اسم المادة : الميكانيك الهندسي

اسم التدريسي : م د صباح معن بدن
م. حميد ندا حميد

المرحلة : الاولى

السنة الدراسية : 2023 - 2024

عنوان المحاضرة: الاجهاد والانفعال

Engineering Mechanic

Stress and Strain

Stress and Strain

Stress and strain are two of the most important concepts in materials science and engineering. Stress refers to the force applied to a material per unit area, while strain is a deformation or change in the shape of the material that results from the applied force. However, the relationship between stress and strain is not always straightforward. Different materials can exhibit very different stress-strain behaviours depending on their composition, structure, and loading conditions.

What Is Stress?

Stress is defined as the force per unit area that acts on a material. This property helps define how different materials behave under specific loading conditions.

Various types of **stress** can occur inside an object, including compressive stress, tensile stress, shear stress, and torsional stress, among others. Different symbols are used to represent each type of stress, with the Greek letter sigma (σ) being the primary symbol.

What Is Strain?

Strain is a measure of the deformation of a material under the influence of an external force. It represents the amount of deformation that occurs in a material when subjected to stress. Strain is defined as the ratio of the change in length (or other dimensions) of a material to its original length (or dimension), and is expressed as a unitless quantity or as a percentage.

Is Stress Cause of Strain?

Yes, stress is the cause of strain. When a force is applied to a material, it creates an internal resistance, which is stress. The stress causes the material to deform, which is the strain. Therefore, stress is the initial force applied to the material, while a strain is the resulting deformation of the material due to the stress.

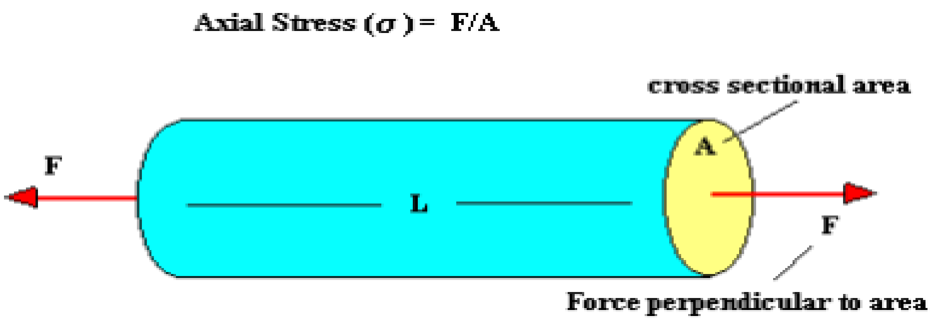
Types of Stresses

Residual Stresses	**Structural Stresses**	**Pressure Stresses**
Flow Stresses	**Thermal Stresses**	**Fatigue Stresses**

Classification of Forces:-

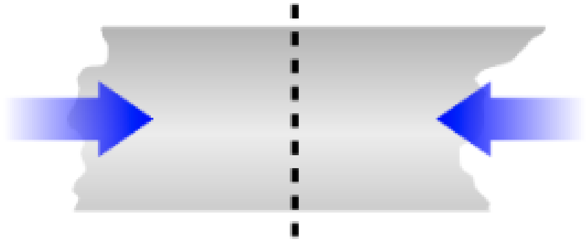
a. Tensile force:

Tensile force is a type of loading in which the two sections of material on either side of a plane along its length tend to be pulled apart or elongated.



b. Compressive force:

Compressive force is a type of loading in which the two sections of material on either side of a plane along its length tend to be pushed or compressed.

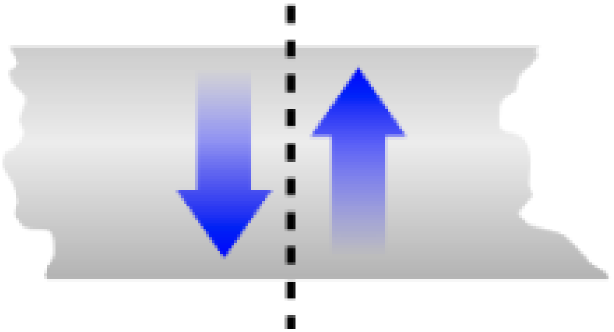


Tensile or compressive stress acts normal to the stress plane.

c. Shear force:

Shear involves applying a load parallel to a plane which caused the material on one side of the plane to want to slide across the material on the other side of the plane.

