UNIT - 1

STRESS AND STRAIN

Part-A

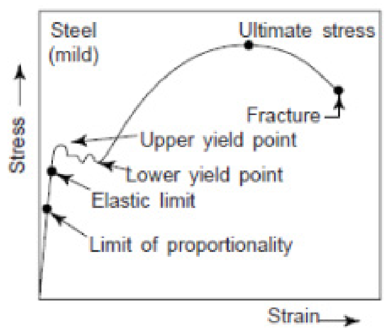
1. **State Hooke's law** **(AU Nov/Dec2016, April/May 2017)**

   It states that within elastic limit stress is proportional to strain. Mathematically

   E= Stress /Strain

   Where E = Young's Modulus

2. **Draw the stress- strain diagram for mild steel and indicate the salient points.** **(AU April/May 2017)**



3. **Define Poisson's Ratio.**

   (AU Nov/Dec 2014, Nov/Dec 2015, Nov/Dec 2016)

   The ratio lateral strain to longitudinal strain produced by a single stress is known as Poisson's Ratio .

   It is denoted by μ (or) 1/m

4. **Expression for strain energy stored in a prismatic bar subjected to an axial load.** **(Nov/Dec 2015)**

   Energy stored in the body

$$U = \frac{\sigma^2}{2E} \times V$$

5. Define Bulk modulus. **(AU Nov/Dec 2014)**

It is defined as the ratio of uniform stress intensity to the volumetric strain. It is denoted by the symbol K.

K = Direct stress/Volumetric strain

6. Define force.

A force is any interaction that, when unopposed, will change the motion of an object. In other words, a force can cause an object with mass to change its velocity (which includes to begin moving from a state of rest), i.e., to accelerate.

7. Define stress.

Stress is the internal resistance offered by the body to the external load applied to it per unit cross sectional area. Stresses are normal to the plane to which they act and are tensile or compressive in nature.

It represneted by 'σ'

$$\sigma = P/A$$

8. What are the types of stresses?

i) Tensile stress

ii) Compressive stress

iii) Shear stress

9. What is the elongation of the bar due its self weight?

$$\delta L = WL/2E$$

10. Define Principle of Superposition.

The principle of superposition states that when there are numbers of loads are acting together on an elastic material, the resultant strain will be the sum of individual strains caused by each load acting separately.

11. Define stain.

When a single force or a system force acts on a body, it undergoes some deformation. This deformation per unit length is known as strain. Mathematically strain may be defined as deformation per unit length.

Strain=Elongation/Original length

12. Deine Elasticity.

The property of material by virtue of which it returns to its original shape and size upon removal of load is known as elasticity.

13. Define shear strain.

The distortion produced by shear stress on an element or rectangular block is shown in the figure. The shear strain or 'slide' is expressed by angle ϕ and it can be defined as the change in the right angle. It is measured in radians and is dimensionless in nature.

14. Define Modulus of Rigidity.

For elastic materials it is found that shear stress is proportional to the shear strain within elastic limit. The ratio is called modulus rigidity. It is denoted by the symbol 'G' or 'C'.

G = shear stress/ shear strain = $\tau/\ \phi$

15. What is the Relationship between modulus of elasticity (E) and bulk modulus (K)?

$E = 3K(1\text{-}2\ \mu)$

16. What is the Relationship between modulus of elasticity (E) and modulus of rigidity(G)?

$E = 2G(1+\mu)$

17. What is the relationship among three elastic contants?

$E = 9KG/3K+G$

18. Define: Young's modulus.

The ratio of stress and strain is constant within the elastic limit. This constant is known as Young‟s modulus. E = Stress /Strain

19. Define: Longitudinal strain.

When a body is subjected to axial load P, there is an axial deformation in the length of the body. The ratio of axial deformation to the original length of the body is called lateral strain. Longitudinal strain= Change in length/Original length = $\partial L/L$

20. What is the radius of Mohr's circle?

Radius of Mohr's circle is equal to the maximum shear stress

21. Define: Lateral strain.

The strain at right angles to the direction of the applied load is called lateral strain. Lateral strain= Change in breadth (depth)/Original breadth (depth) = $\partial b/b$ or $\partial d/d$

22. Define: shear stress and shear strain.

The two equal and opposite force act tangentially on any cross sectional plane of the body tending to slide one part of the body over the other part. The stress induced is called shear stress and the corresponding strain is known as shear strain.

23. Define: volumetric strain.

The ratio of change in volume to the original volume of the body is called volumetric strain. Volumetric strain= change in volume / original volume ev = $\partial V/V$.

24. What is compound bar?

A composite bar composed of two or more different materials joined together such that the system is elongated or compressed in a single unit.

25. What you mean by thermal stresses?

If the body is allowed to expand or contract freely, with the rise or fall of temperature no stress is developed, but if free expansion is prevented the stress developed is called temperature stress or strain.

26. Define principle stresses and principle plane.

Principle stress: The magnitude of normal stress, acting on a principal plane is known as principal stresses. Principle plane: The planes which have no shear stress are.known as principal planes.

27. What Is the use of Mohr's circle?

To find out the normal, resultant and principle stresses and their planes.

28. List the methods to find the stresses in oblique plane?

a) Analytical method b) Graphical method

29. Define strain energy.

Whenever a body is strained, some amount of energy is absorbed in the body. The energy which is absorbed in the body due to straining effect is known as strain energy.

PART-B

Formula Used:

1. $\text{Stress}, (\sigma) = \frac{\text{Load}}{\text{Area}} = \frac{P}{A} .... N/mm^2.$

2. $\text{Strain}, (e) = \frac{\text{Change in length}}{\text{Change Length}} = \frac{\Delta\ell}{\ell} ....$

3. $\text{Young's modulu's} (E) = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{e} .... N/mm^2.$

4. $\text{Factor of safety} = \frac{\text{Ultimate Stress}}{\text{warning Stress}}$

1. Derive a relation for change in length of a bar hanging freely under its own weight. (AU April/May2017)

ELONGATION OF BAR DUE TO ITS OWN WEIGHT

Fig. 1.25 shows a bar AB fixed at end A and hanging freely under its own weight.

Let

L = Length of bar,

A = Area of cross-section,

E = Young's modulus for the bar material,

ω = Weight per unit volume of the bar material.

Consider a small strip of thickness dx at a distance x from the lower end.

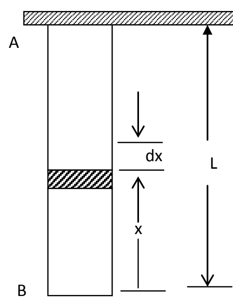


Fig. 1.25

Weight of the bar for a length of x is given by,

P = Specific weight × Volume of bar upto length x

$$= \omega \times A \times x$$

The means that on the strip, a weight of $\omega \times A \times x$ is acting in the downward direction. Due to this weight, there will be some increase in the length of element. But length of the element is dx.

