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# ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

## Mechanical Engineering

### Test-5: Production Engineering and Material Science
### Strength of Materials and Mechanics-1
### Fluid Mechanics and Turbo Machinery-2

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Roll No: M E 1 9 M B D L A 9 0 4

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**Student's Signature**

Anubhav

**Instructions for Candidates**

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

Good attempt

**FOR OFFICE USE**

| Question No. | Marks Obtained |
|---|---|
| Section-A | |
| Q.1 | 35 |
| Q.2 | 51 |
| Q.3 | — |
| Q.4 | 51 |
| Section-B | |
| Q.5 | 18 |
| Q.6 | — |
| Q.7 | — |
| Q.8 | 26 |
| **Total Marks Obtained** | 181 |

Signature of Evaluator: Sumit Kr

Cross Checked by

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## Section A : Production Engineering and Material Science

**1 (a)** Iodine has an orthorhombic unit cell for which the *a*, *b* and *c* lattice parameters are 0.479 nm, 0.725 nm and 0.978 nm, respectively.

(i) If the atomic packing factor and atomic radius are 0.547 and 0.177 nm, respectively. Determine the number of atoms in each unit cell.

(ii) What will be the density of Iodine, if atomic weight of Iodine is 126.9 g/mol?

**[12 marks]**

$$APF = \frac{n \times \frac{4}{3}\pi r^3}{\text{vol. of crystal}}$$

$$APF = 0.547 = \frac{n \times \frac{4}{3}\pi (0.177)^3}{2\left(\frac{a^2+b^2}{2}\right)\left(\frac{c}{3}\right)}$$

$n = 2.89$

$n = 3$

0

(ii) $\rho = \frac{m}{V}$

**Q.1 (b)** A 20 mm deep slot is to be cut through a workpiece of 150 mm length with the help of HSS side and face cutter whose diameter is 120 mm and has 10 teeth. The cutting speed is 40 m/min and feed is 0.20 mm per teeth. Calculate the time required to machine the slot.

**[12 marks]**

$d = 20$ mm ; $L = 150$ mm.

$D = 120$ mm ; $Z = 10$ teeth

$V = 40$ m/min ; $f_t = 0.20$ mm/teeth

Feed velocity $f_m = f_t \cdot Z \cdot N$

$V = \frac{\pi D N}{1000}$ $N = \frac{1000 V}{\pi D}$

$N = \frac{1000 \times 40}{\pi (120)}$

$N = 106.103$ rpm

$\therefore f_m = f_t Z N$

$= 0.2 \times 10 \times 106.103$

$f_m = 212.2$ mm/min.

The approach distance is given by :

$$x = \sqrt{d(D-d)}$$

$$= \sqrt{20(120-20)} = 44.72 \text{ mm.}$$

Time required to machine ;

$$t = \frac{L_e}{f_m} = \frac{150 + 44.72}{(212.2)}$$

$$t = 0.9178 \text{ min}$$

(12)

$$t = 55.057 \text{ sec}$$

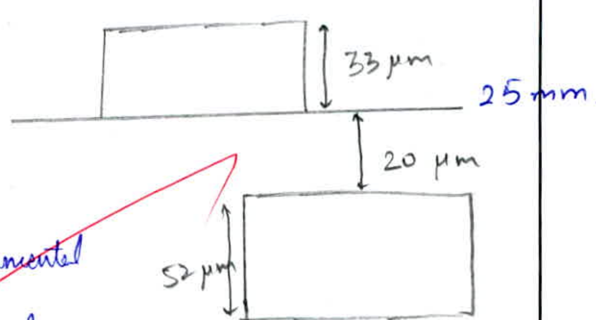
Q.1 (c) Design general type GO and NO GO gauges for components having $25H_8f_9$ fit. The basic size falls in the diameter range of 18 – 30 mm. The fundamental deviation for 'f' shaft = ($-5.5D^{0.41}$) microns. Take gauge tolerance as 10% of work tolerance. Sketch the gauges with important values. The multipliers for 8 and 9 grades are 25 and 40 respectively.

**[12 marks]**

$25 H_8 f_9$

Basic size = 25 mm.

H represents hole with zero fundamental deviation and tolerance grade 8.




'f' represent shaft with 'F' fundamental deviation and 9 tolerance grade.

$$D = \sqrt{18 \times 30} = 23.2379 \text{ mm}$$

$$i = 0.45 D^{1/3} + 0.001 D$$

$$= 0.45(23.2379)^{1/3} + 0.001(23.2379)$$

$$i = 1.307 \, \mu m$$

Fundamental deviation for shaft;

$F = 5.5 D^{0.41} = 20 \mu m.$

Shaft tolerance $= 40 i = 52 \mu m.$

Hole tolerance $= 33 \mu m.$

Sizes:

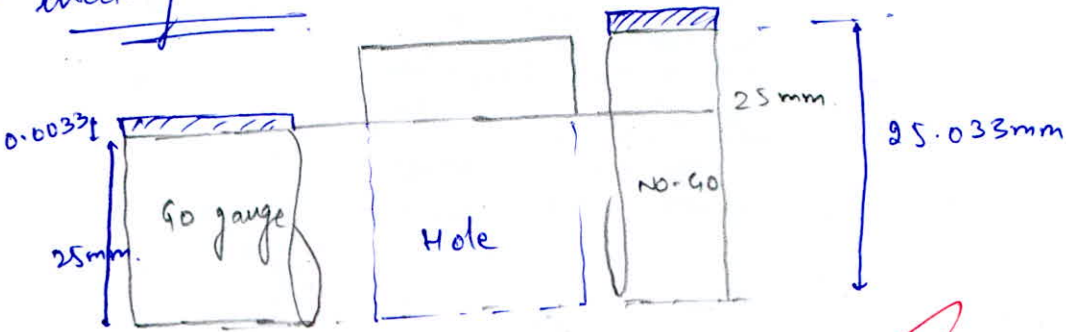
Lower limit of hole = 25 mm.

Upper limit of hole = 25.033 mm

Lower limit of shaft = 24.928 mm

Upper limit of shaft = 24.948 mm

For checking hole:




Work tolerance = $33 \mu m$ = 0.033 mm.

Gauge tolerance = $0.1 \times 0.033$ = 0.0033 mm.

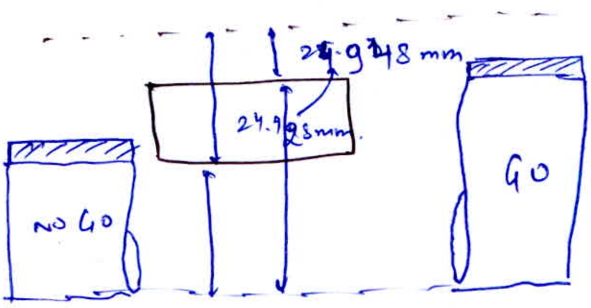
U.L. of GO Gauge = 25.0033 mm.

