# General Engineering

## Unit 1 STRENGTH OF MATERIALS

# STRENGTH OF MATERLAS

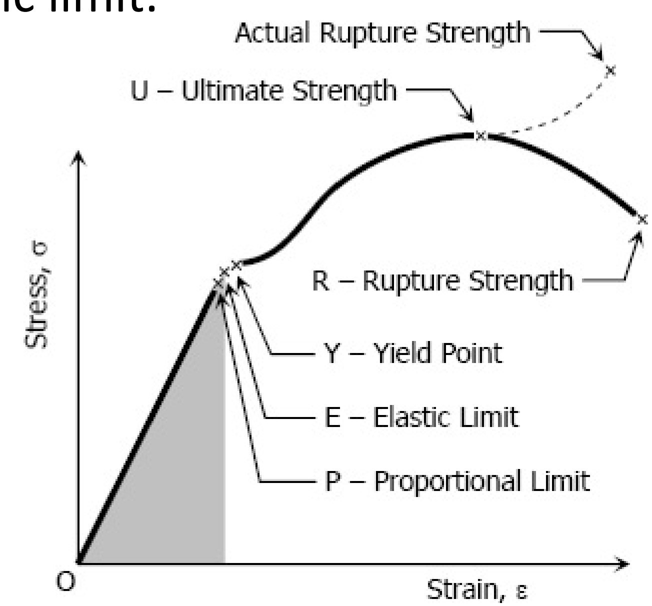
- The field of strength of materials refers to various methods of calculating the stresses and strains in structural members, such as beams, columns, and shafts.
- The methods employed to predict the response of a structure under loading and its susceptibility to various failure modes takes into account the properties of the materials such as its yield strength, ultimate strength, Young's modulus, and Poisson's ratio.
- In addition, the mechanical element's macroscopic properties (geometric properties) such as its length, width, thickness, boundary constraints and abrupt changes in geometry such as holes are considered.

# Mechanical properties of materials

- The mechanical properties of a material are those which affect the mechanical strength and ability of a material to be molded in suitable shape.

# Elasticity

- Elasticity is the ability of a material to return to its previous shape after stress is released. In many materials, the relation between applied stress is directly proportional to the resulting strain (up to a certain limit), and a graph representing those two quantities is a straight line.
- The greatest stress that a material can withstand without taking up some permanent change is called elastic limit.



# Elasticity

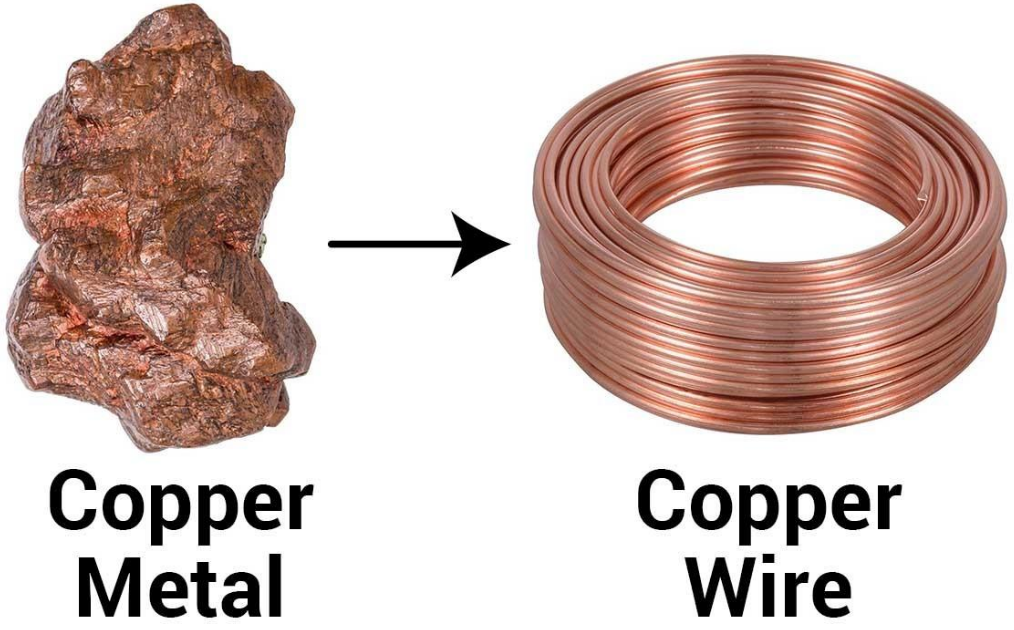
- The slope of this line is known as Young's modulus, or the "modulus of elasticity."
- The modulus of elasticity can be used to determine the stress–strain relationship in the linear-elastic portion of the stress–strain curve.
- The linear-elastic region is either below the yield point, or if a yield point is not easily identified on the stress–strain plot it is defined to be between 0 and 0.2% strain, and is defined as the region of strain in which no yielding (permanent deformation) occurs.

