UNIT- I

MECHANICAL PROPERTIES AND DEFORMATION MECHANISM

Material Properties and Qualities

S.No	Properties	Qualities
1	Physical Properties	Colour, Density, Melting point, Size, Shape, etc.
2	Chemical Properties	Corrosion resistance, atomic weight, molecular weight, chemical composition, atomic number
3	Mechanical Properties	Strength, Elasticity, Plasticity, Ductility, Brittleness, Hardness, Toughness, Stiffness, Resilience, Creep
4	Electrical Properties	Resistivity, Conductivity, Capacity, Dieelectric strength
5	Magnetic Properties	Relative Permeability , Reluctivity, Susceptibiliity
6	Thermal Properties	Specific heat,Thermal capacity,Thermal Conductivity,Thermal stress, Laten heat
7	Technological Properties	Malleability, Machinability,Weldability, Castability, Formability
8	Aesthetic Properties	Appearance, Texture and ability to accept special finishes
9	Economic Properties	Raw material and Processing costs, Availability
10	Other Properties	Optical, Acoustical and Physiochemical Properties

Mechanical Properties

- Mechanical Properties are those characteristics of material that describe its behaviour under the action of external forcees
- A knowledge of mechanical properties is very essential for an engineer to select a suitable material for his various design purposes

Most Important
Mechanical properties

- **Elasticity:** it is the property of a material by virtue of which it is able to retain its original shape and size after the removal of the load.

  Example: Rubber

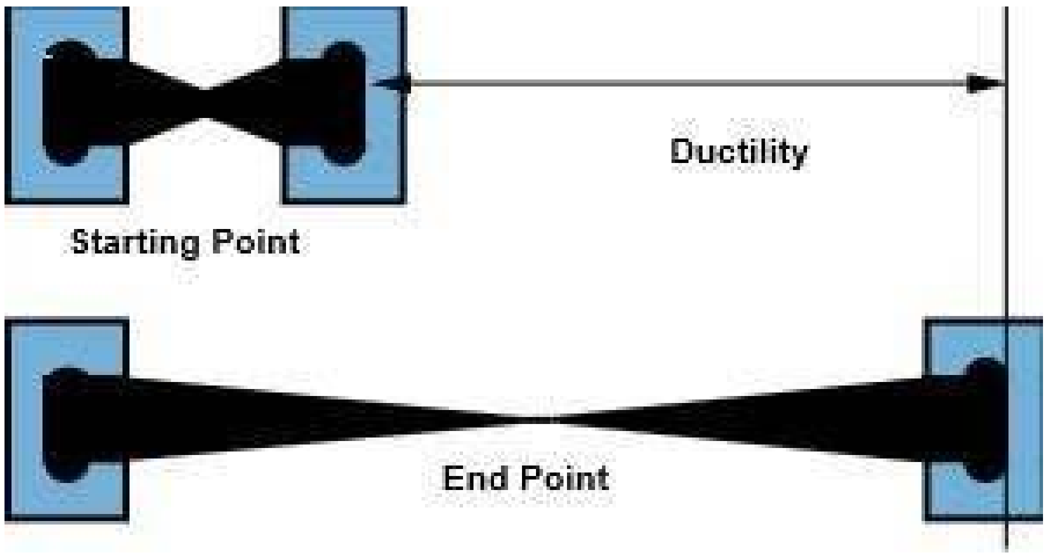
- **Plasticity:** It is the property of the material by virtue of which a permanent deformation (without fracture) takes place, whenever it is subjected to the action of external forces

  Example: Clay

Most Important
Mechanical properties

❖ **Ductility:** It can be drawn into wires before rupture takes place

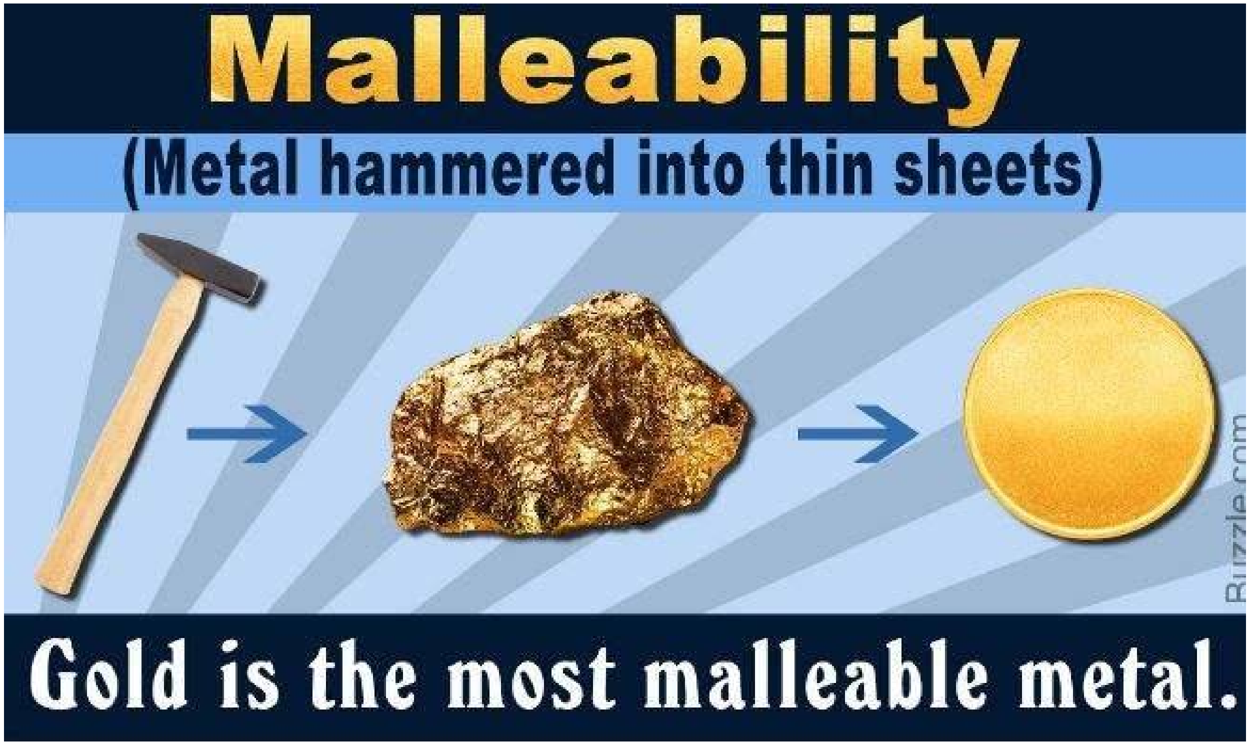
Example: Gold, silver, iron copper and aluminium



Most Important
Mechanical properties

- **Malleability:** It can be withstand deformation under compression without rupture (or) break

  Example: Gold, Lead



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Mechanical properties

- **Brittleness:** It will fracture without any appreciable deformation

  Example: Cast irons, Glass

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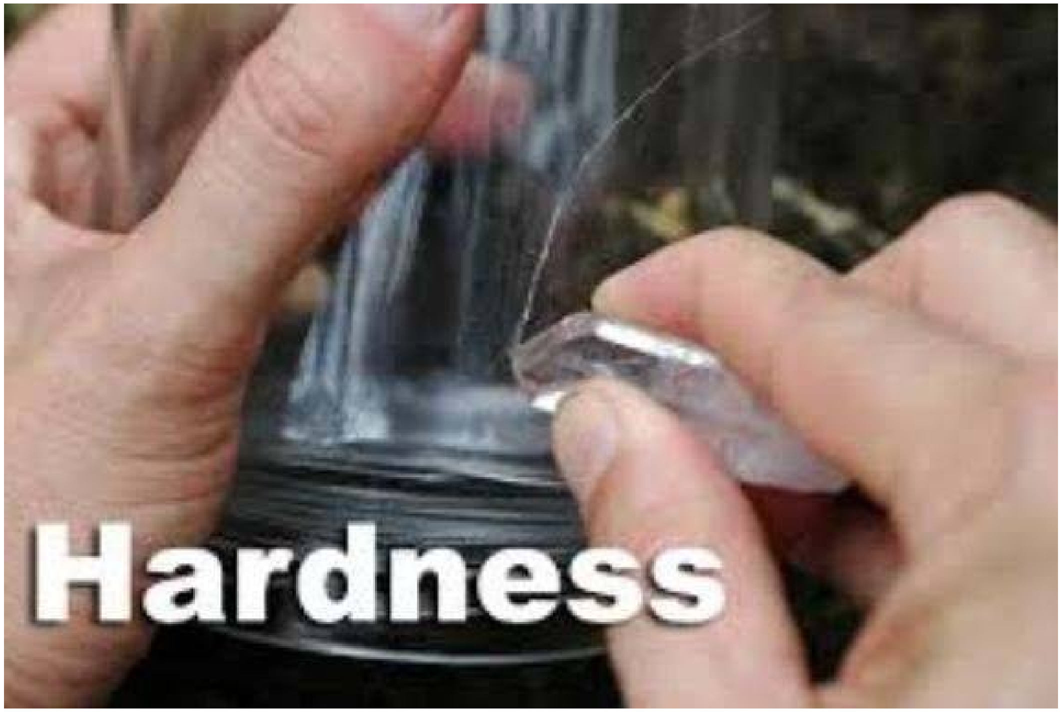
- **Hardness:** It is able to resist abrasion, indentation (or Penetration) , machining and stretching

  Example: Diamond, Glass



Most Important
Mechanical properties

- **Toughness:** It can be absorb maximum energy before fracture takes place

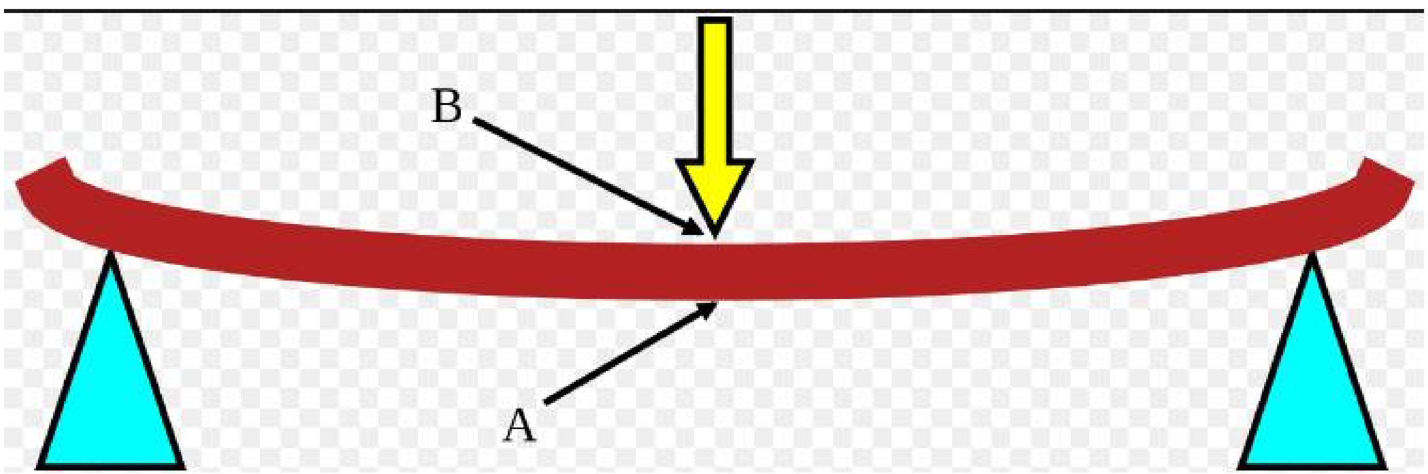
  Example: Mild steel , Brass

Material with high toughness

Material with low toughness

Most Important
Mechanical properties

❖ **Stiffness:** It resist deformation

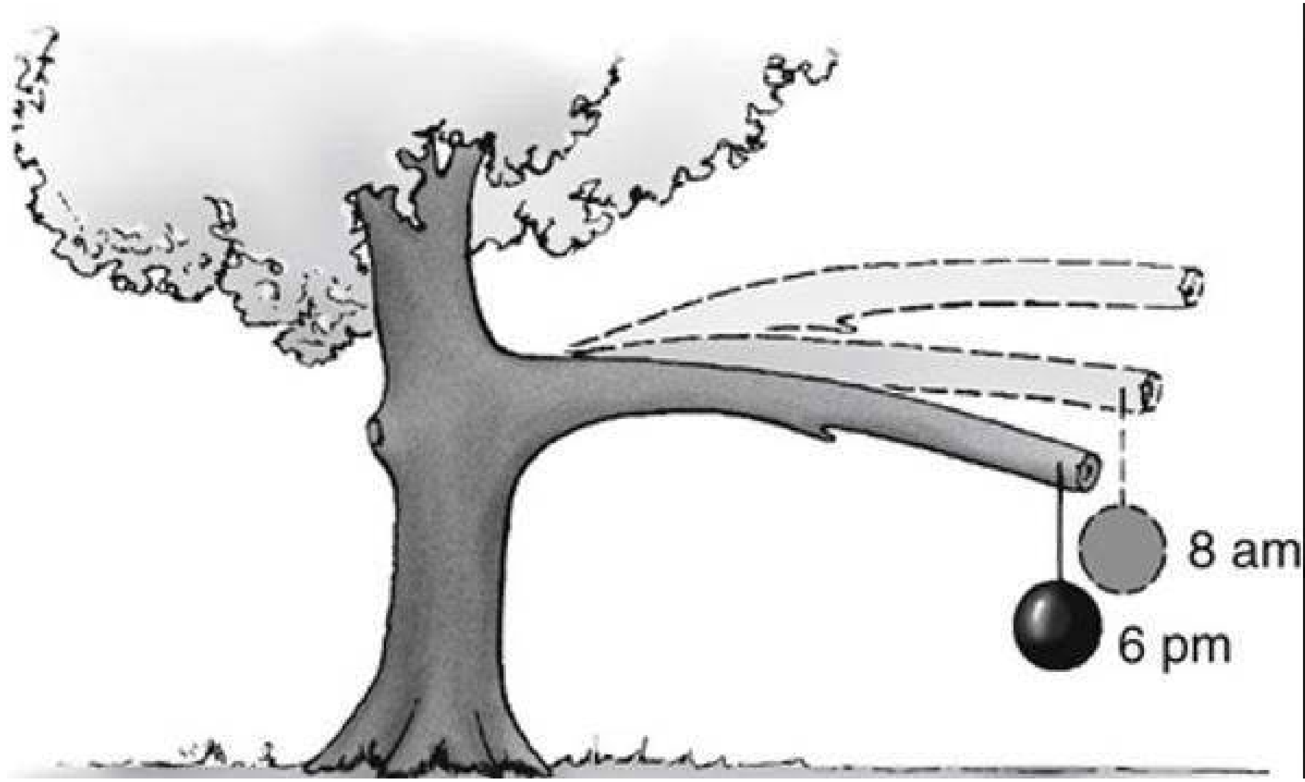


Most Important
Mechanical properties

- **Resilience :** It stores energy and resists shocks or impacts

Most Important
Mechanical properties

❖ **Creep:** It deforms continuously under steady load



Most Important
Mechanical properties

- **Endurance :** It can withstand varying stress

Factors affecting Mechanical Properties

- Grain size
- Heat treatment
- Atmospheric Exposure
- Low and High Temperatures

Deformation of metals

- When force is applied on a metal piece, then the size and/or shape will be altered.
- Any changes in the size and/or shape of the metal is called as **deformation of the metal.**
- Deformation can be either permanent or temporary.