Now stress on the element

$$\frac{\text{weight acting on element}}{\text{Area of cross} - \text{section}} = \frac{\omega \times A \times x}{A} = \omega \times x$$

The above equation shows that stress due to self weight in a bar is not uniforms. It depends on x. The stress increase with the increase of x.

$$\text{Strain in the element} = \frac{\text{Stress}}{E} = \frac{\omega \times x}{E}$$

$\therefore$ Elongation of the element

$$= \text{Strain} \times \text{Length of element}$$

$$= \frac{\omega \times x}{E} \times dx$$

The elongation of the bar is obtained by integrating the above equation between limits zero and L.

$$\delta L = \int_0^L \frac{\omega \times x}{E} dx = \frac{\omega}{E} \int_0^L x.dx$$

$$= \frac{\omega}{E}\left[\frac{x^2}{2}\right]_0^L = \frac{\omega}{E} \times \frac{L^2}{2}$$

$$= \frac{WL}{2E} \qquad (\because\ W = \omega \times L)$$

2. i) Determine the change in length, breath and thickness of a steel bar which is 4m long; 30mm wide; 30mm thick and subjected to an axial pull of 30kN in the direction of its longer. Take E = 2 × 10^5 N/mm^2 and poisons ratio = 0.3.

Given:

$\ell = 4$ m $= 4000$ mm; $b = 30$mm; $d = 20$mm

$P = 30$kN; $E = 2 \times 10^5$ N/mm^2; $1/m = 0.3$

Required:

$\Delta L, \Delta d, \Delta b = ?$

Solution:

Area of the c/s section = b × t =30 × 20 = 600mm^2

Now strain in the direction of land (or) longitudinal strain.

$$=\frac{\text{Stress}}{\text{E}}=\frac{\text{Load}}{\text{Area}\times\text{E}}=\frac{\text{P}}{\text{AE}}$$

$$=\frac{30\times10^3}{600\times2\times10^3}$$

Longitudinal stress = 0.00025

$$\text{But, longitudinal strain} = \text{longitudinal strain}\times\text{length}$$

$$=0.00025\times4000=1\text{mm.}$$

$$\text{Poision's ratio}\left(\frac{1}{\text{m}}\right)=\frac{\text{Lateral strain}}{\text{Linear Strain}}$$

ii) Determine due to young's modulus and poisons ratio of a metallic bar of length 30cm breath 4cm and depth 4cm when the bar is subjected to an axial compressive load of 400cm The decrease in length is given as 0.07500 and increase in breath is 0.003 cm.

Given:

ℓ = 30cm = 300mm; b = 4cm = 40mm; d = 4cm = 40mm;

P = 400KM; ΔL = 0.075cm = 0.75cm; Δb = 0.003cm

Required:

E = ? 1/m = ?

Solution:

A = b × d = 40 × 40 =1600mm^2

$$\text{Longitudinal strain}=\frac{\Delta\ell}{\ell}=\frac{0.75}{300}=0.0025$$

$$\text{Literal Strain}=\frac{\Delta\text{b}}{\text{b}}=\frac{0.03}{40}=0.00075$$

$$\text{Poission's Ratio}\left(1/\text{m}\right)=\frac{\text{Lateral strain}}{\text{Longitudinal strain}}$$

$$=\frac{0.00075}{0.0025}$$

$$\mu\text{ or }1/\text{m}=0.3$$

ii) Young's modulus (E):

$$\text{Longitudinal strain} = \frac{\text{Stress}}{E}$$

$$= \frac{P}{A.E}$$

iii) A steel bar 300mm long, 50mm wide and 40mm is thick is subjected to pull of 300km in the direction of its length. Determine change in the volume, Take E = 2 × 10^5 N/mm^2 and m = 4.

[Nov / Dec 2016]

Given:-

ℓ = 300mm; b = 40mm; t = 40mm; P = 300KM;

E = 2 × 10^5N/mm^2; m =4.

Required:

Change in Volume, dv = ?

Solution:

Original volume, v = ℓ × b × t = 500 × 50 × 40 =600 × 10^3 mm^2

We know,

$$\text{Longitudinal Strain (a)} = \frac{\text{Stress}(\sigma)}{\text{Young's Modulus}(\tau)}$$

$$\text{Stress}(\sigma) = \frac{P}{A} = \frac{300 \times 10^3}{50 \times 40} = 150\text{N} / \text{mm}^2$$

$$\therefore \text{Longitudinal strain} = \frac{150}{2 \times 10^3} = 0.00075$$

Now,

Volumetric strain, (ev) =

$$\frac{\Delta\ell}{\ell}\left(1 - \frac{2}{m}\right)$$

$$= 0.00075\left(1 - \frac{2}{4}\right)$$

$$ev = 0.00375$$

But,

$$\text{Volumetic strain, ev} = \frac{\text{change in volume}(\Delta v)}{\text{Original volume}(v)}$$

$$\text{change in volume}(\Delta v) = ev \times v$$

3. A rod 15cm long and of diameter 2.0cm is subjected to an axial pull of 20kN. Find the

i) Stress ii) Strain and iii) Elongation of the rod. If Young' Modulus = 2x10^5 N/mm^2.

Sol , Given : Length of the rod, L= 150cm

Diameter of the rod, D=2.0cm = 20 mm

Area, $A = \frac{\pi}{4}(20)^2 = 100\pi \text{mm}^2$

Axial pull, P = 20 KN = 20 , 000 N

Modulus of elasticity, E = 2.0 × 10^2 N/mm^2

i) The stress (σ) is given by equation (1.1) as

$$\sigma = \frac{P}{A} = \frac{20000}{100\pi} = 63.662 \, \text{N/mm}^2, \text{Ans}$$

ii) Using equation (1.5), the strain is obtained as

$$E = \frac{\sigma}{e}$$

$$\therefore \text{Strain, } e = \frac{\sigma}{E} = \frac{63.662}{2 \times 10^5} = 0.000318. \text{Ans.}$$

iii) Elongation is obtained by using equation (1.5) as

$$e = \frac{dL}{L}$$

$$\therefore \text{Elongation}, dL = e \times L$$

$$= 0.000318 \times 150 = 0.0477 \text{cm.Ans}$$

4. Find the Minimum diameter of a steel wire, which is used to raise a load of 4000N if the stress in the wire is not to exceed 95 MN/m^2.