- A shearing stress acts parallel to the stress plane.
- Shear properties are primarily used in the design of mechanically fastened components, webs, and torsion members, and other components subject to parallel, opposing loads.

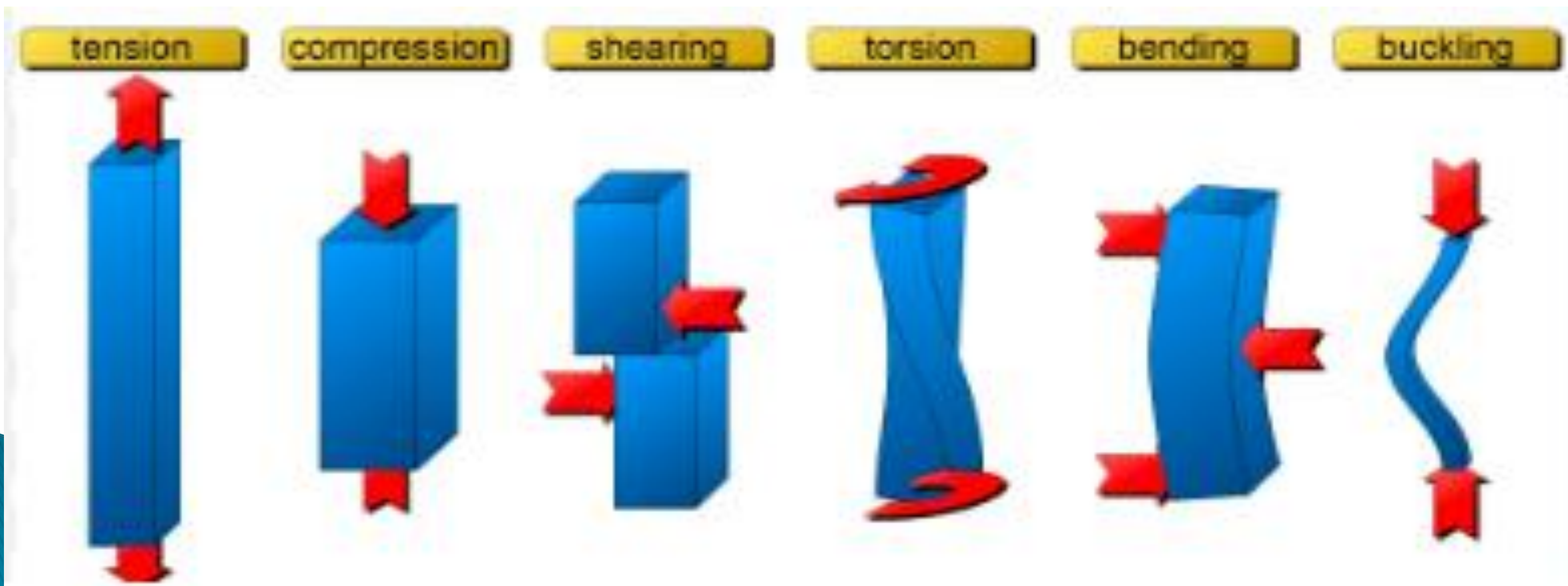


d. Bending moment:

Bending involves applying a transverse load in a manner that causes a material to curve shape and results in compressing the material on one side and stretching it on the other.

e. Torsion or twisting moment:

Torsion is the application of a force that causes twice sting in a material. Torsion induced in the material when the transverse load is not lying on the longitudinal axis (away from the longitudinal axis).



