

Elastic and plastic behavior of materials

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SOME DEFINITIONS

- Stress: Restoring force per unit area
- Strain: Ratio of change in dimension to original dimension
- **Linear strain (α)** - It is the increase per unit length per unit tension along the force
- **Lateral strain (β)** - It is the lateral contraction per unit length per unit tension perpendicular to force.
- **The elastic limit** of a substance is defined as the maximum stress that can be applied to the substance before it becomes permanently deformed and does not return to its initial length.

ELASTICITY

- It is the property of body by the virtue of which it deforms by the application of deforming force and returns original shape after removal of deforming force.
- Materials those show elasticity are called elastic materials. Ex: Shock absorbers of vehicles, Natural rubber, metallic wire, Spider web, Steel, Graphene.

PLASTICITY

- It is the property of body by the virtue of which it deforms permanently and never regain original shape after removal of deforming force.
- Materials those show plasticity are called plastic materials. Ex: Wet clay, Rigid bodies like rocks, metallic glasses etc.

HOOKE'S LAW:

For sufficiently small deforming force, strain is proportional to stress;

$$\text{Stress} \propto \text{Strain} \quad \text{or} \quad E = \frac{\sigma}{\epsilon}$$

E is constant of proportionality known as modulus of elasticity depends on the material being deformed and on the nature of the deformation.

Young's Modulus of Elasticity

It is the ratio of longitudinal stress to linear strain. $Y = \text{Longitudinal stress} / \text{Linear Strain}$,

$$Y = \frac{F \times L}{A \times \Delta L}$$

If a weight suspended to an elastic wire then, $F = mg$, $A = \pi r^2$ for cross section area of cylindrical wire. or

Therefore,

$$Y = \frac{mgL}{A \times \Delta L} \quad \text{or} \quad Y = \frac{mgL}{\pi r^2 \times \Delta L}$$

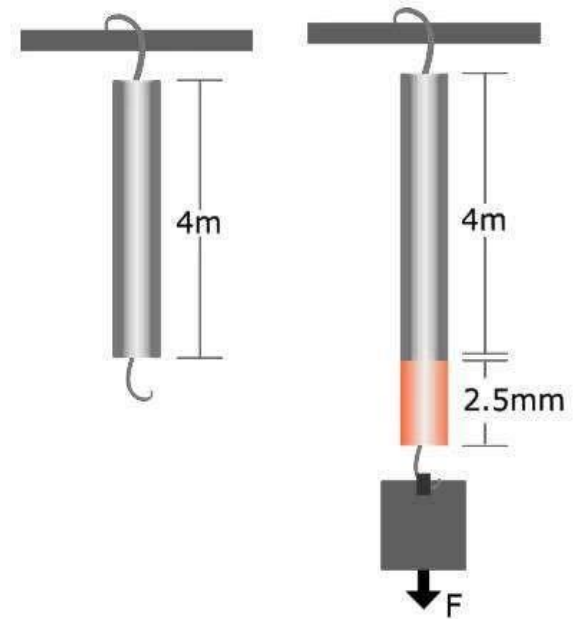
Longitudinal stress or tensile stress is applied along the length and hence causes change in length. Linear strain is the ratio of change in length to original length

Problem

A wire of diameter 3 mm and length 4 m extends by 2.5 mm when a force of 10 N is applied. Find Young's modulus of material of the wire.

Analysis

$$Y = \frac{F/A}{l/L}$$

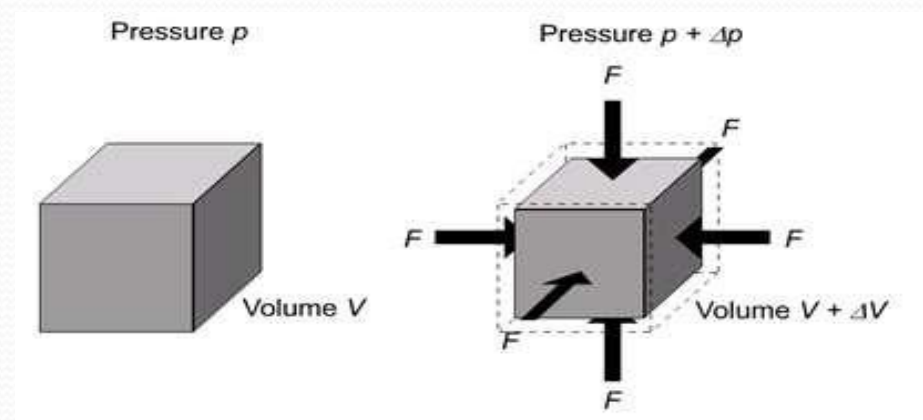


Bulk Modulus of elasticity (B)

It is the ratio of total normal stress per volume strain.

