CHAPTER 3
MECHANICAL PROPERTIES

3.1 INTRODUCTION:

Mechanical properties of material are related to the behavior under load or stress in tension, compression or shear. Properties are determined by engineering tests under appropriate conditions, commonly determined mechanical properties are the tensile strength, elastic limit, creep strength, stress rupture, fatigue, elongation (ductility), impact strength (toughness and brittleness), hardness, and modulus of elasticity(ratio of stress to elastic strain-rigidity). Usually, the strain may be elastic (present only during stressing) or plastic (permanent) deformation.

Mechanical properties are helpful in determining whether or not a material can be produced in the desired shape and also resist the mechanical forces anticipated.

The words mechanical and physical are often erroneously used interchangeably. The above are mechanical properties. Sometimes modulus of elasticity is considered to be a physical property of a material because it is an inherent property that cannot be changed substantially by practical means such as heat treatment or cold working. The mechanical properties of materials are explained as follows

1. Strength

It is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress

2. Stiffness

Stiffness is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. Elasticity

It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines.

It may be noted that steel is more elastic than rubber.

4. Plasticity

Plasticity is a property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. Ductility

Ductility is the property of a material enabling it to be drawn into a wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice are mild steel, copper, aluminum, nickel, zinc, tin and lead.

6. Brittleness

It is the property of breaking of a material with little permanent distortion. Brittleness of a material is opposite to ductility property.

Brittle materials are withstanding compression load. When subjected to tensile loads snap off without giving any sensible elongation. Cast iron is a brittle material

7. Malleability

It is a special case of ductility which permits materials to be rolled or hammered into thin sheets, making wire. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice are lead, soft steel, wrought iron, copper, and aluminum.

8. Machinability

It is the property of a material which refers to a relative ease with which a material can be cut. The machinability of a material can be measured in a number of ways such as comparing the tool life for cutting different materials or thrust required to remove the material at some given rate or the energy required to remove a unit volume of the material. For example, that brass can be easily machined than steel. That means the machinability property of brass is high when compare to steel.

9. Fatigue

Fatigue is the repeated loading and unloading of metal due to direct load variation, eccentricity in a rotating shaft and differential thermal expansion of a structure. Even substantially below the yield point (elastic limit) of a metal or alloy this repeated loading can lead to failure, usually measured in terms of the number of cycles (repeated load applications) to failure

10.Hardness

Hardness is a very important property of the metals and has a wide variety of meanings. It also embraces many different properties such as resistance to wear, scratching, deformation and machinability etc.

Also, it is the property of a metal, which gives it the ability to resist being permanent, deformed (bent, broken, or have its shape changed) when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

11.Resilience

It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for designing the spring materials.

12. Creep

When a material is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called creep. This property is considered in designing internal combustion engines, boilers, and turbines.

In this chapter will be Concentrated the study on the one of important of Mechanical properties it is Elasticity

3.2 What is elasticity?

All materials deform to some extent when subjected to a stress (a force per unit area). **Elastic** materials have internal forces which restore the size and shape of the object when the stress is removed. If the deformation, or strain (the ratio of the change in length to the initial length), is directly proportional to the applied stress and if it is completely reversible so that the deformation disappears when the stress does, then the material is said to be perfectly **elastic**. An elastic material exerts a restoring force when stretched and this can lead to oscillation when the elastic material is attached to a mass.

However, if you apply force to a lump of putty or mud, they have no gross tendency to regain their previous shape, and they get permanently deformed. Such substances are called **plastic** and this property is called **plasticity**. Putty and mud are close to ideal plastics. The elastic behavior of materials plays an important role in engineering design. For example, while designing a building, knowledge of elastic properties of materials like steel, concrete etc. is essential. The same is true in the design of bridges, automobiles, ropeways etc. One could also ask — Can we design an aero- plane which is very light but sufficiently strong? Can we design an artificial limb which is lighter but stronger? Why does a railway track have a particular shape like I? Why is glass brittle while brass is not? Answers to such questions begin with the study of how relatively simple kinds of loads or forces act to deform different solids bodies. In this chapter, we shall study the elastic behavior and which would answer many such questions.

