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Applied Physics

Lecture-4

Unit II-Mechanical Properties of solids

Topics to be discusses in this lecture:

- **Tangential/shearing stress and strain**
- **Hydraulic stress and volume strain**
- **Hooke's Law**
- **Young's Modulus of Elasticity (Y)**
- **Bulk Modulus of Elasticity (B)**
- **Modulus of Rigidity (η)**

In The previous lecture we have introduced longitudinal stress, longitudinal strain, Elastic and plastic deformation in materials. We will now continue that discussion and will gradually cover Hooke's law and elastic moduli (young's modulus, bulk modulus and modulus of elasticity) in solids.

A solid may change its dimension in 3 different ways, resulting in three different types of stress and strain mentioned below:

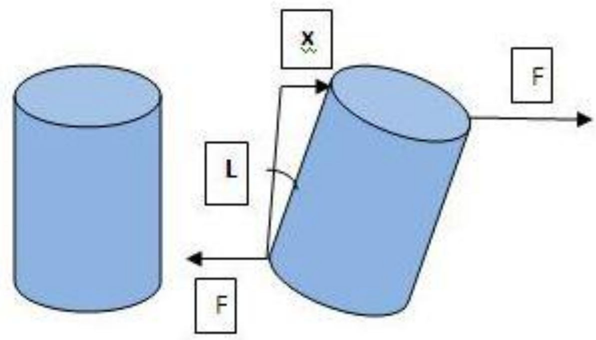
- **Longitudinal (tensile and compressive) stress and strain** (already discussed in previous lecture)
- **Tangential/shearing stress and strain**
- **Hydraulic stress and volume strain**

Tangential/shearing stress

If two equal and opposite deforming forces are applied parallel to the cross-sectional area of a cylinder like object (shown below), then there is a relative displacement between the opposite faces of the cylinder.

In this the restoring force per unit area due to the applied tangential forces called **Tangential/shearing stress.**

Shearing stress = $\frac{\boldsymbol{Force}}{\boldsymbol{Area}}$



Shearing strain

Strain related to shearing stress is called shearing strain.

In the diagram shown above, two equal, opposite and parallel forces with magnitude F cause a relative displacement x between the opposite faces of the cylinder

And during this displacement an angle θ (know as shearing strain) is generated between the original and displaced sidelines.

Shearing strain (tanθ) = $\frac{\boldsymbol{x}}{\boldsymbol{L}}$

If this angle θ is too small then tanθ=θ

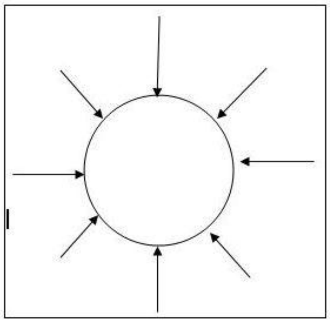
Then **Shearing strain, θ** = $\frac{\boldsymbol{x}}{\boldsymbol{L}}$

Hydraulic stress

When a solid (say sphere) is placed in fluid under high pressure and compressed uniformly on all sides, then the force applied by the fluid acts in perpendicular direction at each point of the surface. This is called **hydraulic compression.** This leads to decrease in volume under **hydraulic pressure**.

The internal restoring force (F) per unit area (A) is called hydraulic stress.

Hydraulic stress (hydraulic pressure) = F/A



Hydraulic stress

Volume strain

Strain related to hydraulic stress is called volume strain which is the ratio of change in volume and initial volume.

$$\textbf{Volume strain} = \frac{\Delta V}{V}$$

Hooke's law

When studying springs and elasticity, the 17th century physicist Robert Hooke noticed that the stress vs. strain curve for many materials has a linear region.