L.L. of GO gauge = 25 mm.

U.L. of NO-GO gauge = 25.0363 mm

L.L. of NO-GO gauge = 25.033 mm

For shaft:




U.L. of GO gauge = 24.9513 mm

L.L. of GO gauge = 24.948 mm

U.L. of NO GO = 24.9313 mm

L.L. of NO GO = 24.928 mm

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.1 (d) What do you understand by fatigue? What are different stages of fatigue failure? What are factors which are necessary for fatigue failure?

**[12 marks]**

The components in machine are continuously working on reversed stresses. Due to which reversed stresses are generally generated inside the components which may cause fatigue ~~fatigue~~ failure. Hence; the failure due to various reversed stresses is termed as fatigue.

Different stages of fatigue failure are:

(2)

**Q.1 (e)** While machining steel with zero rake angle, prove the following expression:

$$\frac{\tau_s}{p_c} = \frac{r(1-\mu r)}{1+r^2}$$

where $\tau_s$ is shear strength of material, $p_c$ is specific cutting power and $r$ is chip thickness ratio $\left(\frac{t_1}{t_2}\right)$.

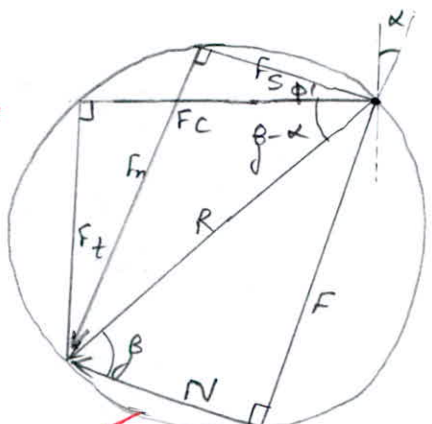
**[12 marks]**

where $\alpha$ is rake angle.

$\beta$ is friction angle

$\phi$ is shear angle

and all $F_i$ are corresponding forces.




Shear strength is given by:

$$\tau_s = \frac{F_s}{\left(\frac{w t_1}{\sin\phi}\right)}$$

where w is the width of plate

t is the uncut chip thickness.

$$\tau_s = \frac{F_s \sin\phi}{w t_1}$$

Using merchant circle;

$$F_s = R\cos(\phi + \beta - \alpha)$$

$$F_c = R\cos(\beta - \alpha)$$

combining these two; $F_s = F_c \dfrac{\cos(\phi + \beta - \alpha)}{\cos(\beta - \alpha)}$

For zero rake angle $(\alpha = 0)$;

$$F_s = \frac{F_c \cos(\phi + \beta)}{\cos(\beta)}$$

Now specific cutting power is given by

$$p_c = \frac{F_c}{bd} = \frac{F_c}{wt_1}$$

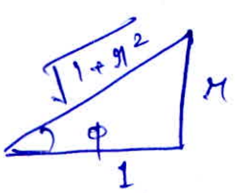
$$\therefore \frac{\tau_s}{p_c} = \frac{\left[\dfrac{F_c \cos(\phi+\beta)}{\cos\beta}\right] \cdot \dfrac{\sin\phi}{wt_1}}{\left(F_c/wt_1\right)}$$

$$\frac{\tau_s}{p_c} = \frac{\cos(\phi+\beta) \cdot \sin\phi}{\cos\beta}$$

$$\frac{\tau_s}{p_c} = \frac{[\cos\phi\cos\beta - \sin\phi\sin\beta]\sin\phi}{\cos\beta}$$

$$\frac{\tau_s}{p_c} = \sin\phi\cos\phi - \sin^2\phi\tan\beta. \quad \text{—— (1)}$$

now $\tan\phi = \dfrac{r\cos\alpha}{1 - r\sin\alpha} = r \quad [\alpha = 0°]$




$\sin\phi = \dfrac{r}{\sqrt{1+r^2}}$ ; $\cos\phi = \dfrac{1}{\sqrt{1+r^2}}$

$[\tan\beta = \mu]$.

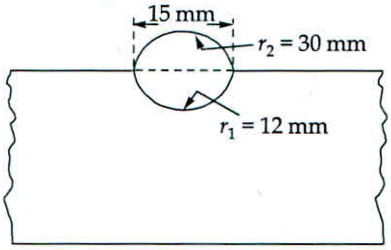
12

Putting in eqn (i)

$$\frac{\tau_s}{p_c} = \frac{r}{\sqrt{1+r^2}}\left(\frac{1}{\sqrt{1+r^2}} - \frac{\mu r}{\sqrt{1+r^2}}\right)$$

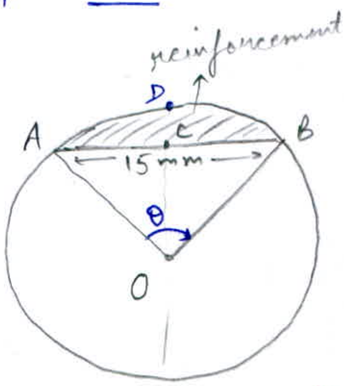
$$\boxed{\frac{\tau_s}{p_c} = \frac{r(1-\mu r)}{1+r^2}}$$

**Q.2 (a)** The cross-section of weld bead is shown in figure. The profile of the bead and the fusion zone are taken circular for convenience. Bead width and radii of curvature of circular profiles are shown in figure. What is percentage dilution?




**[20 marks]**

Reinforcement :




AB = 15 mm.

OA = OB = OD = 30 mm

$OC = \sqrt{OA^2 - AC^2}$

$= \sqrt{30^2 - (7.5)^2}$

$OC = 29.04$ mm.

% dilution is given by :

$$\% \text{ dilution} = \frac{A_p}{A_p + A_r} \times 100$$

where $A_p$ is the area of penetration

$A_r$ is the area of reinforcement.

$A_R$ = area of (ADBC).