$B = \text{stress Normal stress} / \text{Volume Strain}$

$$B = \frac{F \times V}{\text{total surface area} \times \Delta V}$$



Application of normal (compressive) stress causes change in volume. Volume strain is the ratio of change in volume to original volume.

Rigidity Modulus of Elasticity or Shear Modulus (η) : This is the ratio of Shearing stress to shearing strain.

Shearing stress is applied tangential to a surface. As a result, one surface is displaced with respect to another fixed surface.

$$\eta = \text{Tangential stress} / \text{shear Strain}$$

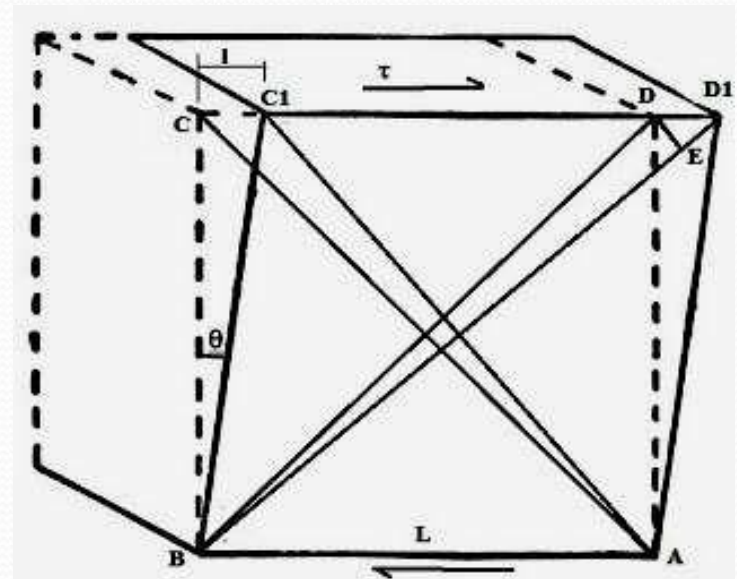
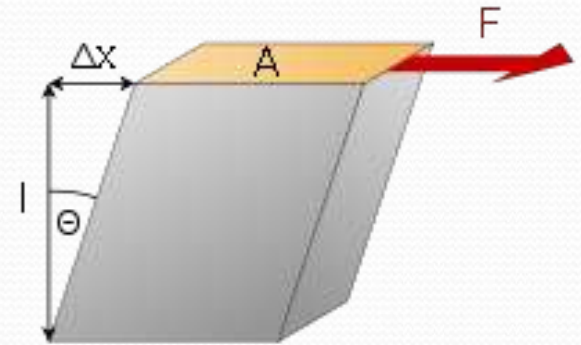
$$\text{Tangential stress} = F/A$$

