Mechanical Engineering Science

Q&A

Unit: 2 – Engineering Materials, Stress Analysis, and Power Transmission Dr. MBK

1. What are engineering materials and why are they important in design and manufacturing?
Answer:
Engineering materials are substances used to create machines, structures, and products. They are critical because their properties—such as strength, durability, and thermal conductivity—determine a component's performance, safety, and cost-efficiency in engineering applications.

2. How are materials classified in engineering?
Answer:
Materials are broadly classified into:
- Metals (ferrous and non-ferrous)
- Polymers (Plastics)
- Ceramics
- Composites
- Smart Materials

3. What distinguishes ferrous metals from nonferrous metals?
Answer:
- Ferrous metals contain iron as the base element (e.g., steel, cast iron) and are usually magnetic and prone to rust.
- Nonferrous metals do not contain iron (e.g., aluminum, copper) and are typically corrosion-resistant and lighter in weight.

4. What is stainless steel, and what makes it corrosion-resistant?
Answer:
Stainless steel is an alloy of iron with at least 10.5% chromium, which forms a passive oxide layer on the surface, protecting it from rust and corrosion. It's widely used in kitchenware, medical instruments, and construction.

5. What are aluminum alloys, and what are their advantages?
Answer:
Aluminum alloys are mixtures of aluminum with elements like copper, magnesium, or zinc. They offer high strength-to-weight ratio, corrosion resistance, and good thermal conductivity, making them ideal for aerospace and automotive applications.

6. Define smart materials and explain their types with examples. Discuss the working principle, types, and engineering applications of rheological materials.
Answer:
Smart Materials – Definition:

Smart materials are advanced materials that respond to external stimuli such as temperature, stress, magnetic field, or electric field, and undergo a reversible change in their properties (e.g., shape, stiffness, color, or conductivity).

Types of Smart Materials and Examples:

Type	Response to Stimulus	Example Application
Piezoelectric Materials	Mechanical stress → electric voltage (and vice versa)	Sensors, actuators, medical ultrasound
Shape Memory Alloys (SMA)	Heat → returns to original shape	Stents, actuators, robotics
Electrochromic Materials	Electric field → change in color	Smart windows, display panels
Magnetostrictive Materials	Magnetic field → change in shape	Precision actuators, sonar
Thermochromic Materials	Temperature → change in color	Thermometers, novelty items

Rheological Materials – Definition:

Rheological materials are smart fluids whose viscosity changes dramatically in response to an applied electric or magnetic field.

Types of Rheological Materials:

- Electro-Rheological (ER) Fluids – Change viscosity with an electric field
- Magneto-Rheological (MR) Fluids – Change viscosity with a magnetic field

Working Principle:

When an electric or magnetic field is applied:

- The particles suspended in the fluid align themselves, increasing the fluid's resistance to flow (viscosity).
- This allows real-time control of damping or stiffness.

Applications of Rheological Materials:

- Automotive: Semi-active shock absorbers in high-end cars (e.g., Cadillac, Ferrari)
- Robotics: Adaptive grippers and dampers
- Prosthetics: Artificial limbs with variable stiffness
- Seismic Dampers: Building foundations to absorb vibrations

7. The speed of a driving shaft is 80 rpm and the speed of driven shaft is 120 rpm. Diameter of the driving pulley is given as 600 mm. Find the diameter of driven pulley in the following cases:

   (a) If belt thickness is negligible
   (b) If belt thickness is 5 mm
   (c) If total slip is 10% (considering thickness of belt)
   (d) If a slip of 2% on each pulley (considering thickness of belt)

Solution:

- Speed of driving shaft (N_1) = 80 rpm
- Speed of driven shaft (N_2) = 120 rpm

- Diameter of driving pulley (D_1) = 600 mm
- Belt thickness (t) = 5 mm (only for parts b, c, and d)
- Slip varies as per cases

D_2 be the diameter of the driven pulley.