3.3 STRESS AND STRAIN

When forces are applied on a body in such a manner that the body is still in static equilibrium, it is deformed to a small or large extent depending upon the nature of the material of the body and the magnitude of the deforming force. The deformation may not be noticeable visually in many materials but it is there. When a body is subjected to a deforming force, a restoring force is developed in the body. This restoring force is equal in magnitude but opposite in direction to the applied force. The restoring force per unit area is known as **stress.** If ***F*** is the force applied and ***A*** is the area of cross section of the body,

Magnitude of the stress = F/A

The **SI unit** of stress is **N** m^{-2} **or pascal (Pa)** and its dimensional formula is $[ML^{-1}T^{-2}]$.

There are three ways in which a solid may change its dimensions when an external force acts on it. These are shown in Fig.(1 a, b and c) .

- In Fig.(1a), a cylinder is stretched by two equal forces applied normal to its cross-sectional area. "***The restoring force per unit area "*** is called **tensile stress**.

However, if two equal and opposite deforming forces are applied parallel to the cross-sectional area of the cylinder, as shown in Fig. (1b), there is relative displacement between the opposite faces of the cylinder.

- ***The restoring force per unit area developed due to the applied tangential*** force is known as **shearing stress**.

As a result of **tensile stress** there is a change in the length of the cylinder. "***The change in the length ΔL to the original length L of the body***" is known as **strain**.

Magnitude of the strain = $\Delta L / l$

Also, as a result of applied tangential force, there is a relative displacement Δx between opposite faces of the cylinder as shown in the Fig. 1(b). **The strain** so produced is known as **shearing strain** and it is "***defined as the ratio of relative displacement of the faces Δx to the length of the cylinder L".***

Shearing strain $x/L = \tan\theta$

Where θ is the angular displacement of the cylinder from the vertical (original position of the cylinder).

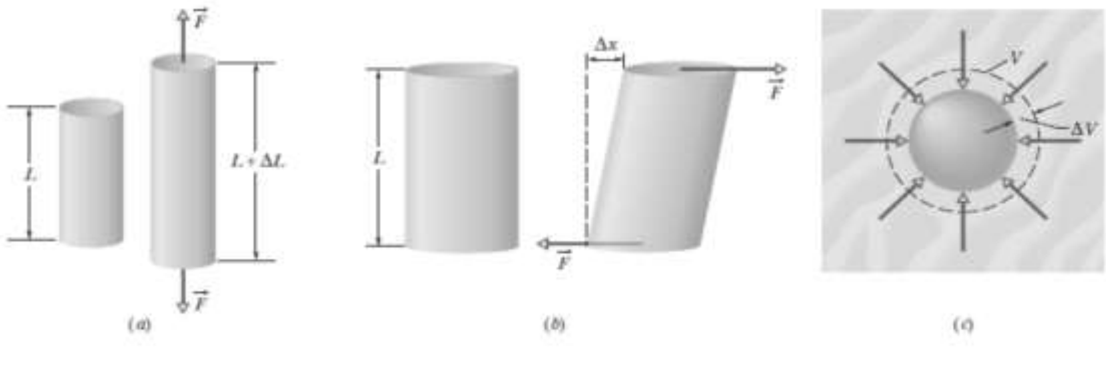


Fig 1(a, b and c)

On the other hand, when a solid sphere placed in the fluid under high pressure is compressed uniformly on all sides as shown in the Fig. 1(c). The force applied by the fluid acts in perpendicular direction at each point. This leads to decrease in its volume without any change of its geometrical shape. In this case the internal restoring force per unit area in this case is known as **hydraulic stress**. As a result, there is the strain produced by a hydraulic pressure is called **volume strain** and is defined as the ratio of change in volume ***(ΔV)*** to the original volume ***(V)***.

Volume strain = $\Delta V / V$

Since the strain is a ratio of change in dimension to the original dimension, it has no units or dimensional formula.

