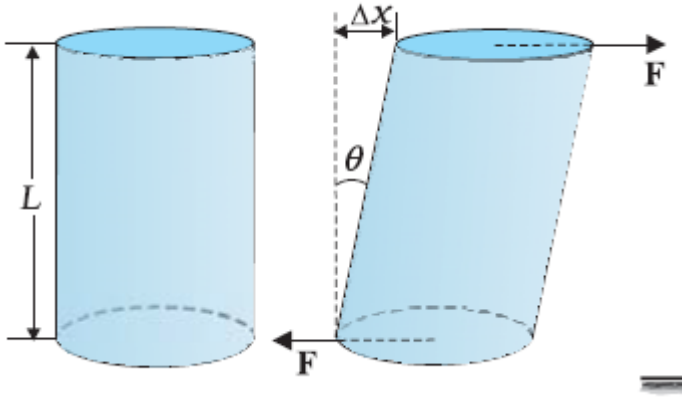
MECHANICAL PROPERTIES OF SOLIDS

- Theproperty of a body, by virtue of which it tends to regain itsoriginal size and shape when the applied force is removed, isknown as **elasticity** and the deformation caused is knownas **elastic** deformation.
- However, if you apply force to a lumpof putty or mud, they have no gross tendency to regain theirprevious shape, and they get permanently deformed. Suchsubstances are called plastic and this property is calledplasticity.
- When a solid isdeformed, the atoms or molecules are displacedfrom their equilibrium positions causing achange in the interatomic (or intermolecular)distances. When the deforming force is removed,the interatomic forces tend to drive them backto their original positions. Thus the body regainsits original shape and size.
- When a body issubjected to a deforming force, a restoring forceis developed in the body. This restoring force isequal in magnitude but opposite in direction tothe applied force. The restoring force per unitarea is known as stress. If F is the force appliedand A is the area of cross section of thebody,

Magnitude of the stress = F/A (9.1)

The SI unit of stress is N m^{-2} or pascal (Pa)

- The restoring force per unit area is called tensile stress. If the cylinder iscompressed under the action of applied forces,the restoring force per unit area is known ascompressive stress. Tensile or compressivestress can also be termed as longitudinal stress.
- The change in the lengthΔL to the original length L of the body (cylinderin this case) is known as longitudinal strain .
- The restoring forceper unit area developed due to the appliedtangential force is known as tangential orshearing stress.
- Shearing strain is defined as the ratio of relativedisplacement of the faces Δx to the length ofthe cylinder L.

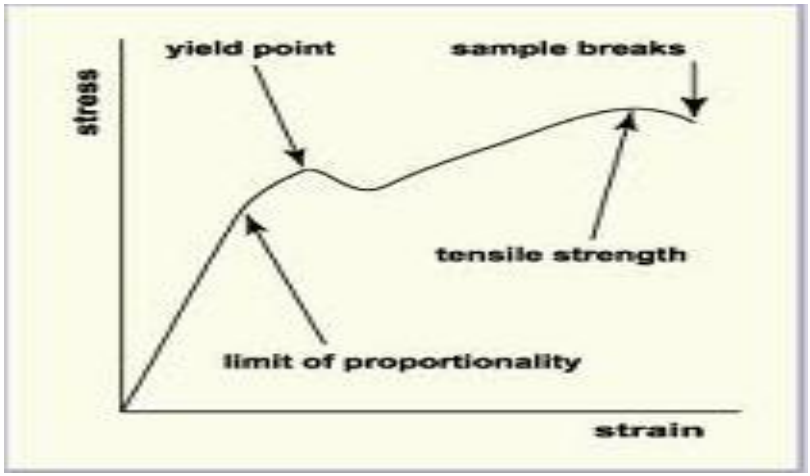


- A solid sphere placed in thefluid under high pressure is compresseduniformly on all sides. The force applied by thefluid acts in perpendicular direction at eachpoint of the surface and the body is said to beunder hydraulic compression. This leads todecrease in its volume without any change ofits geometrical shape.
- The strain produced by a hydraulic pressureis called volume strain and is defined as theratio of change in volume (ΔV) to the originalvolume (V).
- For smalldeformations the stress and strain areproportional to each other. This is known asHooke's law.
- Thus,