(a) Belt thickness negligible, no slip

$$D_2 = \frac{N_1 D_1}{N_2} = \frac{80 \times 600}{120} = \frac{48000}{120} = \boxed{400 \text{ mm}}$$

(b) Belt thickness = 5 mm, no slip

$$D_2 + 2t = \frac{N_1}{N_2} \cdot (D_1 + 2t) \Rightarrow D_2 + 2(5) = \frac{80}{120} \cdot (600 + 10) \Rightarrow D_2 + 10 = \frac{2}{3} \cdot 610 = 406.67 \Rightarrow D_2 = 406.67 - 10 = \boxed{396.67 \text{ mm}}$$

(c) Total slip = 10%, belt thickness = 5 mm

$$\frac{N_2}{N_1} = \frac{D_1 + 2t}{D_2 + 2t} \cdot \left(\frac{100 - S}{100}\right) \Rightarrow \frac{120}{80} = \frac{610}{D_2 + 10} \cdot \frac{90}{100} \Rightarrow 1.5 = \frac{610 \cdot 0.9}{D_2 + 10} \Rightarrow D_2 + 10 = \frac{549}{1.5} = 366 \Rightarrow D_2 = \boxed{356 \text{ mm}}$$

(d) 2% slip on each pulley (total slip not additive), belt thickness = 5 mm

Total effective slip:

$$\text{Total slip} = 1 - (1 - 0.02)^2 = 1 - 0.9604 = 0.0396 = 3.96\%$$

Now solve using:

$$\frac{N_2}{N_1} = \frac{D_1 + 2t}{D_2 + 2t} \cdot \left(\frac{100 - 3.96}{100}\right) \Rightarrow 1.5 = \frac{610}{D_2 + 10} \cdot 0.9604 \Rightarrow D_2 + 10 = \frac{610 \cdot 0.9604}{1.5} = 390.57 \Rightarrow D_2 = \boxed{380.57 \text{ mm}}$$

8.A mild steel specimen with an original diameter of 10 mm and gauge length of 50 mm was found to have an ultimate load of 60 kN and breaking load of 40 kN. The gauge length at rupture was 55 mm and diameter at rupture cross-section was 8 mm. Determine (i) the ultimate stress, (ii) breaking stress, (iii) true breaking stress, (iv) percentage elongation, and (v) percentage reduction in area.

Solution:

Given: l_g=50 mm, d_o=10 mm, l_f = 55 mm, P_{ult} =60 kN, P_{break} = 40 kN, and d_f = 8 mm.

$$A_o = \frac{\pi d_o^2}{4} = \frac{\pi \times 10^2}{4} = 78.53 \text{mm}^2$$

$$A_f = \frac{\pi d_f^2}{4} = \frac{\pi \times 8^2}{4} = 50.26 \text{mm}^2$$

(i) Ultimate stress, $\sigma_{ult} = \frac{P_{ult}}{A_o} = \frac{60 \times 10^3}{78.53} = 764.039 \text{ N/mm}^2$

(ii) Breaking stress, $\sigma_{brak} = \frac{P_{break}}{A_o} = \frac{40 \times 10^3}{78.53} = 509.359 \text{ N/mm}^2$

(ii) True breaking stress, $\sigma_{Tru_{break}} = \frac{P_{break}}{A_f} = \frac{40 \times 10^3}{50.26} = 795.861 \text{ N/mm}^2$

(iii) Percentage elongation $= \frac{l_f - l_o}{l_o} \times 100 = \frac{55 - 50}{50} \times 100 = 10\%$

(iv) Percentage reduction in area $= \frac{A_f - A_o}{A_o} \times 100 = \frac{78.53 - 50.26}{78.53} \times 100 = 35.9\%$

9. A brass rod in static equilibrium is subjected to axial load as shown in Figure a

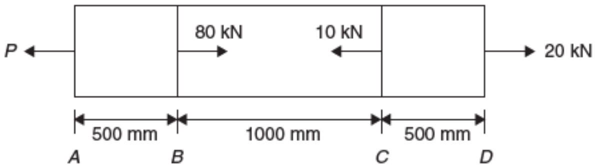

Figure a: A Bar Under Static Equilibrium

Find the load P and change in length of the rod if its diameter is 100 mm. Take E = 80 GN/m^2.