From the previous discussion the deformation of solids in terms of the concepts of stress and strain. Also, it is found that, **strain** is proportional to **stress**; the constant of proportionality depends on the material being deformed and on the nature of the deformation. We call this proportionality constant the **elastic modulus**. The elastic modulus is therefore the ratio of the stress to the resulting strain:

Elastic modulus = stress / strain

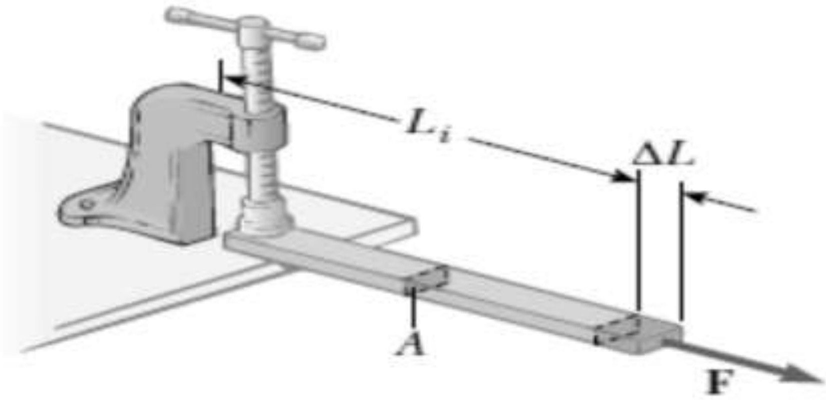
So, three types of deformation for the elastic materials are considered, an elastic modulus will be defined for each:

1. **Young's modulus**, which measures the resistance of a solid to a change in its length
2. **Shear modulus,** which measures the resistance to motion of the planes of a solid sliding past each other
3. **Bulk modulus**, which measures the resistance of solids or liquids to changes in their volume

3.3.1 YOUNG'S MODULUS

Young's modulus (*Y*) is a material property, that describes its stiffness and is therefore one of the most important properties of solid materials.

Observation show that for a given material, when an external force is applied perpendicular to the cross section, internal forces in the bar resist distortion ("stretching"), but the bar attains an equilibrium in which its length L_f is greater than L_i and in which the external force is exactly balanced by internal forces as in Figure 2. In such a situation, the bar is said to be stressed. We define the tensile stress as the ratio of the magnitude of the external force F to the cross-sectional area A. The tensile strain in this case is defined as the ratio of the change in length ΔL to the original length L_i .



We define **Young's modulus** by a combination of these two ratios:

$$Y = \frac{\text{tensile stress}}{\text{tensile strian}} = \frac{F/A}{\Delta L/Li}$$

Young's modulus is typically used to characterize a rod or wire stressed under either tension or compression. Note that because strain is a dimensionless quantity, *Y* has units of force per unit area.

EXAMPLE 1 A structural steel rod has a radius of 10 mm and a length of 1.0 m. A 100 kN force stretches it along its length. Calculate (a) stress, (b) elongation, and (c) strain on the rod. Young's modulus, of structural steel is 2.0 × 10^{11} N m^{-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

a) stress

$$Stress = \frac{F}{A} = \frac{F}{\pi r^2}$$

$$Stress = \frac{100 \times 10^3}{3.14 \times 10^2} = 3.18 \times 10^8 Nm^2$$

b) The elongation is

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

$$\therefore \Delta L = \frac{(F/A)L}{Y} = \frac{(3.18 \times 10^8 Nm^2) \times 1m}{2.0 \times 1011\ Nm^2}$$

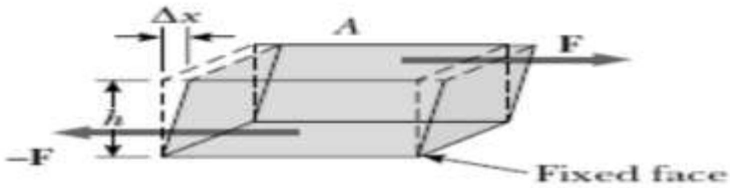
∴ ΔL = 1.5×10^{-3} m = 1.5 mm

c) The strain is

Strain = ΔL / L = 1.5×10^{-3} m / 1 m = 1.5×10^{-3} m = 0.16 %

3.3.2 SHEAR MODULUS

The second type of deformation occurs when an object is subjected to a force tangential to one of its faces while the opposite face is held fixed by another force Figure (a, b).



