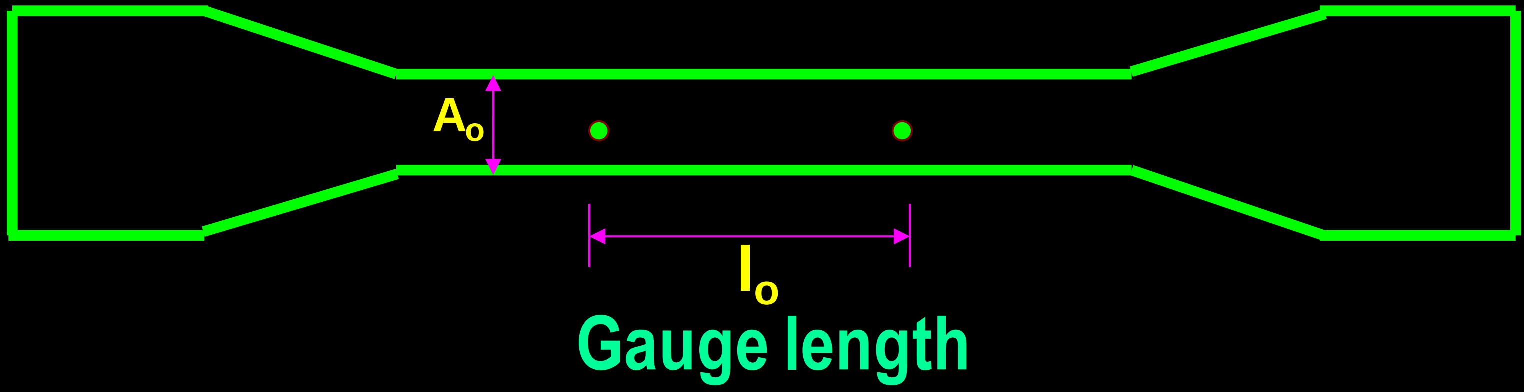
Definition of stress-strain

$$\text{Engineering Stress}(\sigma_E) = \frac{\text{Applied load}(P)}{\text{Orignal area of crosssection}(A_o)}$$

$$\text{Engineering Strain}(\varepsilon) = \frac{\text{Change in length}(dl)}{\text{Orignal length}(l_o)}$$

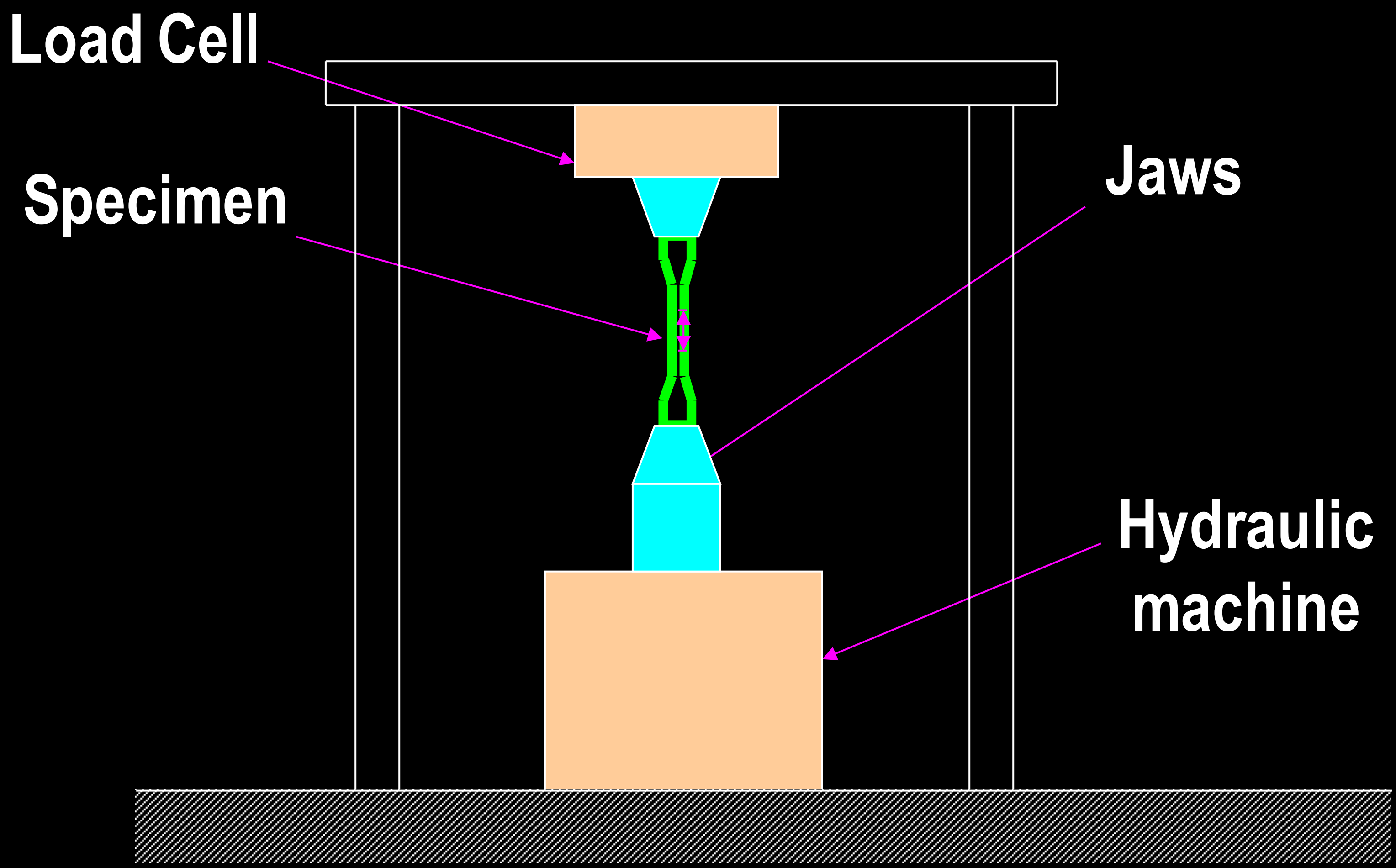
NEXT

Tensile Test



Standard Tensile Test Specimen

Tensile Test



TENSILE TESTING MACHINE

Tensile Test

Testing procedure

- The original gauge length (l_o) is the permanent marks made on the specimen before commencement of the test.

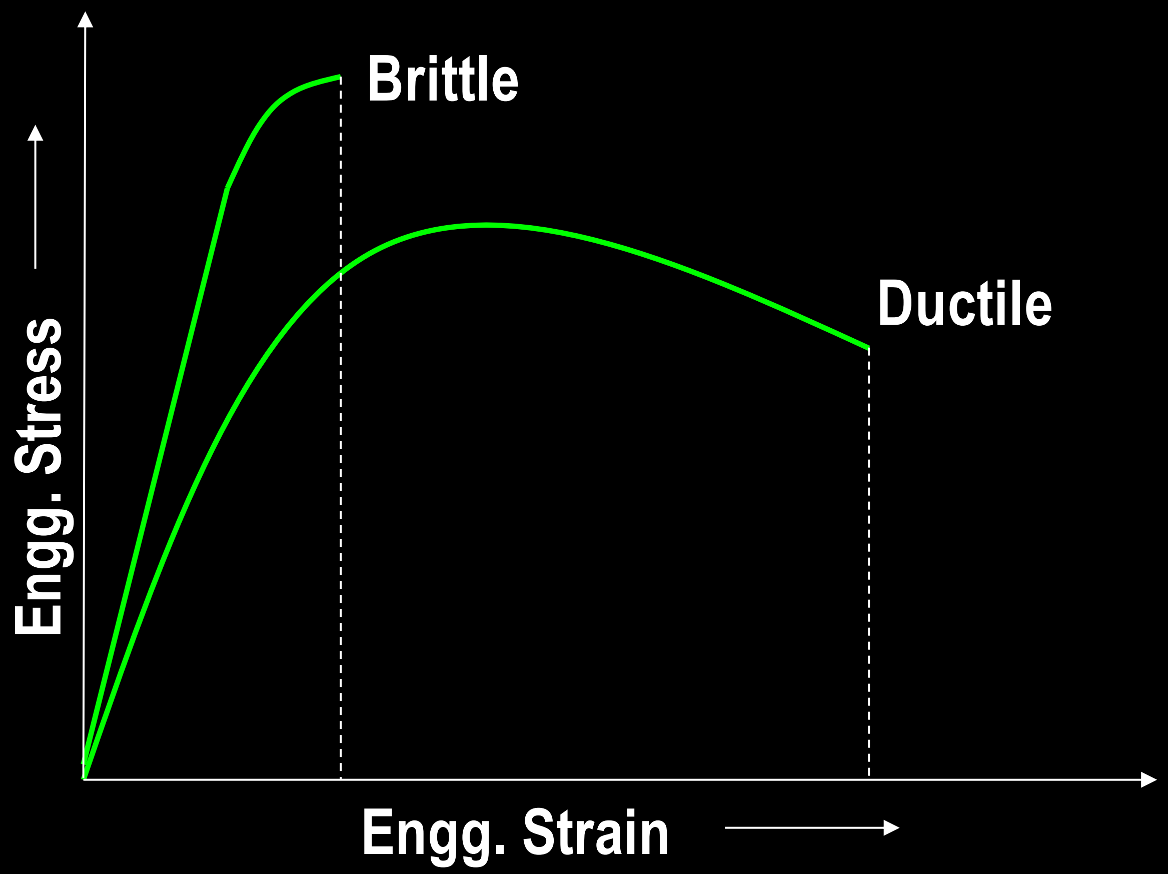
- The specimen is gripped at the two ends in a Tensile Testing Machine, and pulled apart by the application of load.

Tensile Test

- The load applied on the material is measured by a transducer called load cell.

