UNIT - 2 ENGINEERING MATERIALS

Engineering Materials

→ Substances used for various engineering applications

Classification of Materials

→ Solids
- Metals
- Ceramic
- Polymers

→ Metal Alloys
- Ferrous
  - Steels
  - Cast Irons
- Non - Ferrous

→ **Steels**

- Iron Carbon Alloys
- < 2.0 %

Steels
- Low Alloy
  - Low Carbon
    - Plain
    - High Strength, Low Alloy
  - Medium Carbon
    - Plain
    - Heat Transferrable
  - High Carbon
    - Plain
    - Tool
- High alloy
  - Tool
  - Stainless

- Plain Carbon Steels ⇒ Contain residual conc. of impurities other than carbon and little manganese

- Alloy Steels ⇒ Alloying elements are intentionally added in specific concentrations

Low Carbon Steel

- < 0.25% Carbon by weight
- Soft, Weak, Ductile, Tough
- Good machinability, weldability
- Least expensive
- Low hardability ~~[illegible]~~
- Automobile body components, Structural shapes, Sheets used in tin cans, buildings etc.,

Medium Carbon Steel

- 0.25 - 0.6% Carbon by weight
- Less tough, more stronger than low C
- Good mix of ductility & strength
- Railways wheels & Tracks, Gears, Crankshafts

High Carbon Steel

- 0.6% to 1.4% carbon by weight
- Hardest, strongest, least ductile
- Best range to make tools
- Can't be used where ductility is required
- Knives, Razors, Hacksaw blades, Wootz Steel

Alloy Steels

→ Addition of alloying elements other than Carbon
→ Increase hardenability, strength, corrosion resistance, toughness etc.,

Cast Irons

- Alloys > 2.1 % C
- Easily melt ; can be casted
- Brittle

1) Grey Cast Iron

Compⁿ • 2.5 – 4 % C ; 1 – 3 % Si

Microstruc. • Graphite exists as flakes surrounded by matrix
• Grey appearance ; hence, the name

Prop. • Weak, Brittle, high compressive strength, effective in damping vibrations, high wear resistance, High fluidity at molten state, Low cost

Applⁿ • Automotive engine blocks, Brake disc & drum

2) Ductile / Nodular Cast Iron

Compⁿ • 3 – 4 % C ; 1.6 – 2.8 % C

Microstruc. • Dark graphite nodules surrounded by matrix, add little Mg (and/or) Cerium to Grey Iron to form this
• Mg reacts w small amt. of S present and oxygen in molten iron resulting in carbon precipitation in small sphere form (Also called Spheroidal Graphite Iron [SG Iron])

Prop. • Highly ductile, V. Good Machinability, High corrosion resistance

Applⁿ • Used for making valves, pump bodies, crankshaft, Gears & other automobile & machine components

3) White Cast Iron

Comp^n • 1.8% to 3.2% Carbon
0.3% to 1.8% Si

Microstruc • Iron Carbide (Light phase)
Pearlite (Dark phase)
No Graphite

• For Low Si casts & Rapid cooling rates, most C exists as Fe_3C & not as Graphite

• Fractured surface of alloy has white appearance

Prop. • V. Hard & Brittle, Highly wear resistant, No ductility & malleability, Not machinable

Appl^n's • Liners for cement mixers, Ball mill, Extrusion Nozzles etc.,

4) Malleable Cast Iron

Comp^n • 1.8% – 3.2% C
0.3% – 1.8% Si Rest Iron

Microstruc • Dark Graphite Rosettes in a matrix

• Heating white cast iron at 800–900°C for prolonged period of time & neutral atmosphere causes decomposition of cementite, forming graphite

Prop • Highly malleable, V. good machinability, Good magnetic prop, wear resistance

Appl^n • Connecting rods, Transmission gears, Flanges, Pipe fittings, differential cases for automobiles etc.,

Non-Ferrous Alloys

Copper & Alloys

- **Copper**
  - Excellent thermal & electrical conductivity
  - Ease of getting cast, machined & brazed
  - High corrosion resistance
  - Poor Strength
- **Brass**
  - Alloy of Cu & Zn. (May contain small amts of Sn, Pb, Al, Mg)
  - Used for tubes for condensors, & heat exchangers, automotive radiator cores, rivets, value stems, bellow springs etc.
- **Bronze**
  - Alloy of Cu & other elements except Zn like Al Bronze, Phosphor Bronze & Sn Bronze