$A_R$ = area of sector (OADB) − area of (Δ OAB)

$A_R = \left(\frac{\theta}{360}\right) \times \pi r^2 - \frac{1}{2} \times AB \times OC$

For calculating θ ;

$\tan(\theta/2) = \frac{BC}{OC} = \frac{7.5}{29.04}$

$\frac{\theta}{2} = 14.477$

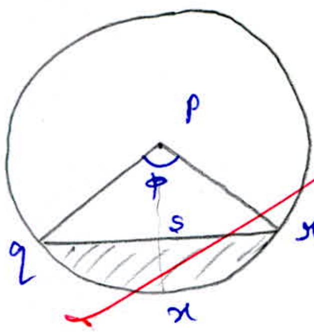
$\theta = 28.955°$

$$A_p = \left(\frac{28.955}{360}\right) \times \pi (30)^2 - \frac{1}{2} \times 15 \times 29.04$$

$$A_p = 227.4122 - 217.8$$

$$\boxed{A_p = 9.6122 \ mm^2}$$

Penetration :




$$pq = pr = px = 12 \ mm.$$

$$qr = 15 \ mm.$$

$$qs = sr = 7.5 \ mm.$$

$$ps = \sqrt{(pq)^2 - (qs)^2}$$

$$ps = \sqrt{(12)^2 - (7.5)^2}$$

$$\boxed{ps = 9.3675 \ mm.}$$

$$\tan\left(\frac{\phi}{2}\right) = \frac{qs}{ps} = \frac{7.5}{9.3675} \Rightarrow \left[\frac{\phi}{2} = 38.682\right].$$

$$\boxed{\phi = 77.36^\circ}$$

Area $A_p = \left(\frac{\phi}{360}\right) \times \pi r^2 - \frac{1}{2} \times ps \times qr$

$$= \frac{77.36}{360} \times \pi (12)^2 - \frac{1}{2} \times 9.3675 \times 15$$

$$A_p = 97.2189 - 70.256$$

$$\boxed{A_p = 26.96 \ mm^2}$$

$$\% \text{ dilution} = \frac{A_p}{A_p + A_R} \times 100$$

$$\% \text{ dilution} = \frac{26.963}{26.963 + 9.6122} \times 100$$

% dilution = 73.72 %

20

.2 (b) What are linear defects in crystal? Describe different types of linear defects.

**[20 marks]**

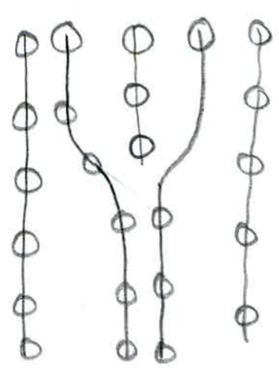
The defects occuring in a particular linear array in a crystal is termed as linear defects. Due to shear; the various layers of the crystal displaces to form voids of various strain field in b/w the crystal known as linear deflect in crystal. The various types of linear defects are:

1) Edge Dislocation
2) Screw Dislocation
③ Mixed dislocation.

Edge Dislocation:

In this; the application of shear causes the upper and lower crystal to deviate from the original arrangement. The central line posses the linear defect.

If the upper half plane is distorted; then it is known as positive edge dislocation:

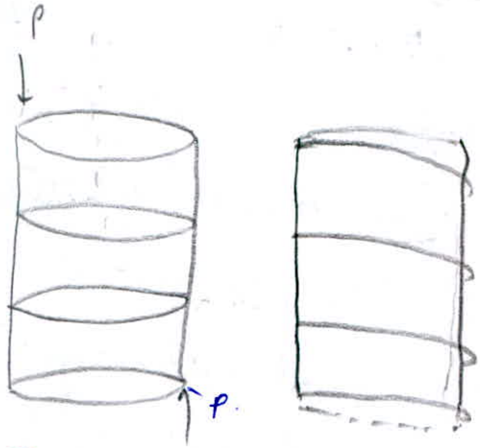


If the plane of dislocation is at the lower side of dislocation plane; then it is termed as negative edge dislocation.

Burger vector always acts in the perpendicular direction to the dislocation line

in edge dislocation.
Due to dislocation ; the upper elements possess a compressive strain field while the lower half of the element possess tensile strain field.

Screw Dislocation :



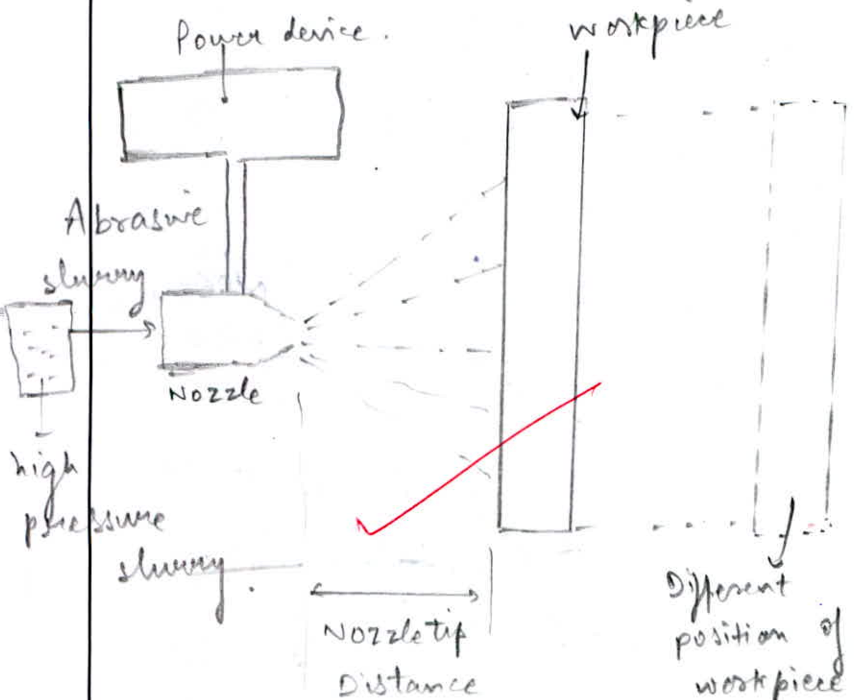

In screw dislocation ; the dislocation line is generally parallel to the dislocation plane.
The shape distorts to provide various strain fields in the crystal. Burger vector in this case is also parallel to the dislocation angle and hence the crystal possess both tensile and compressive strain field.

line

15

.2 (c) Explain the principle of abrasive water-jet machining using suitable schematic diagram. Write the advantages and applications of AWJM.

**[20 marks]**



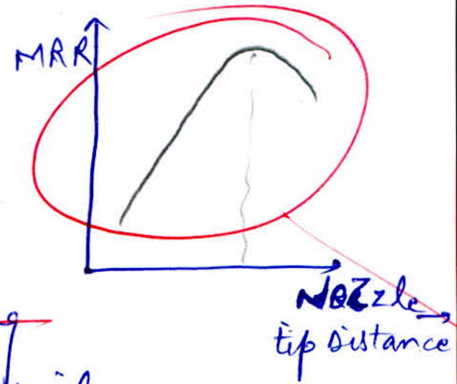

Speed : 80-100 m/s

Nozzle tip diameter is very small so as to provide very high kinetic energy.