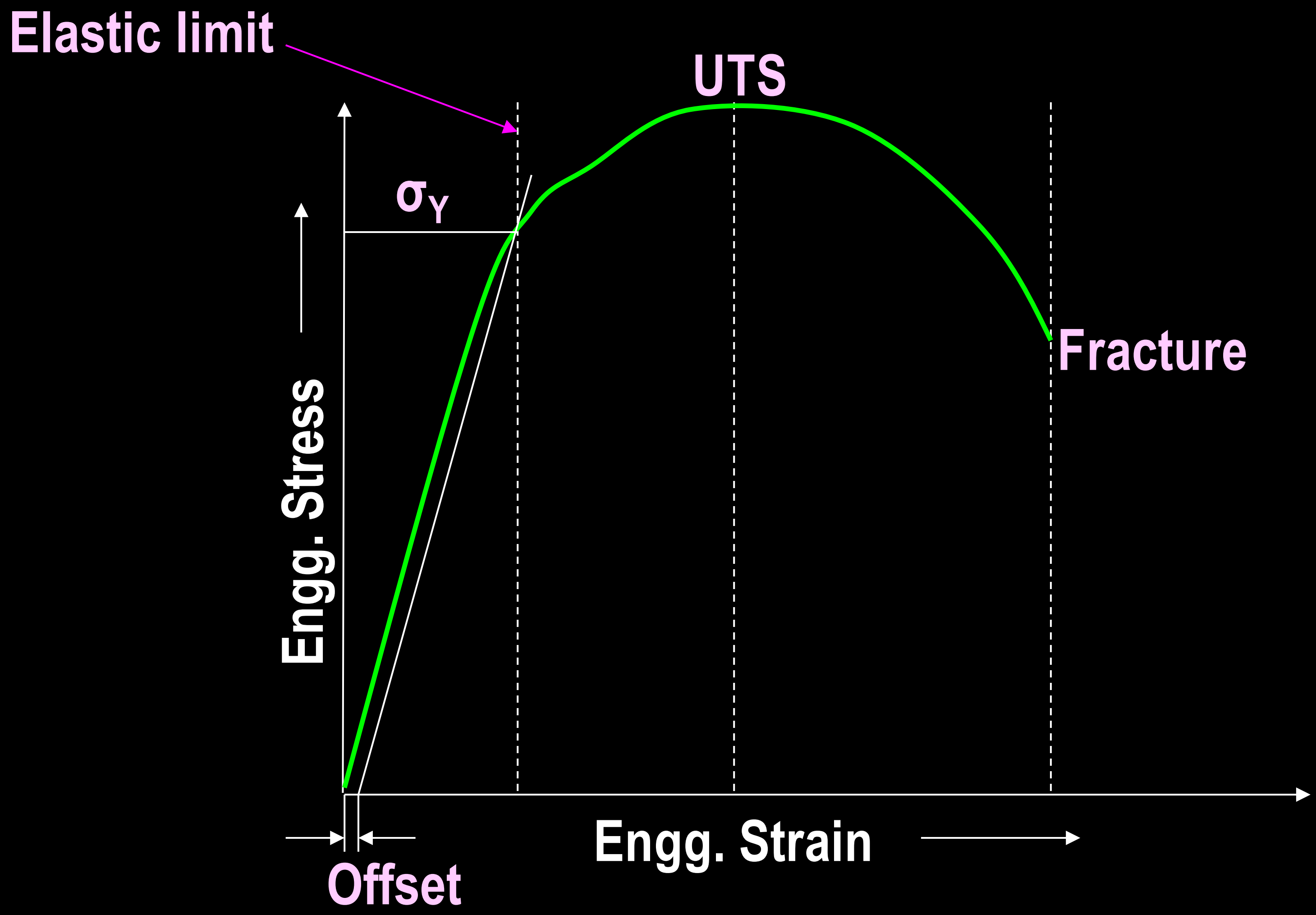
- And the strain is measured using a strain gauge called extensometer.

Tensile Test



Tensile stress-strain behavior for brittle and ductile materials loaded to fracture

Tensile Test



The Different regions of a stress-strain curve

Tensile Test

DESCRIPTION OF THE CURVE

- Initially the deformation is elastic up to yield stress, and the variation of stress and strain is proportional.

- Beyond yield stress the deformation is plastic but the stress keeps on increasing up to UTS due to strain hardening.

Tensile Test

- Beyond UTS the necking (cross section of the material reduces) takes place, therefore the stress required for further deformation decreases.

NEXT

Tensile Test

ELASTIC LIMIT (*EL*)

- **It is the highest value of stress up to which the deformation are elastic and beyond which they are plastic or permanent.**

Tensile Test

- It has two regions as proportional region (obeys Hooks law) and non proportional region.

- In practice non proportional region is assumed to be proportional.

NEXT

Tensile Test

YIELD STRESS (OR) PROOF STRESS (σ_y)

- **Yield stress (YS) is the stress value where plastic deformation starts.**

- **In certain materials like low carbon steels and mild steels there are two yield stress values.**

- **The starting point of plastic deformation is called upper yield stress.**

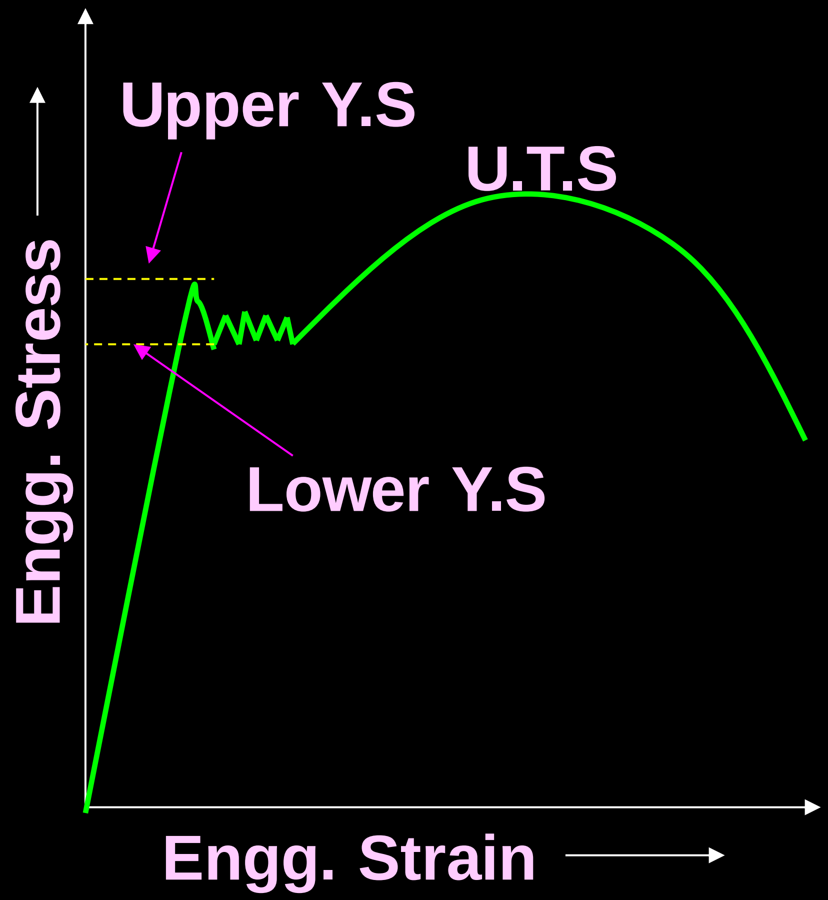
Tensile Test

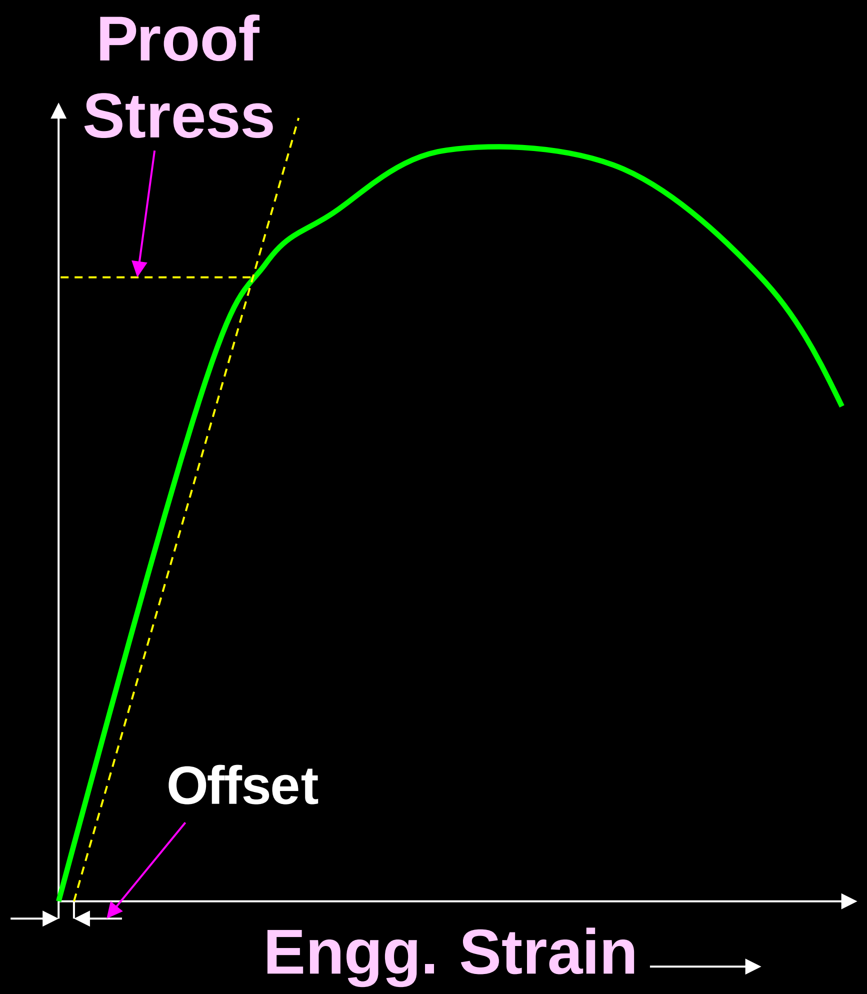
- The stress value corresponding to the plastic deformation at almost constant stress is called **lower yield stress.**

- The lower yield stress is almost remains unaffected with the condition of the steel.