Mechanism of Plastic deformation (Modes of Plastic deformation)

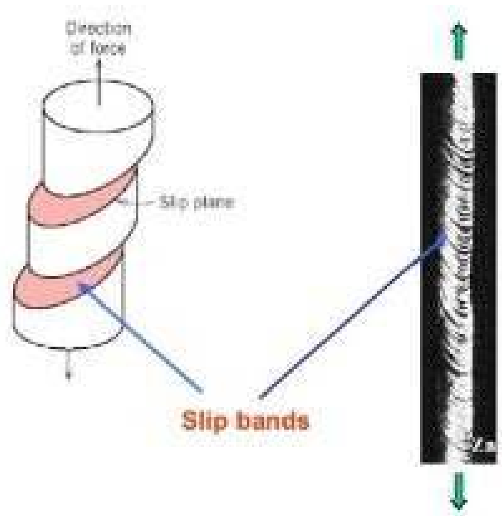
- Slip
- Twinning

Deformation by Slip

- The sliding of blocks of the crystal over one anther along definite crystallographic planes called slip planes.

(or)

- Slip Represents a displacement of one part of the crystal relative to another along particular crystallographic planes and in crystallographic directions



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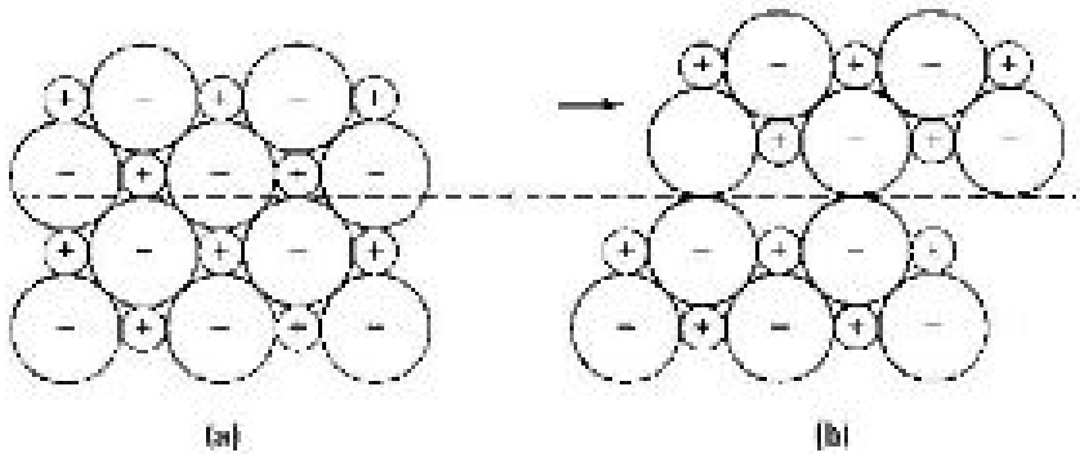
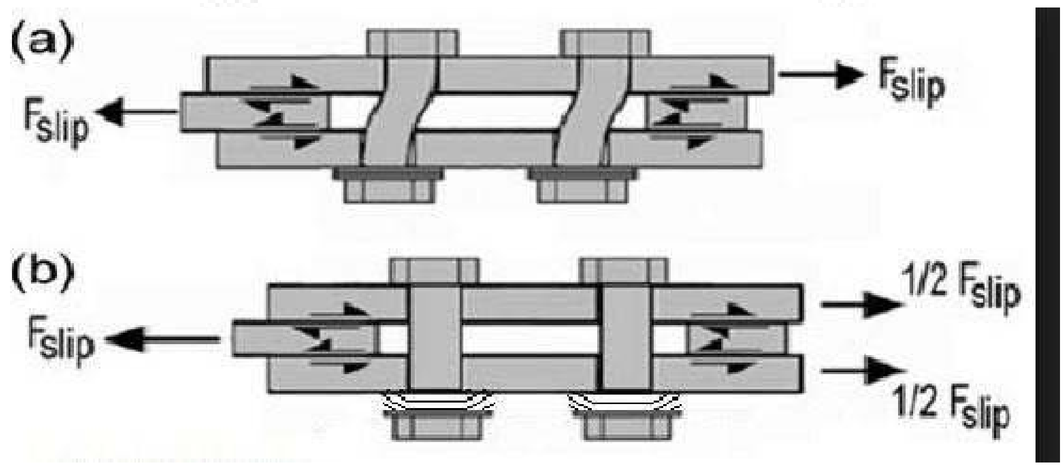




Types of Fracture

- Brittle fracture
- Ductile fracture
- Fatigue fracture
- Creep fracture

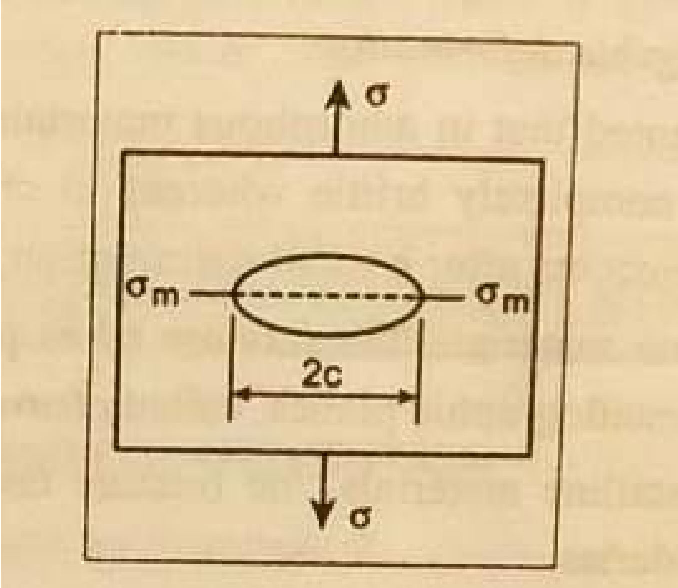
Brittle Fracture

- Fracture will take place by rapid propagation of crack with a negligible deformation
- Mechanism of Brittle fracture: **Griffith's Theory**

Griffith's Theory

1. In a brittle material, there are many fine cracks. These cracks concentrate the applied stress at their tips or ends
2. When the stress at the tips of a crack exceeds the theoretical stress value, the crakes expands and fracture occurs

Explanation of mechanism of Brittle fracture



Let σ = Tensile stress applied to the specimen,

σ_m = Maximum stress at the tip of the crack,

c = Half length of the crack,

ρ = Radius of curvature at the ends

Explanation of mechanism of Brittle fracture

- It is observed that when a tensile stress is applied to the specimen, then the applied stress is distributed about the crack in such way that the maximum stress occurs at its tips.
- The maximum stress at the tip of the crack is given by

$$\sigma_m = 2\sigma\sqrt{\frac{c}{\rho}}$$

- When elastic material is stresses, **potential energy** is stored in the material before it cracks. This stored energy is known as **elastic strain energy**. When crack begins propagating, elastic energy is released.
- The crack propagates, new surfaces are created and a certain amount of energy, called **surface energy**, must be provided to create them

Derivation for fracture strength

- Griffith supposed that the crack propagates when the released **strain energy** is just sufficient to provide the **surface energy** necessary for the creation of the new surfaces
- According to the elastic theory

The strain energy per unit volume $= \frac{\sigma^2}{2E}$

where E = Young's modulus of the material.

- The elastic strain energy is released by the spreading of a crack of unit width is given by,

$$U_E = \frac{\sigma^2}{2E} \times \text{Area} \times \text{Width} = \frac{\sigma^2}{2E} \times \pi c^2 \times 1$$

$$= \frac{\sigma^2 \pi c^2}{2E} \quad \ldots (i)$$

Derivation for fracture strength

- It shows that the strain free volume is larger the elastic energy released will be twice the value given in Eqn (i)

$$U_E = \frac{-\sigma^2 \pi c^2}{E} \quad \ldots (ii)$$

- The negative sign indicated that the energy stored in the material is released as a crack forms
- If γ = Surface energy/ unit area in Joules/m^2, then the surface energy (Us) for a crack of length 2c with unit width is given by

$$Us = 4\gamma C$$

- Total Change in Potential Energy

$$U = U_E + U_S = \frac{-\sigma^2 \pi c^2}{E} + 4\gamma c$$

Derivation for fracture strength

$$\frac{dU}{dc} = 0$$

$$\therefore \frac{dU}{dc} = \frac{d}{dc}\left(\frac{-\sigma^2 \pi c^2}{E} + 4\gamma c\right) = 0$$

or $$-\frac{2\sigma^2 \pi c^2}{E} + 4c\gamma = 0$$

or $$\boxed{\sigma = \sqrt{\frac{2E\gamma}{\pi c}}} \quad \ldots (5.3)$$

Mechanical test of metals

- The engineer and designer need to know the hardness, strength, and other characteristics of the materials they use
- The engineer and designer should also know about the way in which the properties are determined
- It can be noted that the tests need to be conducted according to standard procedures so that one can have confidence in published that results

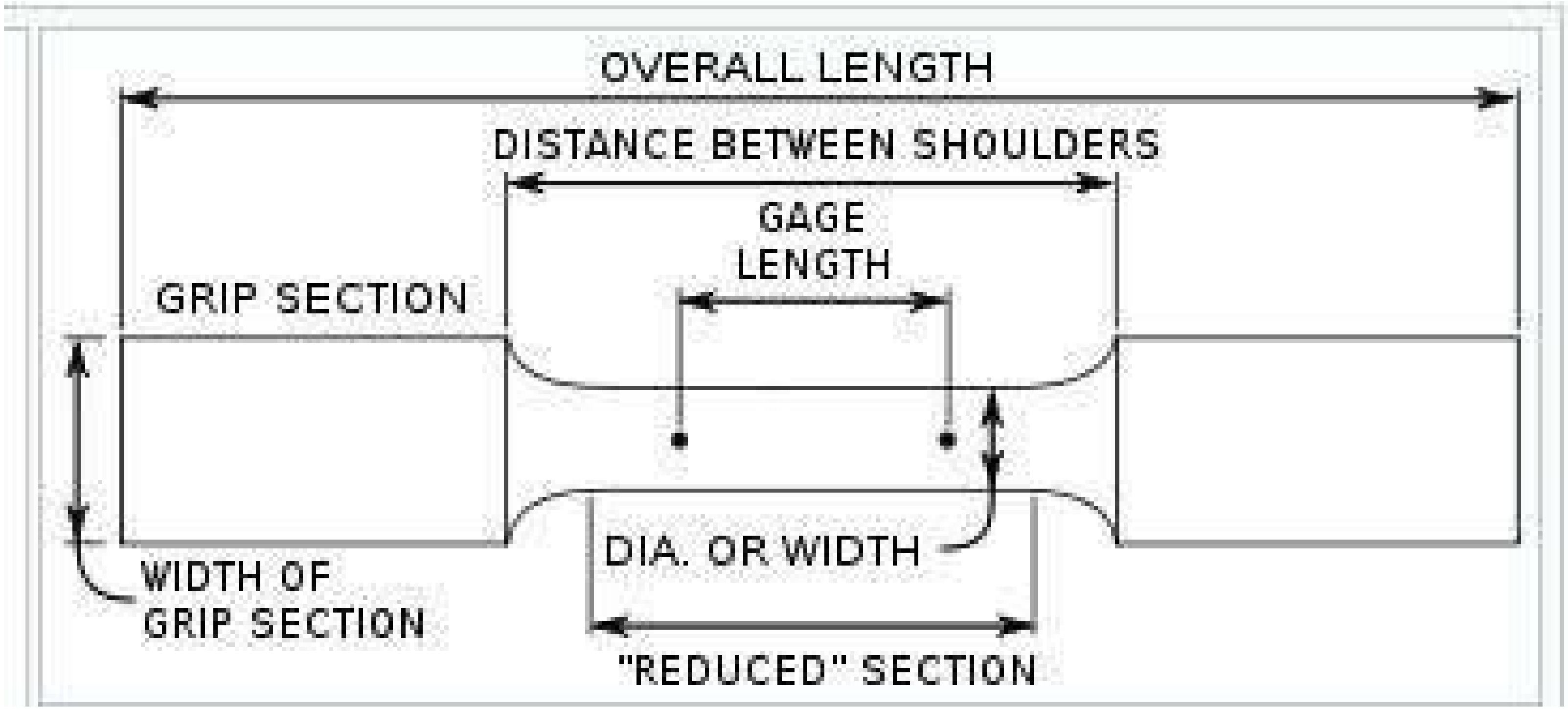
Classifications of Mechanical tests

- **Destructive tests-** In this type of testing, the component or specimen to be tested is ***destroyed*** and ***cannot be reused***
- **Examples:**
  - Tensile test, Impact test, bend test, Fatigue test,Torsion test, Creep test
- **Non-Destructive tests-** In this type of testing, the component or specimen to be tested is ***not destroyed*** and ***can be reused*** after the test
- **Examples:**
  - Radiography, Ultrasonic inspection etc.