Types of loads

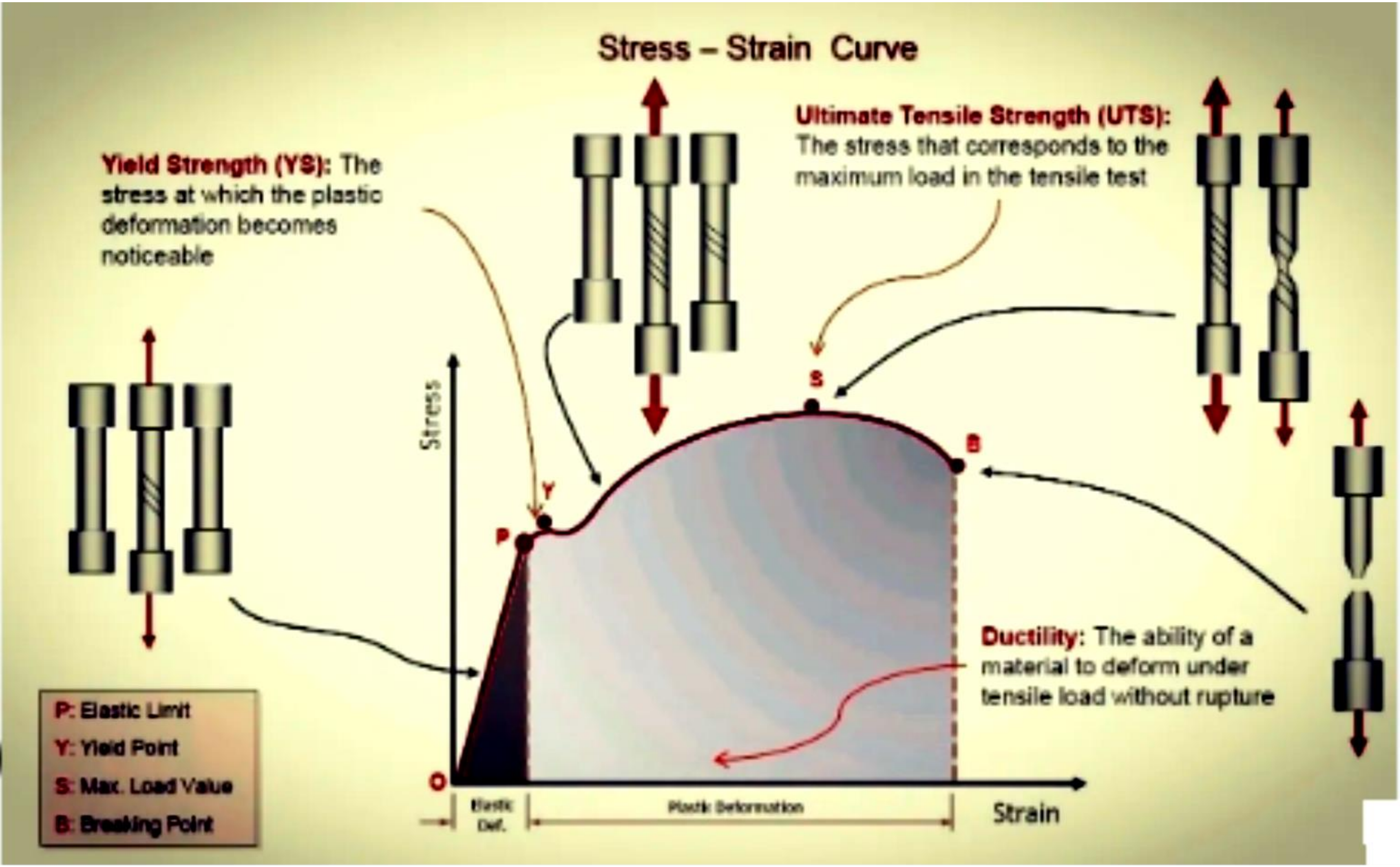
- **Static loading** is a constant force acting on a material.
- **Dynamic or cyclic loading** is not constant force but fluctuates on the material.
- Load is the combined effect of external forces acting on a body.

a) Point load or concentrated load: It is the load considered to act at a point.