# Plasticity

- The plasticity of a material is its ability to change some degree of permanent deformation without failure.
- Plastic deformation will take place only after the elastic range has been exceeded.
- This property is widely used in several mechanical processes like forming shaping extruding rolling etc.
- Due to this properties various metal can be transformed into different products of required shape and size.
- This conversion into desired shape and size is effected either by the application of pressure heat or both.
- Plasticity increase with increase in temp.

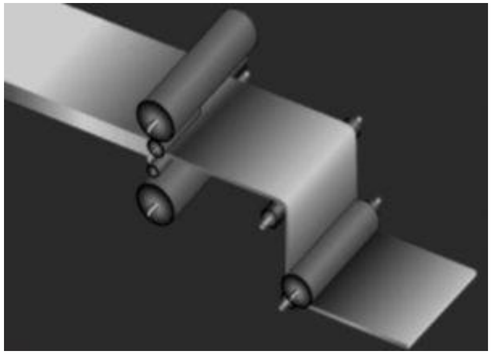
# Ductility

- Ductility is that property of a material which enables it to draw out into thin wire. Mild steel is a ductile material.
- The percent elongation and the reduction in area in tension is often used as empirical measures of ductility.



# Malleability

- Malleability of a material is its ability to be flattened into their sheets without creaking by hot or cold working.
- Aluminum copper tin lead steel etc are malleable metals.
- Lead can be readily rolled and hammered into thin sheets hat can not be drawn into wire.
- Ductility is a tensile property whereas malleability is a compessive property.
- Malleability increases with increase of temperature.



# Wear resistance

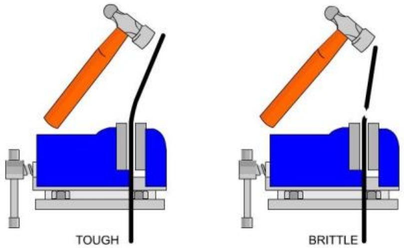
- Wear resistance is a measure of a material's ability to withstand the effect of two materials rubbing against each other.
- This can take many forms including adhesion, abrasion, scratching, gouging, galling, and others.
- When the materials are of different hardness, the softer metal can begin to show the effects first, and management of that may be part of the design.
- Even rolling can cause abrasion because of the presence of foreign materials.
- Wear resistance may be measured as the amount of mass lost for a given number of abrasion cycles at a given load.

# Toughness

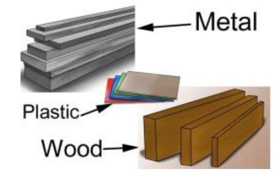
- Toughness is a measure of the amount of energy a material can absorb before actual fracture or failure takes place.
- The toughness of a material is its ability to withstand both plastic and elastic deformation.
- The work or energy a material absorbs is called modulus of toughness
- If a load is suddenly applied to a piece of mild steel and then to a piece of glass the mild steel will absorb much more energy before failure occurs. Thus mild steel is said to be much tougher than a glass.