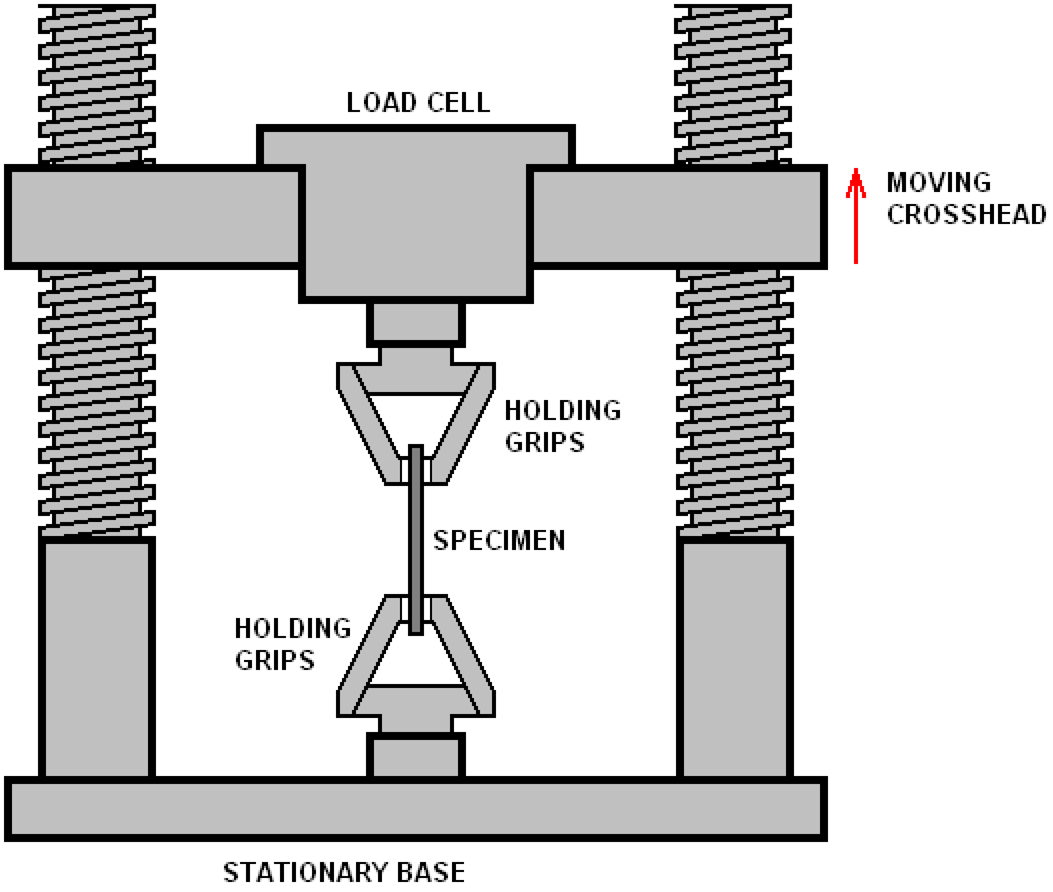
Tensile Test

- A tensile test of a material is performed on ductile materials to determine tensile properties such as ,
  - Yield point
  - Maximum tensile strength
  - Breaking strength
  - Percentage elongation
  - Percentage reduction in area
- The tensile test is usually carried out with the help of a "universal Testing Machine" (UTM)

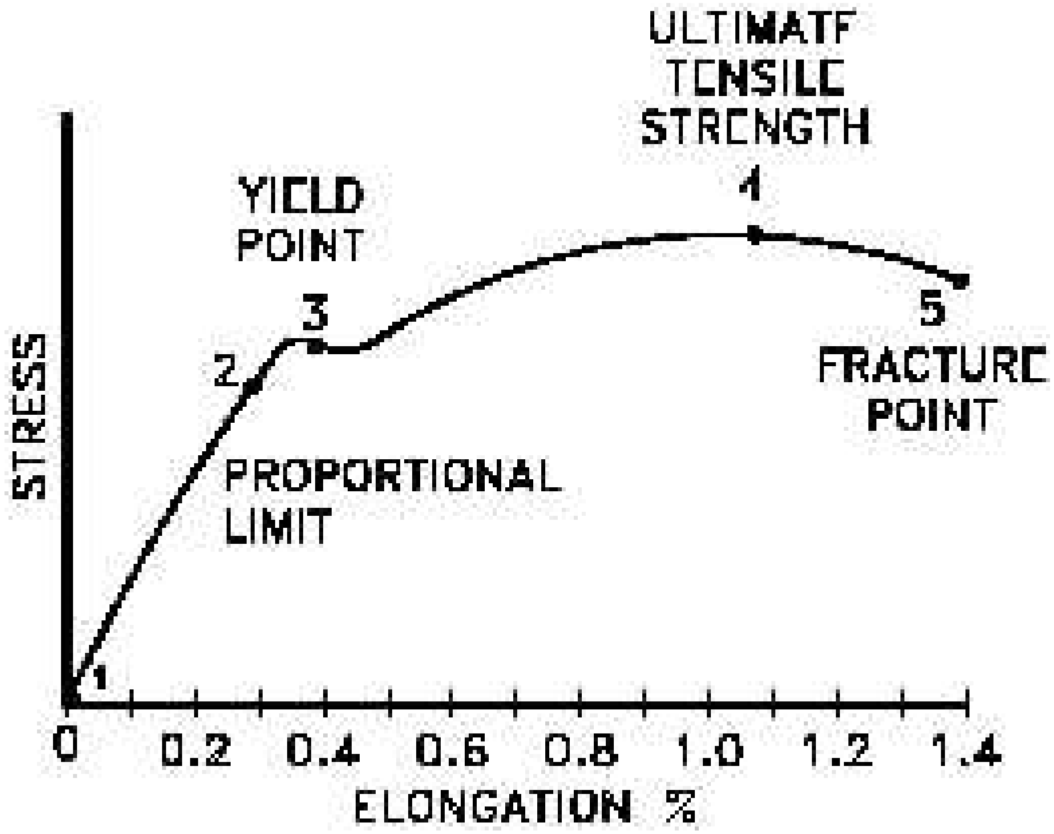
Tensile Test- Specimen



Tensile Test- UTM



Stress –Strain Curve



Hardness tests

- Hardness maybe defined asthe ability of amaterial to resist scratching, abrasion, cutting or penetration
- The hardness test is performed on amaterial to know its resistance against indentation andabrasion

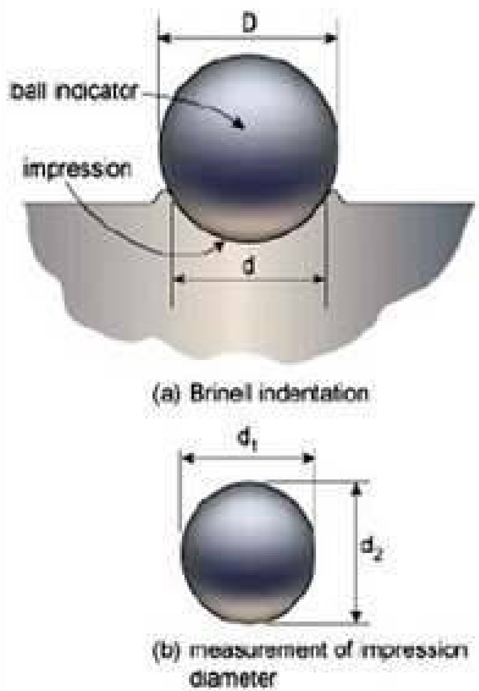
Types of Hardness tests:

- Brinell hardness test
- Vickers hardness test
- Rockwell hardness test

Hardness tests

- Generally an indenter is presses in to surface of the material by a slowly applied known load and the extend of the resulting impression is measured mechanically.
- A large impression for a given load and indenter indicates a soft material and a small impression indicates a hard material

Brinell Hardness



$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

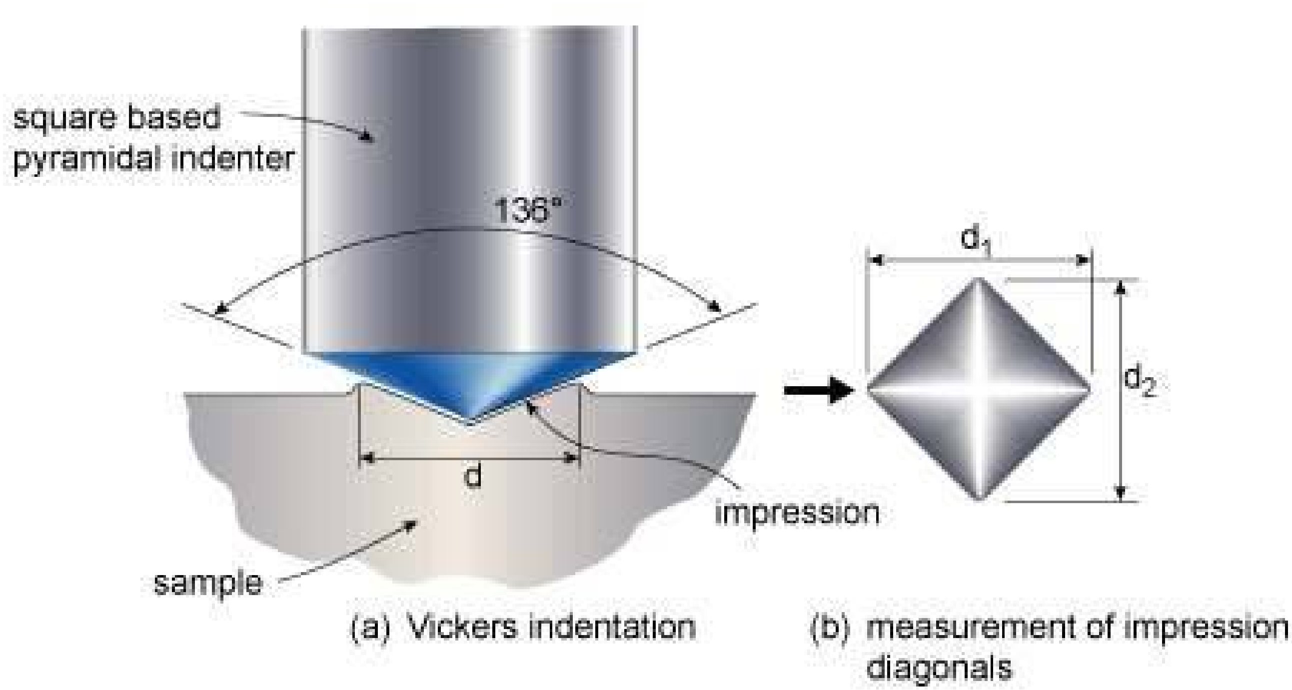
Where:

P is the test load [kg]

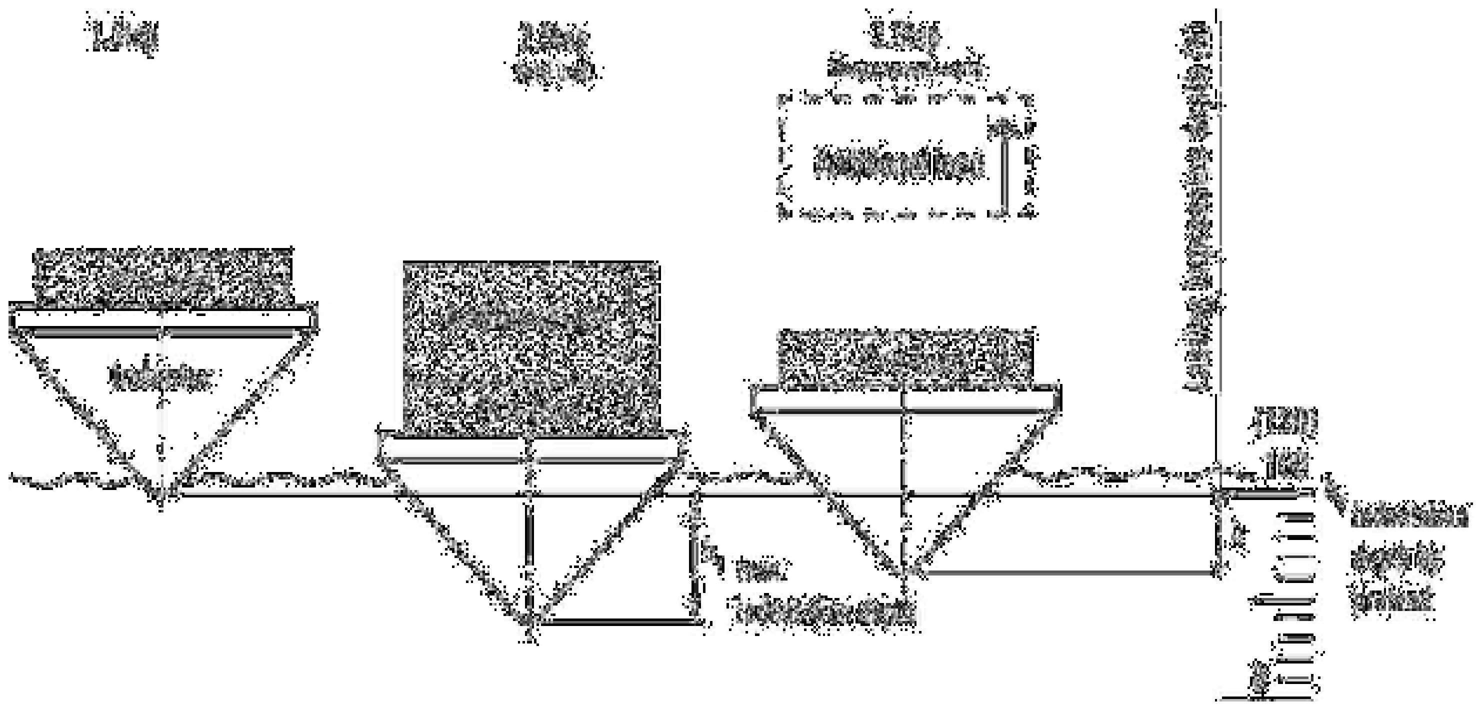
D is the diameter of the ball [mm]

d is the average impression diameter of indentation [mm]