Sol, Given: load, P = 4000N

Stress, σ = 95 MN/m^2 (M = Mega = 10^6)

= 95 N/mm^2 (10^6 N/mm^2)

Let, d = Diameter of wire in mm

$$\therefore \text{Area}, \quad A \frac{x}{4} D^2$$

$$\text{Now} \quad \text{Stress} = \frac{\text{Load}}{\text{Area}} = \frac{P}{A}$$

$$95 = \frac{4000}{\frac{x}{4}D^2} = \frac{4000 \times 4}{\pi D^2} \text{ or } D^2 = \frac{4000 \times 4}{\pi \times 95} = 53.61$$

$$\therefore \quad D = 7.32\text{mm. Ans.}$$

5. A tensile test was conducted on a mild steel bar. The following data was obtained from the test:

i) Diameter of the steel bar = 3cm
ii) Gauge length of the bar = 20cm
iii) Load at elastic limit = 250kN
iv) Extension at a load of 150kN = 0.21 mm
v) Maximum load = 380kN
vi) Total extension = 60mm
vii) Diameter of the rod at the failure = 2.25cm.

Determine : (a) the young's modulus
(b) the stress at lastic Limit.
(c) the percentage elongation, and
(d) the percentage decrease in area.

Sol,m Area of the rod

$$A = \frac{\pi}{4}D^2 = \frac{\pi}{4}(3)^2 \text{ cm}^2$$

$$= 7.0685\,\text{cm}^2 = 7.0685 \times 10^{-4}\,\text{m}^2. \quad \left[\therefore \text{cm}^2 = \left(\frac{1}{100}\text{m}\right)^2\right]$$

,

(a) To find young's modulus, first calculate the value of stress and strain with elastic limit. The load at elastic limit is given but the extension corresponding to the load at elastic limit is not given. But a load of 150kN (which is within elastic limit) and corresponding extension of 0.21 mm are given. Hence these values are used for stress and strain within elastic limit.

$$\therefore \quad \text{stress} = \frac{\text{Load}}{\text{Area}} = \frac{150 \times 1000}{7.0685 \times 10^{-4}}\text{N/m}^2 \qquad (\therefore 1\text{kN} = 1000\,\text{N})$$

$$\text{and} \quad \text{Strain} = \frac{\text{Increase in length (or Extension)}}{\text{Original length (or Gauge length)}}$$

$$= \frac{0.21\text{mm}}{20 \times 10\,\text{mm}} = 0.00105$$

$\therefore$ Young's Modulus,

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{21220.9 \times 10^4}{0.00105} = 20209523 \times 10^4 \text{ N/m}^2$$

$$= 202.095 \times 10^9 \text{ N/m}^2 \qquad (\therefore\ 10^2 = \text{Giga} = \text{G})$$

$$= 202.095 \text{ GN/m}^2. \text{Ans}$$

(b.) The stress elastic limit is given by,

$$\text{Stress} = \frac{\text{Load at elastic lim it}}{\text{Area}} = \frac{250 \times 1000}{7.0685 \times 10^{-4}}$$

$$= 35368 \times 10^4 \text{ N/m}^2$$

$$= 353.68 \times 10^6 \text{ N/m}^2 \qquad (\therefore \quad 10^6 = \text{Mega} = \text{M})$$

$$= 353.68 \text{ MN/m}^2. \text{Ans.}$$

(c) The percentage elongation is obtained as,

$$\text{Percentage elongation} = \frac{\text{Total increase in Length}}{\text{Original length (or Gauge Length)}} \times 100$$

$$= \frac{60 \text{ mm}}{20 \times 10 \text{ mm}} \times 100 = 30\% \qquad \text{Ans.}$$

(d) The percentage decrease in area is obtained as,

$$\text{Percentage decrease in area} = \frac{(\text{Original area} - \text{Area at the failure})}{\text{Original area}} \times 100$$

$$= \frac{\left(\frac{\pi}{4} \times 3^2 - \frac{\pi}{4} \times 225^2\right)}{\frac{\pi}{4} \times 3^2} \times 100$$

$$= \left(\frac{3^2 - 225^2}{3^2}\right) \times 100 = \frac{(9 - 5.0625)}{9} \times 100 = 43.75\%$$

6. The ultimate stress for a hollow steel column which carries an axial load of 1.9MN is 480 N/mm² If the external diameter of the column is 200mm, determine the internal diameter. Take the Factor of safety as

SOL, Given :

Ultimate stress, $= 480 \text{ N/mm}^2$

Axial load, $P = 1.9\ MN = 1.9 \times 10^6\ N (M = 10^6)$

$= 1900000\ N$

External Dia., $D = 200$ mm

Factor of safety $= 4$

Let d = internal diameter in mm

Area of cross-section of the column,

$$A = \frac{\pi}{4}\left(D^2 - d^2\right) = \frac{\pi}{4}\left(200^2 - d^2\right) mm^2$$

Using equation (1.7) we get,

$$\text{Factor of safety} = \frac{\text{Ultimate stress}}{\text{Working stress or Permissible stress}}$$

$$\therefore \quad 4 = \frac{480}{\text{Working stress}}$$

Or working stress

$$= \frac{480}{4} = 120\ N/mm^2$$

$$\therefore \quad \sigma = 120\ N/mm^2$$

Now using equation (1.1),. We get

$$\sigma = \frac{P}{A} \text{ or } 120 = \frac{1900000}{\frac{\pi}{4}\left(200^2 - d^2\right)} = \frac{1900000 \times 4}{\pi\left(40000 - d^2\right)}$$

Or $$4000 - d^2 = \frac{1900000 \times 4}{\pi \times 120} = 20159.6$$

Or $$d^2 = 4000 - 20159.6 = 19840.4$$

$$\therefore d = 140.85\ mm \qquad \text{Ans.}$$

7. A stepped for shown in fig. 1.6 is subjected to an axially applied compressive load of 35 kN Find the maximum and minimum stresses produced.

Sol Given:

Axial load, $P = 35\ kN = 35 \times 10^3\ N$

Dia. Of upper part, $D_1 = 2\ cm = 20\ mm$

Area of upper part, $$A_1 = \frac{\pi}{4}\left(20^2\right) = 100\pi \, mm^2$$

Area of lower part, $$A_2 = \frac{\pi}{4}D^2{}_2 = \frac{\pi}{4}\left(30^2\right) = 225\pi \, mm^2$$

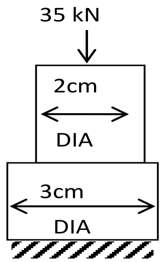


Fig. 1.6

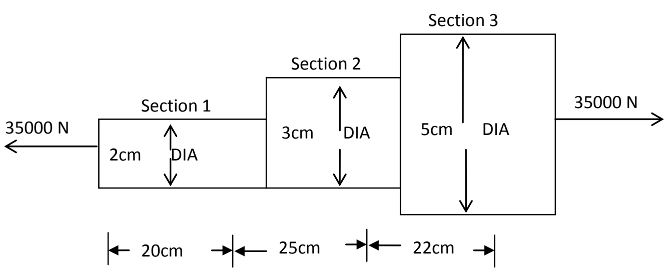
The stress is equal to load divided by area. Hence stress will be maximum where area is minimum. Hence stress will be maximum in upper part and minimum in lower part.