  $\text{stress} \propto \text{strain}$

  $\text{stress} = k \times \text{strain}$ (9.6)

  where k is the proportionality constant and isknown as modulus of elasticity.
- The relation between the stress and the strainfor a given material under tensile stress can befound experimentally.The fractionalchange in length (the strain) and the appliedforce needed to cause the strain are recorded.The applied force is gradually increased in stepsand the change in length is noted. A graph isplotted between the stress (which is equal inmagnitude to the applied force per unit area)and the strain produced.



- Substances like tissue of aorta, rubberetc. which can be stretched to cause large strainsare called elastomers.
- The ratio of stress and strain is called modulus of elasticity.
- The ratio of tensile (or compressive)stress (σ) to the longitudinal strain (ε) is defined asYoung's modulus and is denoted by the symbol Y.

  $Y = (F/A)/(\Delta L/L)$
- The ratio of shearing stress to the correspondingshearing strain is called the shear modulus ofthe material and is represented by G. It is alsocalled the modulus of rigidity.

  G = shearing stress (σ_s)/shearing strain

$G = (F/A)/(\Delta x/L) = (F \times L)/(A \times \Delta x)$

$G = (F/A)/\theta$

$= F/(A \times \theta)$

The shearing stress σ_s can also be expressed as $\sigma_s = G \times \theta$

- The ratio of hydraulicstress to the corresponding hydraulic strain iscalled bulk modulus. It is denoted by symbol B.

  $B = - p/(\Delta V/V)$

  The negative sign indicates the fact that withan increase in pressure, a decrease in volumeoccurs. That is, if p is positive, ΔV is negative.Thus for a system in equilibrium, the value ofbulk modulus B is always positive.

- The reciprocal of the bulk modulus is calledcompressibility and is denoted by k. It is definedas the fractional change in volume per unitincrease in pressure.

  $k = (1/B)$

Sample Examples

- A square lead slab of side 50cm and thickness 10 cm is subject to ashearing force (on its narrow face) of 9.0 ×
- 10^4 N. The lower edge is riveted to the floor.How much will the upper edge be displaced?

Solution

The lead slab is fixed and the force isapplied parallel to the narrow face. The area of the face parallel to whichthis force is applied is

$A = 50\ cm \times 10\ cm = 0.5\ m \times 0.1\ m = 0.05\ m^2$

Therefore, the stress applied is

$= (9.4 \times 10^4\ N/0.05\ m^2) = 1.80 \times 10^6 N.m^{-2}$

We know that shearing strain = $(\Delta x/L)$=Stress /G.

Therefore the displacement Δx = (Stress × L)/G

$= (1.8 \times 10^6\ N\ m^{-2} \times 0.5m)/(5.6 \times 10^9\ N\ m^{-2}) = 1.6 \times 10^{-4}\ m = 0.16\ mm$

- A structural steel rod has aradius of 10 mm and a length of 1.0 m. A100 kN force stretches it along its length.Calculate (a) stress, (b) elongation, and (c)strain on the rod. Young's modulus, ofstructural steel is 2.0 × 1011 Nm^{-2}.

  Solution

  We assume that the rod is held by a clamp at one end, and the force F is applied at the other end, parallel to the length of the rod. Then the stress on the rod is given by

  Stress = F/ A = $F/\pi r^2$ = = 3.18×10^8 N m^{-2}

  The elongation, $\Delta L = \{(F/A)L\}/ Y = (3.18 \times 10^8 * 1)/2\times 10^{11}$

  = 1.59×10^{-3} m

  = 1.59 mm

  The strain is given by

  Strain = $\Delta L/L$

  = $(1.59 \times 10^{-3}$ m)/(1m)

  = 1.59×10^{-3}

  = 0.16 %