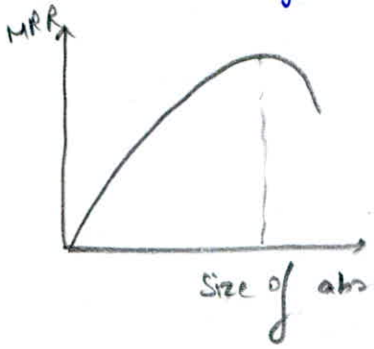
The abrasive water jet machining uses a nozzle through which abrasive slurry comes out. The Principle of AJM is the high kinetic energy of abrassive slurry is converted into the heat energy due to sudden change in the momentum of slurry particles.

The high pressure slurry goes through the nozzle where its pressure energy is converted into the kinetic energy. The high k.E. slurry strikes the workpiece and the abrasive action on the surface of the workpiece occurs.

On increasing the nozzle tip distance, initially the MRR increases because of more area exposed to it. But after a certain distance the intensity of slurry decreases, and hence the MRR also starts decreasing.




Similarly if we start increasing the size of abrasives, the material removal rate increases only upto a certain value ~~below~~ above which it starts decreasing.




Advantages:

1) Can be used to machine hard materials.
2) MRR is quite high compared to other processes.
3) The distance can be varied manually and process can be easily controlled.

16

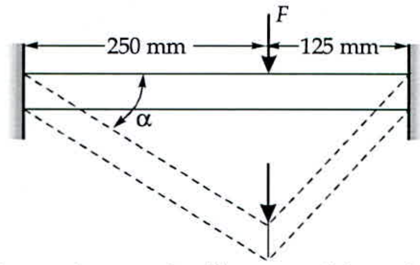
Disadvantages:

1) Wear of nozzle is very high, hence nozzle changing cost is high.
2) Nozzle should be made of very hard materials.

Applications:

1) For cutting materials like titanium, stainless steel, Molybdenum, etc.
2) Used in many aerospace & automobile applications.

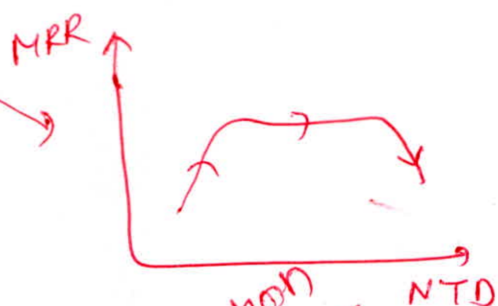
Q.3 (a) A 375 mm long sheet with a cross-sectional area of $5 \times 10^{-4}$ m$^2$ is stretched with a force, $F$, until $\alpha = 20°$. The material has a true stress-true strain relationship as, $\sigma = (700 \text{ MPa})\epsilon^{0.3}$. Calculate:




(i) The total workdone, ignoring end effects and bending.

(ii) What is $\alpha_{max}$ before necking begins?

**[20 marks]**




Improve presentation

**Q.3 (b)** Sketch the setup for spot welding and also explain about spot welding in detail. Show the pressure v/s time graph for different phases. Explain how melting efficiency is calculated? Write down major drawbacks of spot welding process and also write down process parameters for spot welding.

**[20 marks]**

**Q.3 (c)** For the lead-tin alloy 40 wt% Sn and 60 wt% Pb at 150°C. Assume that 10 wt% Sn is fully soluble in Pb at 150°C and 2 wt% Pb is fully soluble in Sn at 150°C. At 150°C densities of Pb and Sn are 11.23 g/cm$^3$ and 7.24 g/cm$^3$ respectively. Calculate the relative amount of $\alpha$ and $\beta$ phase present in terms of (i) mass fraction and (ii) volume fraction. Also draw Pb-Sn phase diagram.

**[20 marks]**

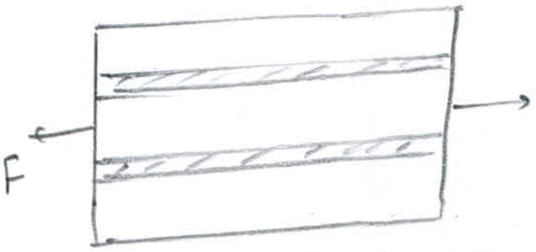
**Q.4 (a)** For a continuous and oriented fiber reinforced composite, the moduli of elasticity in the longitudinal and transverse directions are 33 GPa and 3.65 GPa, respectively. If the volume fraction of fibers is 0.30, determine the moduli of elasticity of fiber and matrix phases. Derive the relation used for modulus of elasticity in transverse direction.

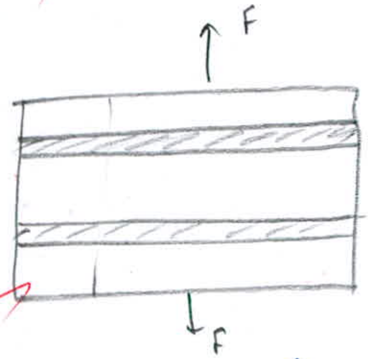
**[20 marks]**

The modulus of elasticity in longitudinal and transverse direction is given by :

$$E_L = (\% V_m) \times E_m + (\% V_f) E_f$$

$$(1/E_T) = \left(\frac{\% V_m}{E_m}\right) + \left(\frac{\% V_f}{E_f}\right)$$




Generally ; the properties of a component formed by mixing two or more parts is given by :

$$\frac{1}{P} = \sum_{i=1}^{n} \frac{\% f_i}{P_i}$$

where $f_i$ = fraction of part present

$P_i$ = Properties of individual component present.

$P$ = Properties of complete structure.

$$\therefore \frac{1}{E} = \sum_{i=1}^{n} \frac{\% f_i}{E_i}$$

To determine Modulus of elasticity for transverse direction ; 2 components i.e fibre and matrix are present.

$$\frac{1}{E_T} = \frac{\% V_f}{E_f} + \frac{\% V_m}{E_m}$$

where $E_T$ is the modulus of elasticity in transverse direction.

$E_f$ is the modulus of elasticity of fibre.

$E_m$ is the modulus of elasticity of matrix.

$\% V_f$ is the volume fraction of fibre.

$\% V_m$ is the volume fraction of matrix.

Let us take a small element which bears a force dF.

derivation?