# Brittleness

- The brittleness of a material is the property of breaking without much permanent distortion.
- There are many materials which break or fail before much deformation take place.
- Such materials are brittle e.g. glass cast iron.
- Therefore a non-ductile material is said to be a brittle material. Usually the tensile strength of brittle materials is only a fraction of their compressive strength.
- A brittle material should not be considered as lacking in strength. It only shows the lack of plasticity.



# Hardness




- Hardness is the ability of a material to resist deformation, which is determined by a standard test where the surface resistance to indentation is measured.
- Typically, the harder the material, the better it resists wear or deformation.
- The term hardness, thus, also refers to local surface stiffness of a material or its resistance to scratching, abrasion, or cutting.
- Hardness is measured by employing such methods as Brinell, Rockwell, and Vickers, which measure the depth and area of a depression by a harder material, including a steel ball, diamond, or other indenter.

# Fatigue

- Fatigue strength is the highest stress that a material can withstand for a given number of cycles without breaking.
- Fatigue strength is affected by environmental factors, such as corrosion.
- Fatigue can lead to fracture under repeated or fluctuating stresses (for example loading or unloading) that have a maximum value less than the tensile strength of the material.
- Higher stresses will accelerate the time to failure, and vice versa, so there is a relationship between the stress and cycles to failure.
- Fatigue limit, then, refers to the maximum stress the metal can withstand (the variable) in a given number of cycles.
- Conversely, the fatigue life measure holds the load fixed and measures how many load cycles the material can withstand before failure.
- Fatigue strength is an important consideration when designing components subjected to repetitive load conditions.

# Creep

- Creep is the tendency of a solid material to move slowly or deform permanently under the influence of persistent mechanical stresses.
- It can occur as a result of long-term exposure to high levels of stress that are still below the yield strength of the material.
- Creep is more severe in materials that are subjected to heat for long periods and generally increases as they near their melting point.
- Creep strength is defined as the maximum stress in a material that will result in a specified amount of creep in a given time at a constant temperature.
- It is essentially used to measure the material's ability to withstand sustained loading without significant continuous deformation.
- In steels, creep strength is only a significant factor at significantly elevated temperatures.

# Creep

- To understand Creep lets take an example of high tension electric wire as shown.
- Over a span of time these wire sag due to their constant weight that acts continuous.
- So Creep is the slow plastic deformation of metal under constant stress.
- Creep can take place and lead to failure at static stresses much smaller than those which will fail the specimen by loading it quickly.