Solution:

Draw the free body diagram for each part of the rod as shown in Figure

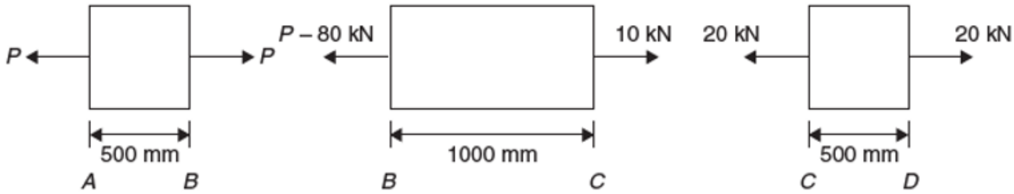

Fig. Free body diagram

$$P - 80 = 10 \Rightarrow P = 90 \text{ kN}$$

$$\text{Change in length, } \Delta l = \frac{1}{EA}\left(P_{AB} \times l_{AB} + P_{BC} \times l_{BC} + P_{CD} \times l_{CD}\right)$$

$$= \frac{4}{\pi \times 0.1^2}\left(\frac{90\times10^3}{80\times10^9}\times0.5+\frac{10\times10^3}{80\times10^9}\times1.0+\frac{20\times10^3}{80\times10^9}\times0.5\right)$$

$$= 9.549 \times 10^{-3} \text{ m}$$

10. A concrete column of 37.5 cm2 cross-section, reinforced with steel rods having a total cross-sectional area 7.5 cm2 carries a load of 800 kN as shown in Figure a.

If E for steel is 15 times greater than that of concrete, calculate the stresses produced in steel, and concrete.

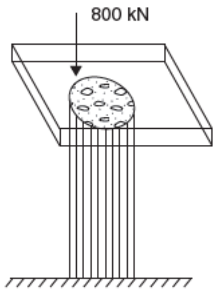

Figure a: Concrete Column

Solution:

$$E_{steel} = 15E_{concrete};$$

$$A_{concrete} = (37.5 - 7.5) \text{ cm}^2 = 30 \text{ cm}^2; \text{ and } A_{steel} = 7.5 \text{ cm}^2$$

Contraction in both the steel and concrete will be same.

$$\delta l_{steel} = \delta l_{concrete} \text{ also, } \in_{steel} = \in_{concrete}$$

and load, $$P = P_{steel} + P_{concrete}$$

Since, $\in_{steel} = \in_{concrete}$

$$\frac{\sigma_{steel}}{E_{steel}} = \frac{\sigma_{concrete}}{E_{concrete}} \Rightarrow \frac{P_{steel}}{A_{steel}E_{steel}} = \frac{P_{concrete}}{A_{concrete}E_{concrete}}$$

or $$P_{steel} = \frac{A_{steel}E_{steel}}{A_{concrete}E_{concrete}} \times P_{concrete} = \frac{7.5 \times 15 E_{concrete}}{30 \times E_{concrete}} \times P_{concrete}$$

or $$P_{steel} = 3.75\, P_{concrete}$$

$$P = P_{steel} + P_{concrete} = 3.75\, P_{concrete} + P_{concrete} = 4.75\, P_{concrete}$$

$$P_{concrete} = \frac{P}{4.75} = \frac{800}{4.75} = 168.42 \text{kN}$$

$$P_{steel} = 800 - 168.42 = 631.58 \text{ kN}$$

11. A bar of 50 mm diameter is subjected to a load of 100 kN. The measured extension on the gauge length of 250 mm is 0.12 mm and the change in diameter is 0.0040 mm. Calculate Poisson's ratio, and value of E and G.

Solution:

$$A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(50)^2 = 1{,}963.49 \text{ mm}^2$$

$$P = 100 \text{ kN}$$

$$\sigma = \frac{P}{A} = \frac{100 \times 10^3}{1{,}963.49} = 50.92 \text{ N/mm}^2$$

$$\delta l = 0.12 \text{ mm and } l = 250 \text{ mm}$$

Longitudinal strain $= \dfrac{0.12}{250} = 4.8 \times 10^{-4}$

Original diameter $= 50$ m

Change in diameter $= 0.0040$ mm

Lateral strain $= \dfrac{0.004}{50} = 8 \times 10^{-5}$

Poisson's ratio $= \nu = -\dfrac{\text{Lateral strain}}{\text{Longitudinal strain}} = -\dfrac{8 \times 10^{-5}}{4.8 \times 10^{-4}} = -0.166$

Modulus of elasticity, $E = \dfrac{\sigma}{\in_1} = \dfrac{50.92}{4.8\times10^{-4}} = 1.06\times10^5\ \text{N/mm}^2$

$$E = 2G\,(1 + V)$$
$$= 2G\,(1 + 0.166) \quad \text{or} \quad G = 45.490\ \text{kN/mm}^2$$

12. For a given material, Young's modulus is 110 GN/m2 and shear modulus is 42 GN/m2. Find the lateral contraction of a round bar of 37.5 mm diameter and 2.4 m long when stretched by 2.5 mm.