- Therefore, lower stress value is taken as the **yield stress** of the material.

Tensile Test





Tensile Test

- In materials like copper or aluminum the yield point is not well defined.

- Therefore, the yield stress of these materials are given by the stress corresponding to the plastic strain of 0.2% and it is called as 0.2% offset yield stress.

Tensile Test

- **It is determined by drawing a parallel line to the initial linear portion of the curve and passing through the point 0.002 on the strain axis.**

NEXT

Tensile Test

UTS AND FRACTURE STRESS

- **UTS(Ultimate Tensile stress) is the highest value of the stress the material can sustain without fracture.**

- **Fracture stress is the stress where the fracture occurs (material fails).**

NEXT

Tensile Test

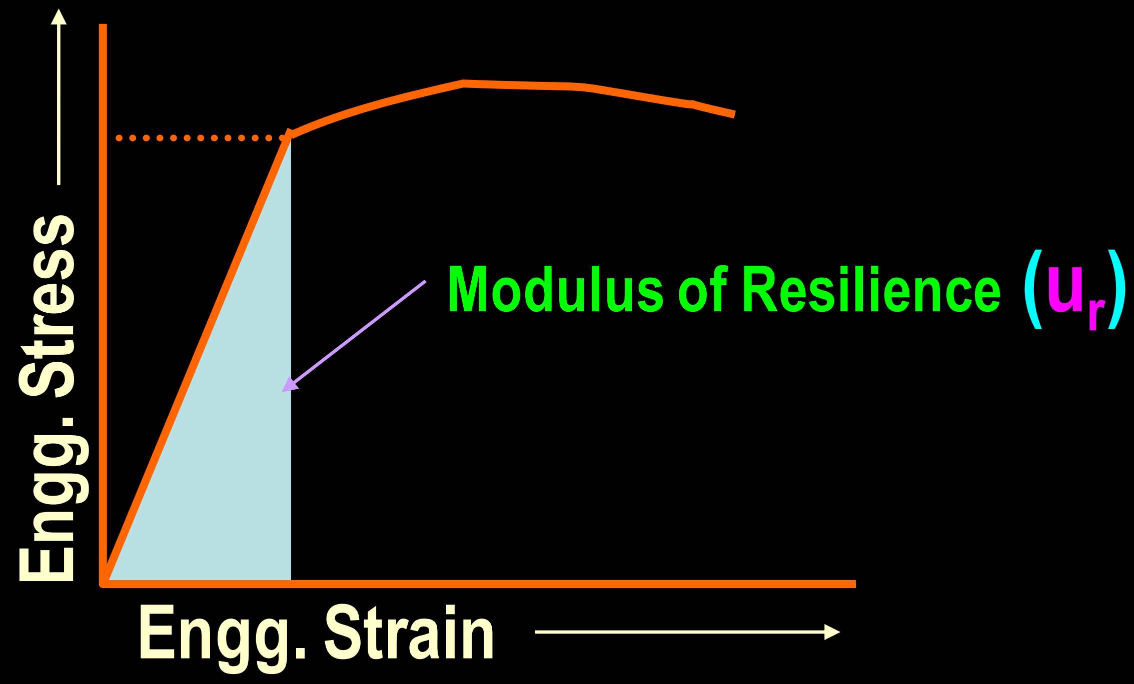
RESILIENCE

- It is defined as the total energy absorbed by the material during its elastic deformation.

$$\text{Modulus of Resilience } (u_r) = \frac{\text{Resilience}}{\text{Volume}}$$

- It is equal to the area under the stress-strain curve up to elastic region.

Tensile Test



Stress-strain curve shows the modulus of resilience

Tensile Test

$$\text{Modulus of resielence} = \frac{\sigma_y \times \varepsilon}{2}$$

$$\text{Where, engg. strain}(\varepsilon) = \frac{\sigma_y}{E}$$

$$\therefore \text{Modulus of Resilence}(u_r) = \frac{{\sigma_y}^2}{2E}$$

σ_y - Yield strength

E - Elastic modulus

NEXT

Tensile Test

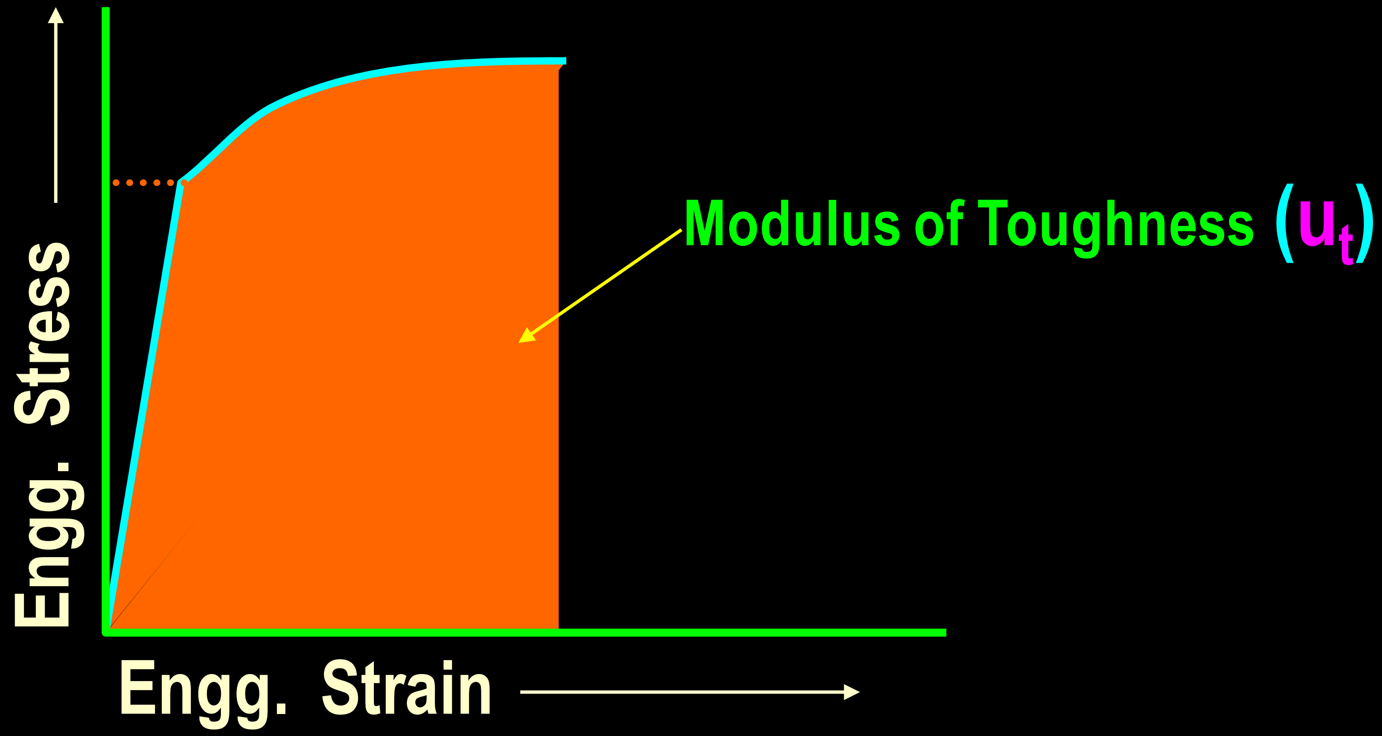
TOUGHNESS

- It is defined as the total energy absorbed by the material upto fracture.

$$\text{Modulus of Toughness } (u_t) = \frac{\text{Toughness}}{\text{Volume}}$$

- It is equal to the total area under the stress-strain curve.

Tensile Test



Stress-strain curve shows the modulus of Toughness

NEXT

Tensile Test

STIFFNESS

- **It is the resistance of the material for elastic deformation and it is nothing but modulus of elasticity.**

NEXT

Tensile Test

DUCTILITY

- **It is the ability of the material to exhibit large plastic deformation prior to fracture under loading conditions.**

$$\%\,Elongation = \frac{Finallength(l_f) - Oringnallength(l_o)}{Oringnallength(l_o)}\, X\, 100$$