(a)

(b)

The stress in this case is called **a shear stress**. If the object is originally a rectangular block, **a shear stress** results in a shape whose cross-section is a parallelogram. Thus, can be defined the **shear stress** as *F*/*A*, the ratio of the tangential force to the area *A* of the face being sheared. The shear strain is defined as the ratio $\Delta x/h$, where Δx is the horizontal distance that the sheared face moves, and h is the height of the object. In terms of these quantities, the shear modulus is

$$S = \frac{\text{shear stress}}{\text{shear strian}} = \frac{F/A}{\Delta x/h}$$

The unit of shear modulus is force per unit area.

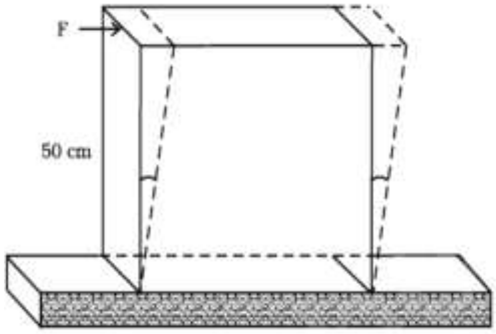
EXAMPLE 2 A square lead slab of side 50 cm and thickness 10 cm is subject to a shearing force (on its narrow face) of 9.0×10^4 N and the shear modulus of lead $S = 5.6 \times 109$ N m^{-2}. The lower edge is riveted to the floor. How much will the upper edge be displaced?

Solution: The lead slab is fixed and the force is applied parallel to the narrow face as shown in Figure. The area of the face parallel to which this force is applied is

A = 50 cm × 10 cm

= 0.5 m × 0.1 m

= 0.05 m^2



Therefore, the stress applied is

= (9.4 × 104 N / 0.05 m^2)

= 1.80 × 106 N.m^{-2}

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

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

= (1.8 × 106 N m^{-2} × 0.5m)/(5.6 × 109 N m^{-2})

= 1.6×10^{-4} m = 0.16 mm

3.3.3 BULK MODULUS

Bulk modulus characterizes the response of a substance to uniform squeezing or to a reduction in pressure when the object is placed in a partial vacuum. The ***volume stress*** is defined as the ratio of the magnitude of the normal force ***F*** to the area A. The quantity P = ***F/A*** is called the pressure. If the pressure on an object changes by an amount $\Delta P = \Delta F/A$, then the object will experience a volume change ΔV. The volume strain is equal to the change in volume ΔV divided by the initial volume ***Vi*** . Thus, ***Bulk modulus B is defined as:***

$$B = \frac{\text{volume stress}}{\text{volume strian}} = -\frac{F/A}{\Delta V/V_i} = -\frac{\Delta P}{\Delta V/V_i}$$

The negative sign indicates the fact that with an increase in pressure, a decrease in volume occurs. That is, if p is positive, ΔV is negative. Thus, for a system in equilibrium, the value of bulk modulus B is always positive. SI unit of bulk modulus is the same as that of pressure *i.e.*, N m^{-2} or Pa.

Example 3: The average depth of Indian Ocean is about 3000 m. Calculate the fractional compression, $\Delta V/V$**,** 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})

Solution:

The pressure exerted by a 3000 m

column of water on the bottom layer

$P = h\rho\, g$ = 3000 m × 1000 kg m^{-3} × 10 m s^{-2}

= 3 × 107 kg m^{-1} s^{-2}

= 3 × 107 N m^{-2}

Fractional compression $\Delta V/V$, is

$\Delta V/V$ = stress/B = (3 × 10^7 N m^{-2})/(2.2 × 10^9 N m^{-2}) = 1.36 × 10^{-2} or 1.36 %

Example 4: Find the stress on a bone (1 cm in radius and 50 cm long) that supports a mass of 100 kg. Find the strain on the bone if it is compressed 0.15 mm by this weight. After then find the proportionality constant C for this bone.