Al Bronze → Hydraulic valves, bearings, imitation gold

Phosphor Bronze → Pumps, valves & chemical equipment

Sn Bronze → Pump castings, bearings

Aluminium & Alloys

- Low specific gravity
- Corrosion resistance
- Ease of Fabrication (FCC structure, hence ductile)
- High electrical & thermal conductivity
- used for food/chemical handling & storage equipment, Aircraft structural parts, highly stressed applications, flywheel etc.,

Magnesium & Alloys

- Lowest ($1.7 g/cm^3$) density of all structural metals & light weight.
- HCP structure, so, soft, low elastic modulus (45 GPa)
- Applications – Hand held devices (chain saw, Power tools etc.,), automobiles, audio-video-computer-communication equipment (Laptops, cameras, TVs etc.,)

Titanium & Alloys

- Pure metal has low density ($4.5 g/cm^3$), high MP ($1668°c$) elastic modulus high (107 GPa)
- Ti metals are extremely strong, & room temp tensile strength very high. Alloys are highly ductile, easily forged & machined
- Used in airplane structures, space vehicles, surgical implants, in petroleum & chemical industries.

Ceramics

→ Compound of metallic + non-metallic elements with predominantly 'ionic' interatomic bonding

ex: MgO — Magnesia
Al_2O_3 — Alumina
ZrO_2 — Zirconia
BeO — Beryllia
SiC — Silicon Carbide
TiC — Tungsten Carbide

→ High hardness, High MP, Good thermal insulators, High electrical resistivity, Low density, Chemically resistant to most acids, alkali & organic sub.

→ Brittle, 0 Ductility, Poor Tensile Strength, Wide variation in strength values, difficult to shape

→ Ceramic substrates for electronic devices, turbochargers for rotors, aerospace turbine blades, nuclear fuel rods, lightweight armour, cutting tools, abrasives, furnace etc.;)

Plastics

→ Synthetic Materials processed by heat & pressure.

→ Solid material of organic polymer, long molecular chain, & high m.wt.

→ 2 Types:

- Thermoplastic – Polymeric materials which softens on heating & hardens on cooling
  linear chain, recyclable, flexible
  ex: Polyethylene, Polypropylene, PVC, PTFE, Nylon

- Thermosetting – Polymeric material once cured / hardened, can't be soften or melt upon heating
  cross linked chain, not recyclable, rigid
  ex: Phenolics, Aminos, Polyesters, Phenol-formaldehyde

Adv → Low specific gravity, Lightweight
Corrosion resistance,
Low coefficient of friction, self lubricating property
Fabrication is easy.

Disadv → Poor Tensile strength.
Mechanical prop vary wrt Temp.
Have Visco elastic mechanical behaviour
Many materials are susceptible to time dependant deformation (which is called creep)

Used in → Gears, Bearings, Gaskets, Washers, pipes, clutch, Brake linings.

Composites

→ Structural material consisting 2 or more combined constituents that are combined at macroscopic level & not soluble in each other.

→ One constituent is called reinforcing phase, other in which it is embedded is called matrix

ex: Concrete reinforced w steel,
exposy reinforced w graphite fibers

Adv → Combination of 2 or more materials is a better solution in this current generations technological demands.
They are more efficient, stronger, stiffer, fatigue & impact resistance, thermally conductive, corrosion resistive etc.,

Classification → Geometry of Reinforcement : Particulate, Flake, Fibers
Type of matrix : Polymer, Metal, ceramic, Carbon

Application → Aircrafts, Sports goods, Medical devices, Automobiles.

SMART MATERIALS

→ Respond to stimulii & environmental changes, & activate functions according to changes.