$$\text{Tangential strain} = \Delta L/L$$

$$\eta = \frac{F/A}{\Delta L/L} \quad \tan\theta = \frac{\Delta L}{L}$$

for small angle of shear $\tan\theta = \theta$

$$\eta = \frac{F}{A \times \theta}$$



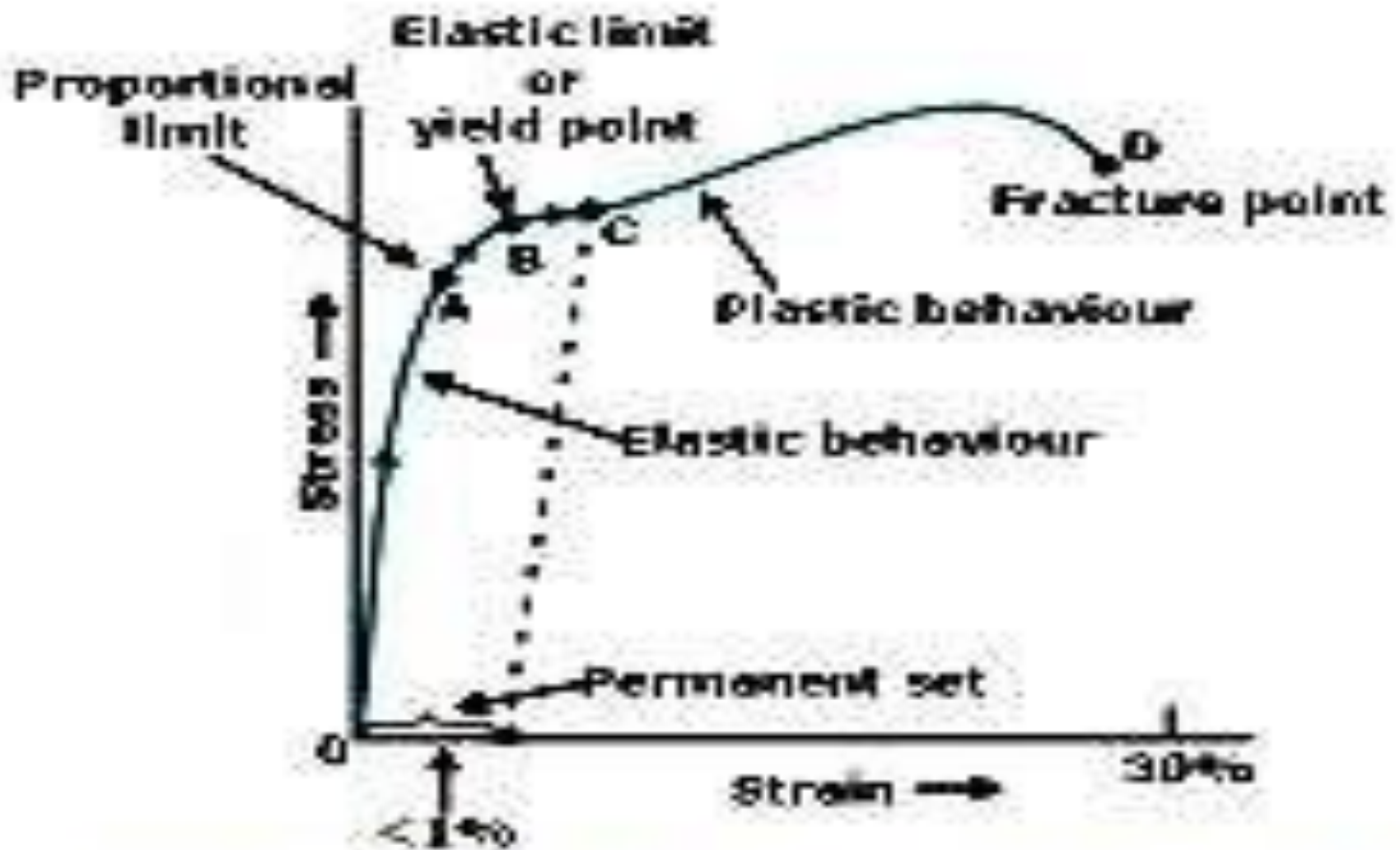
FACTOR OF SAFETY

- To avoid permanent elastic limit with a working stress.
- Factor of safety deformation is due to maximum stress above which a material loses, the engineering tools are to be used within the factor of safety
- Factor of safety = Breaking stress / Working stress.

Stress-strain graph.

It is the plot drawn variation of stress versus strain.

The stress - strain curve for different material is different. It may vary due to the temperature and loading condition of the material.



A typical stress-strain curve for a ductile metal

Elastic Deformation:

- **proportional limit:** it is the point up to which hooks law is applicable i.e., stress is directly proportional to strain.
- **Elastic limit:** there is always the limiting value of load up to which strain totally disappear on removal of load
 - material possesses elastic nature and properties till elastic limit.
 - up to this point material obtains its original configuration on removing load.
- **Yield point:** The stress beyond which material becomes plastic.
 - Load at which permanent deformation of material starts.

Plastic Deformation:

- **Ductile point:** beyond this point neck forms where the local cross-sectional area becomes significantly smaller than original.
 - material acquires plastic nature.
- **Ultimate point:** The point at which material can withstand maximum load and ultimate strength with maximum elongation.
 - large deformation possible before failure.
- **Point of rupture:** the stress which makes the material failure or break.

FACTORS AFFECTING ELASTICITY

The material will have change in their elastic property because of the following factors.

a)Effect of stress: For large number of cycles of stresses, it loses its elastic property even within the elastic limit. Therefore, the working stress on the material should be kept lower than the ultimate tensile strength and the safety factor.

b)Effect of Annealing: Annealing is made to a material it results in the formation of large crystal grains, which ultimately reduces the elastic property of the material.

c)Effect of temperature: Normally the elasticity increases with the decrease in temperature and vice-versa.