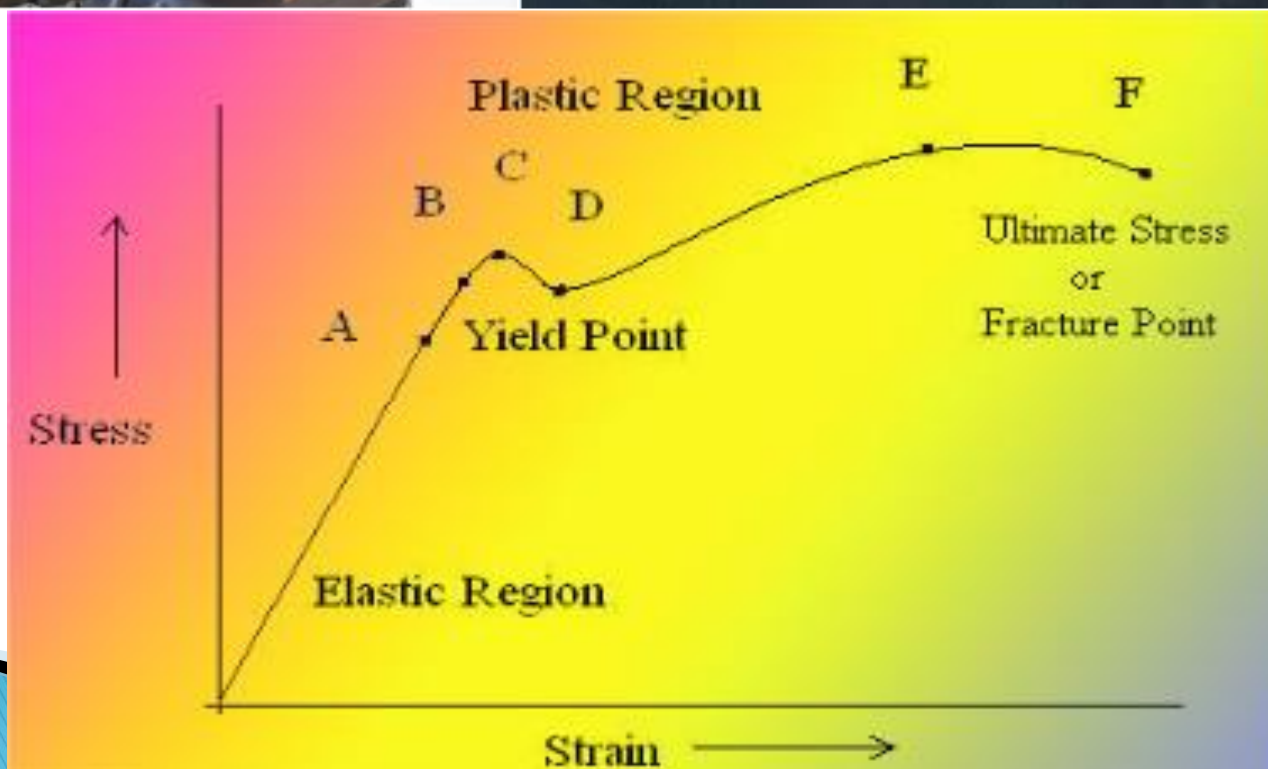
b) **Distributed load :** The load is distributed or spread in some manner over the length of the beam.

c) **Uniformly distributed load (u.d.l):** The load is distributed or spread uniformly.

d) **Uniformly varying load (u.v.l):** The load distributed or spread is not uniform i.e. varying along the length. Triangular load, trapezoidal load, parabolic load, etc



Stress – Strain Curve
Yield Strength (YS): The stress at which the plastic deformation becomes noticeable
Ultimate Tensile Strength (UTS): The stress that corresponds to the maximum load in the tensile test
Ductility: The ability of a material to deform under tensile load without rupture
Stress
Strain
O
P
Y
S
B
Elastic Def.
Plastic Deformation
P: Elastic Limit
Y: Yield Point
S: Max. Load Value
B: Breaking Point


Plastic Region
E
F
C
B
D
Ultimate Stress
or
Fracture Point
A
Yield Point
Stress
Elastic Region
Strain

Hook's law: Hook's law is defined as the stress is directly proportional to strain.

$$\text{Stress} \propto \text{Strain}$$

$$\frac{\text{Stress}}{\text{Strain}} = \text{a constant}$$

- proposed by Robert Hook.