→ Key elements : Sensor, Actuator, Control System, Power & Signal Controlling electronics, Computer

Piezoelectric Materials

→ Piezoelectricity occurs in anisotropic crystals which are subjected to change in mechanical deformation

→ Upon deformation, electric dipoles are generated & potential difference develops. (Direct effect)

→ By applying potential diff, mechanical deformations are also generated. (Converse effect)

ex: Lead Zirconate Titanate (PZT), Polyvinylidene fluoride

→ Used for voltage/current sources, sensors, actuators, piezoelectric motors, active vibration control, surgery etc,

Shape Memory Alloys

→ Ability to memorize shape at low temperature & recover large deformations.

→ 2 Types

One Way SME

- deformation in low temp martensite phase is fully recovered upon heating as material completely transforms to high temp. austenite phase.

On cooling, material returns to austenite phase but no further change in shape of material cuz shape changes occurs only during heating

Two Way SME

- Material remembers both high & low temperature shape. Material can continuously cycle b/w 2 shapes as temp is raised & lowered w/o need for external stress.

Applications : Braces, Stents, Aerospace, Automotive

Rheological Fluids

→ Fluids that change rheological properties on application of electric / magnetic field

→ 2 Types : 1) Electrorheological fluids
2) Magnetorheological fluids

→ Electric field causes change in viscosity of ER fluids
Magnetic field causes change in viscosity of MR fluids

→ ER & MR fluids have colloidal suspension of particles in carrier fluid

ER fluids ⇒ particles should be micro-sized dielectric particles → corn starch / alumino-silicate
carrier fluid should be electrically non conducting → Mineral oil / Silicone oil / Paraffin oil

MR fluids ⇒ similar to ER fluids but particle must be ferromagnetic

→ When field is applied, particles are polarized & attract each other, chains of particles form in fluid b/w electrodes

→ Absence of field, allows free flow of fluid across electrode

→ Breaking & Forming chains result in change of viscosity of fluid

Applications → Clutches, Suspension shock absorbers, Valves, Brakes, robotic arms

Magnetostrictive Material

→ Active materials that exhibit magneto mechanical coupling

→ ~~Magnetic~~ material undergo change in dimension in response to applied magnetic field. Induced strain depends on magnetic field magnitude & independant of polarity.

ex: Terfenol - D,

Appl^{n} → sensors, actuators

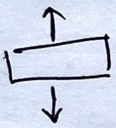
Normal Stress & Strain

→ **Prismatic bar** : Straight structural member having same cross section throughout length & axial force acting on axis of member

→ **Stress** : Avg. Intensity of the distributed forces is equal to force per unit area

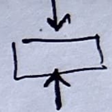
$$\boxed{\sigma = \frac{P}{A}} \quad (N/m^2)$$

→ Stress can be either tensile / compressive



pulling (+ve)

pushing (-ve)



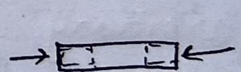
→ **Strain** : Elongation per unit length

$\frac{\text{length of segment}}{\text{total length } L} \times \delta$

$$\boxed{\varepsilon = \frac{\delta}{L}} \quad (\text{dimensionless})$$

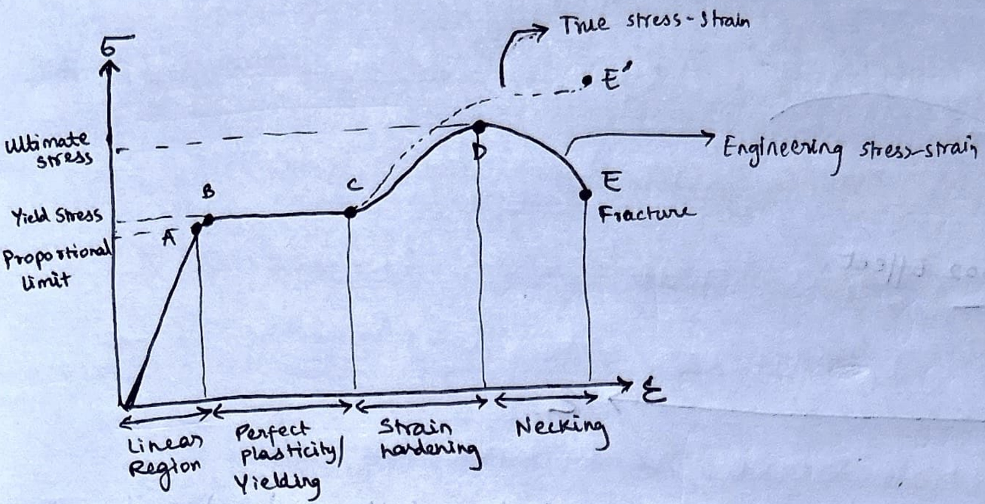
→ Strain can also be tensile / compressive