Vickers Hardness

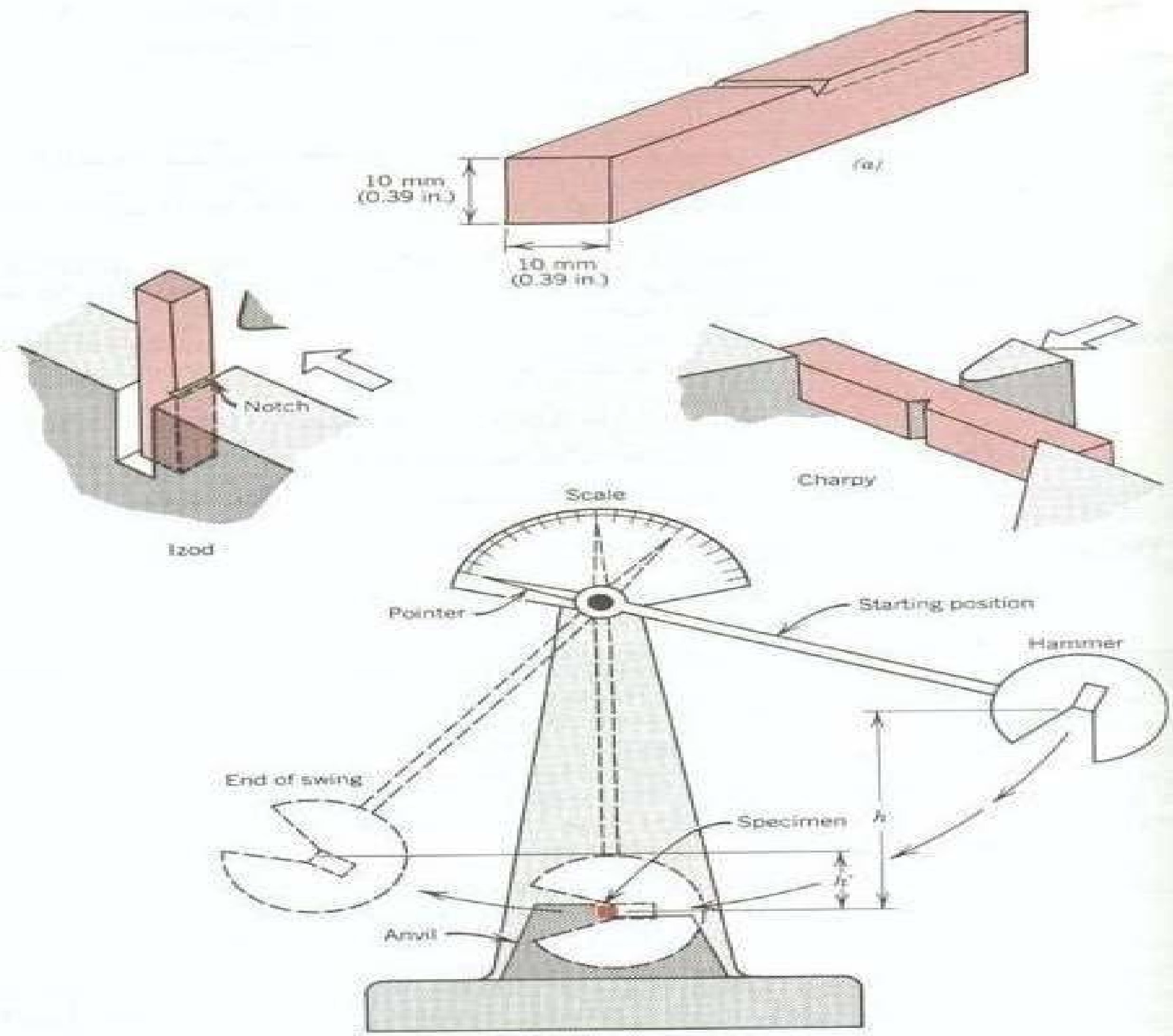


Rockwell Hardness



Impact Tests

- Izod tests
- Charpy tests



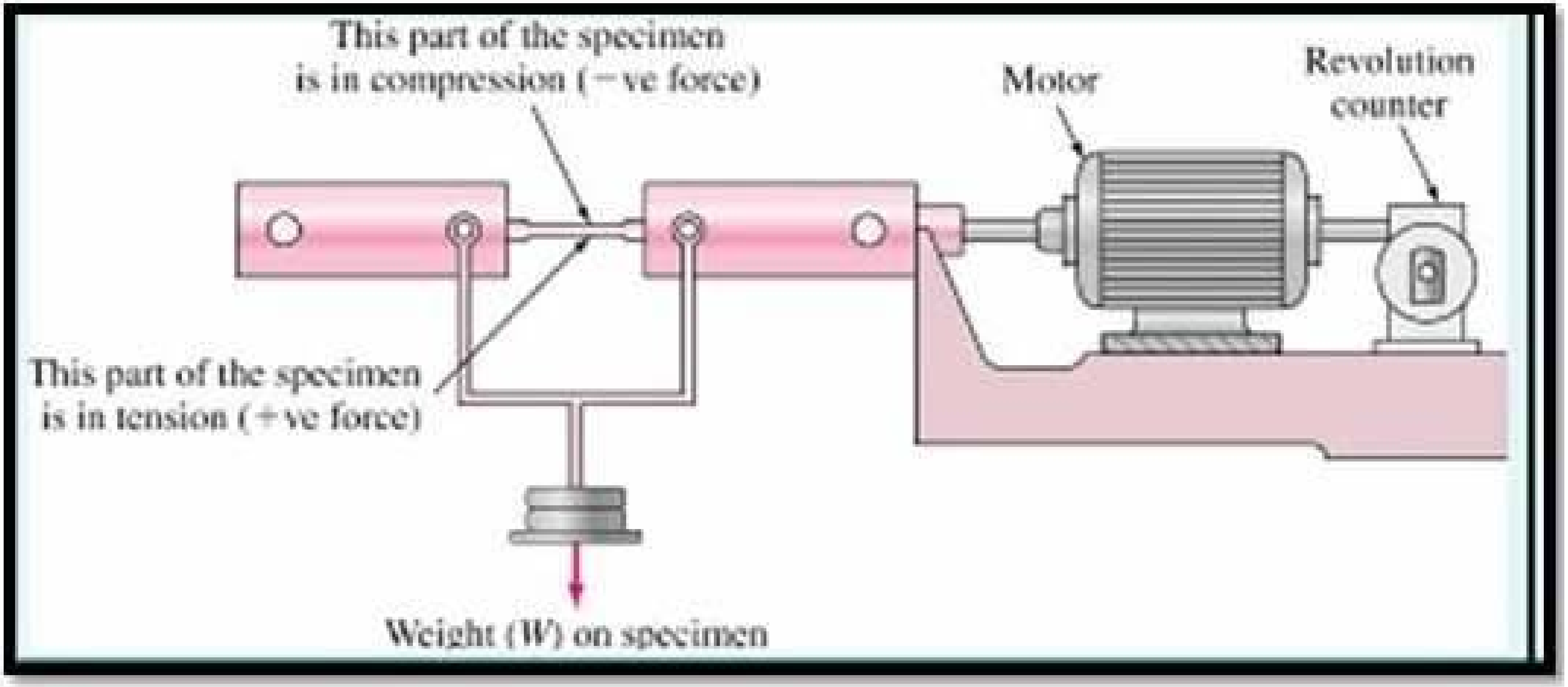
Impact Testing

Fatigue Test

- Fatigue tests determine the resistance of material to repeated fluctuating loads

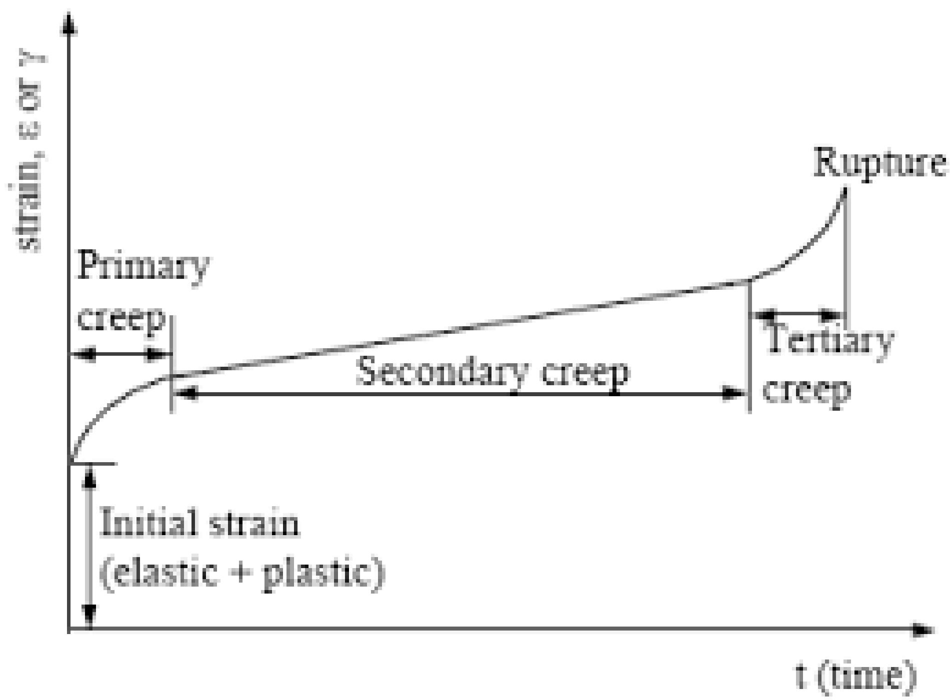
- The capacity of material to withstand repeatedly applied stresses is known as fatigue

Fatigue Test



Creep Fracture

- The creep is defined as the property of a material by virtue of which it deforms continuously under a steady load



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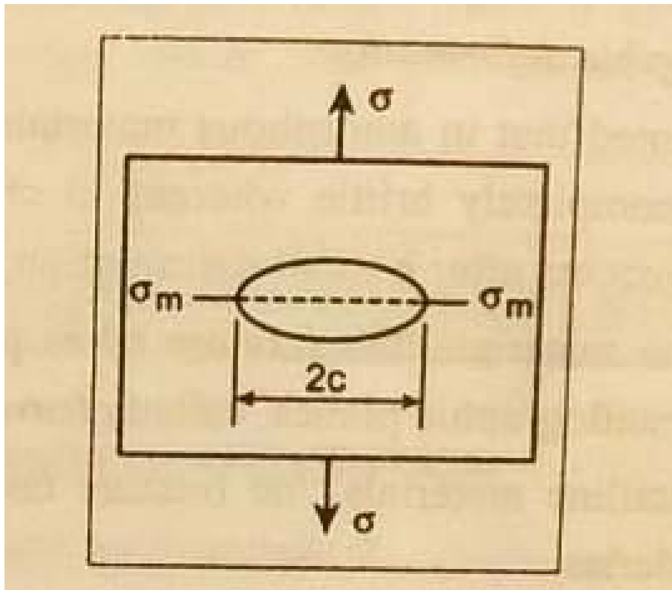

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Ductile Fracture

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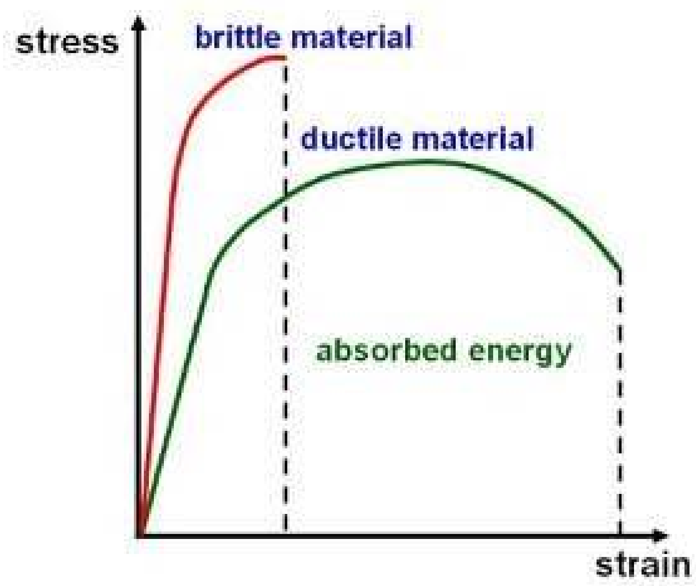
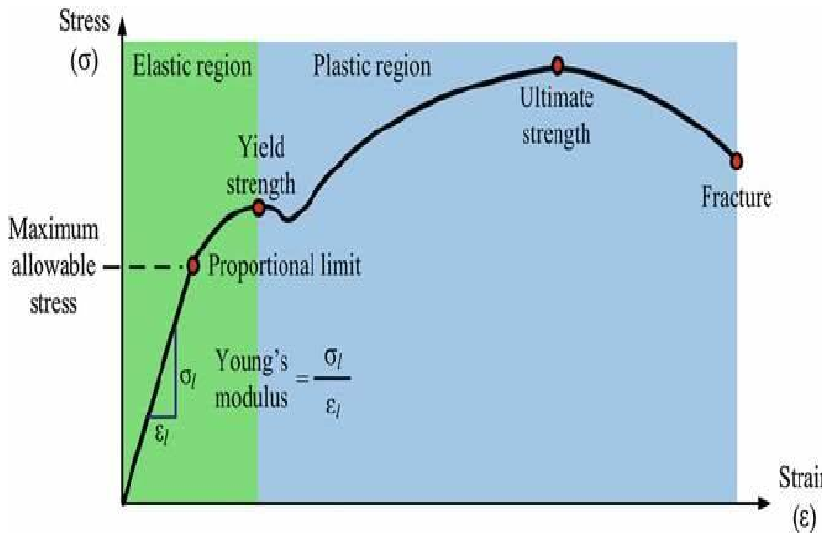
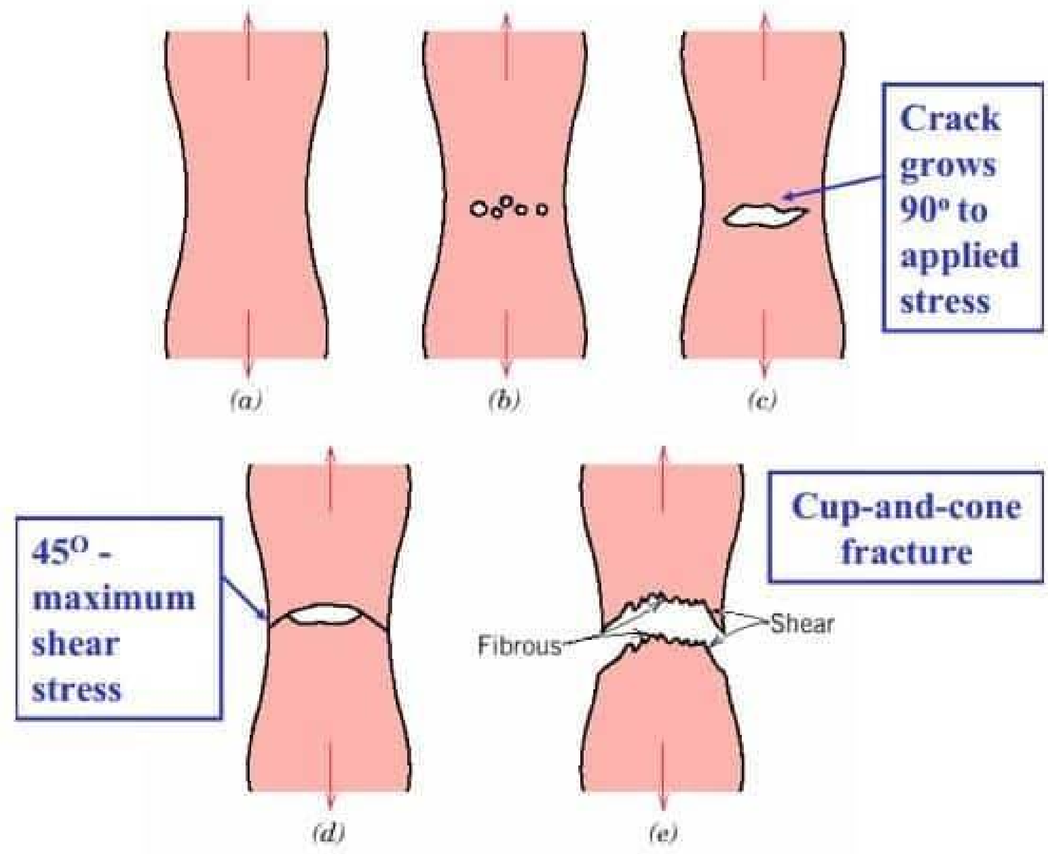