Solution:

a) **stress = F/A** = (100 kg) (9.8 m/s^2)/π x (0.01 m)^2

= 3.1 x 10^6 N/m^2

b) **strain= $\Delta L/L_0$**

= (0.15 x 10^{-3} m)/(0.5 m)

= 3.0 x 10^{-4}

c) **Since strain = C x stress**

∴ C = strain/stress = 0.96 x 10^{-10} m^2/N.

Example 5: Find the pressure necessary to change a volume of water by 1.0 percent. Express the pressure in terms of atmospheric pressure units 1 bar = 10^5 N/m^2.

Solution:

$P = B\Delta V/V$ = 2.2 x 10^9 N/m^2 x 1.0 x 10^{-2}

$= 2.2 \times 10^7$ N/m^2 $= 2.2 \times 10^2$ bars = 220 bars

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Example 6: A steel bar 6.00 m long and with rectangular cross section of 5.00 cm x 2.50 cm supports a mass of 2000 kg and Young's modulus *Y* for steel is 20.0 x 1010 N/m2. How much is the bar stretched?

Solution:

for ΔL, we get

$\Delta L = FL/YA$ = (2000) (9.80) (6.00)/(20.0 x 1010) (.050 x .025)

= 4.70 x 10-4 m = 0.47 mm

Example 7 : Your leg bones (cross-sectional area about 9.50 cm2) experience a force of approximately 855 N when you walk. Find the fractional amount your leg bones are compressed by walking. Using *Y* = 1010 N/m2 for bone we get:

Solution:

$\Delta L/L = 8.55 \times 10^2$ N/(9.5×10^{-4} m^2) (1010 N/m^2) $= 9 \times 10^{-5}$

Quiz

A spacecraft carries a steel sphere to a planet on which atmospheric pressure is much higher than on the Earth. The higher pressure causes the radius of the sphere to decrease. To describe the relationship between stress and strain for the sphere, you would use

(a) Young's modulus (b) shear modulus (c) bulk modulus (d) none of these.

Quiz

A block of iron is sliding across a horizontal floor. The friction force between the block and the floor causes the block to deform. To describe the relationship between stress and strain for the block, you would use

(a) Young's modulus (b) shear modulus (c) bulk modulus (d) none of these.

Table 1. shows the various types of stress, strain, elastic moduli, and the applicable state of matter at a glance.

Type of Stress	Stress	Strain	Change in		Elastic modulus	Modulus of modulus	State of Mater
			shape	volume			
Tensile or compressive	Two equal and opposite faces perpendicular to parallel to force ($\sigma = F/A$)	Elongation or compression parallel to faces direction ($\Delta L/L$) (longitudinal strain)	Yas	No	$\frac{F/A}{\Delta L/L}$	Young's modulus	Solid
Shearing	Two equal and opposite forces parallel to opposite Surfaces [forces in each case such that total force and total torque on the body vanishes ($\sigma_s = F/A$)	Pure shear	Yas	No	$\frac{F/A}{\Delta x/h}$	shear modulus	Solid
Hydraulic	Forces perpendicular everywhere to the force per unit elongation area same everywhere.	Volume change (compression or elongation ($\Delta V/V$)	No	Yas	$-\frac{\Delta P}{\Delta V/V_i}$	Bulk modulus	Solid, liquid and gases

3.4 STRESS-STRAIN CURVE

The relation between the **stress** and the **strain** for a given material under tensile stress can be found experimentally. In a standard test of tensile properties, a test cylinder or a wire is stretched by an applied force. The fractional change in length (the strain) and the applied force needed to cause the strain are recorded. The applied force is gradually increased in steps and the change in length is noted. A graph is plotted between the stress (which is equal in magnitude to the applied force per unit area) and the strain produced. A typical graph for a metal is shown in Fig. 2.