- **It is also defined as the ability of the material to be drawn into wire.**

NEXT

Tensile Test

Definition of True stress-strain

$$\text{True Stress}(\sigma_T) = \frac{\text{Instantaneous load}(P_i)}{\text{Instantaneous area of crosssection}(A_i)}$$

$$\text{True Strain}(e) = \frac{l_1 - l_o}{l_o} + \frac{l_2 - l_1}{l_1} + \frac{l_3 - l_2}{l_2} + \ldots..$$

$$= \ln\left(\frac{l_i}{l_o}\right)$$

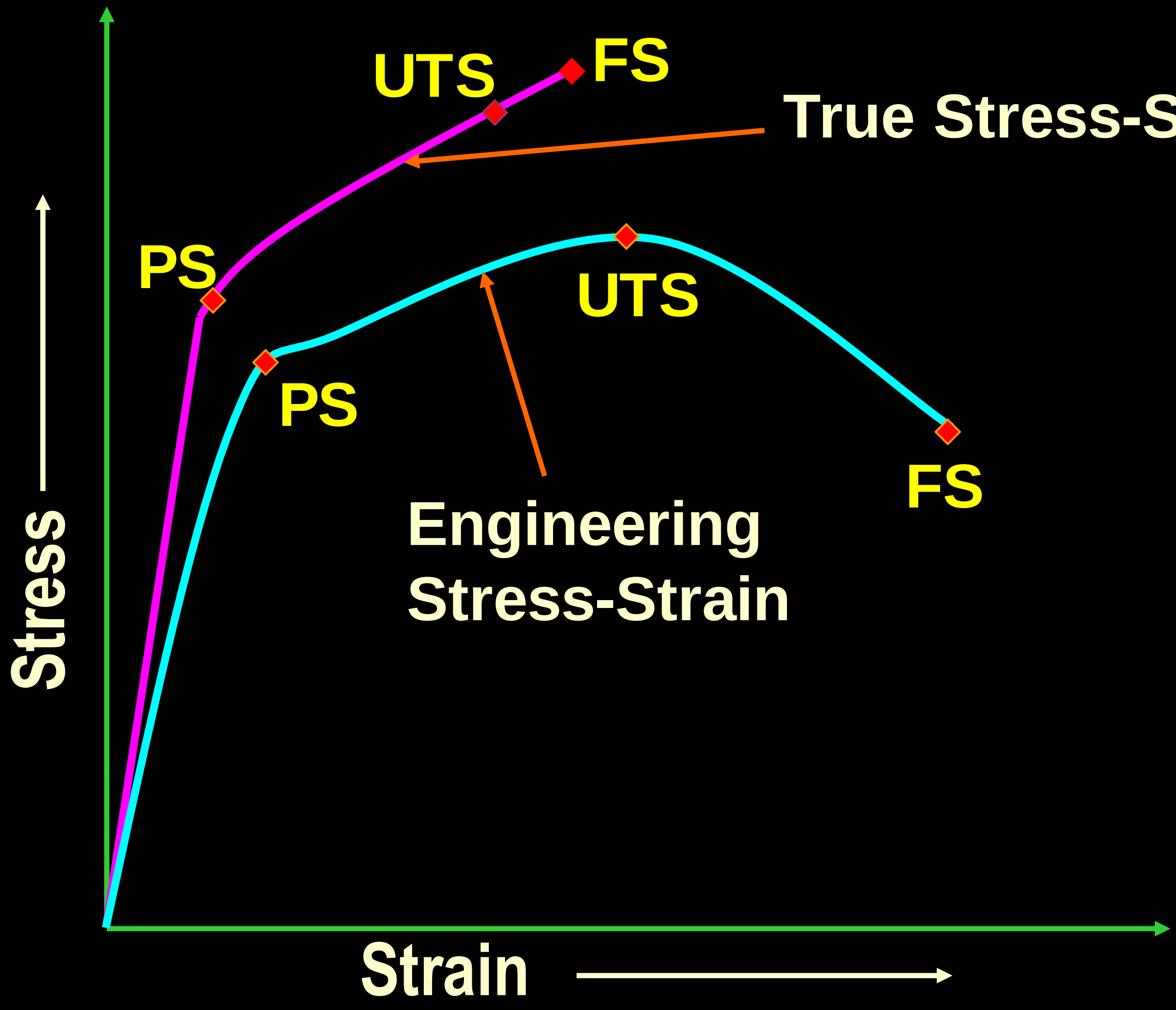
Tensile Test

Relationship between True and Engg. Stress-Strain

True stress(σ_T) = σ_E $(1+\varepsilon)$

True strain(e) = $\ln(1+ \varepsilon)$

Tensile Test



NEXT

Fatigue Test

- **INTRODUCTION**
- **DIFFERENT TYPES OF STRESS**
- **TESTING PROCEDURE**
- **FACTORS AFFECTING FATIGUE LIFE**
- **IMPROVING FATIGUE LIFE**

Fatigue Test

DEFNITION

Due to cyclic loading (I.e. load fluctuation) the material fails at a stress level far below its static UTS. This phenomena is called fatigue of materials.

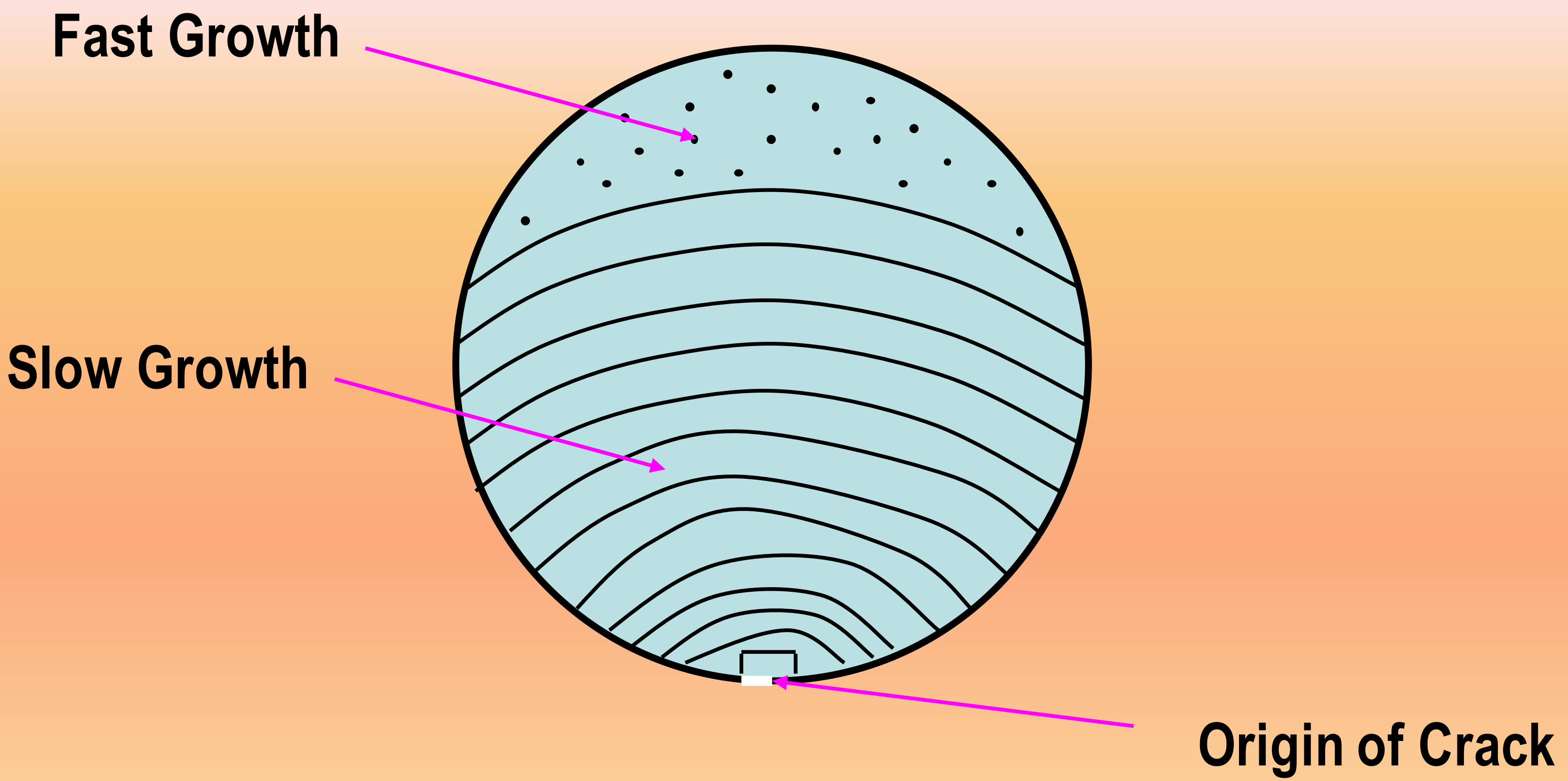
- **The fatigue fracture is a brittle fracture.**

Fatigue Test

- The fractured surface is usually normal to the direction of the principle tensile stress.

- Usually the progress of fracture is indicated by a series of rings called bench marks, progressing inward from the point of initiation of the failure.

Fatigue Test



Typical Fatigue Fracture Surface

NEXT

Fatigue Test

Different Stress Cycles

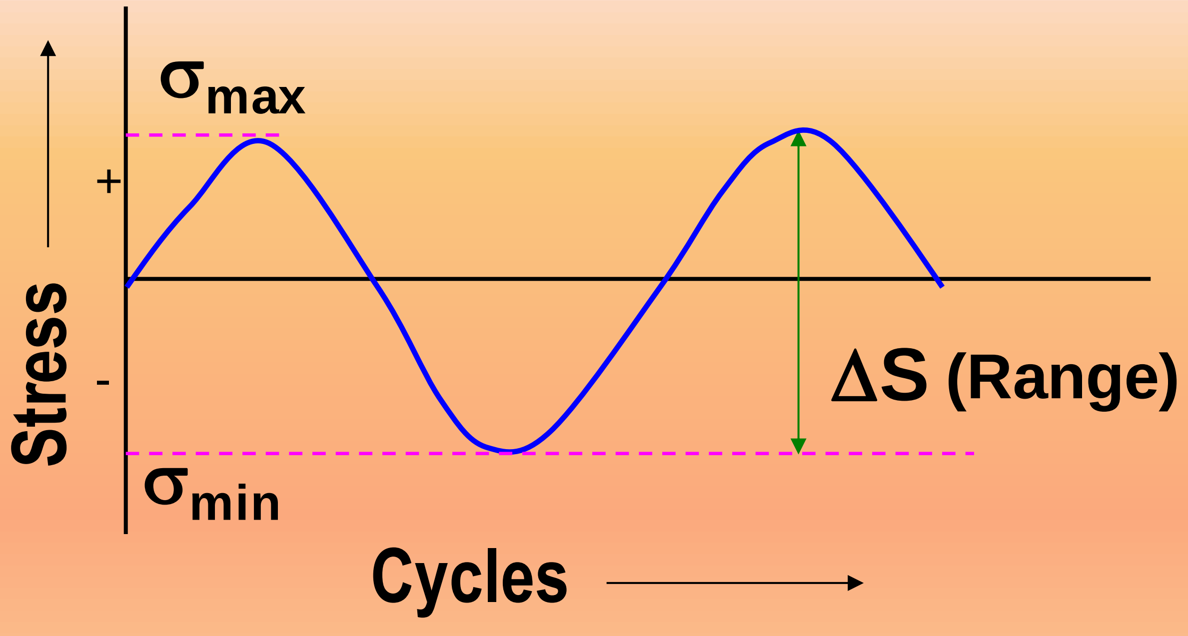
There are different types of cyclic loads as below:

a) Tension – Compression

b) Tension – Tension

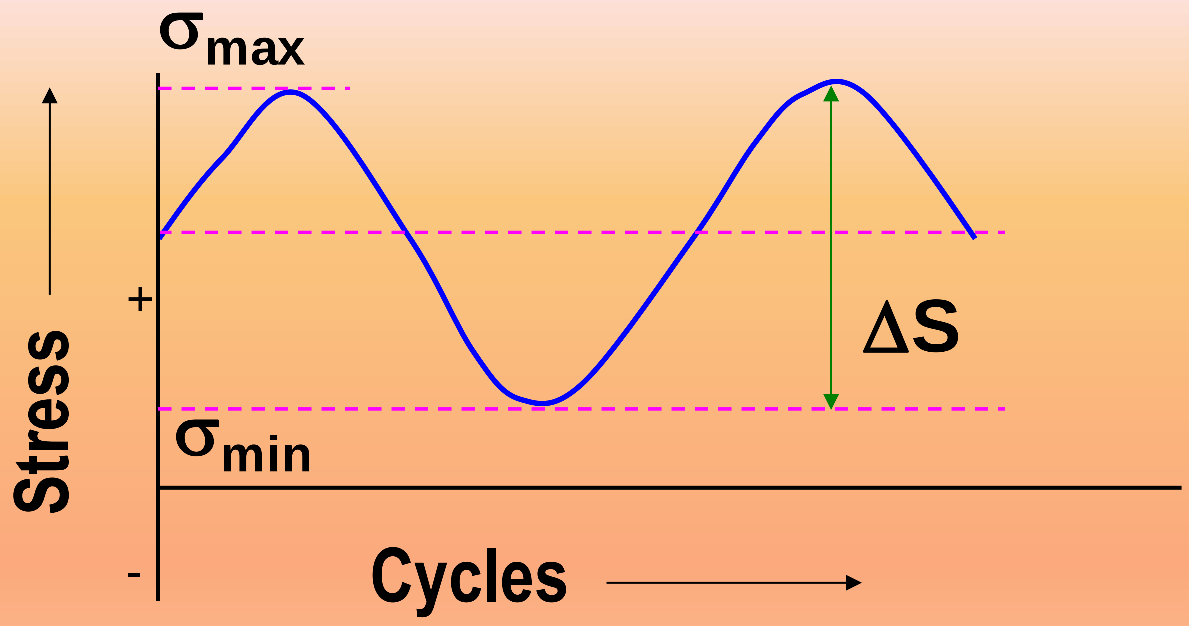
c) Irregular or random

Fatigue Test



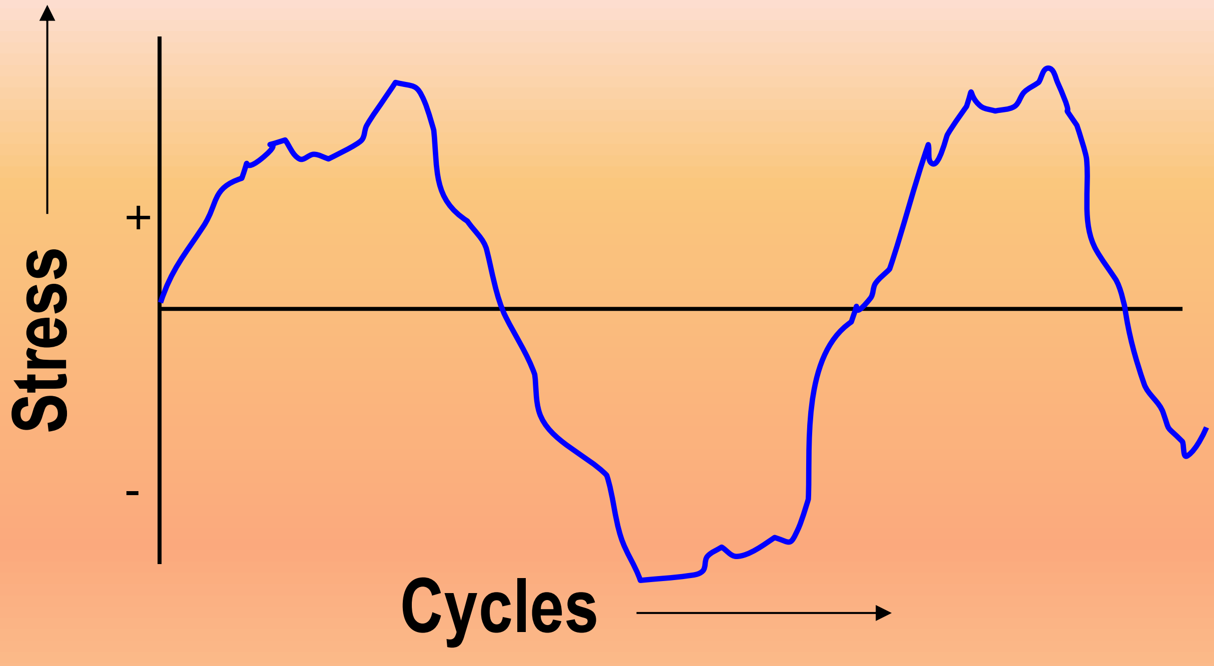
a) Tension - Compression

Fatigue Test



b) Tension - Tension

Fatigue Test



c) Irregular or Random stress

Fatigue Test

- The value $\Delta S = \sigma_{max} - \sigma_{min}$ is called the range of stress.

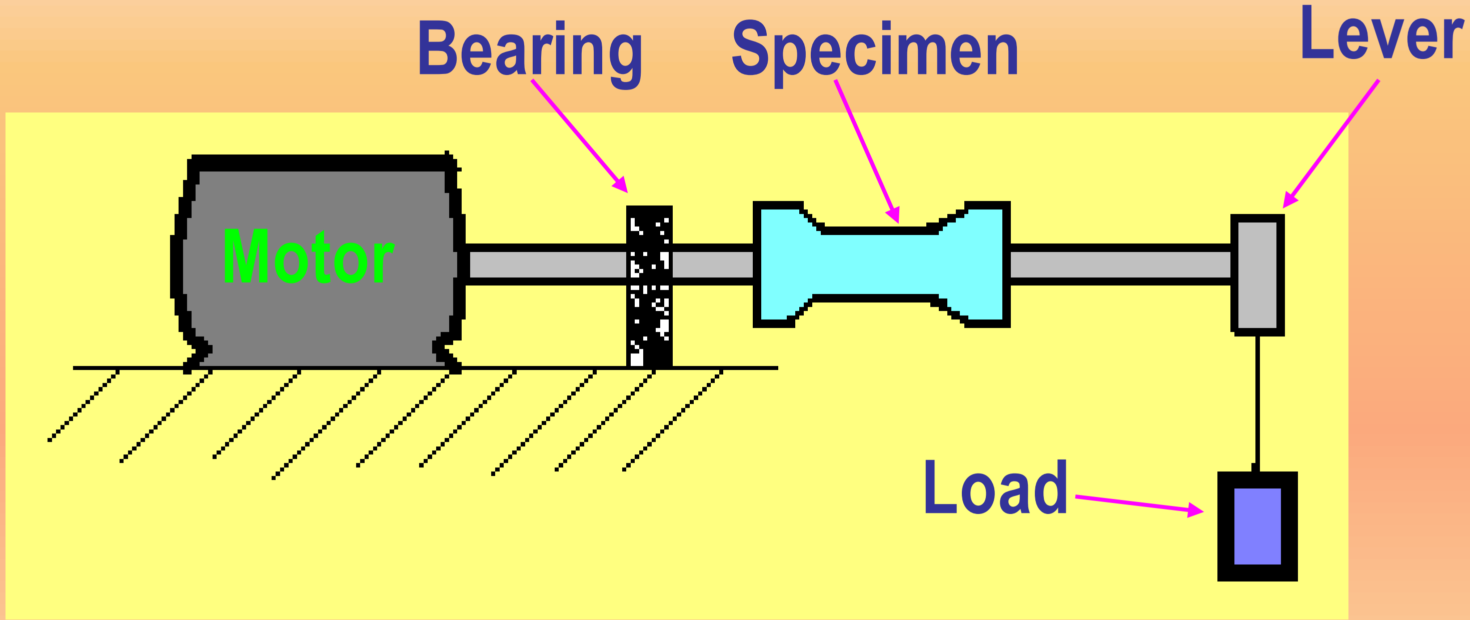
- The stress amplitude (σ_a) is defined as half of the difference between the maximum and minimum stress levels.

$$\sigma_a = \frac{\Delta S}{2} = \frac{\sigma_{\max} - \sigma_{\min}}{2}$$

NEXT

Fatigue Test

Testing procedure



Experimental setup for cantilever fatigue test

Fatigue Test

- **A cantilever type specimen is loaded at one end through a ball bearing and is rotated by means of a high speed motor.**

- **During each revolution, the surface layer pass through a full cycle of tension and compression.**

Fatigue Test

- **The no. of cycles to cause failure will vary with the applied stress(higher the stress lower the cycles and vice versa).**