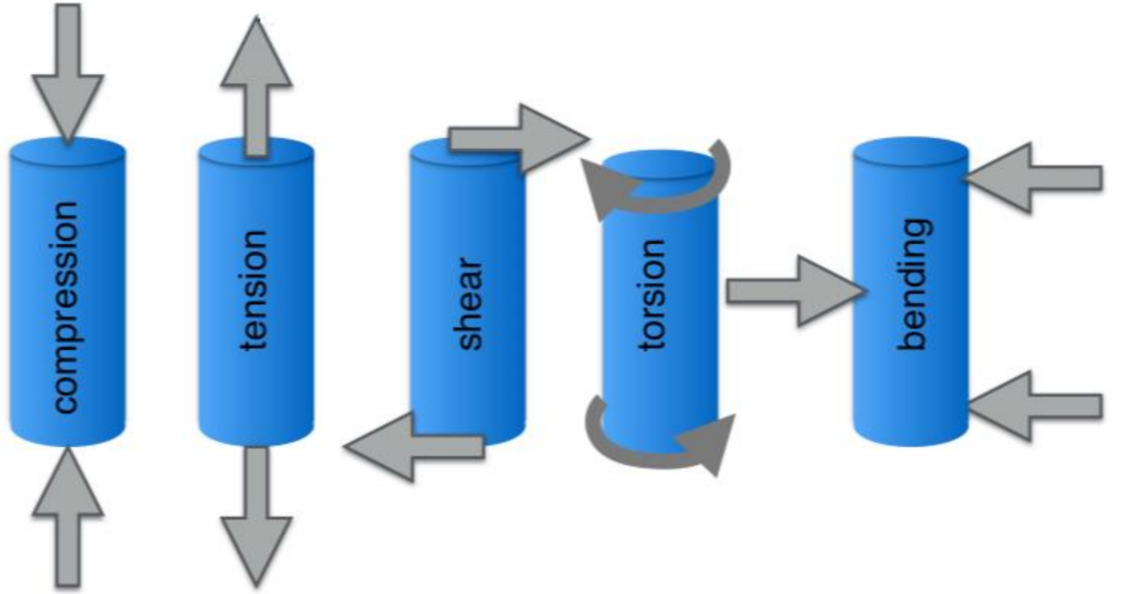
# Simple stresses and strains

- In a Machine, every component subjected to various forces. Due to these forces acting on the machine components, there are various types of stresses are induced.
- Simple stress is defined as the internal resistance force that opposes the external force per unit area.
- Strain is defined as the deformation per unit length.
- A simple Stress and strain are produced due to any of the following type of actions done on the machine parts. they are
  - Self-weight of the machine
  - Energy Transmitted
  - Change of temperature
  - Frictional resistance
  - The inertia of reciprocating parts
  - Unbalance of Moving parts.

# Simple stresses and strains

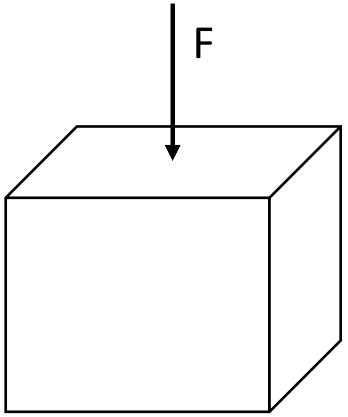
These actions cause a different variety of stresses.

- Tensile Stresses
- Compressive Stresses
- Shear Stresses
- Bending Stresses
- Torsion Stresses



# Simple Stress

- Consider a force is acting on a body on a unit area. a simple stress is defined as the internal force which is resisting the external force per unit area. It is denoted with σ




**Stress (σ )= F/A**

Where,

F = Force acting on the body

A = Cross-sectional Area where the force is acting

# Simple Strain

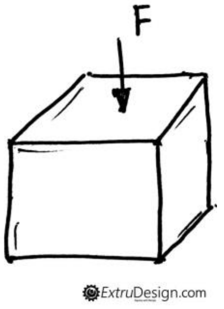
- Due to the external forces, the body may undergo some deformation. This deformation per unit length is said as the Strain. Strain represented by ε

**Strain (ε) = δl/l**

Where,

δl = Change in the length of the body

l = Original length of the body



# Tensile Stresses

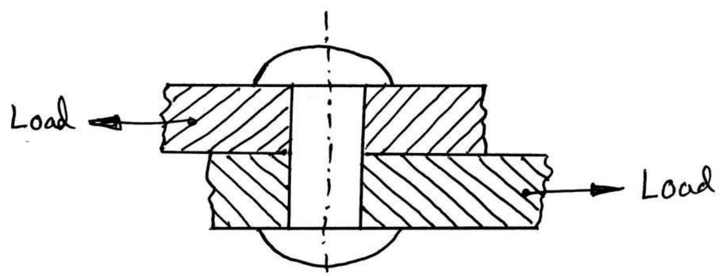
- When a body subjected to two equal and opposite axial pulling forces(Tensile Load) then the stress produced in every section of the body is called Tensile stresses.

# Compressive Stresses

- When a body subjected to two equal and opposite axial pushing forces(Compression Load) then the stress produced in every section of the body is called Compressive stresses.
- Compressive strain Is the change in length by its original length.

# Shear Stresses

Consider a Rivet has joined two metal sheets together. Then the two sheets subjected to two equal and opposite forces acting tangentially across the Rivet section. Then the stress induced in the Rivet is called Shear stresses.



# Shear Stresses

- Shear stress can be calculated as the ratio of Tangential force acting on the Rivet to the Cross section area of the Rivet.

Mathematically

**Shear stress($\tau$) = Tangential Force/ Resisting cross-sectional Area.**

- Shear strain can be defined as the ratio of deformation to its original length or shape.
- Shear strain can be represented by $\Phi$
- Here the shear stress directly proportional to the Shear strain within the elastic limit.