The **stress-strain curves** vary from material to material. These curves help us to understand how a given material deforms with increasing loads. From the graph, we can see:

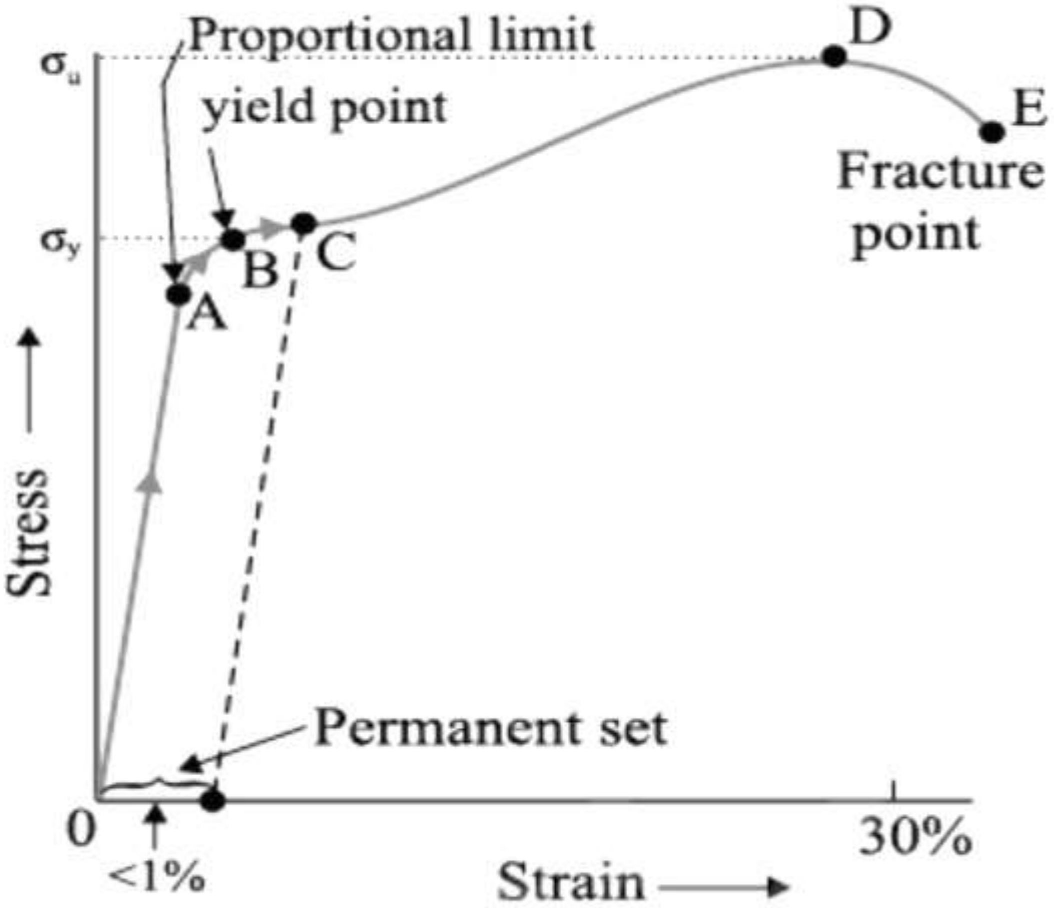


Fig.2

- The region between (**O to A**) the curve is linear. In this region, Hooke's law is obeyed. The body regains its original dimensions when the applied force is removed. In this region, the solid behaves as an **elastic body**.
- In the region from **(A to B)** stress and strain are not proportional. Nevertheless, the body still returns to its original dimension when the load is removed. The point B in the curve is known as yield point (also known as **elastic limit**) and the corresponding stress is known as yield strength (σ_y) of the material.
- The point C in the curve is known as **Ultimate point**: At this point at up to which a material can withstand maximum load and ultimate strength with maximum elongation.
- In region between (**C to D**) the load is increased further, the stress developed exceeds the yield strength and strain increases rapidly even for a small change in the stress. The portion of the curve between C and D shows this. When the load is removed, the body does not regain its original dimension. In this case, even when the stress is zero, the strain is not zero. The material is said to have a permanent set. The deformation is said to be **plastic deformation.**
- The point D on the graph is the **ultimate tensile strength (σu)** of the material. Beyond this point, additional strain is produced even by a reduced applied force and **fracture occurs at point E.**
- If the **ultimate strength** and **fracture points** D and E are close, the material is said to be **brittle** but If they are **far apart**, the material is said to be **ductile.**

3.5 APPLICATIONS OF ELASTIC BEHAVIOR OF MATERIALS

The elastic behavior of materials plays an important role in everyday life. All engineering designs require precise knowledge of the elastic behavior of materials.