Stages in the formation of a cup-and-cone fracture



Creep Fracture

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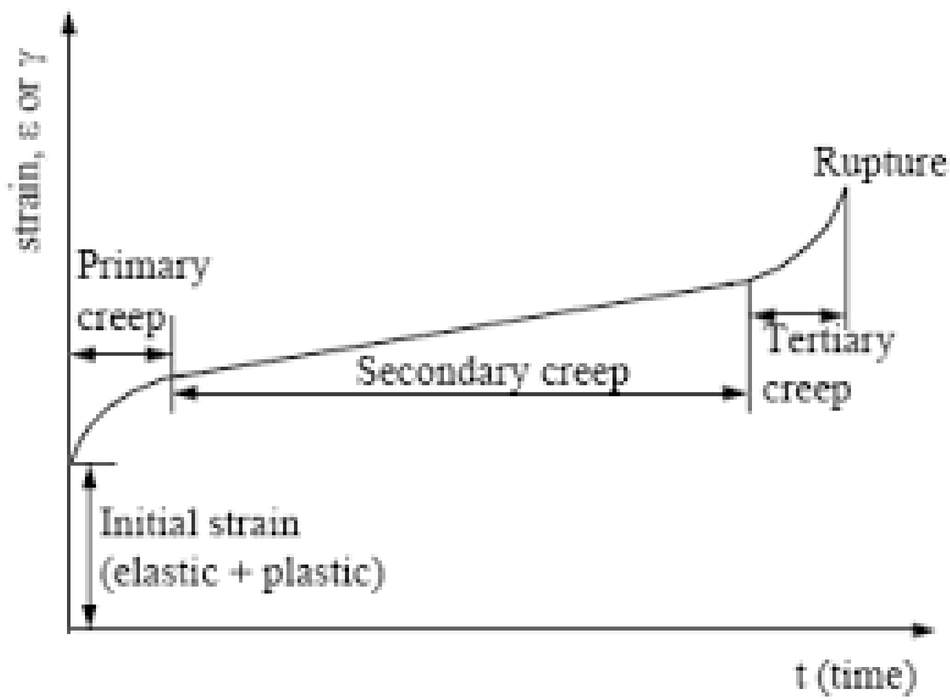

UNIT-V
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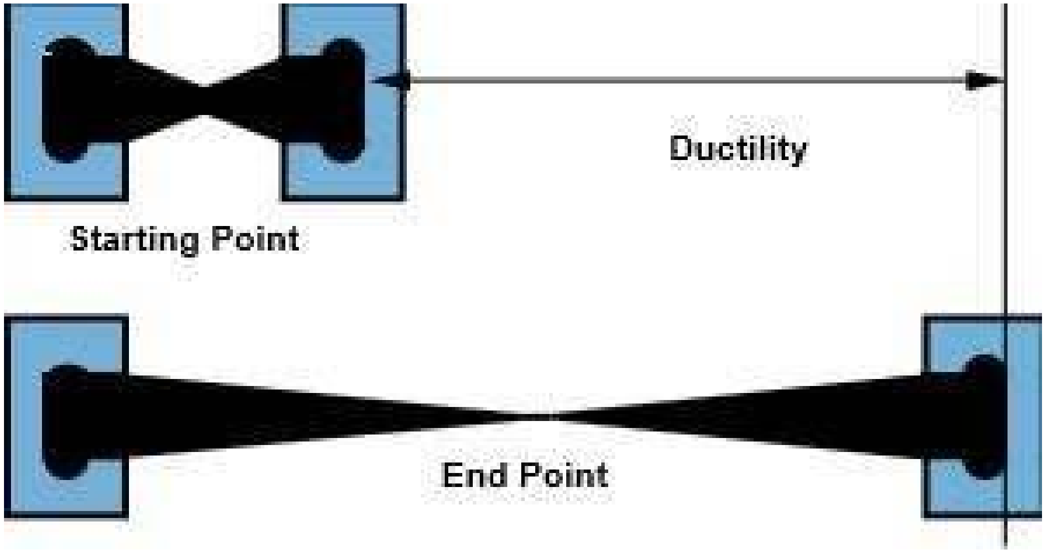

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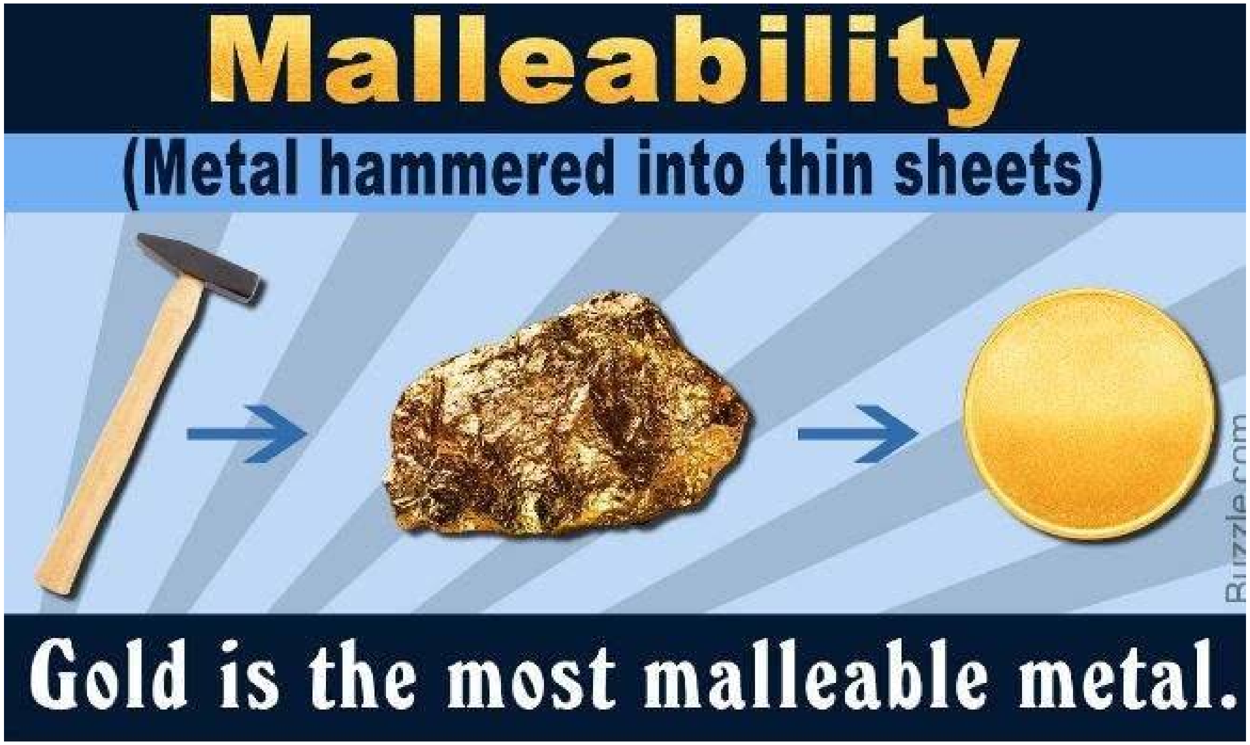

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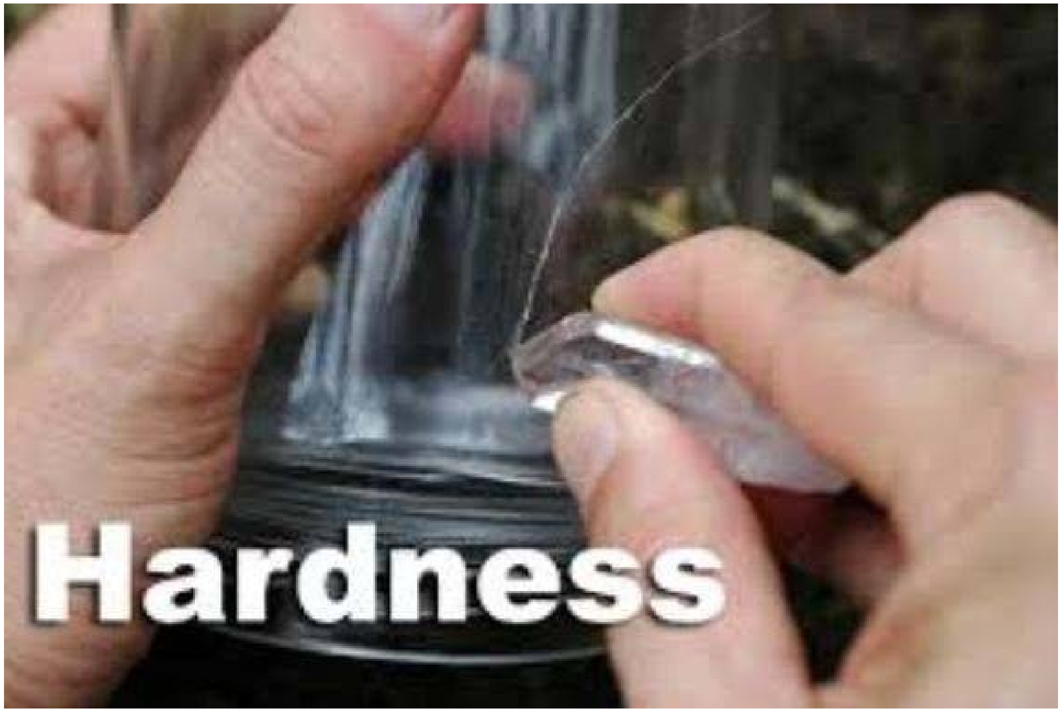

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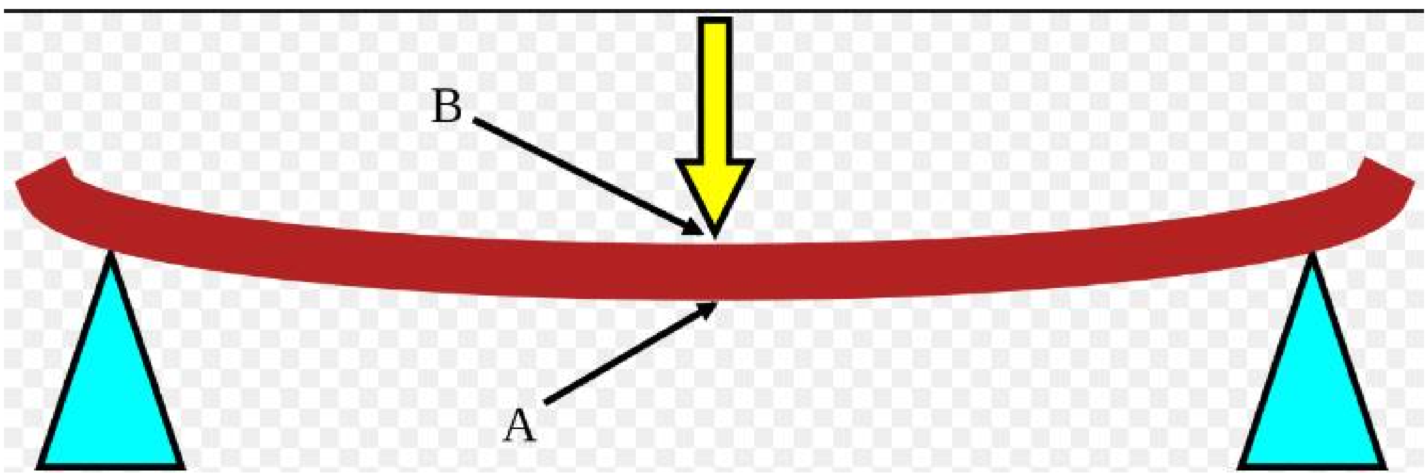

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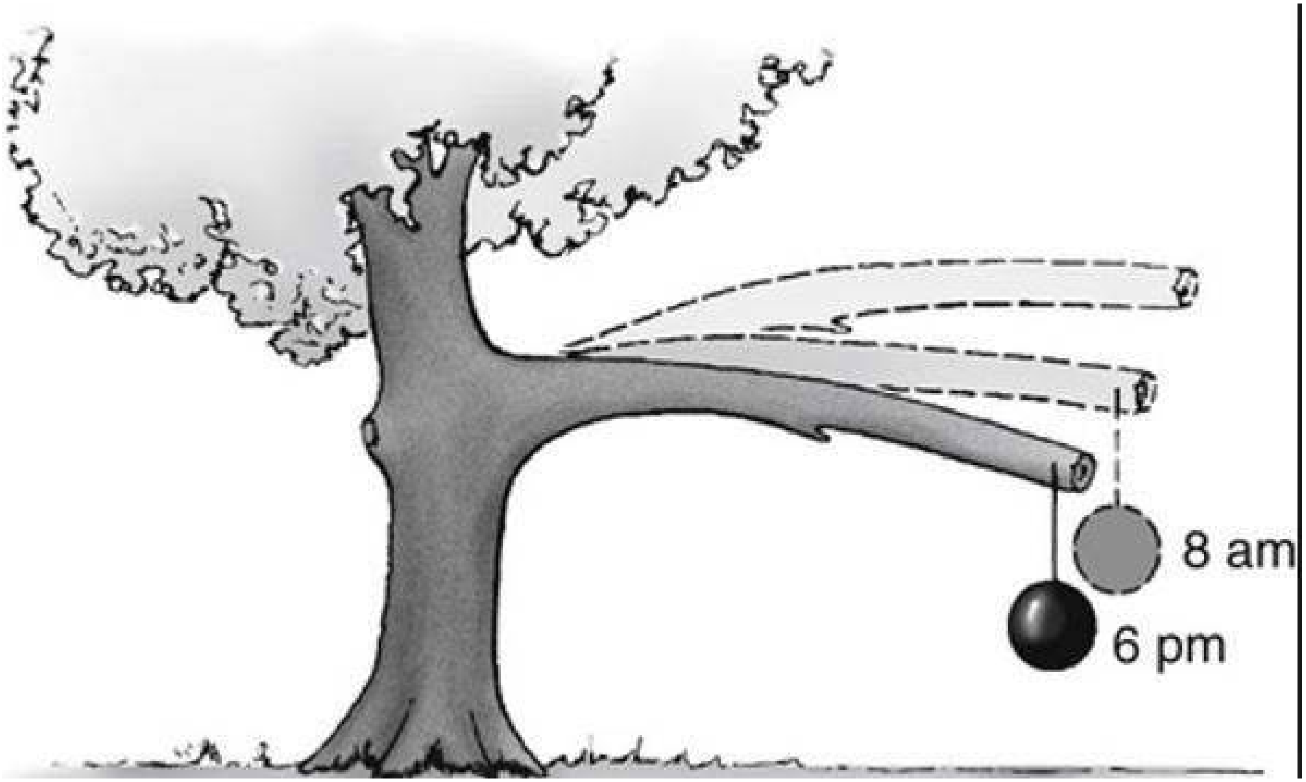