**Shear Stress ∝ Shear Strain**

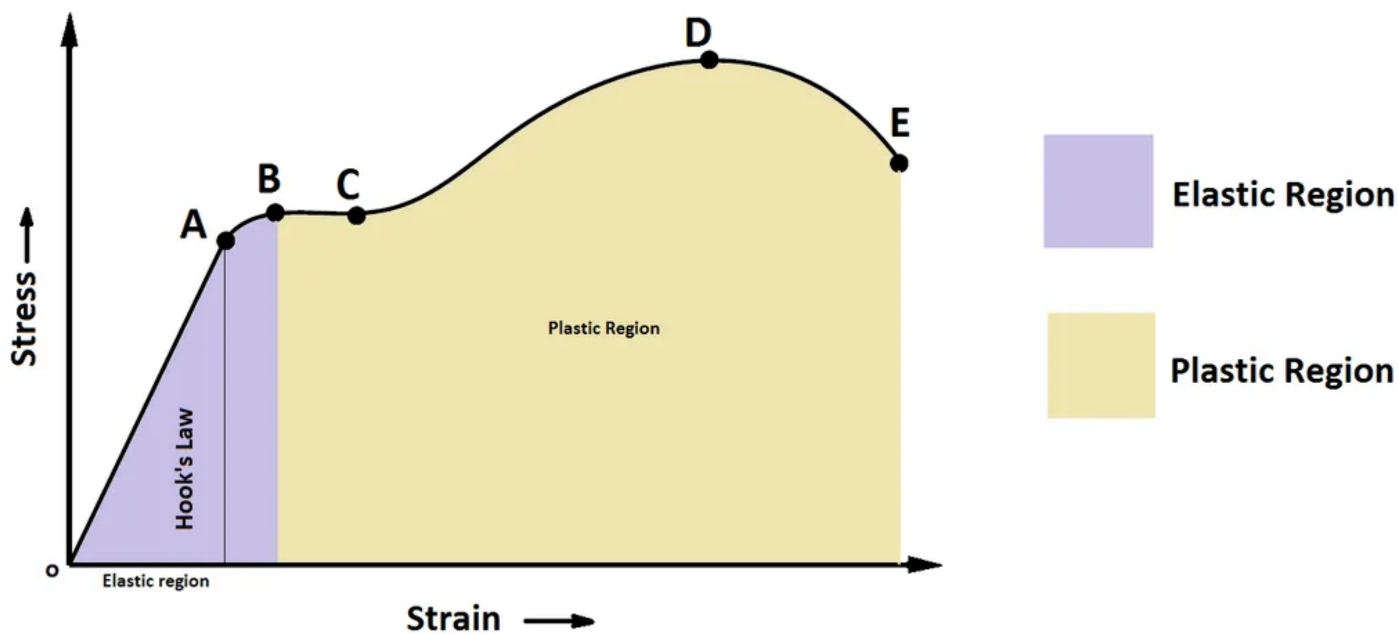
$$\tau \propto \Phi$$

$$\tau = C * \Phi$$

Where C= Constant of Proportionality Known the Modulus of rigidity or Shear Modulus.

# Stress - Strain diagram

To study the behaviour of any material which is subjected to a load, it is possible by relating the stress with strain while gradually increasing the load. The graph between the stress and strain is known as Stress strain Curve.



# Stress - Strain diagram

- If we draw a graph between stress and strain while applying a load on a body, the above Stress strain curve represents the behaviour of the body with respect to the applied load. (Take Stress on Y-axis and Strain on X-axis.)
- There are two behaviours of the metals, in this case as represented in the above diagram, they are
  - Elastic behavior: the body will get its original shape when the load is removed.
  - Plastic behavior: Permanent deformation happen (No restoring forces).
- As the curve is divided into five regions as noted on the curve as shown in the  diagram.