(+ve)



(-ve)

Stress - Strain Diagram of Mild Steel



O → A : Stress ∝ Strain (linear & proportional)

No proportionality beyond A, hence proportional limit

Slope from O to A is called 'Modulus of elasticity'

A → B : Very small slope until B

B → C : There is considerable elongation without any increase in tensile force. This is called yielding & B is called yield point.

In this region, material is perfectly plastic

C → D : Elongation in this region requires increase in tensile load, hence +ve slope.

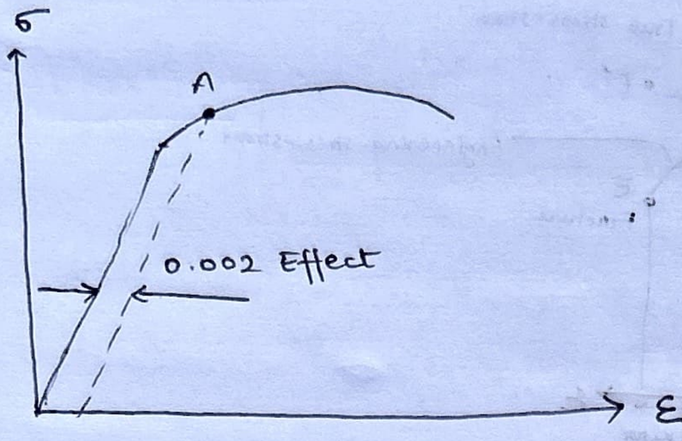
Load reaches max value & corresponding stress is called 'ultimate stress'. (strain hardening)

D → E : Further stretching requires reduction of load & fracture occurs at E.

This is called necking.

(True stress-strain is generally not considered because cross-sectional area changes but for calculation purposes, we use engineering stress-strain)

Stress - Strain of Other Materials



→ Presence of a yield point followed by large plastic strains is an imp. characteristic of structural steel. (used in practical design)

→ Structural steel undergo large permanent strains before failure (& are called ductile).
ex: Al, Cu, Mg, Pb, Mo, Ni, Brass, Bronze etc,

→ Even though Al is ductile, but they don't have clearly defined yield point, then an arbitrary yield stress maybe defined by offset method.

→ A straight line is drawn $||^{el}$ to initial linear part of curve but offset of 0.002 or 0.2%. The intersection of offset line & stress-strain curve defines yield stress

Measure of ductility

→ **Ductility** : Characterized by elongation & reduction in area of cross section where fracture occurs

$$\% \text{ elongation} = \frac{L_1 - L_0}{L_0} \times 100$$

L_1 → Distance b/w gage marks at fracture

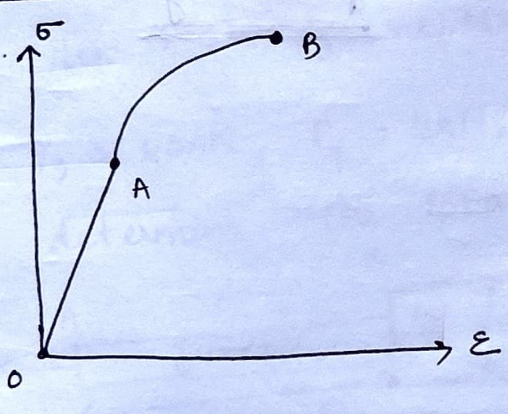
L_0 → Original gage length

$$\% \text{ reduction in area} = \frac{A_0 - A_1}{A_0} \times 100$$

A_1 → Final area at fracture section

A_0 → Original cross sectional area

Stress - Strain of Brittle Materials



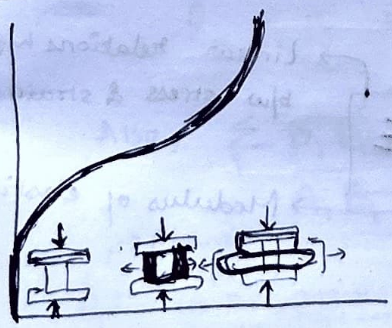
→ Materials which fall under tension at low values of strain are brittle

ex : Concrete, stone, Glass etc.,

→ They fail with only little elongation after proportional limit is exceeded.