In the construction of various structures like bridges, columns, pillars, beams, etc. Knowledge of the strength of the materials used in the construction is of prime importance.

For example: While constructing a bridge, a load of traffic that it can withstand should be adequately measured beforehand. Or while constructing a crane used to lift loads, it is kept in mind that the extension of the rope does not exceed the elastic limit of rope. To overcome the problem of bending under force the elastic behavior of the material used must be considered primarily.

Have you ever thought why the beams used in construction of bridges, as supports etc. have a cross-section of the type I? Why does a heap of sand or a hill have a pyramidal shape? Answers to these questions can be obtained from the study of structural engineering.

- **Why is steel used in the construction of bridges?**

Answer: Amongst bridge materials steel has the highest and most favorable strength qualities, and it is, therefore, suitable for the most bridges. Normal building steel has compressive and tensile strengths of 370 N/sq mm, about ten times the compressive strength of a medium concrete and a hundred times its tensile strength. A special merit of steel is its ductility due to which it deforms considerably before it breaks because it begins to yield above a certain stress level.

Example 8: A solid brass sphere is initially surrounded by air, and the air pressure exerted on it is 1.0×10^5 N/m^2 (normal atmospheric pressure). The sphere is lowered into the ocean to a depth at which the pressure is 2.0×10^7 N/m^2. The volume of the sphere in air is 0.50 m^3. By how much does this volume change once the sphere is submerged?

Solution:

From the definition of bulk modulus, we have

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

$$\Delta V = -\frac{\Delta P V_i}{B}$$

Because the final pressure is so much greater than the initial pressure, we can neglect the initial pressure and state that

$\Delta P = P_f - P_i \approx P_f = 2.0 \times 10^7$ N/m^2

Therefore,

$$\Delta V = -\frac{(0.5\ m^3)(2.0 \times 10^7 N/m^2)}{(6.1 \times 10^{10} N/m^2)}$$

$\Delta V = 1.6 \times 10^{-4}$ m^{-3}

The negative sign indicates a decrease in volume.

Quiz

A spacecraft carries a steel sphere to a planet on which atmospheric pressure is much higher than on the Earth. The higher pressure causes the radius of the sphere to decrease. To describe the relationship between stress and strain for the sphere, you would use

(b) Young's modulus (b) shear modulus (c) bulk modulus (d) none of these.

Quiz

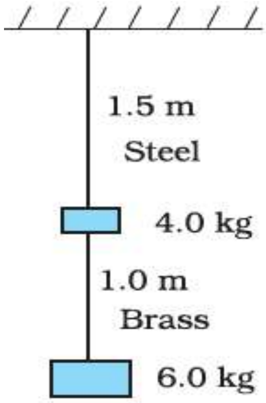
A block of iron is sliding across a horizontal floor. The friction force between the block and the floor causes the block to deform. To describe the relationship between stress and strain for the block, you would use

(a) Young's modulus (b) shear modulus (c) bulk modulus (d) none of these.

PROBLEMS

1) A steel wire of length 4.7 m and cross-sectional area 3.0×10^{-5} m^2 stretches by the same amount as a copper wire of length 3.5 m and cross-sectional area of 4.0×10^{-5} m^2 under a given load. What is the ratio of the Young's modulus of steel to that of copper?

2) Two wire of diameter 0.25 cm one made of steel and the other made of brass are loaded as shown in Figure. The unloaded length of steel wire is 1.5 m and that of brass wire is 1.0 m. Compute the elongations of the steel and the brass wires.