Stress: Stress is defined as the internal resistance offered by the body against deformation.

$$\sigma = \frac{P}{A}$$

σ : Stress (tensile or compressive)

P : Axial load

A : Cross sectional area

Units of stress : N/mm^2, kN/m^2

Simple stress is also called direct stress.

Stress is the force required per unit cross sectional area.

- Crushing stress is a localized compressive stress at the area of contact between two members.
- Maximum stress of a material depends on the type of material.

Strain: Strain is defined as the ratio of change in length to original length.

$$e = \frac{\delta l}{l}$$

e : Compressive or tensile strain

δl : Change in length

l : Original length

- Strain is the deformation produced by stress.
- Strain is the deformation per unit length.

Modulus of Elasticity: Modulus of Elasticity is defined as the linear stress to linear strain. It is denoted by E .

$$E = \frac{\text{Linear stress}}{\text{Linear strain}} = \frac{\sigma}{e}$$

- E is the slope of a linear part of stress-strain curve.

Material	Modulus of elasticity, GPa
Aluminium	70
Bronze	80
Brass	100
Copper	120
Steel	200
Diamond	1200

Modulus of Rigidity: Modulus of Rigidity is defined as the shear stress to shear strain. It is denoted by G, C or N. It is also called shear modulus of elasticity.

$$G = \frac{\text{shear stress}}{\text{shear strain}} = \frac{\tau}{\phi}$$

Bulk modulus: Bulk modulus is defined as the normal stress to volumetric strain. It is denoted by K.

$$K = \frac{\text{Volumetric stress}}{\text{volumetric strain}} = \frac{\sigma_v}{e_v}$$

WORKED EXAMPLE No.1

A metal wire is 2.5 mm diameter and 2 m long. A force of 12 N is applied to it and it stretches 0.3 mm. Assume the material is elastic. Determine the following.

i. The stress in the wire σ.
ii. The strain in the wire ε.

SOLUTION

$$A = \frac{\pi d^2}{4} = \frac{\pi \text{ x } 2.5^2}{4} = 4.909 \text{ mm}^2$$

$$\sigma = \frac{F}{A} = \frac{12}{4.909} = 2.44 \text{ N/mm}^2$$

Answer (i) is hence 2.44 MPa

$$\varepsilon = \frac{x}{L} = \frac{0.3 \text{ mm}}{2000} = 0.00015 \text{ or } 150\ \mu\varepsilon$$

WORKED EXAMPLE No.2

A steel tensile test specimen has a cross sectional area of 100 mm^2 and a gauge length of 50 mm, the gradient of the elastic section is 410 x 10^3 N/mm. Determine the modulus of elasticity.

SOLUTION

The gradient gives the ratio F/A = and this may be used to find E.

$$E = \frac{\sigma}{\varepsilon} = \frac{F}{x} x \frac{L}{A} = 410 \times 10^3 \times \frac{50}{100} = 205\,000 \text{ N/mm}^2 \text{ or } 205\,000 \text{ MPa or } 205 \text{ GPa}$$

WORKED EXAMPLE No.3

A Steel column is 3 m long and 0.4 m diameter. It carries a load of 50 MN. Given that the modulus of elasticity is 200 GPa, calculate the compressive stress and strain and determine how much the column is compressed.