$\sigma_m = \sigma_f = \sigma_c$

$$dF = dF_{fibre} + dF_{matrix}$$

$$(d\sigma)A = (d\sigma_{fibre}) \times A_{fibre} + (d\sigma)_{matrix} \times A_{matrix}.$$

$$\varepsilon A E_L = E_{fib} \varepsilon_{fibre} \times A_{fibre} + \varepsilon_{matrix} E_{mat} . A.$$

$\therefore$ Since strain remains same for all.

$$\therefore E_L = V_f E_f + V_m E_m$$

For longitudinal.

$$33 = (0.3)E_f + 0.7(E_m) \quad \text{———— (1)}.$$

$$\frac{1}{E_T} = \frac{0.3}{E_f} + \frac{0.7}{E_m}$$

$$\frac{1}{3.65} = \frac{0.3}{E_f} + \frac{0.7}{E_m}$$

$$\frac{E_f}{3.65} = 0.3 + 0.7\frac{E_f}{E_m} \quad \text{———— (2)}$$

from (i); $33 = 0.3E_f + 0.7E_m$.

$$\frac{33 - 0.3E_f}{0.7} = E_m.$$

Putting $E_m$ in eq^n (2);

$$\frac{1}{3.65} = \frac{0.3}{E_f} + \frac{0.7 \times 0.7}{(33 - 0.3E_f)}$$

$$\frac{1}{3.65} = \frac{0.3}{E_f} + \frac{0.49}{(33 - 0.3E_f)}$$

$$E_f(33 - 0.3E_f) = 3.65[(0.3)(33 - 0.3E_f) + 0.49E_f]$$

$$33E_f - 9.9E_f^2 = 3.65[9.9 - 0.09E_f + 0.49E_f]$$

$$33E_f - 9.9E_f^2 = 3.65[9.9 + 0.4E_f]$$

$$9.9E_f^2 - 33E_f + 1.46E_f + 36.135 = 0$$

$$9.9E_f^2 - 31.54E_f + 36.135 = 0$$

$$E_f = 1.5929 \text{ GPa}.$$

$$E_m = 46.46 \text{ GPa}.$$

16

Not satisfied $E_f > E_m$

one more values 103.9 GPa

2.158 GPa

**Q.4 (b)** What is hardening of materials? Briefly explain different types of case hardening process used in heat treatment.

**[20 marks]**

The process of increasing the hardness of the surface without affecting the inner properties is known as hardening of materials. It is done so as to improve the surface resistant properties of metal and also providing it with sufficient toughness.

The various case hardening processes used in heat treatment are:

1) Carburising
2) Cyaniding
3) Nitriding
4) Induction hardening
5) Flame Hardening

Carburising:
In this process, the powder containing carbon is made to penetrate on the surface and quench it to provide sufficient hardness.
The process can be done in various atmosphere such as solid (charcoal, coal, etc). liquid (mixture of carbon) & gaseous (carbon fumes).

The temperature generally ~~remains~~ is around 900°C. → 950°C

Cyaniding:
In this process, the mixture of carbon and nitrogen penetrates on the surface.
Temperature is generally 900°C → 850°C

Due to heating, the component is suddenly quenched to possess the required hardness of component.

Nitriding:

- The workpiece is hardened in the presence of nitrogenous atmosphere.
- Temperature is generally around 1000°C → 550
- No Quenching is required.

Provides a great amount of hardness but not used due to various harmful effects.

Induction Hardening:

The two components encloses a workpiece in which due to changing magnetic field, current and e.m.f induces which rotates and made the surface heat. The part is then quenched to provide sufficient amount of hardness.

mention the temperature range also

8 (15)

Flame Hardening:

The workpiece is generally heated with the help of carburising flame which contains adequate amount of carbon. The workpiece is suddenly quenched during heating with the help of water spray which provides sufficient hardness to the surface of final product.

Q.4 (c) During turning a steel rod of 180 mm diameter by a carbide tool of geometry 0°, –12°, 7°, 5°, 30°, 60°, 0 (mm) at a speed of 600 rpm, feed of 0.32 mm/rev and 4 mm depth of cut, the following observations were made:

Tangential component of the cutting force, $F_z$ = 1000 N

Radial component of the cutting force, $F_y$ = 200 N

Chip thickness (after cut), $t_2$ = 0.8 mm

For the above machining conditions, determine:

(i) Friction force, F and normal force, N acting at the chip-tool interface.

(ii) Yield shear strength of the work material under this machining condition.

(iii) Cutting power consumption in kW.

**[20 marks]**

The specification of tool given is in the form of orthogonal rake system ;

$i - \alpha - \gamma_s - \gamma_e - C_e - \lambda - R$

Principal cutting angle $\lambda = 60°$

Rake angle $\alpha = -12°$

Tangential component ; $F_z = F_c = 1000$ N

Radial component $= F_y = 200$ N

$F_t = \frac{F_y}{\cos\lambda} = \frac{200}{\cos 60} = 400$ N

$t_c = 0.8$ mm.

$f = 0.32$ mm / rev

turning ; $t = f \sin\lambda = (0.32) \sin 60 = 0.2771$ mm

Chip thickness ratio $r = \frac{t}{t_c} = \frac{0.2771}{0.8}$

$r = 0.3464$

Shear angle : $\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$   $\phi = 17.54°$

(i) Friction force ;

$F = F_c \sin\alpha + F_t \cos\alpha$

$= 1000 \sin(-12) + 400 \cos(-12)$

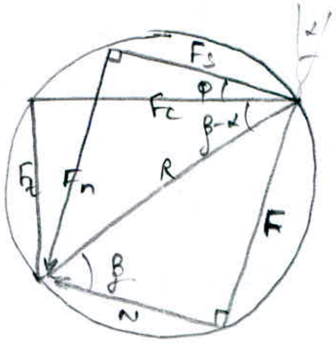
$F = 183.3473$ N

Normal force ;

$N = F_c \cos\alpha - F_t \sin\alpha$

$N = 1000 \cos(-12) - 400 \sin(-12)$

$\boxed{N = 1061.31\ N}$




(ii) Using merchant relation ;

$F_s = \frac{F_c \cos(\phi + \beta - \alpha)}{\cos(\beta - \alpha)}$

$\tan\beta = \frac{F}{N}$ ⇒ $\beta = 9.8°$.

$F_s = 1000 \frac{\cos(17.54 + 9.8 + 12)}{\cos(9.8 + 12)}$

$\boxed{F_s = 832.95\ N}$

$\tau_s = \frac{F_s}{\left(\frac{w t_1}{\sin\phi}\right)}$

width of cut

$w = \frac{d}{\sin k} = \frac{4}{\sin 60} = 4.6188\ mm$

$\tau_s = \frac{832.95 \times \sin(17.54)}{4.6188 \times 0.2771}$

$\boxed{\tau_s = 196.135\ MPa}$

20

(iii) Power = $F_c \times v$

$v = \frac{\pi D N}{60} = \frac{\pi(0.18)(600)}{60}$

$(v = 5.654\ m/s.)$

$P = 1000 \times 5.654$

$\boxed{P = 5.654\ kW}$

**Section B : SOM & Mechanics - 1, Fluid Mechanics and Turbo Machinery - 2**

**Q.5 (a)** The velocity field of a flow is described by $\vec{V}=(4x)\vec{i}+(5y+3)\vec{j}+(3t^2)\vec{k}$. What is the pathline of a particle at a location (1 m, 2 m, 4 m) at time $t = 1$ s?