# Stress - Strain diagram

**O-A: Proportional limit** : In the above Stress strain diagram, the curve o-A represents Proportional limit. It obeys Hook's law. The stress is directly proportional to strain. The material will get its original shape when the load is removed.

**A-B: Elastic Region** : n this region this will not obey Hook's law, However, the material still elastic in this region. which means the material can get its original shape when the applied load is removed. but not in a proportional manner. The point B Is called Elastic limit.

**B-C: Yield Stress** : Where in stress strain diagram The path B-C represents the yield stress. where the body takes the deformation permanently with no/Little increase in the stress. This stress is called yield stress point.

# Stress - Strain diagram

**C-D: Ultimate Stress** : From Yield stress point (C) to Ultimate stress point, within a small increase in stress Cause the more deformation. This is the maximum stress that material has to bear before it going to be brake or fail.

**E: Rupture Point/Breaking** : If the applied load crosses the Ultimate stress(maximum bearing capacity of the material), with no increase in the stress, the body will fail at this point. This is called breaking point or Rupture point. See the curve between the D and E, The stress drops after the point D and at point E this body starts breaking.

# Hooke's law

- Robert Hooke was the scientist who gave Hooke's law.
- Hooke's law states that within the elastic limit, stress developed is directly proportional to the strain produced in a body.
- Consider a scenario where we apply external force to the body. As a result stress develops in the body due to this stress there will be a strain produced in the body which implies that there will be some deformation in the body.
- Because of stress, strain is produced.
- According to Hooke's law, if strain increases the stress will increase and vice-versa.
- The Hooke's law is applicable to all elastic substances. It does not apply to plastic deformation.

Mathematically :

**stress ∝ strain**

**stress = k × strain**

Where, k is the proportionality constant and is known as modulus of elasticity.

# Hooke's law

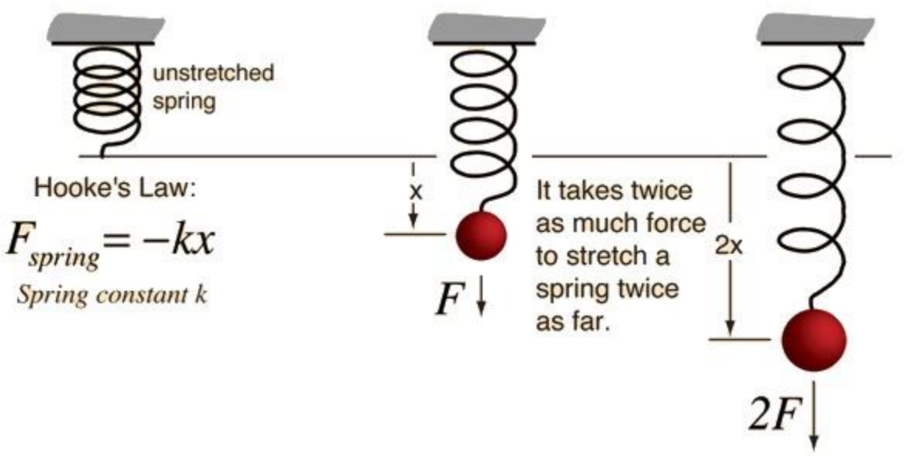
**F = -kx**

Where,

F is the force,

x is the length of extension/compression and

k is a constant of proportionality known as the spring constant which is usually given in N/m.



# Young's modulus

- Young's modulus is derived from the name of the scientist who defined it.
- It is the ratio of longitudinal stress to longitudinal strain.
- It is denoted by Y.