SOLUTION

$$A = \frac{\pi d^2}{4} = \frac{\pi \text{ x } 0.4^2}{4} = 0.126 \text{ m}^2$$

$$\sigma = \frac{F}{A} = \frac{50 \text{ x} 10^6}{0.126} = 397.9 \text{ x} 10^6 \text{ Pa}$$

$$E = \frac{\sigma}{\varepsilon} \quad \text{so} \quad \varepsilon = \frac{\sigma}{E} = \frac{397.9 \text{ x} 10^6}{200 \text{ x} 10^9} = 0.001989$$

$$\varepsilon = \frac{x}{L} \quad \text{so } x = \varepsilon L = 0.001989 \text{ x } 3000 \text{ mm} = 5.97 \text{ mm}$$

WORKED EXAMPLE No. 4

Calculate the force needed to punch a hole 30 mm diameter in a sheet of metal 3 mm thick given that the ultimate shear stress is 60 MPa.

SOLUTION

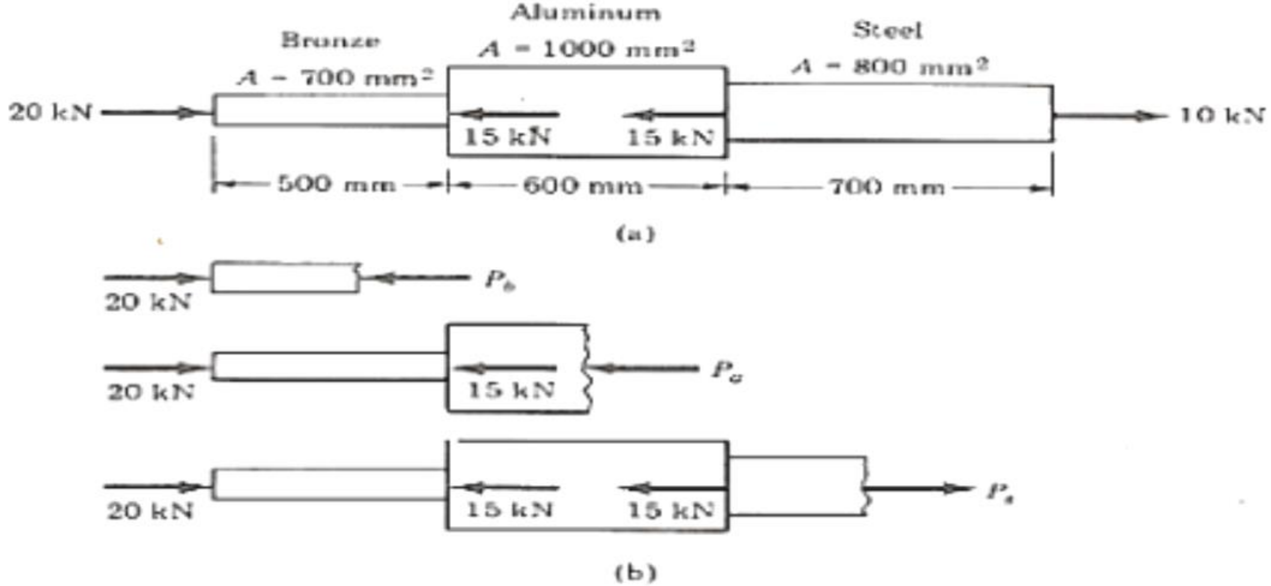
The area to be cut is the circumference x thickness = $\pi d \times t$

$A = \pi \times 30 \times 3 = 282.7 \text{ mm}^2$ The ultimate shear stress is 60 N/mm^2

$\tau = \frac{F}{A}$ so $F = \tau \times A = 60 \times 282.7 = 16965$ N or 16.965 kN

Example No. 5

An aluminum tube is rigidly fastened between a bronze rod and a steel rod shown in the figure. Axial loads are applied at positions indicated. Determine stress in each material.



Solution:

From the free body diagram

$$P_b = 20\ kN\ , \qquad P_a = 5\ kN\ , \quad P_s = 10\ kN$$

The stresses can be computed as:

$$\sigma = \frac{F}{A}$$

For Bronze: $\sigma_b = \frac{20\times10^3}{700\times10^{-6}} = 28\times10^6\ \frac{N}{m^2} = 28\ \text{MPa}$