$$\therefore \text{Maximum Stress} = \frac{\text{Load}}{A_1} = \frac{35\times10^2}{100\times\pi} = 111.408\,N/mm^2.\text{Ans.}$$

$$\text{Minimum Stress} = \frac{\text{Load}}{A_2} = \frac{35\times10^2}{225\times\pi} = 49.5146N/mm^2.\text{Ans.}$$

8. An axial pull of 35kN is acting on a bar consisting of three lengths as shown in figure. If the young's modulus (E) = 2.1 × 10³ N/mm², determine i)Stresses in each section and

ii)Total extension of the bar



Sol, Given:

Axial pull, $P = 35000$ N

Length of section 1, $L_1 = 20$ cm $= 200$ mm

Dia. Of section 1,	$D_1 = 2$ cm = 20 cm
Area of section 1,	$A_1 = \frac{\pi}{4}(20^2) = 100\ \pi$ mm^2
Length of section 2,	$L_2 = 25$ cm = 250 mm
Dia. Of section 2,	$D_2 = 3$ cm = 30 mm
Area of section 2,	$A_2 = \frac{\pi}{4}(30^2)\ 225\ \pi$ mm^2
Length of section 3,	$L_3 = 22$ cm = 220 mm
Dia. Of section 3,	$D_3 = 5$ cm = 50 mm
Area of section 3,	$A_3 = \frac{\pi}{4}(50^2) = 625\ \pi$ mm^2
Young's modulus	$E = 2.1 \times 10^5$ N/mm^2.

i) Stresses in each section

$$\text{Stress in sec tion 1, } \sigma_1 = \frac{\text{Axial load}}{\text{Area of sec tion 1}}$$

$$= \frac{P}{A_1} = \frac{35000}{100\pi} = 111.408\ \text{N / mm}^2.\text{Ans}$$

$$\text{Stress in sec tion 2, } \sigma_2 = \frac{P}{A_2} = \frac{35000}{225 \times \pi} = 49.5146\ \text{N / mm}^2.\text{Ans}$$

$$\text{Stress in sec tion3, } \sigma_3 = \frac{P}{A_3} = \frac{35000}{625 \times \pi} = 17.825\ \text{N / mm}^2.\text{Ans.}$$

ii) Total extension of the bar using equation(1.8), we get

$$\text{Total Extension} = \frac{P}{E}\left[\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3}\right]$$

$$= \frac{35000}{2.1 \times 10^5}\left(\frac{200}{100\pi} + \frac{250}{225 \times \pi} + \frac{220}{625 \times \pi}\right)$$

$$= \frac{35000}{2.1 \times 10^5}\left(6.366 + 3.536 + 1.120\right) = 0.183\ \text{mm. Ans}$$

9. The bar shown in fig. 1.8 is subjected to a tensile load of 160 kN. If the stress is the middle portion is limited to 150 N/mm², determine the diameter of the middle portion. Find also the length of middle portion if the load if the total elongation of the bar is to be 0.2 mm. Young's modulus is given as equal to 2.1 × 10⁵ N/mm².

Sol, Given:

Textile load, $P = 160\text{ kN} = 160 \times 10^3\text{ N}$

Stress in middle portion, $\sigma_2 = 150\text{ N/mm}^2$

Total elongation, $dL = 0.2\text{ mm}$

Total length of the bar $L = 40\text{ cm} = 400\text{ mm}$

Young's modulus $E = 2.1 \times 10^5\text{ N/mm}^2$

Diameter of both end portions, $D_1 = 6\text{ cm} = 60\text{ mm}$

Area of cross-section of both end portions,

$$A_1 = \frac{\pi}{4} \times 60^2 = 900\pi\,\text{mm}^2.$$

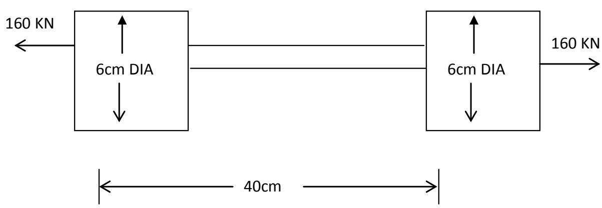


Fig. 1.8

Let D_2 = Diameter of the middle portion

L_2 = Length of middle portion in mm.

Length of both end points of the bar,

$L_1 = (400 - L_2)$ mm

Using equation (1.1), we have

$$\text{Stress} = \frac{\text{Load}}{\text{Area}}$$ For the middle portion, we have

$$\sigma_2 = \frac{P}{A_2} \qquad \text{where } A_2 = \frac{x}{4} D^2{}_2$$

OR

$$150 = \frac{160000}{\frac{\pi}{4} D^2{}_2}$$

$$\therefore \qquad D^2{}_2 = \frac{4 \times 160000}{\pi \times 150} = 1358 \text{ mm}^2$$

$$\text{Or} \qquad D_2 = \sqrt{1358} = 36.85 \text{ mm} = 3.685 \text{ cm}$$

$\therefore$ Area of cross – sec tion of middle portion,

$$A_3 = \frac{\pi}{4} \times 36.85 = 1066 \text{ mm}^2$$

Now equation (1.8), we get

$$\text{Total extension, dL} = \frac{P}{E}\left[\frac{L_1}{A_1} + \frac{L_2}{A_2}\right]$$

$$\text{Or } 0.2 = \frac{160000}{2.1 \times 10^5}\left[\frac{(400 - L_2)}{900\pi} + \frac{L_2}{1066}\right]$$

[$L_1 = (400 - L_2)$ and $A_2 = 1066$]

$$\text{Or } \frac{0.2 \times 2.1 \times 10^5}{160000} = \frac{(400 - L_2)}{900\pi} + \frac{L_2}{1066}$$

$$\text{Or } 0.265 = \frac{1066(400 - L_2) + 900\pi L_2}{900\pi \times 1066}$$

$$\text{Or } 0.265 \times 900\pi \times 1066 = 1066 \times 400 - 1066 L_2 = 900\pi \times L_2$$

$$\text{Or } 791186 - 426400 = L_2 (2827 - 1066)$$

$$\text{Or } 364786 = 1761 L_2$$

$$\therefore \qquad L_2 = \frac{364786}{1761} = 207.14 \text{ mm} = 20.714 \text{ cm. Ans.}$$

10. A Compound bar of length 500mm consists of a strip of aluminum 40mm widex15mm thick and a strip of steel 40mm wide x 10mm thick rigidly joined at ends. If the bar is subjected to a load of 50kN, find the stress developed in each material and the extension of the bar. Take modulus of elasticity of aluminum and steel as 1.1×10^5 N/mm^2 and 2.1×10^5 N/mm^2

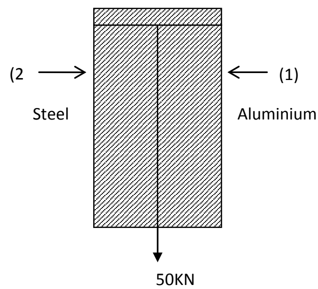
Given:

Length, L = 500 mm

$A_a = 40 \times 15 = 600$ mm^2,

$A_s = 40 \times 10 = 400$ mm^2,

Load, P = 50 KN = 50000 N.Ea = 1.1×10^5 N/mm^2



$E_s = 2.1 \times 10^5$ N/mm^2

Required

i) Stress developed in each material

ii) Extension each material.