Nominal fracture stress = True ultimate stress

Stress - Strain in Compression



→ Some ductile metals like steel, Al, Cu, have proportional limits similar to tension stress - strain diagrams.

But, yielding is different

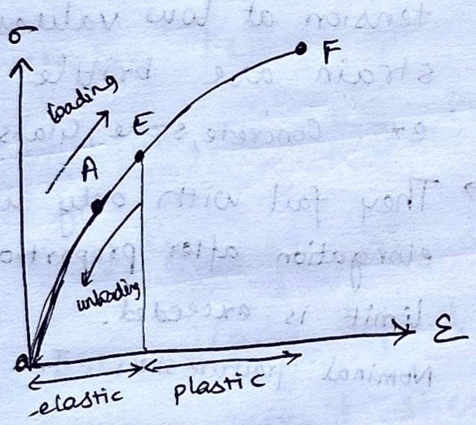
→ In compression, material bulges out on the sides & becomes barrel shaped

Elasticity & Plasticity

→ Elasticity : When we load a material & remove the load, it returns back to original shape

Stress-strain curve doesn't have to be linear to be elastic.

→ Stress-strain curve will have different effect after crossing elastic limit, where it will not come back to original state even after load is unloaded. This is called perm. strain & from then it is called plasticity



Hooke's law

$$\delta = \frac{PL}{AE}$$

δ → elongation, P → internal force, L → length, E → Modulus of elasticity, A → Area

&

$$\boxed{\sigma = E\varepsilon}$$

→ Linear relationship b/w stress & strain

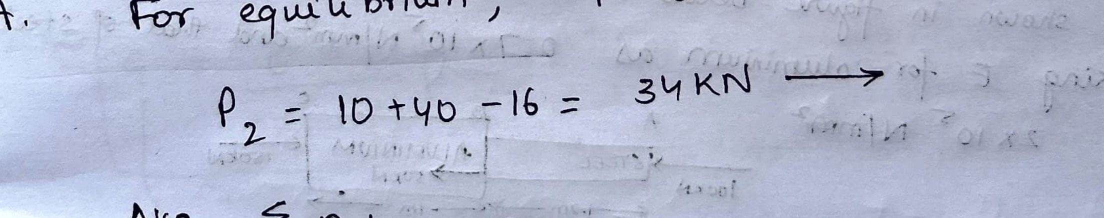
E → Modulus of elasticity

$$\boxed{\delta = \sum_i \frac{P_i L_i}{A_i E_i}}$$

Q. A circular rod of 12 mm diameter was tested for tension. The total elongation on a 300 mm Length was 0.22 mm under tensile load of 17 KN. Determine value of E.

A. $$E = \frac{PL}{A\delta} = \frac{17\times10^3}{\frac{\pi}{4}\times12^2} \times \frac{300}{0.22} = 2.05\times10^5\ N/mm^2$$
$$= 205\ KN/mm^2$$

Q. A member ABCD is subjected to point loads P_1, P_2, P_3 & P_4 as shown in figure below. Calculate the force P_2 necessary for equilibrium if $P_1 = 10KN$, $P_3 = 40KN$, $P_4 = 16KN$, Taking $E = 2.05\times10^5\ N/mm^2$, determine the total elongation of the member



A. For equilibrium, $P_1 + P_3 = P_2 + P_4$

$P_2 = 10 + 40 - 16 = 34\ KN \longrightarrow$

Also, $\sum_i \frac{P_i L_i}{A_i E_i} = \delta$

Expansion

$$\delta_1 = \frac{10\times1000\times1000}{\frac{\pi}{4}\times(25)^2\times2.05\times10^5} = 0.099$$

Compression

$$\delta_2 = -\frac{24\times1000\times600}{\frac{\pi}{4}\times(50)^2\times2.05\times10^5} = -0.036$$