According to Hooke's law for a small deformation, the stress in a body is proportional to the corresponding strain." i.e.,

stress ∝ strain

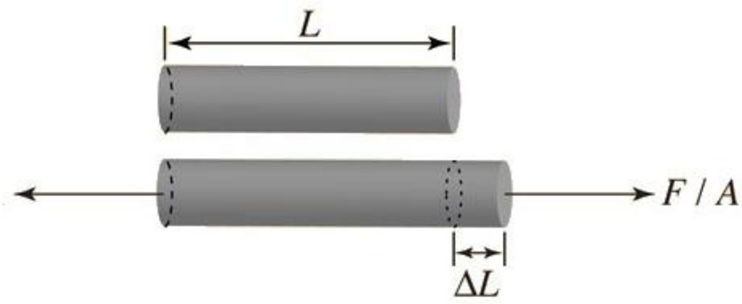
stress = (E) (strain)

Here, E = stress/strain is a constant called **modulus of elasticity**.

Depending upon the nature of force applied on the body, the **modulus of the elasticity is classified in the following three types**:

1. Young's Modulus of Elasticity (Y)

When a wire is acted upon by two equal and opposite forces in the direction of its length, the length of the body is changed. The change in length per unit length ($\Delta L/L$) is called the longitudinal strain and the restoring force (which is equal to the applied force in equilibrium) per unit area of cross-section of wire is called the longitudinal stress.



For small change in the length of the wire, the ratio of the longitudinal stress to the corresponding strain is called the **Young's modulus of elasticity (Y)** of the wire. Thus,

$$Y = \frac{F/A}{\Delta L/L} = \frac{F.L}{\Delta L.A}$$

Let there be a wire of length 'l' and radius 'r'. Its one end is clamped to a rigid support and a mass M is attached at the other end. Then

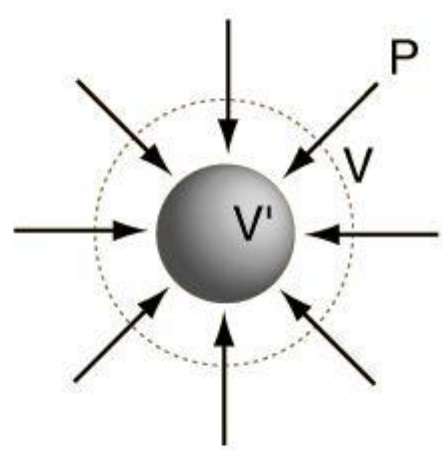
F = Mg and A = πr^2

Substituting in above equation, we have

$$Y = \frac{Mg.L}{\Delta L.\pi r^2}$$

2. Bulk Modulus of Elasticity (B)

When a uniform pressure (normal force) is applied all over the surface of a body, the volume of the body changes. The change in volume per unit volume of the body is called the 'volume strain' and the normal force acting per unit area of the surface (pressure) is called the normal stress or volume stress. For small strains, the ratio of the volume stress to the volume strain is called the '**Bulk modulus' of the material of the body**. It is denoted by B. Then



$$\mathbf{B} = \frac{-P}{\Delta V/V}$$

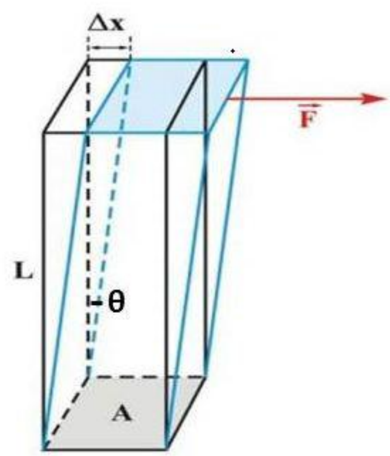
Here, the negative sign in formula implies that when the pressure increases volume decreases and vice-versa.

Compressibility

The reciprocal of the Bulk modulus of the material of a body is called the "compressibility' of that material. Thus,

Compressibility = 1/B

3. Modulus of Rigidity (η)



When a body is acted upon by an external force tangential to a surface of the body, the opposite surfaces being kept fixed, it suffers a change in shape of the body, and its volume remains unchanged. Then the body is said to be sheared.

The ratio of the displacement of a layer in the direction of the tangential force and the distance of the layer from the fixed surface is called the shearing strain and the tangential force acting per unit area of the surface is called the 'shearing stress'.

For small strain in the ratio of the shearing stress to the shearing strain is called the **'modulus of rigidity**'of the material of the body. It is denoted by 'η'.

$$\eta = \frac{F/A}{\theta} = \frac{F}{A.\theta}$$