**[12 marks]**

$\vec{V} = 4x\hat{i} + (5y+3)\hat{j} + (3t^2)\hat{k}$.

$u = 4x$ ; $v = (5y+3)$ ; $w = 3t^2$

[on comparing with $\vec{V} = u\hat{i} + v\hat{j} + z\hat{k}$)

Now $u = \frac{dx}{dt} = 4x$.

$\frac{dx}{x} = 4\,dt$ ⇒ on integrating;

$\int \frac{dx}{x} = 4\int dt$ → $\ln x = 4t + \ln c$

$x = ce^{4t}$

at $t = 0$ s ; $x = 0$ m. $c = e^{0}$

$0 = ce^{0}$

$\therefore x = e(4t)$

Now; in y-direction:

$v = \frac{dy}{dt} = 5y+3$. on integrating;

$\ln(5y+3) = t + \ln c$

$5y+3 = ce^{t}$

at $y = 2$ ; $t = 1$ $\quad 03 = ce^{0}$ $\quad$ [$c = 03$]. $c = 3$

$\therefore 5y + 3 = 13e^{t-1}$

$y = \frac{13e^{t-1} - 3}{5}$ $\quad$ $y = \frac{3e^{t} - 3}{5}$

In z-direction; $w = \frac{dz}{dt} = 3t^2$

On integrating ; $z = \frac{3t^3}{3} + c$

$z = t^3 + c$

at $t = 0\,s$ ; $z = 0$ ; $0 = 0 + c \Rightarrow c = 0$

$\therefore z = t^3 + 0 \Rightarrow z = t^3$

Path line of a particle is given by:

$X = x\hat{i} + y\hat{j} + z\hat{k}$

$= (e^{4t})\hat{i} + \frac{3(e^t - 1)}{5}\hat{j} + t^3\hat{k}$

at $t = 1\,s$: $X = e^4\hat{i} + \frac{3(e-1)}{5}\hat{j} + \hat{k}$

Now merged all three variable

$Z = f(x, y)$

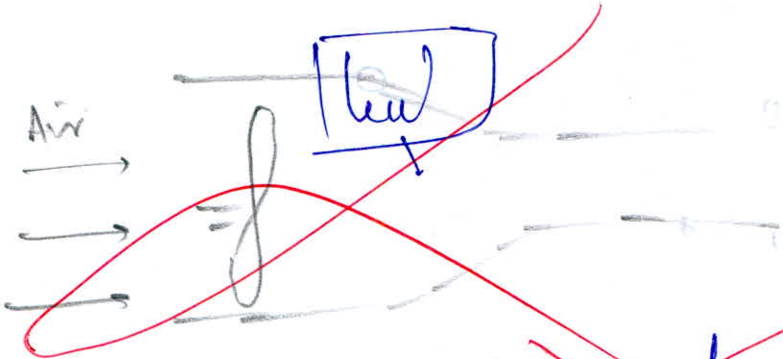
↳ that is path line

Make single eqn in $x, y, Z$

05

**Q.5 (b)** With the aid of a neat diagram, explain the working principle of a Ramjet engine. Also write its advantages.

**[12 marks]**

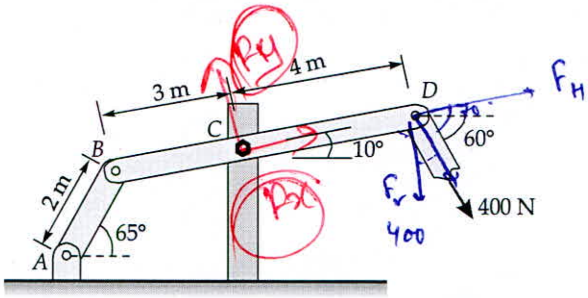



Air enters the fan and the combustion chamber burns the high pressure air to produce a thrust into the bottom part of the jet.

00

Incomplete

**Q.5 (c)** Member BD is hinged to a fixed support with the help of a bolt of diameter 2 cm. Member BD is 10 cm wide and 5 cm thick. Determine the shear stress in the bolt and bearing stress at C in member *BD*.




**[12 marks]**

$F_h = 400 \cos 70° = 136.81$ N.

$F_v = 400 \sin 70° = 375.877$ N

$\tau = \frac{F_v}{\frac{\pi}{4} D^2} = \frac{375.877}{\frac{\pi}{4}(20)^2}$

$\tau = 1.196$ MPa

Wrong FBD

03

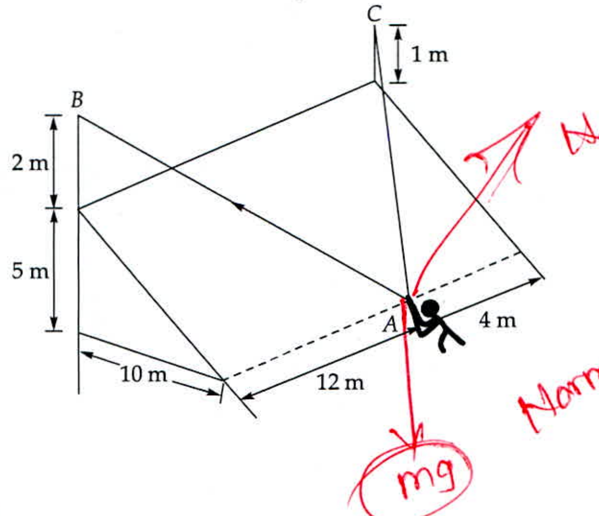
Direct stress ; $\sigma = \frac{F_H}{\frac{\pi}{4} d^2}$.

$\sigma = \frac{136.81}{\frac{\pi}{4}(20)^2}$ $\sigma = 0.4354$ MPa.

Bearing stress at C is given by :

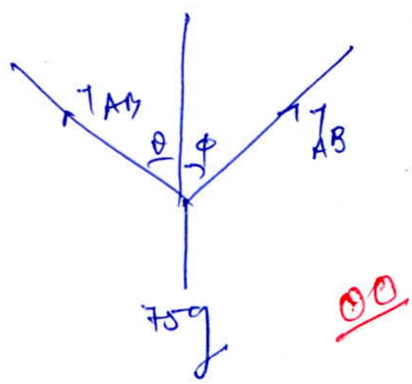
$\sigma = 0.4354$ MPa.

**Q.5 (d)** In trying to move across a slippery icy surface, a 75 kg man uses two ropes, *AB* and *AC*. Knowing that the force exerted on the man by the icy surface is perpendicular to the icy surface, determine the tension in each rope.




Normal reaction also come

**[12 marks]**




$T_{AB}\cos\theta + T_{AC}\cos\phi = 75g$

$T_{AB}\sin\theta = T_{AC}\sin\phi$

**Q.5 (e) (i)** Allowable stress is determined from ultimate strength after considering factor of safety. State the rationale behind considering factor of safety.