- **For materials like ferrous and its alloys, there are stress values below which the material doesn't fail for infinite no. of cycles and the corresponding stress value is called** ***fatigue limit or endurance limit.***

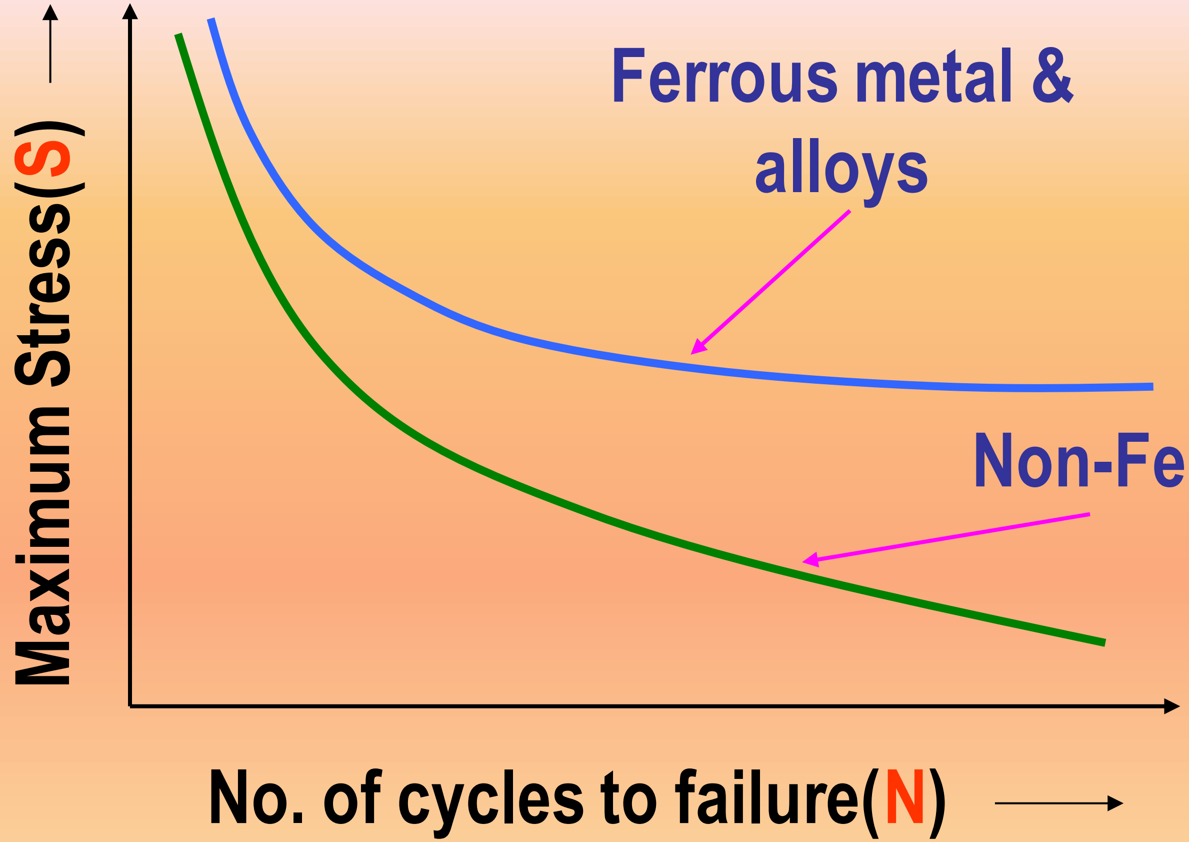
Fatigue Test

- For materials like Cu, Al, etc doesn't have a well defined endurance limit.

- Therefore an operational endurance limit (usually 10^8 cycles) is defined for those materials.

- Fatigue property is understood by S-N curves.

Fatigue Test



Typical fatigue curves (S-N curves)

NEXT

Fatigue Test

FACTORS AFFECTING FATIGUE LIFE

1. The form of stress cycle such as square, triangular or sinusoidal waves has no effect on fatigue life.

2. The frequency of cyclic loading has only a small effect.

3. The environment in which the component undergoes stress reversal has a marked effect on fatigue.

NEXT

Fatigue Test

IMPROVING FATIGUE LIFE

1. By preventing or delaying the initiation of crack at the surface.

2. Carbarizing and Nitriding, introduces residual compressive stress on the surface (this tend to cancel out the fatigue tensile stress on areas of stress concentration there by increasing the fatigue life).

Fatigue Test

3. A fine grain size improves the fatigue life.

4. Polishing of surface increases the fatigue life by reducing stress raisers.

NEXT

Creep Test

- Introduction
- Creep curves
- Creep mechanisms
- Creep reduction & prevention

Creep Test

DEFITION

Creep is the permanent deformation of material under a constant load as a function of time.

- **Creep is more active only above $0.4T_m$, where T_m is the melting point of the material in Kelvin.**

Creep Test

- For example, room temperature is $0.16T_m$ for iron, $0.22T_m$ for copper and $0.5T_m$ for lead.

- Therefore, creep is observed for lead and not observed in iron & copper at room temperatures.

NEXT

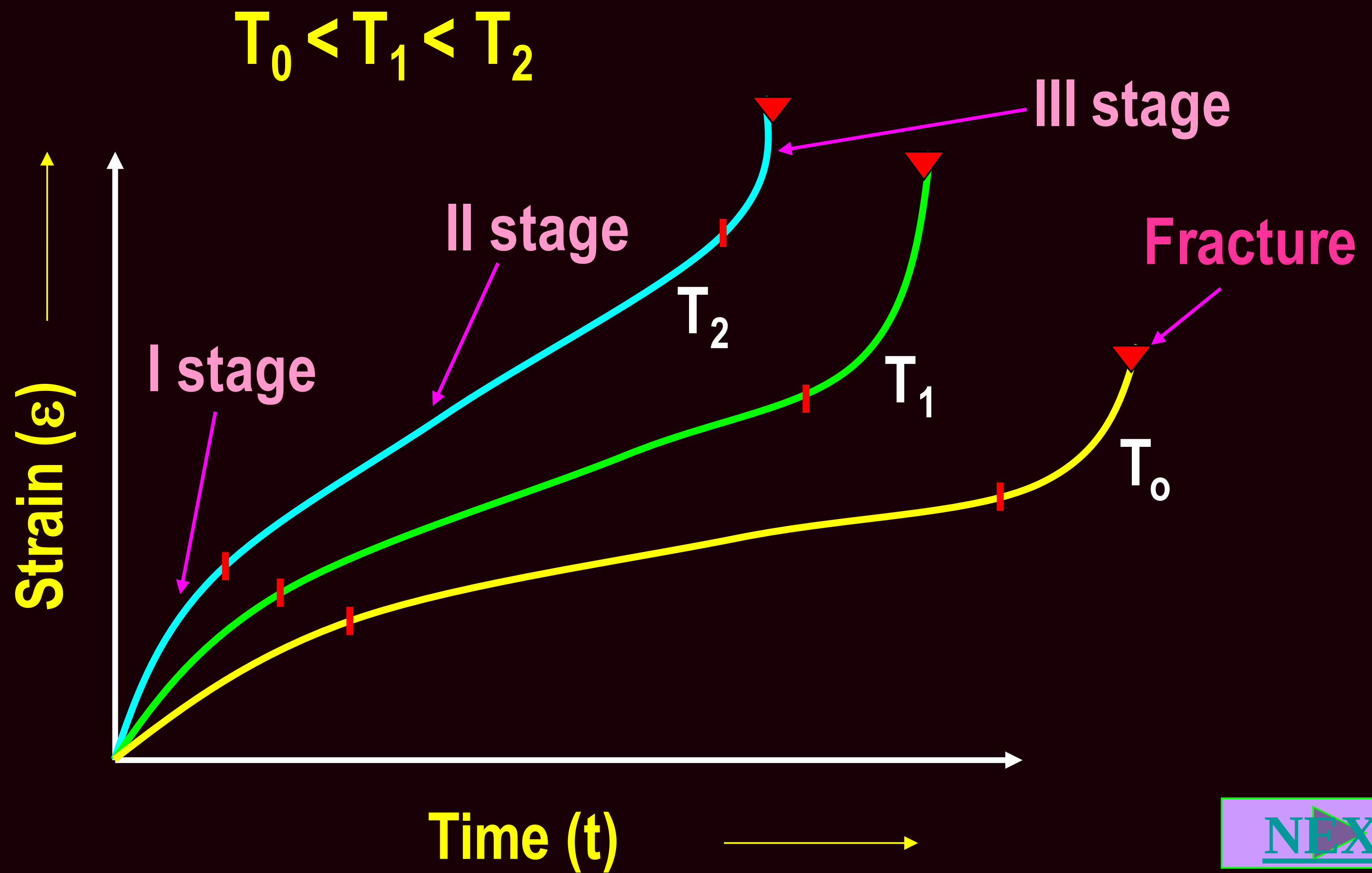
Creep Test

Creep Curves

- A curve which is drawn between strain (ε) and time (t) for a constant load is called creep curves.

- These curves consists of three stages like *primary creep (I stage), secondary creep (II stage)* and *tertiary creep (III stage)* respectively.

Creep Test



NEXT

Typical Creep Curves at different temperatures

Creep Test

Creep mechanisms

- Mechanisms activating the creep behavior are the diffusion of vacancies through grain boundaries, dislocation climb and grain boundary sliding.

- In the primary stage strain rate (or creep rate) is decreasing with time due to more work hardening effect than the softening effect.

Creep Test

- In the second stage the work hardening and softening exactly balance each other.

- In the third stage the softening effect dominates, at this stage voids form at grain junctions, necking occurs and fracture takes place at the end.

NEXT

Creep Test

Prevention or reducing the creep

- The material should have high melting point.

- Strengthening mechanisms like solute strengthening is effective for creep resistance.