Solution:

$$E = 110\ \text{GN/m}^2,\ G = 42\ \text{GN/m}^2$$
$$E = 2G\,(1 + v) \quad \text{or} \quad v = \frac{E}{2G} - 1 = \frac{110}{2\times42} - 1 = 0.3$$
$$v = \frac{\text{Lateral strain}}{\text{Longitudinal strain}} = \frac{\delta d/D}{\delta l/L} = \frac{\delta d\times L}{\delta l\times D}$$
$$\delta d = \frac{v\times\delta l\times D}{L} = \frac{0.3\times2.5\times37.5}{2.4\times10^3} = 0.0117\ \text{mm}$$

13. A bar 2 cm × 4 cm in cross-section and 40 cm long is subjected to an axial tensile load of 70 kN as shown in Figure a. It is found that the length increases by 0.175 mm and lateral dimension of 4 cm decreases by 0.0044 mm. Find (i) Young's modulus, (ii) Poisson's ratio.

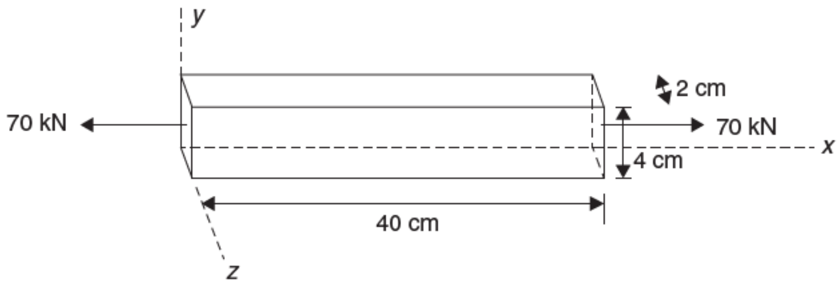

Figure a: A Rod Under Tensile Load

Solution:

Cross-sectional area of bar = 2 × 4 = 8 cm²

$$A_o = 8\,\text{m}^2;\quad \sigma = \frac{P}{A_o} = \frac{70\times10^3}{8} = 8.75\times10^3\ \text{N/cm}^2 = 87.5\ \text{N/mm}^2$$
$$\in_1 = \frac{\delta l}{L} = \frac{0.175\times10^{-1}}{40} = 4.4\times10^{-4}$$

Similarly, $\in_y = \dfrac{0.00044}{4} = 1.1\times10^{-4}$

(i) $E = \dfrac{\sigma}{\in_l} = \dfrac{87.5}{4.4\times10^{-4}} = 1.98\times10^5\ \text{N/mm}^2$

(ii) $v = \dfrac{\in_y}{\in_l} = \dfrac{1.1\times10^{-4}}{4.4\times10^{-4}} = 0.25$

$$v = 0.25 = \frac{\in_z}{\in_l} = \frac{\delta z/2}{4.4\times10^{-4}} \Rightarrow \delta z = 2\times0.25\times4.4\times10^{-4} = 2.2\times10^{-4}\ \text{cm}$$

14. An 80-m-long wire of 5-mm diameter is made of a steel with $E = 200$ GPa and an ultimate tensile strength of 400 MPa. If a factor of safety of 3.2 is desired, determine (*a*) the largest allowable tension in the wire, (*b*) the corresponding elongation of the wire.

SOLUTION

(*a*) $\sigma_U = 400\times10^6\,\text{Pa} \qquad A = \frac{\pi}{4}d^2 = \frac{\pi}{4}(5)^2 = 19.635\ \text{mm}^2 = 19.635\times10^{-6}\ \text{m}^2$

$$P_U = \sigma_U A = (400\times10^6)(19.635\times10^{-6}) = 7854\ \text{N}$$

$$P_{\text{all}} = \frac{P_U}{F.S} = \frac{7854}{3.2} = 2454\ \text{N}$$

(*b*) $\delta = \frac{PL}{AE} = \frac{(2454)(80)}{(19.635\times10^{-6})(200\times10^9)} = 50.0\times10^{-3}\,\text{m}$