3) The edge of an aluminum cube is 10 cm long. One face of the cube is firmly fixed to a vertical wall. A mass of 100 kg is then attached to the opposite face of the cube. The shear modulus of aluminum is 25 GPa. What is the vertical deflection of this face?

4) A piece of copper having a rectangular cross-section of 15.2 mm × 19.1 mm is pulled in tension with 44,500 N force, producing only elastic deformation. Calculate the resulting strain?

5) If the volume of an iron sphere is normally 100 cm^3 and the sphere is subjected to a uniform pressure of 108 N/m^2, what is its change in volume?

6) If the stress produced in stretching a wire is $5.00 \text{ x } 10^6$ N/m^2 by an applied force of 10.0 N, what is the cross-sectional area of the wire?

7) If the strain for the wire above is 0.100 percent, what is the length of the wire that will have an elongation of 1.00 mm?

8) A 5.00 cm cube of gelatin has its upper surface displaced 1.00 cm by a tangential force 0.500 N. What is shear modulus of this substance?

9) A 200-kg load is hung on a wire having a length of 4.00 m, cross-sectional area 0.200 - 10'4 m^2, and Young's modulus 8.00 - 1010 N/m^2. What is its increase in length?

10) Assume that Young's modulus is 1.50 - 10^{10} N/m^2 for bone and that the bone will fracture if stress greater than 1.50 - 10^8 N/m^2 is imposed on it.
(a) What is the maximum force that can be exerted on the femur bone in the leg if it has a minimum effective diameter of 2.50 cm?
(b) If this much force is applied compressively, by how much does the 25.0-cm-long bone shorten?

FILL THE SPACE IN THE FOLLOWING STATEMENTS

1) Any object can be deformed by applying a force to the object. An object is elastic if ________ after the force is removed. However, if the object has been deformed beyond its________, it will remain in a deformed state.

2) he stress on an object is defined as the ratio of the________ to the_________.

3) The strain of an object is defined as the ratio of the________ to the_________.

4) The generalized statement of Hooke's law states that________ is proportional to________ of the system.

5) Young's modulus is a constant with units of _________, which characterizes the response of a solid to _________ and which has a magnitude equal to ________.

6) The bulk modulus of a material is a constant with units of ________, which characterizes the response of a material to _________.

7) The shear modulus, also called the________, is a constant with units of _________, which characterize the response of a material to_________ and which has a magnitude equal to _________.

MULTIPLE CHOICE QUESTIONS

1) **Stress can be measured in:**

A) N/m^2

B) $N \cdot m^2$

C) N/m

D) N· m

E) none of these (it is unitless)

2) **Strain can be measured in:**

A) N/m^2

B) $N \cdot m^2$

C) N/m

D) N· m

E) none of these (it is unitless)

3) **Young's modulus can be correctly given in:**

A) N· m

B) N/m^2

C) N· m/s

D) N/m

E) joules

4) **Young's modulus is a proportionality constant that relates the force per unit area applied perpendicularly at the surface of an object to:**

A) The shear

B) The fractional change in volume

C) The fractional change in length

D) The pressure

E) The spring constant

5) **Young's modulus can be used to calculate the strain for a stress that is:**

A) Just below the ultimate strength

B) Just above the ultimate strength

C) Well below the yield strength

D) Well above the yield strength

E) None of the above

6) The ultimate strength of a sample is the stress at which the sample:

A) Returns to its original shape when the stress is removed

B) Remains underwater

C) Breaks

D) Bends 180◦

E) Does none of these

7) The bulk modulus is a proportionality constant that relates the pressure acting on an object to:

A) The shear

B) The fractional change in volume

C) The fractional change in length

D) Young’s modulus

E) The spring constant

8) To shear a cube-shaped object, forces of equal magnitude and opposite directions might be applied:

A) To opposite faces, perpendicular to the faces

B) To opposite faces, parallel to the faces

C) To adjacent faces, perpendicular to the faces

D) To adjacent faces, neither parallel or perpendicular to the faces

E) To a single face, in any direction