Creep Test

- Dispersion hardening (Insoluble particles like Oxides are embedded in a metal matrix)

- Strain hardening cannot be used since recrystalization and associated softening mechanism can occur.

NEXT

Hardness Test

- **INTRODUCTION**
- **MOH’S HARDNESS**
- **BRINELL HARDNESS**
- **ROCKWELL HARDNESS**

Hardness Test

DEFINITION

In general Hardness can be defined as the ability of a material to resist plastic deformation, abrasion, etc .

- **Hardness is expressed using different scales such as Moh's, Brinell, Rockwell, Vickers, etc.**

NEXT

Moh's hardness

- Moh's hardness test measures the hardness of the material as resistance to scratching.

- The scale consists of 10 standard minerals arranged in order of increasing hardness and each mineral is numbered according to its position in the series.

Moh’s hardness

1. TALC
2. GYPSUM
3. CALCITE
4. FLUORITE
5. APPETITE
6. ORTHOCLASE
7. QUARTZ
8. TOPAZ
9. CORUNDUM
10. DIAMOND

Moh’s hardness

- In this method, a scratch is tried to obtain on the specimen surface by these standard minerals.

- If any one mineral doesn't produce a scratch and the other mineral next higher in the series produces a scratch ,then the hardness of the material is between the hardness of these two minerals.

Moh's hardness

- **This method finds limited application in the engineering field because a large number of metals and alloys show same Moh's hardness.**

- **However, it is widely used in the field of Geology for identification of minerals.**

NEXT

Brinell hardness

- **PRINCIPLE**
- **HARDNESS CALCULATION**
- **INDENDER SELECTION**
- **LOAD SELECTION**

Brinell hardness

- **GENERAL PRECAUTIONS**
- **ADVANTAGES**
- **DRAWBACKS**

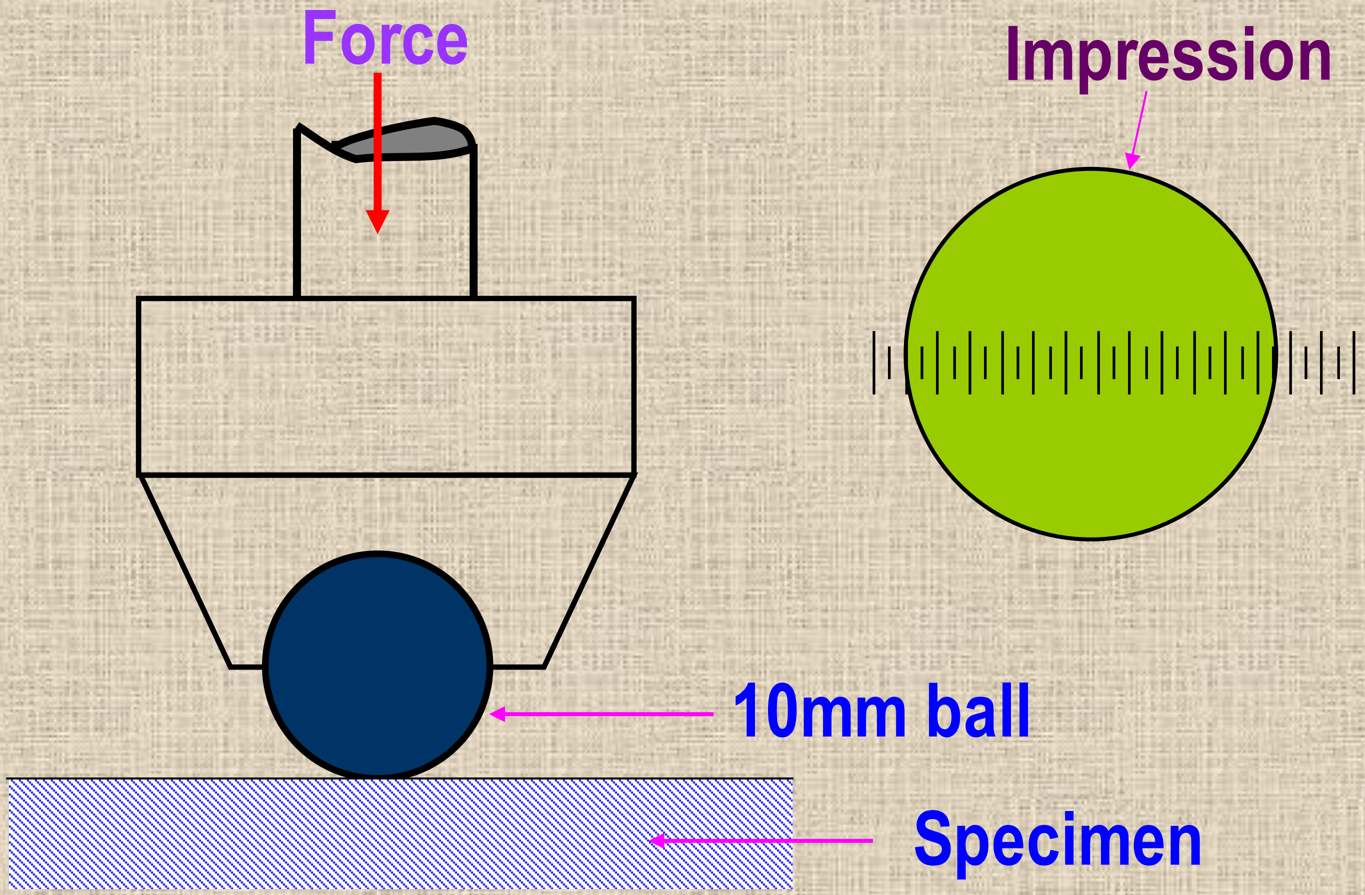
Brinell hardness

PRINCIPLE

- Brinell hardness test is the indentation test which consists of applying a constant load (force) usually between 500 and 3000 Kg for a specific time(10 to 30s) using a 5 or 10 mm diameter hardened steel or tungsten carbide ball on a flat surface of the work piece.

Brinell hardness

PRINCIPLE



Schematic of Brinell hardness testing

Brinell hardness

- After full application of load for the above times, load is slowly removed and the indenter is taken out.

- The diameter of the circular impression is measured in millimeters using a low power microscope.

NEXT

Brinell hardness

The Brinell hardness number(HB) is calculated as below:

$$BHN = \frac{\text{Load applied in kg}}{\text{Area of indentation in sq.mm}}$$

$$= \frac{2P}{\pi D\left(D - \sqrt{D^2 - d^2}\right)}$$

Where,

P - load applied in Kg.

D - Diameter of the ball in mm.

d - Diameter of the indentation in mm.

NEXT

Brinell hardness

Indenter selection and geometry

- Hardened steel balls can be used for testing materials up to 444HB (2.9mm dia), since testing at higher hardness may cause appreciable error due to possible flattering and permanent deformation of the steel ball.
- Tungsten carbide ball indenter is used for hardness of 444 to 627HB (2.9-2.45mm)

NEXT

Brinell hardness

Load Selection

- Standard loads used are 500, 1000, 1500, 2000, 2500 and 3000 kgs.
- For softer materials like Cu and Al alloys the 500kg load is usually used and the 3000kg load is often used for testing harder materials like steels and cast irons.

Brinell hardness

- **Also the test load should be chosen such that the diameter of the impression be in the range of 25 to 60% of ball diameter (i.e 2.5 – 6 mm)**

NEXT

Brinell hardness

General Precaution for BH testing

- **The thickness of the specimen should be at least ten times the depth of the indentation.**

- **Curved test surfaces of less than 25.4mm (1”) radius should not be tested.**

Brinell hardness

- The distance from the center of the indentation to any edge of the work piece should be more than three times the diameter of the indentation.

- The distance between the centers of the adjacent indentation should be at least three times the diameter of the indentation.

Brinell hardness

- **The surface of the work piece should be milled, ground, or polished before testing to get the accuracy.**

NEXT

Brinell hardness

ADVANTAGES

- For materials with varying hardness from point to point, the Brinell hardness is better (because, the larger sized indenter measures the average hardness).

- BH testing is useful in measuring hardness of cast components like cast iron and porous powder metallurgical components.

NEXT

Brinell hardness

Drawbacks of BH testing

- The impression produced on the test specimen is larger and this may decrease the life of the component.

- The ball indenter is likely to deform while testing hard materials hence increases the diameter and lower the hardness value.

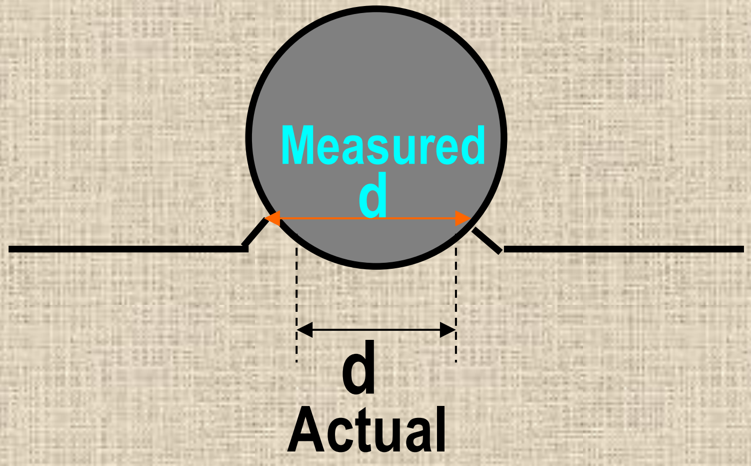
Brinell hardness

- Thin materials cannot be tested because of larger depth of indentation.