$\boxed{34-10 = 24 \quad 40-16 = 24}$

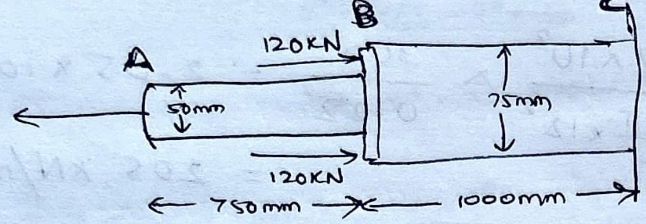
Expansion

$$\delta_3 = \frac{16\times1000\times800}{\frac{\pi}{4}\times(30)^2\times2.05\times10^5} = 0.088$$

$\Rightarrow \delta = 0.099 - 0.036 + 0.88$

$= 0.151\ mm$

Q. Two solid cylindrical rods AB & BC are welded together at B and loaded as shown. Determine magnitude of the force P for which tensile stress in rod AB has same magnitude as compressive stress in rod BC.



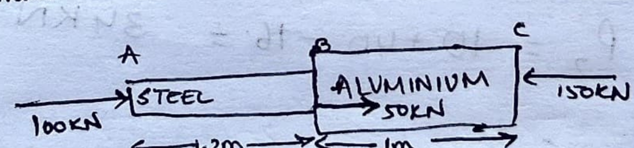
$$\sigma_{AB} = \frac{P}{A_{AB}} = \frac{P}{\frac{\pi}{4}\times(50\times10^{-3})^2}$$

$$\sigma_{BC} = \frac{2(120)-P}{A_{BC}} = \frac{240-P}{\frac{\pi}{4}(75\times10^{-3})^2}$$

$$\sigma_{AB} = \sigma_{BC}$$

$$\frac{P}{\cancel{2500}\ \cancel{100}\ 4} = \frac{240-P}{\cancel{75}\times\cancel{75}\ 3\ 3} \Rightarrow \frac{13P}{4} = 240 \Rightarrow P = 73.84\text{KN}$$

Q. A member ABC is formed by connecting a steel bar of 20mm diameter to an Aluminium bar of 30mm diameter & subjected to forces as shown in figure below. Determine total deformation of bar taking E for aluminium as 0.7×10^5 N/mm² and that of steel as 2×10^5 N/mm²



A. For AB,

$P_1 = 100$KN

$A_1 = \frac{\pi}{4}\times(20)^2$ mm²

$L_1 = 1200$mm

$E_1 = 2\times10^5$ N/mm²

$P_2 = 150$KN

$A_2 = \frac{\pi}{4}\times(30)^2$

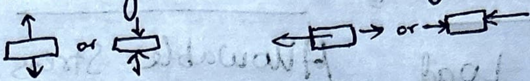
$L_1 = 1000$mm

$E_1 = 0.7\times10^5$ N/mm²

$$\delta = \Sigma\frac{P_i L_i}{A_i E_i} = \frac{100\times10^3\times1200}{\frac{\pi}{4}\times(20)^2\times2\times10^5} + \frac{150\times10^3\times1000}{\frac{\pi}{4}\times30^2\times0.7\times10^5} = 1.91 + 3.03 = 4.94$$

Poisson's Ratio

→ When prismatic bar is stretched / compressed, it undergoes force axially & laterally



→ Poisson's ratio = ν = $\dfrac{-\text{lateral strain}}{\text{axial strain}} = \dfrac{-\varepsilon'}{\varepsilon}$

(lies in range of 0.25 - 0.35)

Shear Stress & Strain

→ $\boxed{\tau_{aver} = \dfrac{V}{A}}$

V → Total Shear force

A → Area

τ_{aver} → Avg. shear stress

→ $\boxed{\tau = G\gamma}$

γ → Shear strain

G → Rigidity Modulus

τ → Shear stress

→ $\boxed{G = \dfrac{E}{2(1+\nu)}}$

E → Modulus of Elasticity

ν → Poisson's Ratio

G → Rigidity Modulus

→ If a bolt connects 2 parts, when you pull them apart, they slide against each other, creating pressure on bolt sideways. This is called shear stress

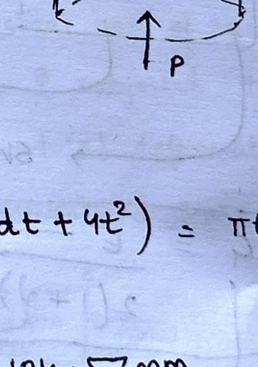
→ Shear force is the force experienced by shear stress along cross-sectional area

→ When material experiences shear stress, it undergoes shear strain. So, material changes shape w/o changing length in any direction.