Mathematically:

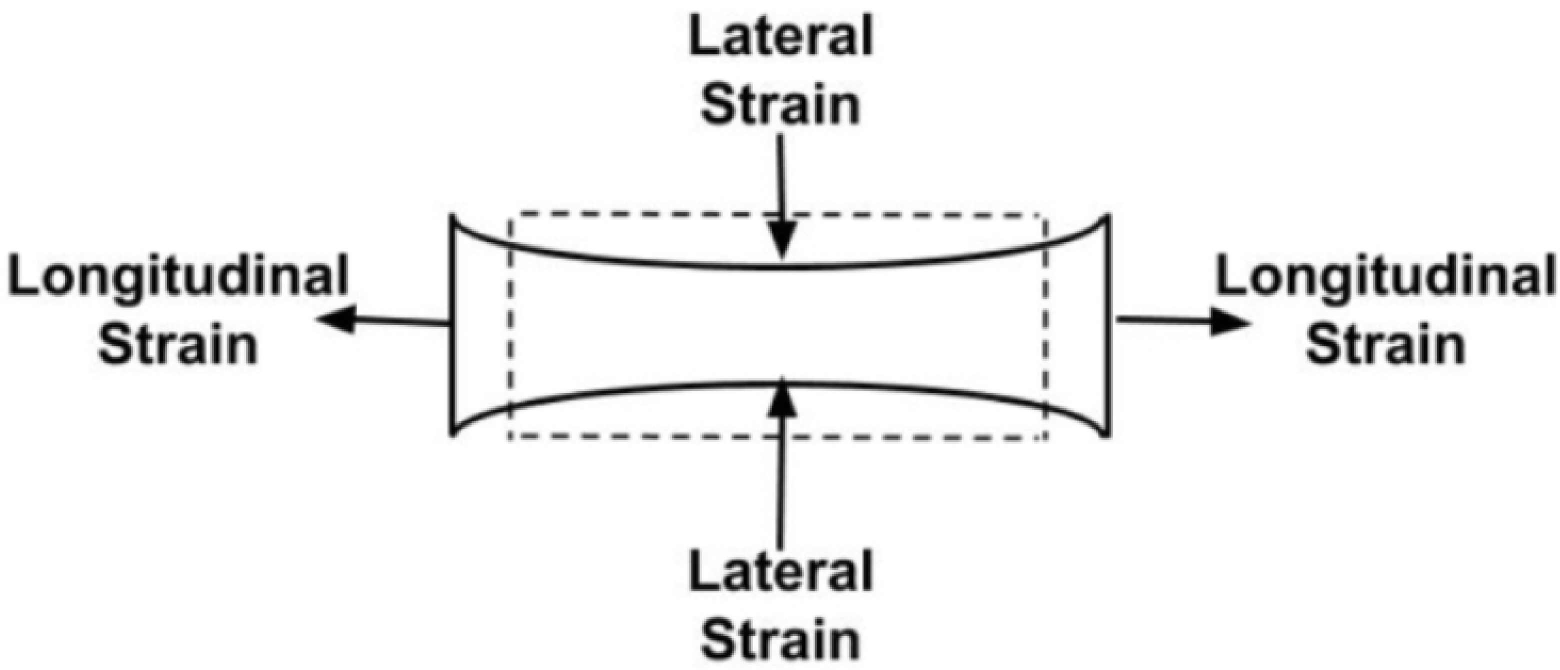
$$\mathbf{Y = \text{longitudinal stress/ longitudinal strain} = \frac{\sigma}{\varepsilon}}$$

$$\mathbf{= \frac{(F/A)}{(\Delta L/L)}}$$

$$\mathbf{Y = \frac{FL}{\Delta L}}$$

- If Young's modulus is more, to produce a small change in length more force required.
- S.I. Unit is Nm–2 or Pascal (Pa).
- Metals have comparatively greater Young's Modulus. To change the length of metals, greater force is required.

# Lateral strain  Longitudinal strain



# Lateral strain

- Lateral strain, also known as transverse strain, is defined as the ratio of the change in diameter of a circular bar of a material to its diameter due to deformation in the longitudinal direction.
- It occurs when under the action of a longitudinal stress, a body will extend in the direction of the stress and contract in the transverse or lateral direction (in the case of tensile stress).
- When put under compression, the body will contract in the direction of the stress and extend in the transverse or lateral direction.
- It is a dimensionless quantity, as it is a ratio between two quantities of the same dimension. **E =** $\frac{\delta D}{D}$

# Longitudinal strain

The longitudinal strain is defined as the ratio of change in length of the material due to the applied force to original length.