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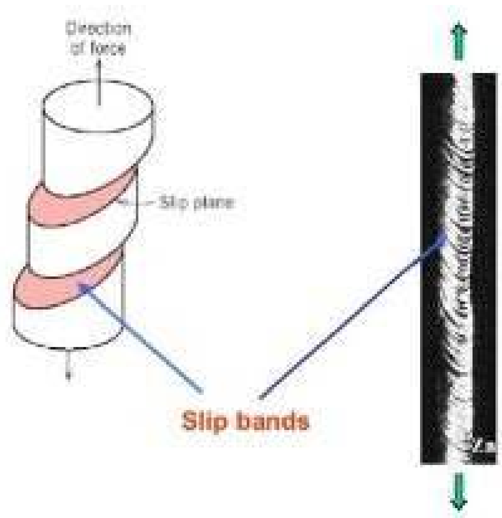

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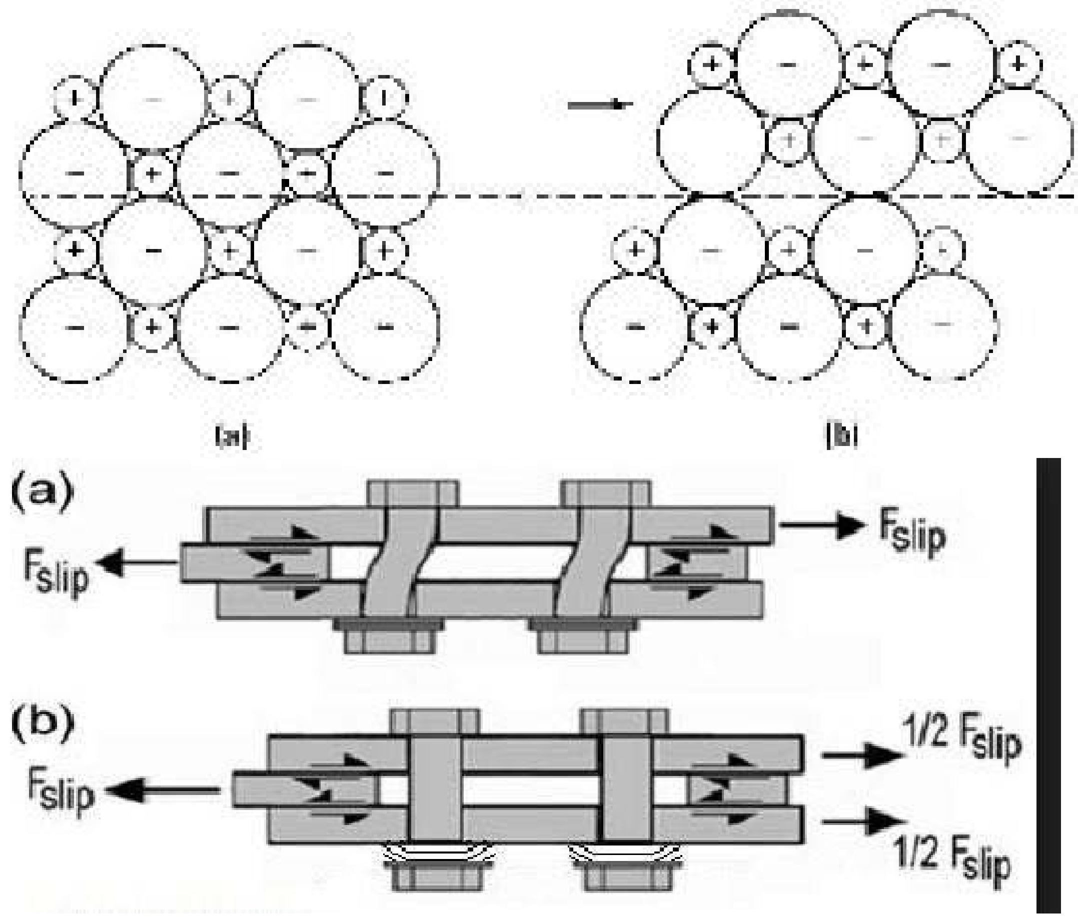
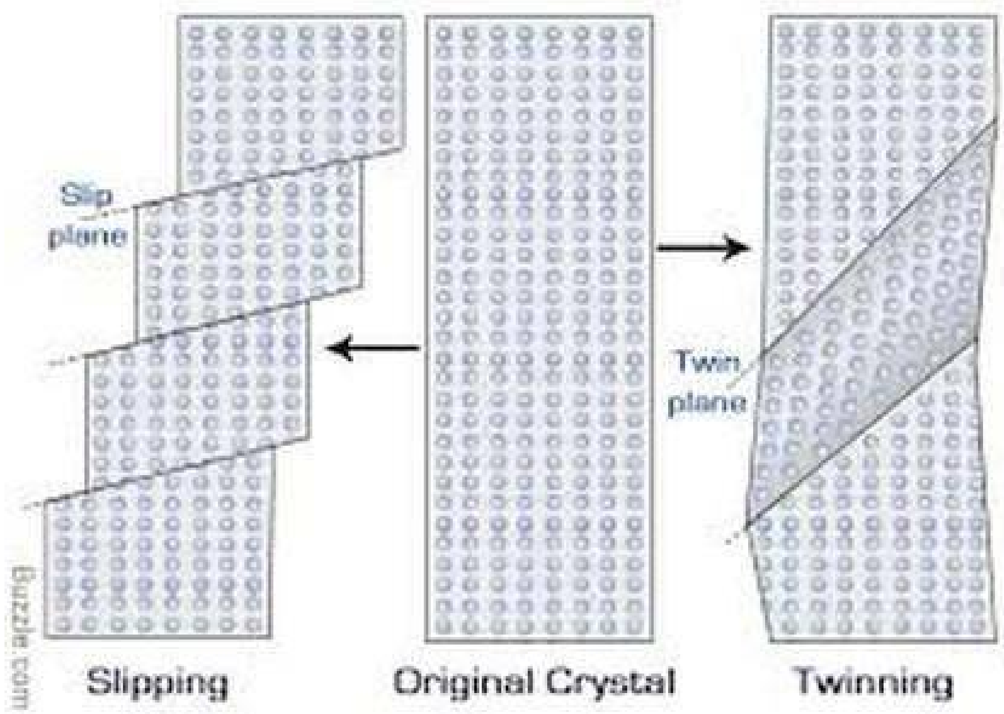


Deformation by Twinning

- It is the process in which the atoms in any part of a crystal subjected to stress, rearrange themselves so that one part of a crystal structure becomes a mirror image of the other part



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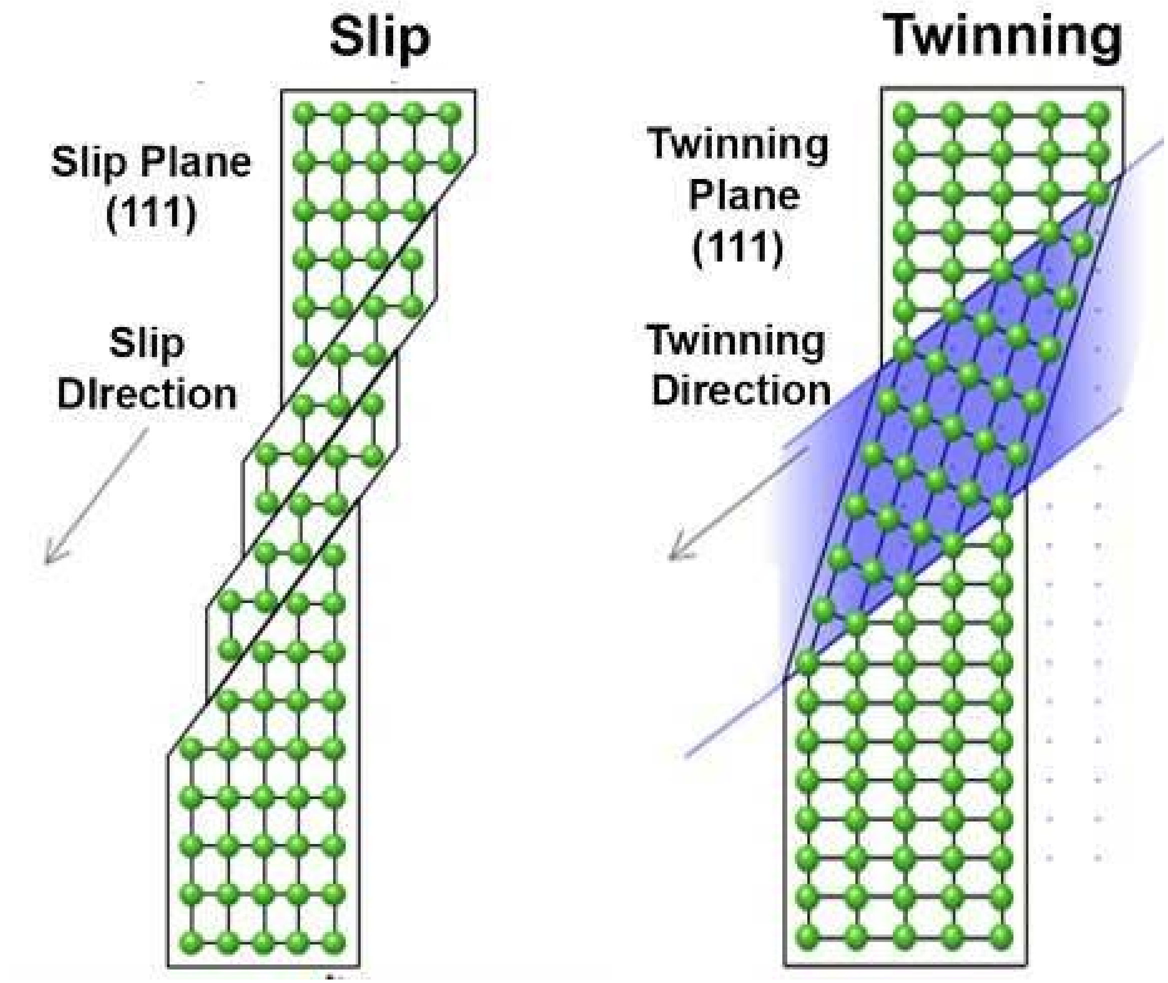

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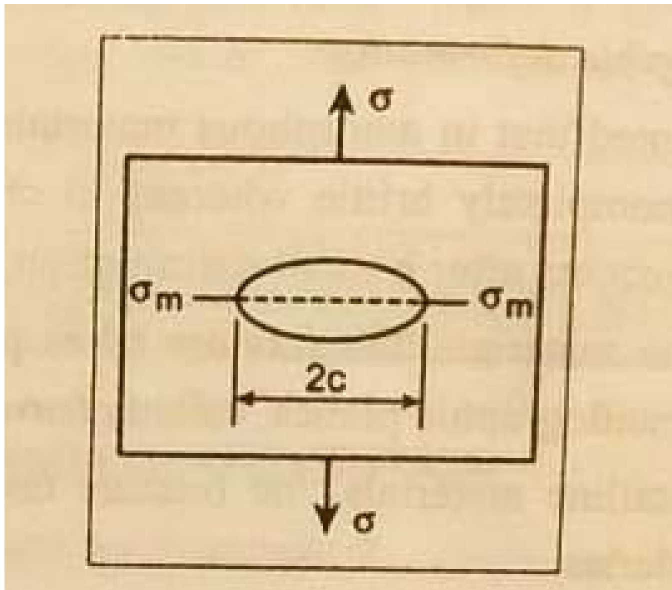

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$$\sigma_m = 2\sigma\sqrt{\frac{c}{\rho}}$$

- When elastic material is stresses, **potential energy** is stored in the material before it cracks. This stored energy is known as **elastic strain energy**. When crack begins propagating, elastic energy is released.
- The crack propagates, new surfaces are created and a certain amount of energy, called **surface energy**, must be provided to create them

Derivation for fracture strength

- Griffith supposed that the crack propagates when the released **strain energy** is just sufficient to provide the **surface energy** necessary for the creation of the new surfaces
- According to the elastic theory

The strain energy per unit volume $= \dfrac{\sigma^2}{2E}$

where E = Young's modulus of the material.

- The elastic strain energy is released by the spreading of a crack of unit width is given by,

$$U_E = \frac{\sigma^2}{2E} \times \text{Area} \times \text{Width} = \frac{\sigma^2}{2E} \times \pi c^2 \times 1$$

$$= \frac{\sigma^2 \pi c^2}{2E} \quad \ldots (i)$$

Derivation for fracture strength

- It shows that the strain free volume is larger the elastic energy released will be twice the value given in Eqn (i)

$$U_E = \frac{-\sigma^2 \pi c^2}{E} \quad \ldots (ii)$$

- The negative sign indicated that the energy stored in the material is released as a crack forms
- If γ = Surface energy/ unit area in Joules/m², then the surface energy (Us) for a crack of length 2c with unit width is given by

$$Us = 4\gamma C$$

- Total Change in Potential Energy

$$U = U_E + U_S = \frac{-\sigma^2 \pi c^2}{E} + 4\gamma c$$

Derivation for fracture strength

$$\frac{dU}{dc} = 0$$

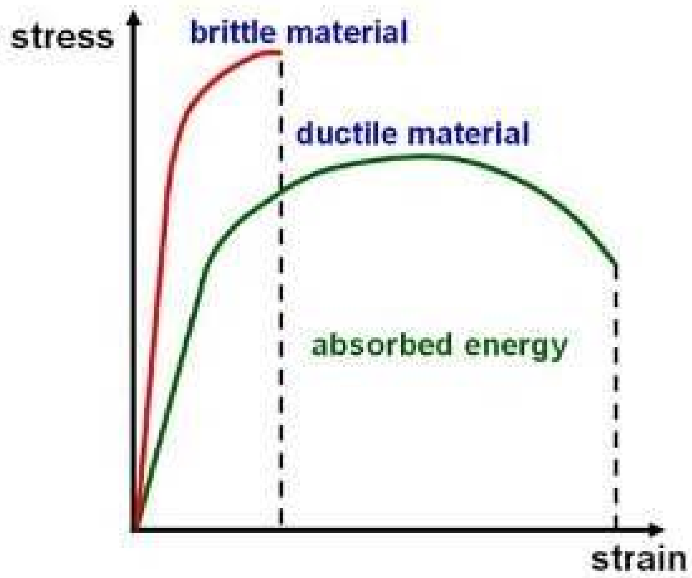
$$\therefore \frac{dU}{dc} = \frac{d}{dc}\left(\frac{-\sigma^2 \pi c^2}{E} + 4\gamma c\right) = 0$$