Solution:

We know,

$$\mathbf{P = P_1 + P_2}$$

Total load, $P = P_a + P_s$

Here $L_a + L_s$

$$\Rightarrow \quad \frac{P_a}{A_a E_a} = \frac{P_s}{A_s E_s}$$

$$P_a = P_s \times \frac{A_a E_a}{A_s E_s}$$

Load on aluminium,

$$P_a = \frac{600 \times 1.1 \times 10^5}{400 \times 2.10 \times 10^5} \times P_s$$

$$\boxed{P_a = 0.785 P_s}$$

Substitute in eqn (1)

$$5000 = P_a + P_s$$
$$5000 = 0.785 P_s + P_s$$
$$P_s = \frac{50000}{1.785}$$
$$\boxed{P_s = 28.011 \times 10^3 \text{ N}}$$

$$\text{New, load on alu min ium}, P_a = 0.785 P_s$$
$$= 0.785 \times 28.011 \times 10^3$$
$$\therefore \boxed{P_a = 21.988 \times 10^3 \text{ N.}}$$

i) Stress developed in each material:

Stress developed in steel,

$$\sigma_s = \frac{P_s}{A_s} = \frac{28.011 \times 10^3}{400}$$
$$\boxed{\sigma_s = 70.02 \text{ N / mm}^2}$$

ii) Extension in each material:

Change in length of aluminium = change in length of steel

$$\Delta L_a = \Delta L_s$$
$$\frac{P_a L_a}{A_a E_a} = \frac{P_s L_s}{A_s E_s}$$
$$\Delta L_a = \frac{21.988 \times 10^3 \times 500}{600 \times 1.1 \times 10^5} = 0.166 \text{ mm}$$
$$\Delta L_s = \frac{28.011 \times 10^3 \times 500}{400 \times 2.1 \times 10^5} = 0.166 \text{ mm.}$$

Result:

i)Stress developed in aluminium (σ_a) = 36.64 N/mm^2

Stress developed in steel (σ_s) = 70.02 N/mm^2

ii) Extension in each material Δ_L = 0.166 mm.

11. A steel rod of 25mm diameter is enclosed centrally in a copper hollow tube of external diameter 40mm and internal diameter 30mm. The composite bar is then subjected to an axial pull of 4500N. If the length of each bar is equal to 130mm, determine

i) The stresses in the rod and tube

ii) Load carried by each bar.

Take Eb = $2.1 \times 10^5 N/mm^2$ and Ec = $1.1 \times 10^5 N/mm^2$

GIVEN:

(i) Steel rod:

Diameter = 25 mm

$$\text{Area As,} = \frac{\pi}{4}(25)^2 = 490.87\,\text{mm}^2.$$

ii) Copper hollow tube:

External diameter, D = 40 mm

Internal diameter, d = 30 mm

$$\text{Area of copper tube (Hollow)}, A_c = \frac{\pi}{4}\left(40^2 - 30^2\right)$$

$$A_c = 549.7\,\text{mm}^2$$

$\text{Load}, p = 4500\,\text{N};$ $\text{Length}, L = 130\,\text{mm}.$

To find:

i) Stress in steel rod and copper tube

ii) Load carried by rod and tube.

Solution:

We know that,

Total load, P = Load on steel rod + load on Copper tube.

$$\boxed{4500 = P_s + P_c}\,.........(1)$$

Change in length of steel rod = Change in length of copper tube.

$$\Delta L_s = \Delta L_C$$

$$\frac{P_s L_s}{A_s E_s} = \frac{P_c L_c}{A_c E_c}$$

Length of two rods of one equal,

So, $L_S = L_c$

$$\Rightarrow \quad \frac{P_s \times 130}{490.87 \times 2.1 \times 10^5} = \frac{P_c \times 130}{549.7 \times 1.1 \times 10^5}$$

$$P_s = \left(\frac{130}{2.15 \times 10^{-6}} \times \frac{103.08 \times 10^6}{130} \right) P_c$$

$$\boxed{P_c = 1.70\, P_c}$$

$$\Rightarrow \quad P_S = 1.70 \times 16666.6$$

$$\boxed{P_s = 2833.22\, \text{N}}$$

Stress in copper tube,

$$\sigma_c = \frac{\text{Load}}{\text{Area}}$$

$$\sigma_c = \frac{P_c}{A_c} = \frac{1666.6}{549.7}$$

$$\boxed{\sigma_c = 3.03\, \text{N / mm}^2}$$

Stress in the steel rod,

$$\sigma_s = \frac{\text{Load}}{\text{Area}}$$

$$\sigma_s = \frac{P_s}{A_s} = \frac{2833.22}{490.87}$$

$$\boxed{\sigma_s = 5.77\, \text{N / mm}^2}$$

Result:

P_c = 1666.6 N

P_s = 2833.22 N

σ_c = 3.03 N/mm^2

σ_s = 5.77 n/mm^2

12. A steel rod of 20 mm diameter passes centrally through a copper tube of 50mm. External diameter and 40mm internal diameter. The tube is enclosed at each and by rigid plates of negative thickness. The nuts are tightened lightly home on the projecting pants of the rod. If the temperature of the assembly is raised by 50°C, Calculated the stress developed in copper and steel. Take E for steel and copper as 200 G N/m² and 100 G N/m² and ∝ for steel and copper 12 × 10^{-6} per °C and 18 × 10^{-6} per °C.

Given:

Dia. Of steel rod = 20 mm

Area of steel rod, $A_s = \frac{\pi}{4}(20)^2 = 314.16\,\text{mm}^2$

Area of copper tube, $A_c = \frac{\pi}{4}\left(50^2 - 40^2\right) = 706.86\text{mm}^2$

Rise of temperature, T = 50°C

$E_s = 200\ \text{GN/m}^3 = 200 \times 10^3\ \text{N/mm}^2$

$E_c = 100\ \text{GN/m}^3 = 100 \times 10^3\ \text{N/mm}^2$

α for steel, $\alpha_s = 12 \times 10^{-6}$ per °C

Let, σ_s = tensile stress in steel

σ_c = Compressive stress in copper

For the equilibrium of the system,

Tensile load on steel = compressive load on copper.

$$\sigma_S A_s = \sigma_c A_c$$

$$\sigma_s = \frac{A_c}{A_s}.\sigma_c$$

$$\sigma_s = \frac{708.54}{314.16} \times \sigma_c$$

$$\sigma_s = 2.25\sigma_c ....(i)$$

We know that the copper tube and steel rod will actually expand by the same amount.