$$E = \frac{\delta L}{L}$$

# Poisson's ratio

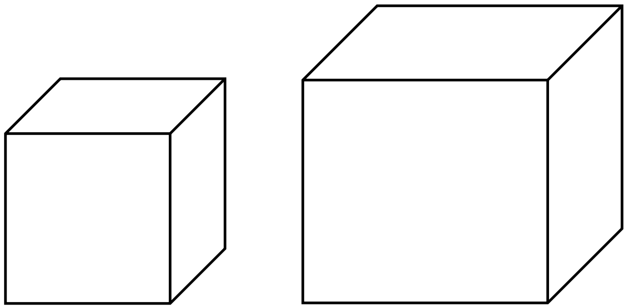
- When a material is stretched in one direction, it tends to compress in the direction perpendicular to that of force application and vice versa.
- The measure of this phenomenon is given in terms of Poisson's ratio.
- For example, a rubber band tends to become thinner when stretched.
- Poisson's Ratio defines the ratio between the negative lateral strain and the longitudinal strain.

$$v = -\varepsilon_{trans} / \varepsilon_{longitudinal}$$

# Volumetric Strain

- Volume strain is defined as ratio of change in volume to the original volume as a result of the hydraulic stress.
- When the stress is applied by a fluid on a body there is change in the volume of body without changing the shape of the body.

**Volume strain = $\Delta V/V$**



For example:-

Consider a cube initially at volume V.

Because of hydraulic stress there is change in volume V'

Therefore, Change in the volume $\Delta V = V' - V$

Conclusion: - Deformation is measured using strain.

# Bulk modulus

Bulk modulus is the ratio of hydraulic stress to the corresponding hydraulic strain.

Denoted by ‘B’

$$\mathbf{B = -\rho/(\Delta V/V)}$$

Where,

$\rho$ =hydraulic stress, $\Delta V/V$ = hydraulic strain

(-) ive signs show that the increase in pressure results in decrease in volume.

S.I. Unit :- N/m2 or Pascal(Pa)

B(solids) > B(liquids) >B(gases)

# Bulk modulus

**Problem:-**The average depth of Indian Ocean is about 3000 m.

Calculate the fractional compression, ΔV/V, of water at the bottom of the ocean, given that the bulk modulus of water is 2.2 × 109 N m–2. (Take g = 10 m s–2)

**Answer:** - The pressure exerted by a 3000 m column of water on the bottom layer

p = hρ g = 3000 m × 1000 kg m–3 × 10 m s–2

= 3 × 107 kg m–1 s-2

= 3 × 107 N m–2

Fractional compression ΔV/V, is

ΔV/V = stress/B = (3 × 107 N m-2)/ (2.2 × 109 N m–2)

= 1.36 × 10-2 or 1.36 %

# Temperature stress and strains Cylindrical shells

- Ordinary materials expand when heated and contract when cooled, hence, an increase in temperature produce a positive thermal strain.
- Thermal strains usually are reversible in a sense that the member returns to its original shape when the temperature return to its original value.
- It is established experimentally that the change in length Δ is directly proportional to the length of the member L and change in temperature t. Thus

$$\Delta \propto tL$$

$$= \alpha tL$$

- The constant of proportionality α is called coefficient of thermal expansion and is defined as change in unit length of material due to unit change in temperature. T

# Thin and thick cylindrical shell comparison.

| Thin cylinder | Thick cylinder |
|---|---|
| The cylinder which have thickness is less than 1/10 to 1/20 of its Diameter, that cylinder is called as thin cylinder. | The cylinder which have Thickness is more than 1/20 of its diameter that Cylinder is called as thick Cylinder. |
| Thin cylinder is only resist to the internal Pressure. | Thick cylinder is resist Internal as well as external pressure. |
| Stress is distributed Uniform throughout thickness. | Stress is not distributed Uniformly throughout thickness. |
| Stress is constant throughout cylinder. | In thick cylinder maximum stress inner side a d minimum stress in outer side. |
| Low stress consuming capacity. | More stress consuming Capacity. |

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