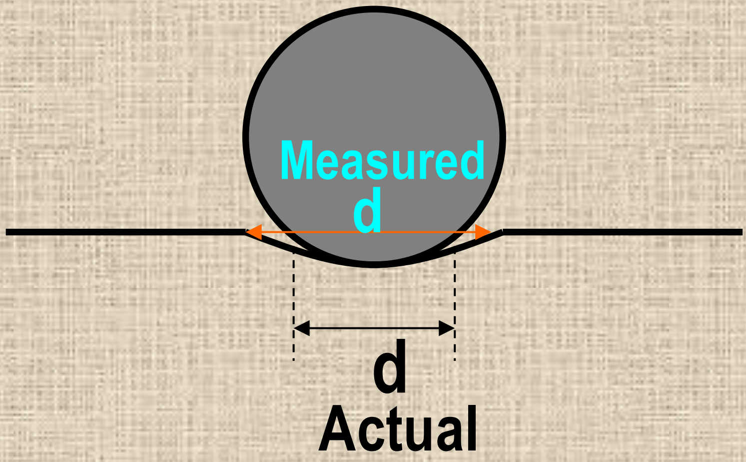
- For some materials (like Pb, Sn, Mg, etc) ridging or piling up effect is observed and for some other materials(like austenitic stainless steels and manganese steels) sinking effect is observed.

Brinell hardness

- Due to this effect measured diameter of impression will be larger than actual and results in lesser hardness value.



a) Ridging



b) Sinking

NEXT

Rockwell hardness

- **Test procedure**
- **Precautions**
- **Advantage**
- **Disadvantage**

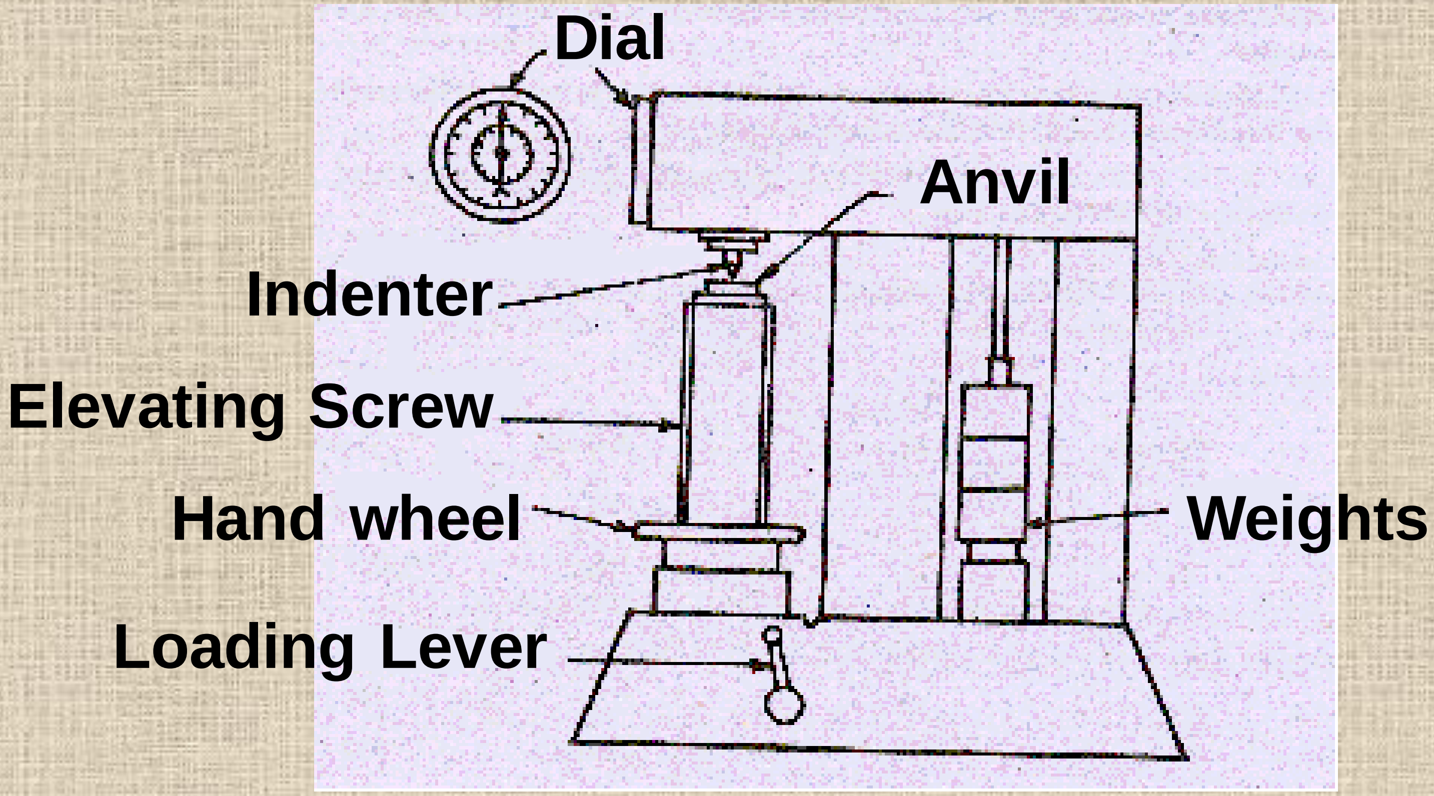
Rockwell hardness

TEST PROCEDURE

- In this method the hardness of a material is correlated with the depth of indentation and not with the area of indentation as in Brinell and Vickers tests.

- The hardness of the material is inversely proportional to the depth of indentation.

Rockwell hardness



Rockwell Hardness Tester

Rockwell hardness

- A dial is present in the Rockwell hardness testing machine and it will give the hardness of the material directly as per the depth of indentation.

- Initially a minor load is applied and a zero datum position is established in the dial.

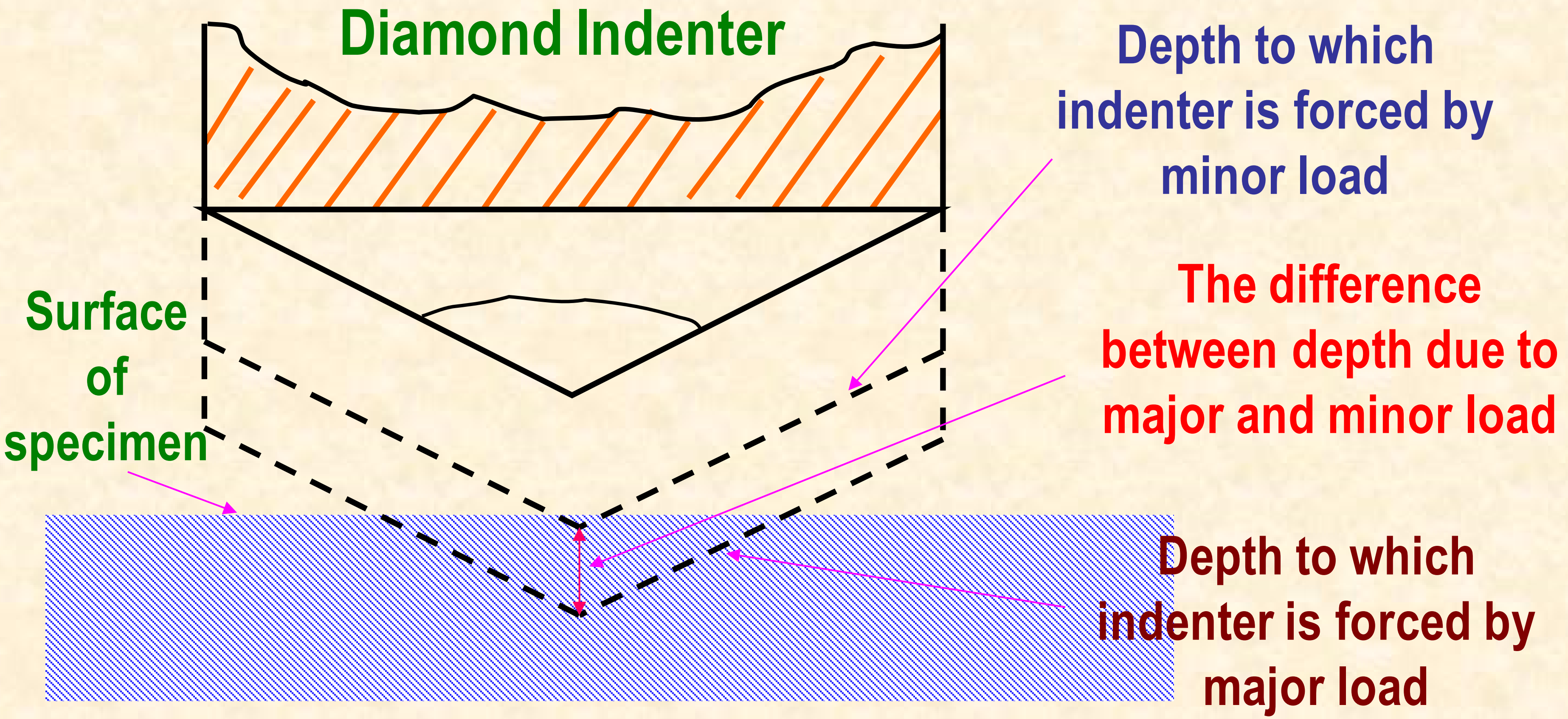
Rockwell hardness

- A major load is then applied for a specified period and removed leaving the minor load applied.

- Now the dial pointing towards some number which is corresponding to the hardness of the material.

- The entire procedure requires 5 to 10 sec.

Rockwell hardness



Principle of Rockwell test

NEXT

Rockwell hardness

PRECATIONS

- **Measurement shouldn't be made too close to the edge.**
- **Surface should be more polished than Brinell hardness testing.**
- **More readings should be taken in order to reduce error.**

NEXT

Rockwell hardness

ADVANTAGES

- **More flexible than Brinell (wide range of materials can be tested by using many combination of loads and indenters)**
- **Lesser time is required for test.**
- **Impression produced is less.**

NEXT

Rockwell hardness

DISADVANTAGES

- Greater care is required in preparation of samples.

The End