Actual expansion of steel = Actual expansion of copper…… (ii)

But actual expansion of steel = Free expansion of steel + Expansion due to tensile stress in copper

$$= d_s.T.L + \frac{\sigma_s}{E_s}.L$$

Actual expansion of copper = Free expansion copper – contraction due to compressive stress in copper

$$= \alpha_c.T.L. - \frac{\sigma_c}{E_c}.L$$

Substituting in eqn (ii) we get

$$12\times10^{-6}\times50 + \frac{2.25\sigma_c}{200\times10^8} = 18\times10^{-6}\times50 - \frac{\sigma_c}{100\times10^3}$$

$$\frac{2.25\sigma_c}{200\times10^8} + \frac{\sigma_c}{100\times10^3} = \left(18\times10^{-6}\times50\right) - \left(12\times10^{-6}\times50\right)$$

$$1.125\times10^{-5}\sigma_c + 10^{-5}\sigma_c = 6\times10^{-6}\times50$$

$$2.125\times10^{-5}\sigma_c = 30\times10^{-5}$$

$$2.125\sigma_c = 30$$

$$\sigma_c = \frac{30}{2.125} = 14.117\,\text{N}/\text{mm}^2$$

Substituting σ_c value in eqn (1)

$\sigma_s = 2.25\ \sigma_c$

$\sigma_s = 14.117 \times 2.25$

$\sigma_s = 31.76$ N/mm^2

Result:

$\sigma_c = 14.117$ N/mm^2

$\sigma_s = 31.76$ N/mm^2

i) Volumetric strain of a rectangular bar subjected to an axial force (P)

$$ev = \frac{du}{v}$$

$$ev = \frac{\Delta L}{L}\left(1 - \frac{2}{m}\right)$$

ii) Volumetric strain of a cylindrical rod subjected to an axial force (P)

$$ev = \frac{dv}{v}$$

$$ev = \frac{\Delta L}{L} - \frac{2\Delta\alpha}{\alpha}$$

iii) Volumetric strain of rectangular bar subjected to three forces which are mutually perpendicular

$$ev = \frac{dv}{v}$$

$$ev = \frac{1}{E}\left(\sigma_x + \sigma_y + \sigma_z\right)\left(1 - \frac{2}{m}\right)$$

13. A steel rod 5m long and 30mm in diameter is subjected to an axial tensile load of 50KM. Determine the change in length diameter and volume of the rod. Take E = 2 × 10^3 N/mm^2 and poison's ratio = 0.25

Given:

$\ell = 5m = 5000mm; d = 30mm$

$E = 2 \times 10^3\ n/mm^2; P = 50KM$

$$v = \frac{\pi}{4}(d)^2 \times \ell = \frac{\pi}{4}(30)^2 \times 5000 = 35.34 \times 10^5\ mm^3$$

$1/m = 0.25$

Required:

Change in length, $\Delta\ell = ?$

Change in diameter $\Delta d = ?$

Change in Volume, $\Delta v = ?$

Solution:

We know, longitudinal strain = $\frac{\Delta\ell}{\ell}$

But, longitudinal strain =

$$= \frac{\text{Stress}}{\text{Young's Modulus}} = \frac{\sigma}{E}$$

$$= \frac{P}{AE} = \frac{50 \times 10^3}{141.37 \times 10^6}$$

$$e_\ell = 0.000354$$

$$\therefore \Delta\ell = e_\ell \times \ell = 0.000354 \times 5000$$

$$\Delta\ell = 1.768mm$$

Lateral strain = 0.25 × 0.00035 = 0.0000875%

But, Lateral strain

$$= \frac{\Delta d}{d}$$

Change in diameter, Δd = Lateral strain × Original diameter

= 0.0000875 × 30

Δd = 0.0026mm.

We know, Volumetric strain of cylindrical rod,

$$\frac{\Delta v}{v} = \frac{\Delta L}{L} = \frac{2\Delta d}{d}$$

$$\frac{\Delta v}{v} = \frac{\Delta \ell}{\ell} - \frac{2\Delta d}{d}$$

$$= 0.000354 - 2 \times 0.00008758$$

$$\frac{\Delta v}{v} = 0.000178$$

$$\therefore \Delta v = 0.000178 \times 35.34 \times 10^3$$

$$\Delta v = 631.17 mm^2$$

Result:

Change in length, Δℓ = 1.768mm

Change in diameter, Δd = 0.0026mm

Change in Volume, Δv = 631.17mm^3.

14. A cylindrical shell 3 meters long which is closed as the ends has an internal diameter of 1m and a wall thickness of 15mm. Calculate the circumferential and longitudinal stresses induced and also changes in the dimensions of the shell, if it is subjected to an internal pressure of 1.5 N/mm². Take E = 2 × 10⁵ N/mm² and μ = 0.3.

Sol Given:

Length of shell, L = 3m =300cm

Internal diameter, d = 1m = 100cm

Wall thickness, t = 15mm = 1.5cm

Internal pressure, P = 1.5 N/mm^2

Young's modulus, E = 2 × 10^5 N/mm^2\

Poisson's ratio, **μ** = 0.3

Let σ_1 = Circumferential (or Hoop) stress, and

σ_2 = Longitudinal stress.

Using equation (17.1) for hoop stress,

$$\sigma_1 = \frac{pd}{2t}$$

$$= \frac{1.5 \times 100}{2 \times 1.5} = 50 N / mm^2 . Ans$$

Using equation (17.2) for longitudinal stress,

$$\sigma_2 = \frac{p \times d}{4t}$$

$$= \frac{1.5 \times 100}{4 \times 1.5} = 25 N / mm^2 . Ans$$

Change in dimensions

Using equation (17.11) for the change in diameter (δd),

$$\delta d = \frac{pd^2}{2tE}\left(1 - \frac{1}{2} \times \mu\right)$$

15. A flat steel plate of trapezoidal form of uniform thickness of 20mm tapers uniformly from a width of 100mm to 200mm in a length of 800mm. If the axial tensile force of 100kN is applied at each end, find the elongation of the plate. (Nov/Dec 2014)

Given:

Length $L = 800mm$

Thickness $t = 20mm$

Axial load $P = 100kN$

Width at bigger end $a = 200mm$

Width at smaller end $b = 100mm$

Let dL = Extension of the plate.

$$dL = \frac{PL}{Et(a-b)} \log_e \frac{a}{b}$$

16. A steel bar 300mm long, 40mm wide and 25mm thick is subjected to a pull of 180kN. Determine the change is volume of the bar. Take $E = 2 \times 10^5$ N/mm² and 1/m = 0.3

Given: Length, L = 300mm; width, b = 40mm

Thickness, t = 25mm; Pull, P = 180kN = 180×10^3 N

Young's modulus, E = 2×10^5 N/mm²

Poisson's ratio, 1/m = 0.3

To find : Change in volume.