Ex. 1. The elastic property of lead increases when the temperature is decreased. 2. The carbon filament becomes plastic at higher temp.

d)Effect of impurities: The addition of impurities produces variation in the elastic property of the materials. The increase and decrease of elasticity depend upon the type of impurity added to it.

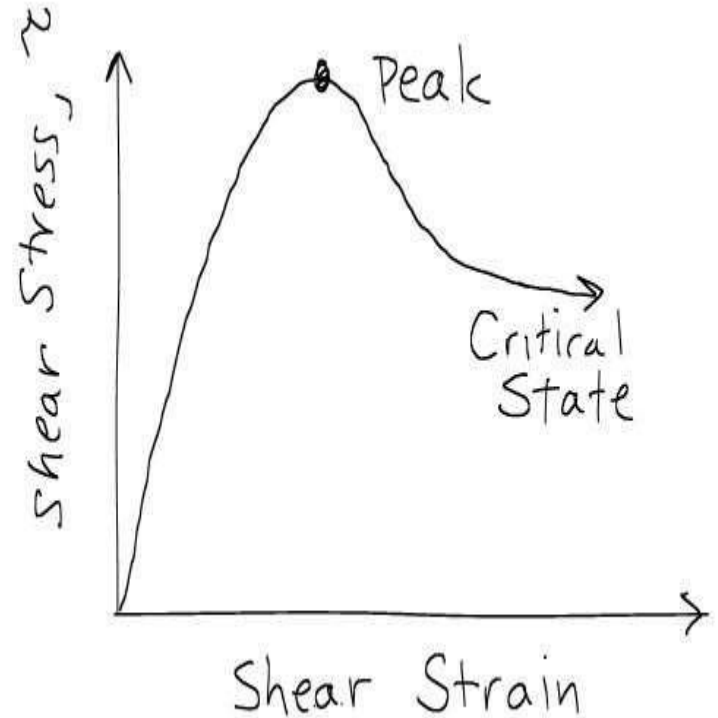
Ex. 1. When potassium is added to gold, the elastic property of gold increases.

2. When carbon is added to molten iron, the elastic property of iron decreases provided the carbon content should be more than 1% in iron.

e)Effect of nature of crystals: The elasticity also depends upon the types of the crystals, whether it is a single crystal or poly crystals. For a single crystal the elasticity is more and for a poly crystal the elasticity is less.

• Stain softening

- Strain softening is defined as the region in which the stress in the material is decreasing with an increase in strain.
- This is observed in certain materials after yielding point as represented in the diagram.
- It causes deterioration of material strength with increasing strain, which is a phenomenon typically observed in damaged quasi brittle materials, including fibre reinforced composites and concrete.
- It is primarily a consequence of brittleness and heterogeneity of the material.