**(ii)** The principal strains at a point loaded biaxially in a strained material are $\epsilon_1 = +500 \times 10^{-6}$, $\epsilon_2 = +300 \times 10^{-6}$. If $E = 200$ kN/mm$^2$, $\nu = 0.3$, what are principal stresses?

**[6 + 6 marks]**

(i) During the working of any component, it is subjected to both static stresses as well as fluctuating stresses. During the calculation of ultimate strength, only static stresses are taken into account and hence the component may fail at a lower value compared to ultimate strength of material. Therefore, a concept of allowable stresses is taken into account which predicts the strength of component after considering all the factors such as climatic conditions, fatigue, stress concentration, etc.

Allowable stress is given by the relation:

Allowable stress = $\frac{\text{Ultimate Strength}}{\text{Factor of safety}} = \frac{S_{ut}}{N}$

where N is the factor of safety considering all the adverse factors.

The various factors considered as
(i) Fluctuating stresses (ii) Corrosion
(iii) Environmental condition (iv) Fatigue
(v) Stress concentration

(ii) $\varepsilon_1 = 500 \times 10^{-6} = 500\ \mu$ (Let) $(\mu = 10^{-6})$.

$\varepsilon_2 = 300 \times 10^{-6} = 300\ \mu$

Principal stresses is given by the relation:

$$\sigma_1 = \frac{E}{1-\mu^2}(\varepsilon_1 + \mu\varepsilon_2)$$

$$\sigma_2 = \frac{E}{1-\mu^2}(\varepsilon_2 + \mu\varepsilon_1)$$

$$\therefore \sigma_1 = \frac{200 \times 10^3}{[1-(0.3)^2]}[500 + 0.3(300)] \times 10^{-6}$$

$$\sigma_1 = 129.67 \text{ MPa.}$$

$$\sigma_2 = \frac{200 \times 10^3}{[1-(0.3)^2]}[300 + 0.3(500)] \times 10^{-6}$$

$$\sigma_2 = 98.9010 \text{ MPa.}$$

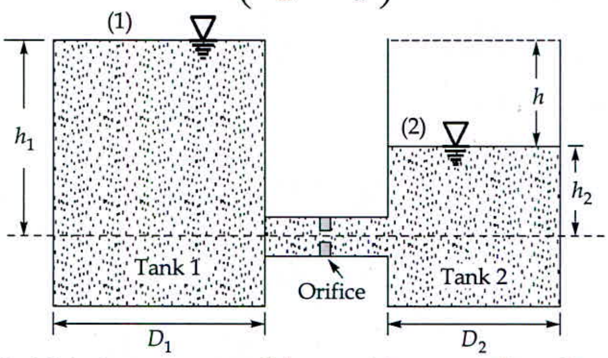
Principal stresses are 129.67 MPa & 98.9 MPa.

4+6=10

Do not write in this margin

**Q.6 (a)** A system that consists of two interconnected cylindrical tanks with diameter $D_1$ and diameter $D_2$ is to be used to determine the discharge coefficient of a short diameter ($D_0$) orifice. At the beginning ($t = 0$ second), the fluid heights in the tanks are ($h_1$) and ($h_2$) as shown in figure. If it takes '$t_f$' second for the fluid levels in the two tanks to equalize and the flow to stop, then show that the discharge coefficient ($C_d$) of the orifice is:

$$C_d = \frac{2\sqrt{(h_1 - h_2)}}{\left(\frac{D_0^2}{D_2^2} + \frac{D_0^2}{D_1^2}\right) \times t_f \times \sqrt{2g}}$$




Assume that the fluid is incompressible, and losses other than that associated with flow through the orifice are negligible.

**[20 marks]**

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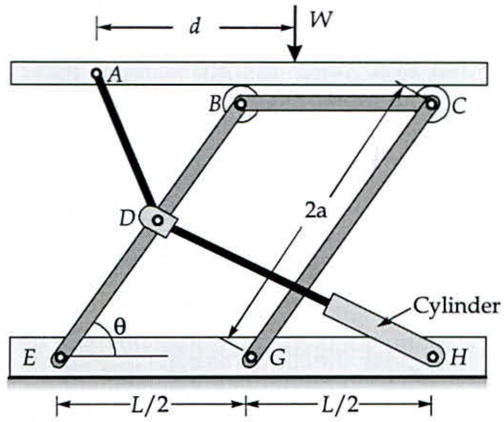
Q.6 (b) A hydraulic lift table is used to raise a 1000 kg crate. Member $EB$ and $GC$ are equal. Cylinder apply force in the direction $DH$. $D$ is at mid point of $EB$. Determine the force exerted by the cylinder in raising the crate for $\theta = 60°$, $a = 0.7$ m, $L = 3.2$ m and $d = 1$ m.




**[20 marks]**

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Q.6 (c) A helicopter gas turbine requires an overall compressor pressure ratio of 12 : 1. This is to be obtained using a two-spool layout consisting of a four stage axial compressor followed by a single stage centrifugal compressor. The polytropic efficiency of the axial compressor is 92% and that of the centrifugal compressor is 83%. The axial compressor is having a stage temperature rise of 32 K, using a 50 percent reaction design with a stator outlet angle of 25°. If mean diameter of each stage is 25.0 cm and each stage is identical, calculate the required rotational speed. Assume a work done factor of 0.85 and a constant axial velocity of 160 m/s.

Assuming an axial velocity at the eye of the impeller, an impeller diameter of 35.0 cm, a slip factor of 0.92 and power input factor of 1.04, calculate the rotational speed required for the centrifugal compressor. Ambient conditions are 1.01 bar and 288 K. Take $c_p$ = 1.005 kJ/kgK and $\gamma$ = 1.4.

**[20 marks]**

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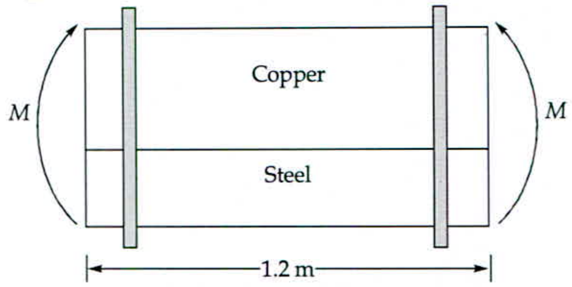
**Q.7 (a)** Two beams are clamped together as shown in figure:




Both are of equal length and both have 5 cm width. Height of copper beam is 10 cm and that of steel beam is 6 cm. What could maximum moment that can be allowed without any failure of $E_{Cu}$ = 120 GPa, $(\sigma_{allowable})_{Cu}$ = 150 MPa, $E_{St}$ = 200 GPa and $(\sigma_{allowable})_{St}$ = 250 MPa?