Solution : Volumetric strain of a rectangular bar subjected to an axial force is given by,

$$e_v = \frac{dV}{V} = \frac{\delta L}{L}\left(1 - \frac{2}{m}\right) \quad ....(A)$$

$$\left[\text{From equation } (1.32)\right]$$

$$\text{Young's Modulus, } E = \frac{\text{Tensile Stress}}{\text{Tensile strain or Longitudinal strain}}$$

$$E = \frac{\sigma}{e_l}$$

$$E = \frac{P/A}{\delta L / L}$$

$$\left[\because \text{Stress}, \sigma = \frac{\text{Load}}{\text{Area}} = \frac{P}{A}; \quad \text{Longitudinal Strain}, e_l = \frac{\delta L}{L}\right]$$

$$\Rightarrow \qquad 2 \times 10^5 = \frac{180 \times 10^3 / b \times t}{\delta L / 300}$$

$$= \frac{\dfrac{180 \times 10^3}{40 \times 25}}{\dfrac{\delta L}{300}}$$

$$\boxed{\delta L = 0.27 \text{ mm}}$$

Substituting δL, L, 1/m values in equation (A),

$$\frac{dV}{V} = \frac{0.27}{300}\left[1 - 2(0.3)\right]$$

$$(A) \Longrightarrow \boxed{\frac{dV}{V} = 3.6 \times 10^{-4}} \quad ....(B)$$

$$\text{Volume, } V = L \times b \times t = 300 \times 40 \times 25$$

$$\boxed{V = 3 \times 10^5 \text{ mm}^3}$$

Substituting V value in equation (B),

$$(B) \Rightarrow \quad \frac{dV}{3\times10^5} = 3.6\times10^{-4}$$

$$\boxed{dV = 108\,mm^3}$$

Result : Change in Volume, dV = 108mm^3.

17. An cylindrical shell 1m diameter and 3m length is subjected to an internal pressure of 2MPa. Calculate the minimum thickness if the stress should not exceed 50MPa. Find the change in diameter and volume of the shell. Poisson's radio = 0.3 and E = 200kN/mm^2.

[MU – Apr 96]

Given:

Diameter of cylinder, d = 1m = 1000mm

Length of cylinder, L = 3mm = 3000mm

Internal Pressure, P = 2MPa = 2 N/mm^2

Young's modulus, E = 200k N/mm^2

= 2 × 10^5 N/mm^2

Poisson's ratio, 1/m= 0.3.

Solution:

Circumferential stress,

$$\sigma_c = \frac{pd}{2t}$$

$$[\text{From equation } (1.47)]$$

$$50 = \frac{2\times1000}{2\times t}$$

$$\boxed{t = 20\,mm}$$

Change in diameter,

$$\delta d = \frac{pd^2}{2tE}\left(1 - \frac{1}{2m}\right)$$

$$[\text{From equation } (1.50)]$$

$$= \frac{2\times(1000)^2}{2\times20\times2\times10^5}\left(1 - \frac{1}{2}\times0.3\right)$$

$$\boxed{\delta d = 0.2125mm}$$

Change in volume,

$$\delta v = \frac{p\,d\,v}{2\,t\,E}\left(\frac{5}{2} - \frac{2}{m}\right)$$

$$\left[\text{From equation } (1.54)\right]$$

Volume in cylinder,

$$v = \frac{\pi}{4} d^2 \times 1$$

$$= \frac{\pi}{4}(1000)^2 \times 3000$$

$$v = 2.3562 \times 10^9\,\text{mm}^3$$

$$\delta v = \frac{2 \times 1000 \times 2.3562 \times 10^9}{2 \times 20 \times 2 \times 10^5}(2.5 - 2 \times 0.3)$$

$$\boxed{\delta v = 1119195\,\text{mm}^3}$$

Results:

Thickness of cylinder, t = 20mm

Change in diameter, δ d = 0.2125mm

Change in volume, δ v =1119195mm^3

18. Derive the relationship between bulk modulus Young's modulus

EXPRESSION FOR YOUNG'S MODULUS IN TERMS OF BULK MODULUS

Fig. 2.7 shows a cube A B C D E F G H which is subjected to three mutually perpendicular tensile stresses of equal intensity.

Let L = Length of cube

dL = Change in length of the cube.

E = Young's modulus of the material of the cube

σ = Tensile stress acting on the faces

μ = Poissons ratio.

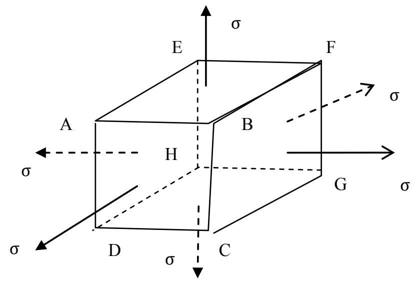


Fig. 2.7

Then volume of cube, $V = L^3$

Now let us consider the strain of one of the sides of the cube (say AB) under the action of the three mutually perpendicular stresses. This side will suffer the following three strains:

1. Strain of AB due to stresses on the faces AEHD and RFGC. This strain is tensile and is equal to $\frac{\sigma}{E}$.
2. Strain of AB due to stresses on the faces. AEFB and DHGC. This is compressive lateral strain and is equal to - $\mu\frac{\sigma}{E}$.
3. Strain of AB due to stresses on the faces ABCD and EFGH. This is also compressive lateral strain and is equal to $-\mu\frac{\sigma}{E}$.

Hence the total strain of AB is given by

$$\frac{dL}{L} = \frac{\sigma}{E} - \mu \times \frac{\sigma}{E} = \frac{\sigma}{E}(1-2\mu) \qquad \text{..........(i)}$$

Now original volume of cube, $V = L^3$ ....(ii)

If dL is the change in length, then dV is the change in volume.