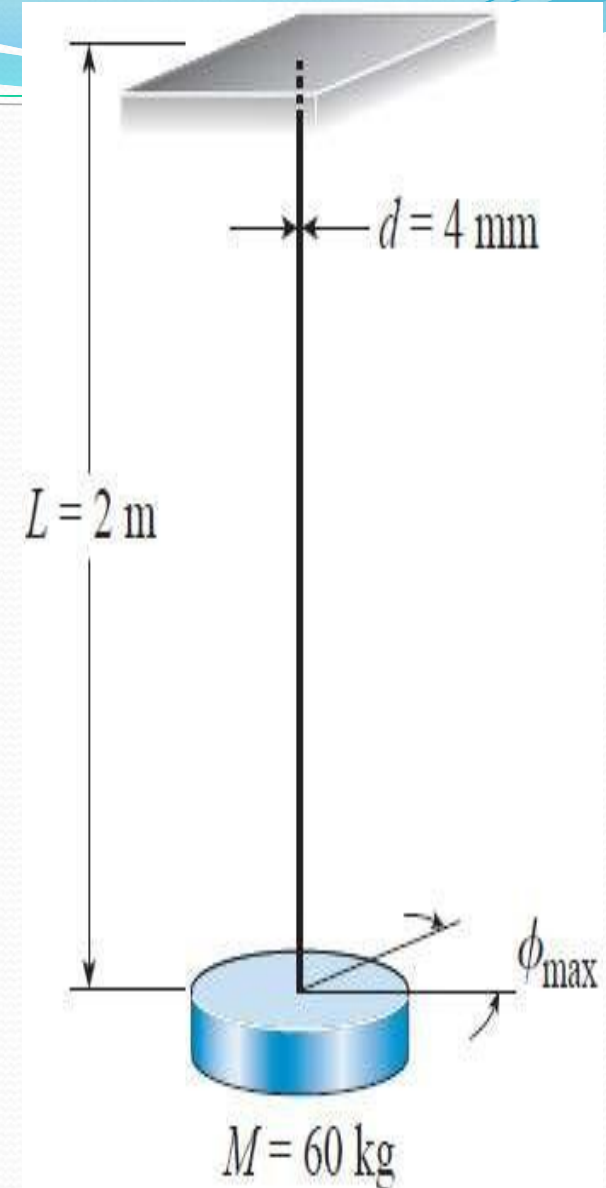


Strain Hardening

- When a material is strained beyond the yield point, more and more stress is required to produce additional plastic deformation and the material becomes stronger and more difficult to deform, this is known as Strain Hardening.
- The material is permanently deformed and increase on its resistance to further deformation. Strain hardening reduces ductility and increases brittleness.
- A material that does not show any strain hardening is said to be perfectly plastic.
- The strain hardening coefficient is given by the expression $n = \frac{\sigma}{K\varepsilon}$. σ – applied stress, ε – strain, K - elasticity strength coefficient). It is a measure of ability of a metal to strain harden.
- The value of n lies between 0.1 and 0.5 for most metals.
- A material with a higher value of n has a greater elasticity than a material with a low value of n .

Torsional Pendulum

- A normal pendulum is a mass that swings periodically back and forth on a string.
- However, torsion pendulum is an object with periodic oscillations, due to rotations about some axis through the object.
- The fibre of the torsion pendulum resists rotation, causing the mass to rotate back to its original equilibrium position when the mass is rotated from its equilibrium position.
- The restoring force is actually proportional to the rotation angle of the mass.



Applications of Torsional Pendulum:

1. The working of Torsion pendulum clocks is based on torsional oscillation.
2. The freely decaying oscillation of Torsion pendulum in medium (like polymers), helps to determine their characteristic properties.
3. Determination of frictional forces between solid surfaces and flowing liquid environments using forced torsion pendulums.
4. Torsion springs are used in torsion pendulum clocks.
5. Clothes Pins. The working of clothes pins is facilitated by the

- **Automotive:** Torsion springs are known for providing even tension, along with smooth and frictionless motion. These springs are widely used in the automotive industry for various parts such as a vehicle suspension system, chassis, automotive valves, clutches, and gear shifters.
- **Medical Equipment:** In the medical industry, the torsion springs are used in medical immobilization devices, hospital beds, several dental applications, wheelchair lifts and many more.
- **Door Hinges:** These springs are widely used in different types of door hinges. These springs allow the door to come back to its original position.

Beam.

When a beam having an arbitrary cross section is subjected to a transverse loads the beam will bend.

In addition to bending the other effects such as twisting and buckling may occur, and to investigate a problem that includes all the combined effects of bending, twisting and buckling could become a complicated one.

Thus, we are interested to investigate the bending effects alone, in order to do so, we have to put certain constraints on the geometry of the beam and the manner of loading.

Assumptions Bending Moment of Beam

1. Material of the beam will be Homogenous, means material composition of the beam will be same throughout the beam.
2. Material of the beam will be Isotropic, means elastic properties i.e. modulus of elasticity of the material will be same in all the directions.
3. Beam will be straight before loading and will remain straight once load will be removed.
4. The sections of the beam which were plane before bending, must remain plain after bending too.

5. Beam material must be stressed within its elastic limit and therefore beam material must follow the principle of Hooke's law.

6. The radius of curvature, during bending of the beam, will be large as compared with the dimensions of the cross-section of the beam and beam will have symmetrical cross-section.

7. Beam will be subjected with the pure bending action.

8. Load will be applied in the plane of bending and each layer of the beam will be free to expand or contract, independently of the layer, above or below it.

•A steel block is suspended with a cylindrical metallic wire of radius 0.2mm. Determine the mass of the steel block, if it develop a stress of $3.6 \times 10^6 \text{Nm}^{-2}$ on wire.

Cross section area of wire,

$$A = \pi r^2 = 3.142 \times 0.2^2 = 0.125 \times 10^{-6} \text{m}^2,$$

$$\begin{aligned} \text{Stress} &= F/A = mg/A, \text{ or } m = \text{Stress} \times A/g \\ &= 3.6 \times 10^6 \times 0.125 \times 10^{-6} / 9.8 = 0.046 \text{kg}. \end{aligned}$$



THANK
YOU