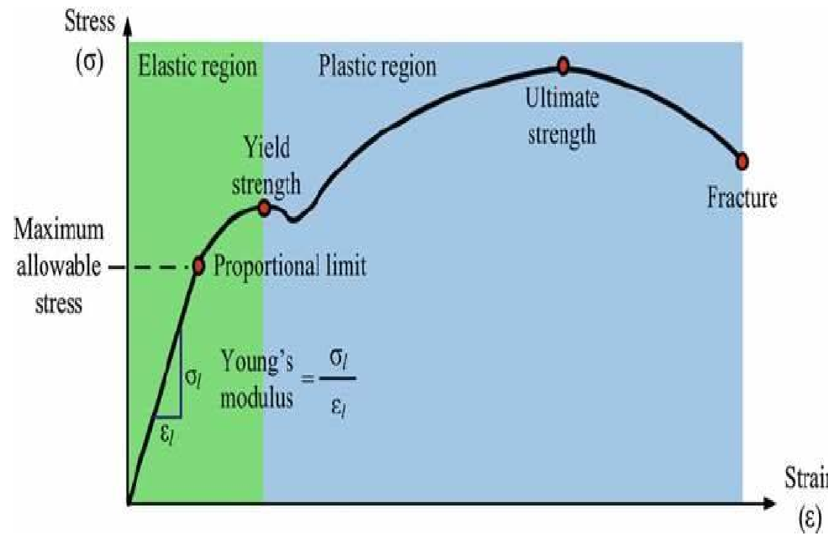
or $$-\frac{2\sigma^2 \pi c^2}{E} + 4c\gamma = 0$$

or $$\boxed{\sigma = \sqrt{\frac{2E\gamma}{\pi c}}} \qquad \dots (5.3)$$

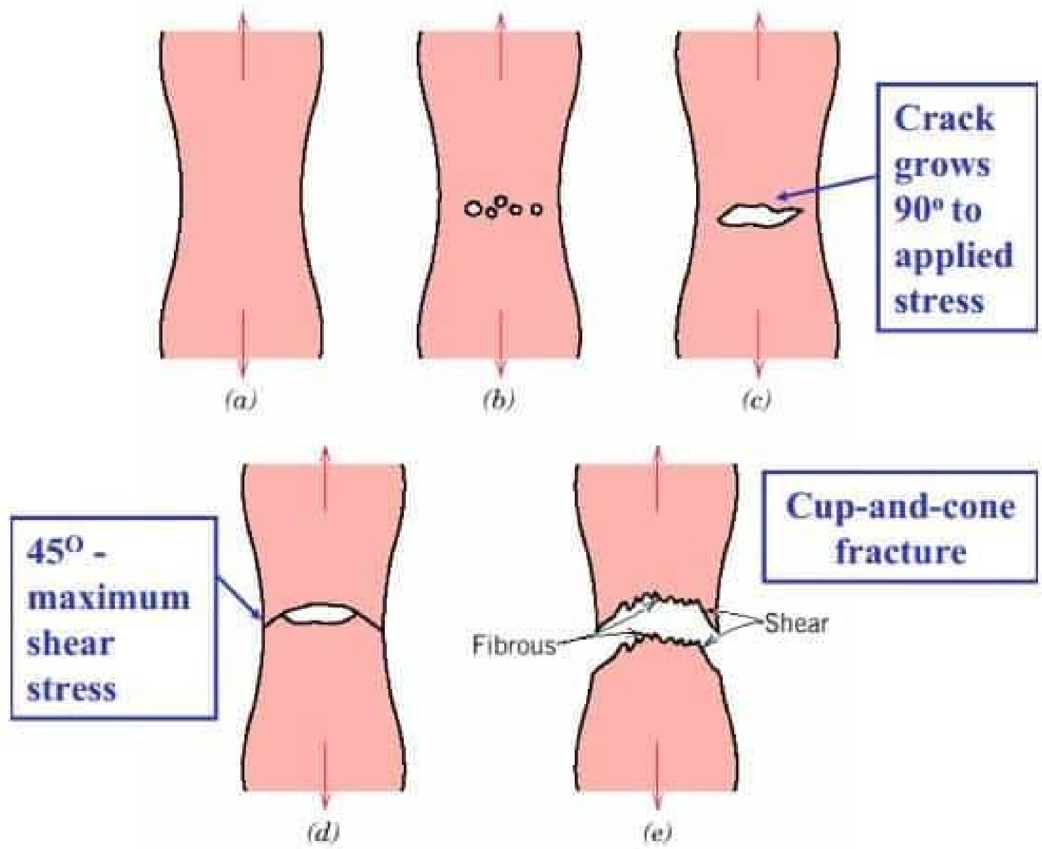
Ductile Fracture

- Ductile fracture may be define as the fracture which takes place by a slow propagation of crack with appreciable plastic



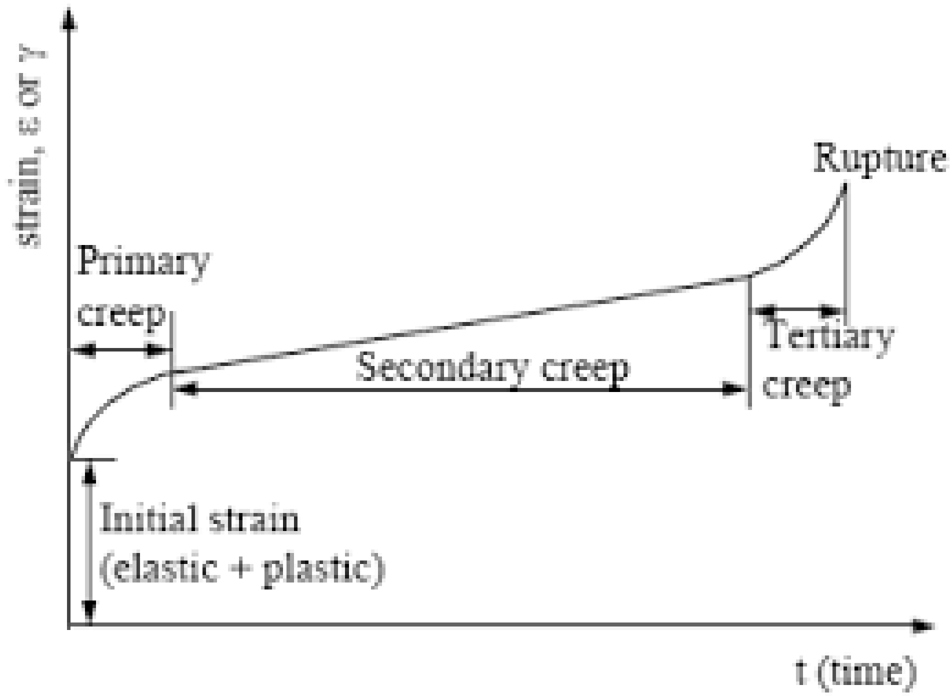


Stages in the formation of a cup-and-cone fracture



Creep Fracture

- The creep is defined as the property of a material by virtue of which it deforms continuously under a steady load



Mechanical test of metals

- The engineer and designer need to know the hardness, strength, and other characteristics of the materials they use
- The engineer and designer should also know about the way in which the properties are determined
- It can be noted that the tests need to be conducted according to standard procedures so that one can have confidence in published that results

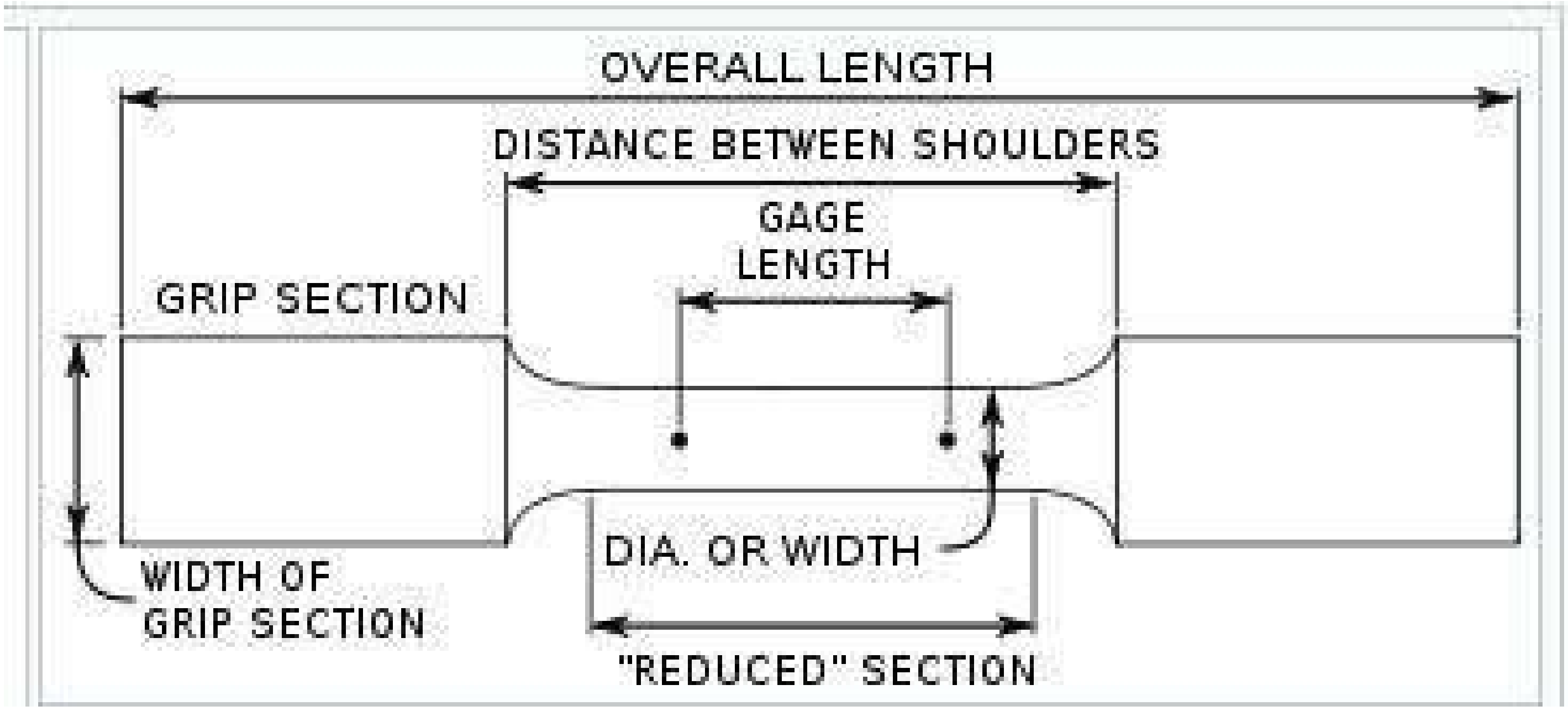
Classifications of Mechanical tests

- **Destructive tests-** In this type of testing, the component or specimen to be tested is ***destroyed*** and ***cannot be reused***
- **Examples:**
  - Tensile test, Impact test, bend test, Fatigue test,Torsion test, Creep test
- **Non-Destructive tests-** In this type of testing, the component or specimen to be tested is ***not destroyed*** and ***can be reused*** after the test
- **Examples:**
  - Radiography, Ultrasonic inspection etc.

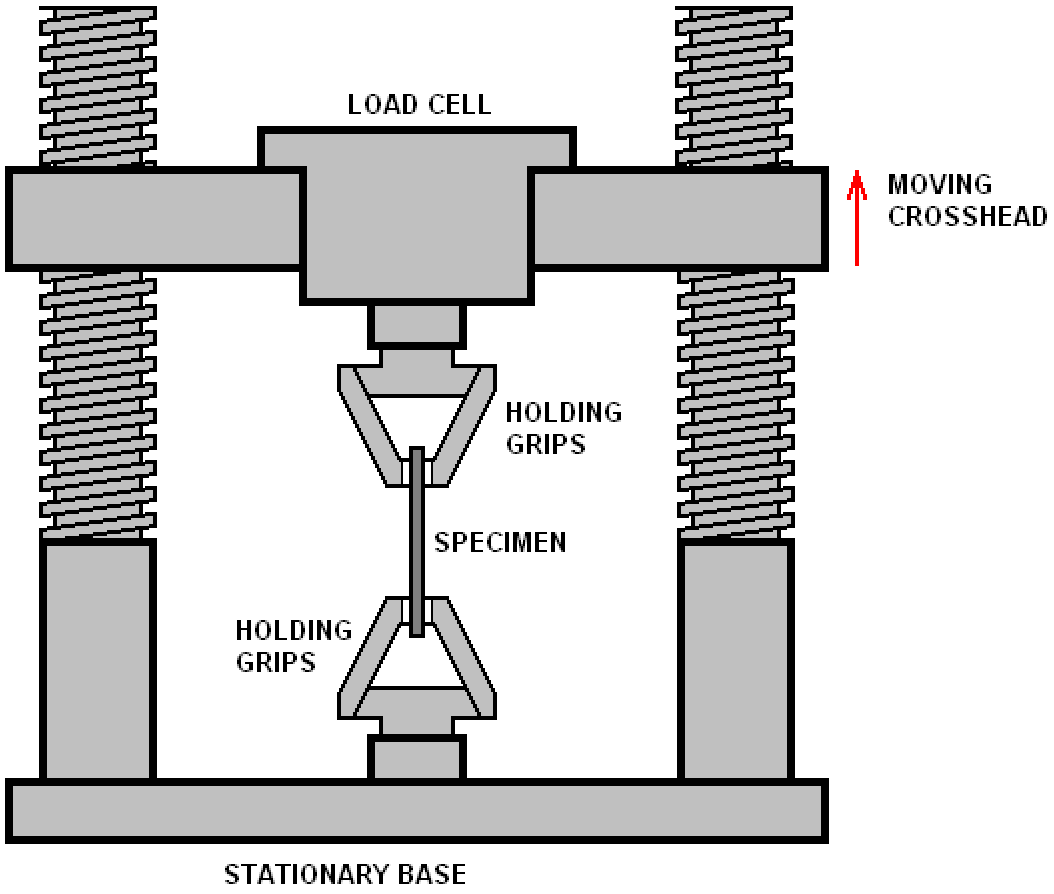
Tensile Test

- A tensile test of a material is performed on ductile materials to determine tensile properties such as ,
  - Yield point
  - Maximum tensile strength
  - Breaking strength
  - Percentage elongation
  - Percentage reduction in area
- The tensile test is usually carried out with the help of a "universal Testing Machine" (UTM)