Factor of Safety

→ $F.S = \dfrac{\text{Ultimate Load}}{\text{Allowable Load}} = \dfrac{\text{Ultimate Stress}}{\text{Allowable Stress}}$

Q. A short hollow circular cast iron cylinder shown in figure below is to support an axial compressive load of P = 500 kN. The ultimate stress in compression for the material is 240 N/mm². Determine minimum required outside diameter d of the cylinder of 25 mm wall thickness, if FS = 3 wrt ultimate strength.



A. $P_{allowable} = \dfrac{P_u}{FS} = \dfrac{240}{3} = 80\ N/mm^2$

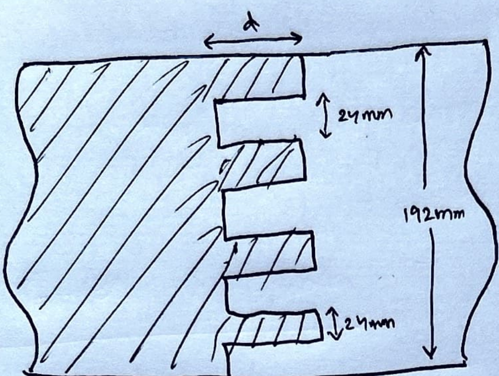
$A = \dfrac{P}{P_{allowable}} = \dfrac{500 \times 10^3}{80}$

$= 6250\ mm^2$

$A = \dfrac{\pi}{4} d^2 - \dfrac{\pi}{4}(d-2t)^2 = \dfrac{\pi}{4}(4dt + 4t^2) = \pi t(d-t)$

$d = \dfrac{A}{\pi t} + t = \dfrac{6250}{\pi(25)} + 25 = 104.57\ mm$

Q. 2 wooden planks, each 20 mm thick & 192 mm wide, joined by glued mortise joint shown. Knowing that the joint will fail when avg. shearing stress in glue reaches 300 kPa, determine smallest allowable length d of the cut if the joint is to withstand an axial load of magnitude $P = 6\,KN$



A. $t = 20mm$, $P = 6KN = 6000N$

$A = dt$

$\tau = \frac{P}{7A} \Rightarrow A = \frac{P}{7\tau} = \frac{6 \times 10^3}{7 \times 800 \times 10^3} = 1.0714 \times 10^{-3}\, m^2$

$= 1.0714 \times 10^3\, mm^2$

$d = \frac{A}{t} = \frac{1.0714 \times 10^3}{20} = 53.57mm$

Q. A bar of steel has rectangular cross-section 30mm × 20mm. Determine dimensions of sides & % decrease of area of cross-section, when it is subjected to a tensile force of 120KN in the direction of its length. $E = 2 \times 10^5\, N/mm^2$ & $\nu = 0.3$

A. Strain in direction of pull $e1 = \frac{P}{AE} = \frac{120 \times 10^3}{30 \times 20 \times 2 \times 10^5} = 10^{-3}$

Lateral strain $= \frac{-e_1}{m} = \frac{-3}{10} \times 10^{-3} = 3 \times 10^{-4}$

$\Rightarrow$ 30 mm side decreased by $30 \times 3 \times 10^{-4} = 0.009\, mm$
20 mm side decreased by $20 \times 3 \times 10^{-4} = 0.006\, mm$

Final dimension of 30mm side $= 30 - 0.009 = 29.991\,mm$
20mm side $= 20 - 0.006 = 19.994\, mm$

New area $= 29.991 \times 19.994 = 599.64$
decrease in area $= \frac{0.36}{600} \times 100 = 0.06\,\%$