Differentiating equation (ii), with respect to L,

$$dV = 3L^2 \times dL \qquad \text{..........(iii)}$$

Dividing equation (iii) by equation (ii), we get

$$\frac{dV}{V} = \frac{3L^2 \times dL}{L^3} = \frac{3dL}{L}$$

Substituting the value of $\frac{dL}{L}$ from equation (i) in the above equation, we get

$$\frac{dV}{V} = \frac{3\sigma}{E}(1-2\mu)$$

From equation (2.9), bulk modulus is given by

$$K = \frac{\sigma}{\left(\frac{dV}{V}\right)} = \frac{\sigma}{\frac{3\sigma}{E}(1-2\mu)} \qquad \left[\because \frac{dV}{V} = \frac{3\sigma}{E}(1-2\mu)\right]$$

$$= \frac{E}{3(1-2\mu)}$$

Or $\quad E = 3K(1-2\mu)$

From equation (2.11) the expression for Poisson's ratio (μ) is obtained as

$$\mu = \frac{3K - E}{6K}.$$

19. A Hollow cast iron cylinder 4m long, 300mm outer diameter and thickness of metal 50mm is subjected to a central load on the top when standing straight. The stress produced is 75000 kN/mm², assume Young's modulus for cast iron as 1.5x10⁸ kN/m² and find (I) magnitude of the load (ii) longitudinal strain (iii) total decrease in length. (Nov/Dec 2014)

Given Data:

Length (ℓ) = 4m = 4000 mm

Outed dia (D) = 300mm

thickness (t) = 50mm

Stress (σ) = 75000 kN/m^2 = 75 N/mm^2

E = 1.5 × 10^8 KN/m^2 = 15000 N/mm^2

To find:

(i) load

(ii) Longitudinal stream

(iii) Total decrease inb length

Solution:

(i) Load (P)

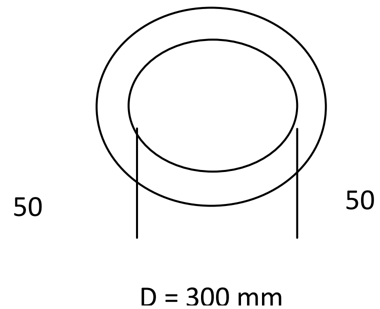
W.K.T

Stress (σ) = P/A

$$A = \frac{\pi}{4}(D^2 - d^2)$$

$$A = \frac{\pi}{4}(300^2 - 200^2)$$

$$A = 39.26 \times 10^3 \text{ mm}^2$$



Load (p) = Stress (σ) × Area (A)

$P = 75000 \times 39.26 \times 10^3$

(or)

$P = 75 \times 39.26 \times 10^3 = 2.94 \times 10^6 N$

$$\boxed{P = 2945\,KN}$$

(ii) Strain (C_ℓ)

$$E = \frac{\sigma}{c_\ell} \Rightarrow e_\ell = \frac{\sigma}{E} = \frac{75}{11.5 \times 10^5}$$

$$e_\ell = 5 \times 10^{-4}$$

(iii) Decrease in length ($\delta\ell$)

$$\delta\ell = \frac{P\ell}{AE} = 2\text{mm}$$

20. A composite bar is made with a copper flat of size 50mmx30mm and a steel flat of 50mmx40mm of length 500mm each placed one over the other. Find the stress induced in the material when the composite bar is subjected to an increase in temperature of 90°C. Take the coefficient of thermal expansion of steel as 12x10^-6 /°C and that of copper as 18x10^-6/°C, Es = 200Gpa and Ec = 100Gpa.

Given data:

Temperature (T) = 90°C

Size of copper flat = 50 mm × 30 mm

Size of steel flat = 50 mm × 40 mm

Length (ℓ) = 500 mm

Increase in Temperature = 90°C

Coefficient of thermal expansion

(α_s) steel = 12×10^{-6} /°C

(α_c) copper = 12×10^{-6} /°C

E_s = 200 GPa = 200×10^3 N/mm^2

E_c = 100 GPa = 100×10^3 N/mm^2

$A_c = 50 \times 50 = 1500$ mm^2

$A_s = 50 \times 40 = 2000$ mm^2

Solution:

Compressive load on copper = Tensile load on steel

$\sigma_c A_c = \sigma_s A_s$

$$\sigma_c = \frac{\sigma_s}{A_c} A_s = \sigma_s . \frac{A_s}{A_c} = \frac{2000}{1500}\sigma_s$$

$$\boxed{\sigma_c = 1.33\sigma_s}$$

Expansion of steel = Expansion of copper

$$\alpha_s TL + \frac{\sigma_s}{E_s}.L = \alpha_c T.L - \frac{\sigma_c}{E_c}L$$

$$\alpha_s T + \frac{\sigma_s}{E_s} = \alpha_c T - \frac{\sigma_c}{E_c}$$

$$12 \times 10^{-6} \times 90 + \frac{\sigma_s}{\left(200 \times 10^3\right)} = \left(18 \times 10^{-6} \times 90\right) - \frac{1.33\sigma_s}{\left(100 \times 10^3\right)}$$

$1.08 \times 10^{-3} + 5 \times 10^{-6}\sigma_s = 1.62 \times 10^{-3} - 1.33 \times 10^{-5}\sigma_s$

$5 \times 10^{-6}\sigma_s + 1.33 \times 10^{-5}\sigma_s = 1.62 \times 10^{-3} - 1.08 \times 10^{-3}$

$1.83 \times 10^{-5}\sigma_s = 5.4 \times 10^{-4}$

$\sigma_s = 29.51$ N/mm^2

$\sigma_c = 39.24$ N/mm^2

21. A thin cylindrical shell 2m long has 800mm internal diameter and 10mm thickness, if the shell is subjected to an internal pressure of 1.5Mpa,

I)find the hoop and longitudinal stresses developed

ii) maximum shear stress induced

iii) the change in diameter, length, volume take E = 205Gpa and Poisson's ratio as 0.3 (AU 2015)

Given data:

Length (ℓ) = 2m

Internal dia (d) = 800mm

Thickness (t) = 10mm

Internal pressure (p) = 1.5 MPa = 1.5 N/m^2

E = 205GPa = $205 \times 10^3 N/mm^2 \mu = 0.3$

Solution:

$$\text{Hoop stress } (\sigma_1) = \frac{p\ell}{2t} = \frac{1.5 \times 800}{(2 \times 10)} = 60\, N/mm^2$$

$$\text{Longitudinal stress } (\sigma_1) = \frac{1}{2}\sigma_1 = 30\, N/mm^2$$

$$\text{Maximum shear stress } (\tau_{max}) = \frac{\sigma_1 - \sigma_2}{2}$$

$$\tau_{max} = \frac{pd}{8t} = \frac{1.5 \times 800}{(8 \times 10)} = 15\, N/mm^2$$

$$\text{Change in diameter } (\delta d) = \frac{pd^2}{2tE}\left[1 - \frac{\mu}{2}\right]$$

$$= \frac{1.5 \times 800^2}{(2 \times 10 \times 205 \times 10^3)}\left[1 - \frac{0.3}{2}\right]$$

$$\delta d = 0.199 \text{ mm}$$

Change in length $(\delta\ell) = \frac{pd\ell}{2tE}\left[\frac{1}{2}-\mu\right]$

$\delta\ell = 0.117$ mm $\left(V = \frac{\pi d^2}{4} \times \ell\right)$

Change in volume $(\delta v) = V\left[\frac{2\delta d}{d}+\frac{\delta\ell}{\ell}\right]$

$\delta\ell = 6005 \times 10^4 [5.56 \times 10^{-4}]$

$\boxed{\delta V = 5.58.78 \times 10^3 \text{ mm}^3}$