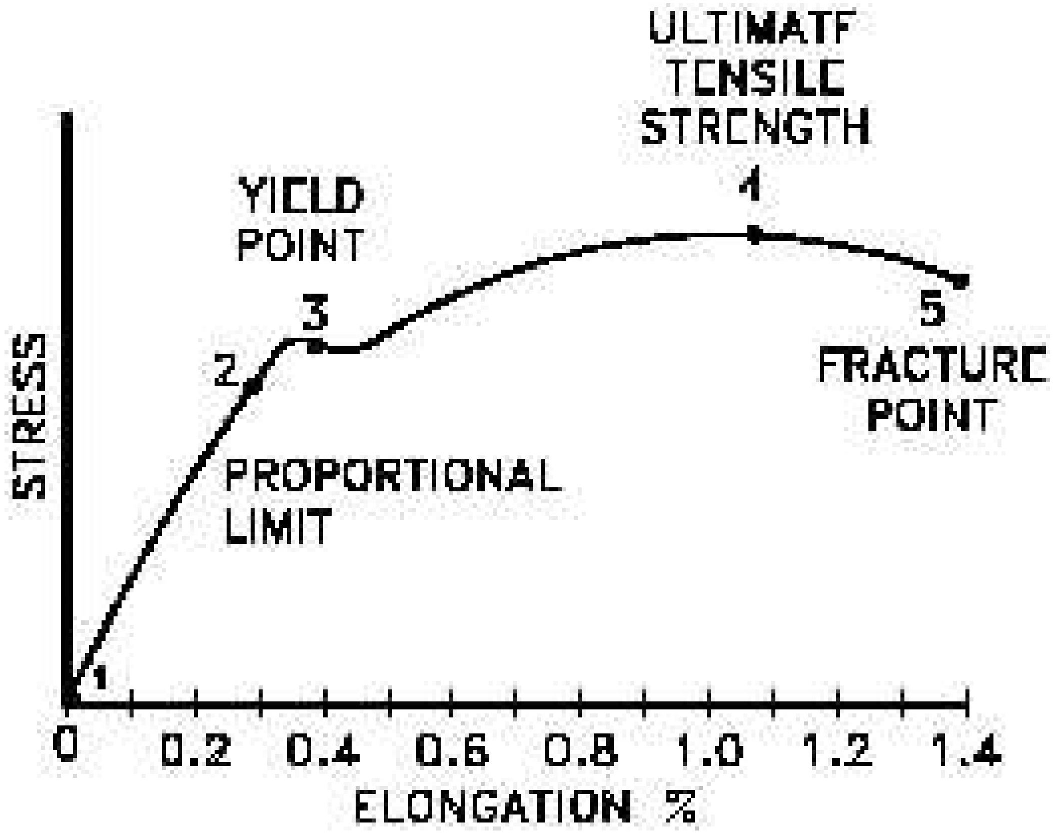
Tensile Test- Specimen



Tensile Test-UTM



Stress –Strain Curve



Compression Test

- The compression test is conducted in a manner similar to the tensile test, except that the force is compressive
- Since brittle materials are unsuitable for tension test, therefore they are tested for compression
- Brittle material such as cast iron, concrete, brick are commonly tested in compression
- The compression test is also conducted on a Universal Testing Machine

Hardness tests

- Hardness may be defined as the ability of a material to resist scratching, abrasion, cutting or penetration
- The hardness test is performed on a material to know its resistance against indentation and abrasion

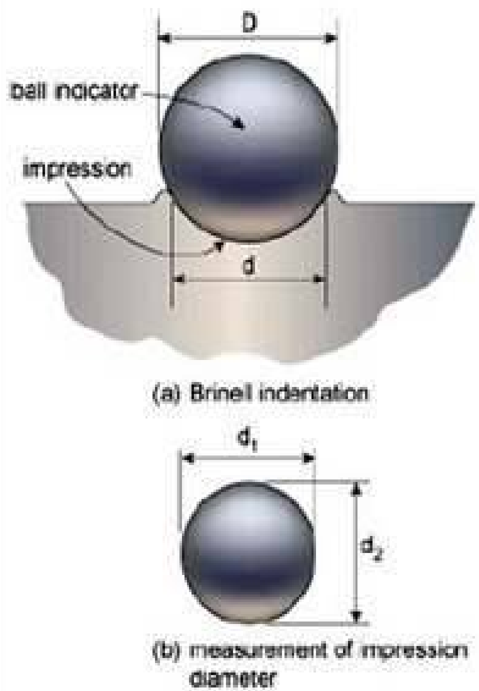
Types of Hardness tests:

- Brinell hardness test
- Vickers hardness test
- Rockwell hardness test

Hardness tests

- Generally an indenter is presses in to surface of the material by a slowly applied known load and the extend of the resulting impression is measured mechanically.
- A large impression for a given load and indenter indicates a soft material and a small impression indicates a hard material

Brinell Hardness



$$BHN = \frac{P}{\frac{\pi D}{2}\left[D - \sqrt{D^2 - d^2}\right]}$$

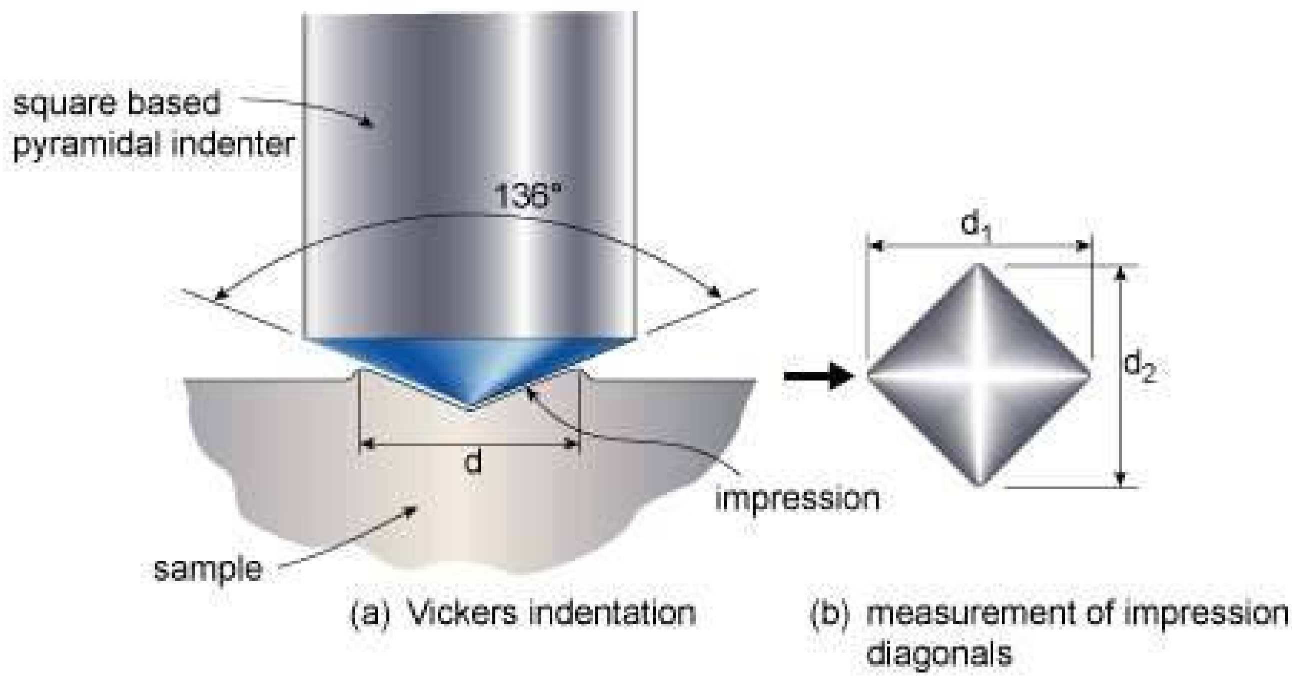
Where:

P is the test load [kg]

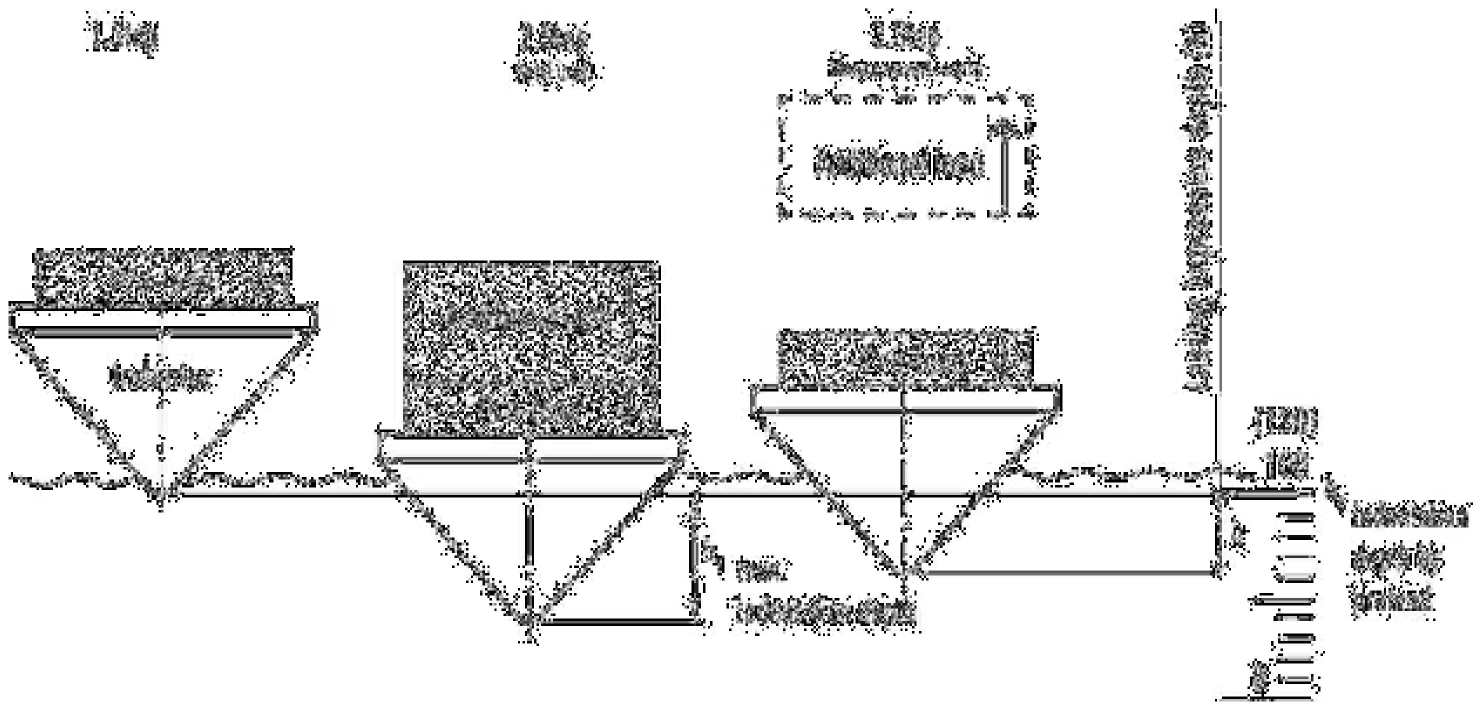
D is the diameter of the ball [mm]

d is the average impression diameter of indentation [mm]

Vickers Hardness

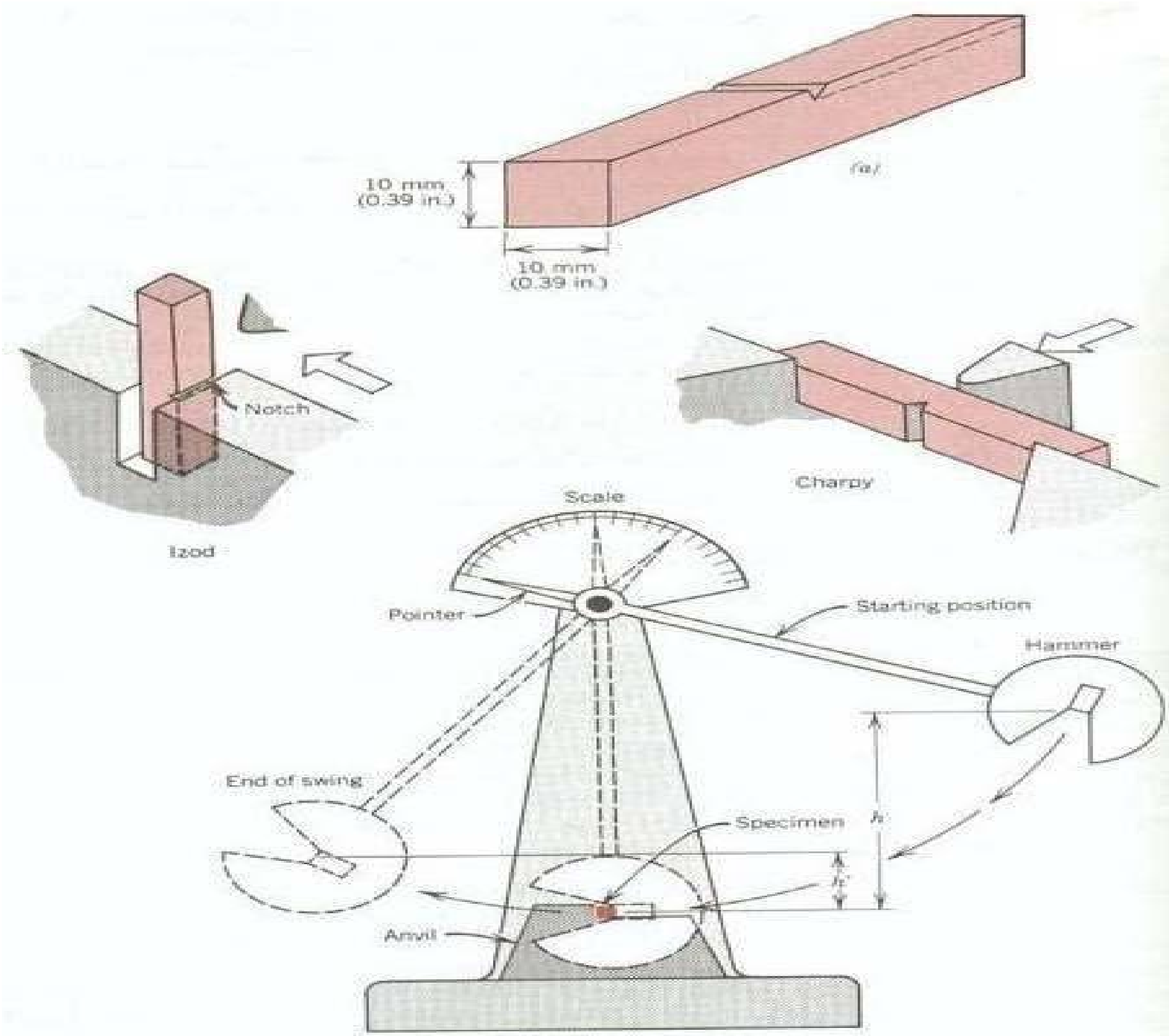


Rockwell Hardness



Impact Tests

- Izod tests
- Charpy tests



Impact Testing

Fatigue Test

- Fatigue tests determine the resistance of material to repeated fluctuating loads

- The capacity of material to withstand repeatedly applied stresses is known as fatigue

Fatigue Test