**[20 marks]**

**Q.7 (b)** **(i)** For a multi-stage steam turbine having same stage efficiency for all stages. Prove that, $\eta_{internal} = R.F. \times \eta_{stage}$

**(ii)** A 20 stage 50% reaction turbine develops a diagram power of 14 MW. The total isentropic enthalpy drop is 900 kJ/kg. The stage efficiency is 76% and the reheat factor is 1.05. The exit angle of blades is 20° and the blade velocity ratio is 0.7.

Calculate:

(p) Flow rate of steam required (in kg per hour) if all the stages develop equal work.

(q) Blade velocity

**[10 + 10 marks]**

**Q.7 (c)** Air enters a 10 m long section of a rectangular duct cross section 15 cm × 20 cm made of commercial steel at 1 atm and 35°C at an average velocity of 7 m/s. Disregarding the entrance effects. Determine the fan power needed to overcome the pressure losses in this section of the duct. Assume the flow is steady and incompressible. Consider the air properties at 1 atm and 35°C.

Density, $\rho = 1.145$ kg/m$^3$

Dynamic viscosity, $\mu = 1.895 \times 10^{-5}$ kg/m-s

kinematic viscosity, $\nu = 1.655 \times 10^{-5}$ m$^2$/s

The roughness of commercial steel surfaces, $\varepsilon = 0.000045$ m.

For the friction factor, the governing equation is Colebrook equation:

$$\frac{1}{\sqrt{f}} = -2.0\log_{10}\left(\frac{\frac{\varepsilon}{D_h}}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}}\right)$$

where, $\varepsilon$ = Roughness of surface, $D_h$ = Hydraulic diameter, Re = Reynolds number, $f$ = Friction factor, $\frac{\varepsilon}{D_f}$ = Relative roughness

**[20 marks]**

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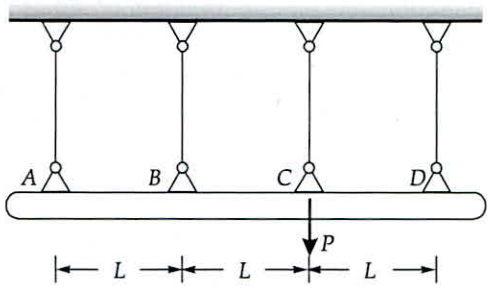
**8 (a)** The rigid rod *ABCD* is hinged with the help of 4 wires of equal length and cross-section area. Determine tension in each wire if force *P* is applied at *C* in downward direction. All the wires have same Young's modulus.




**[20 marks]**

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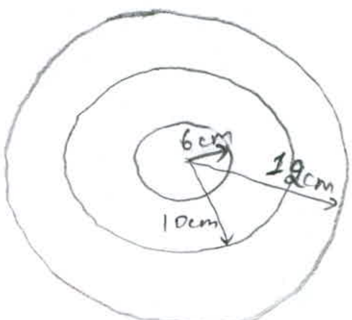
**Q8 (b)** A compound cylinder is formed by shrinking one cylinder onto the other, the final dimensions become inner diameter of 12 cm, external diameter of 24 cm and junction diameter of 20 cm. After shrinking of outer cylinder over inner cylinder the radial pressure at common surface is 20 N/mm$^2$. Calculate the necessary difference in diameters of the two cylinders at the common surface. Take $E$ = 200 GPa, ν = 0.3 for inner cylinder and $E$ = 100 GPa and ν = 0.32 for outer cylinder. What is the minimum temperature through which the outer cylinder should be heated before it can be slipped on?
$\alpha = 11 \times 10^{-6}/°C$ for outer cylinder,

**[20 marks]**




$R_i = 6$ cm

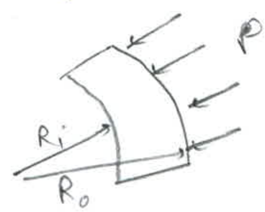
$R_j = 10$ cm

$R_o = 12$ cm.

$P_o = 20$ N/mm$^2$.

Let us consider inner cylinder first ;

Maximum hoop stress for this case on outer surface is :




$$\sigma_h = \frac{-P(R_o^2 + R_i^2)}{R_o^2 - R_i^2} = \frac{20(10^2 + 6^2)}{10^2 - 6^2}$$

$$\sigma_h = -42.5 \text{ N/mm}^2$$

Radial stress at outer surface is :

$$\sigma_r = -P = -20 \text{ N/mm}^2.$$

$$\varepsilon_i = \frac{\sigma_h}{E} - \mu\frac{\sigma_r}{E} = \frac{-42.5}{E} + \frac{20}{E}(0.3)$$

$$\varepsilon_i = \frac{-42.5 + 6}{E}$$

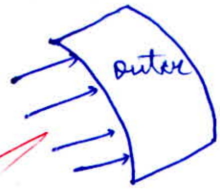
$$\frac{(d_r)}{10} = \frac{-36.5}{E}$$

$$d_{r1} = 0.001825 \text{ mm}$$

$$d_r = -1.825 \times 10^{-3} \text{ mm.}$$

now taking outer cylinder;

Maximum hoop stress at inner surface:




$$\sigma_h = \frac{P(R_o^2 + R_i^2)}{R_o^2 - R_i} = 20\frac{(10^2 + 12^2)}{12^2 - 10^2}$$

$$\sigma_h = 110.91 \text{ N/mm}^2$$

$$\sigma_r = P = 20 \text{ N/mm}^2.$$

$$\frac{dr_2}{r_o} = \frac{\sigma_h}{E} - \frac{\mu\sigma_r}{E} = \frac{110.91 - 0.32(20)}{E}$$

$$dr_2 = 0.01045 \text{ mm.}$$

Radial interference;

$$\delta = |dr_1| + |dr_2|$$

$$= 0.001825 + 0.01045$$

$$\delta = 0.012276 \text{ mm}$$

procedure ok

calculation mistake

Necessary difference b/w two cylinders = 0.012276 mm.

Necessary difference in diameters = 0.02455 mm.

Temp. rise in outer cylinder;

$$\delta = [\alpha \Delta T R_j]_{outer}$$

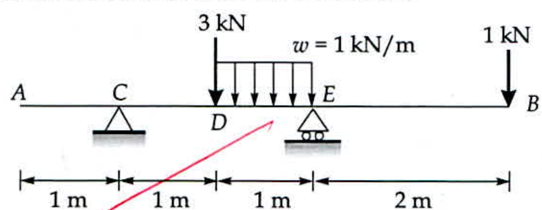
$$0.012276 = 11 \times 10^{-6} \times \Delta T \times 10$$

$$\Delta T = 111.599\ ^\circ C$$

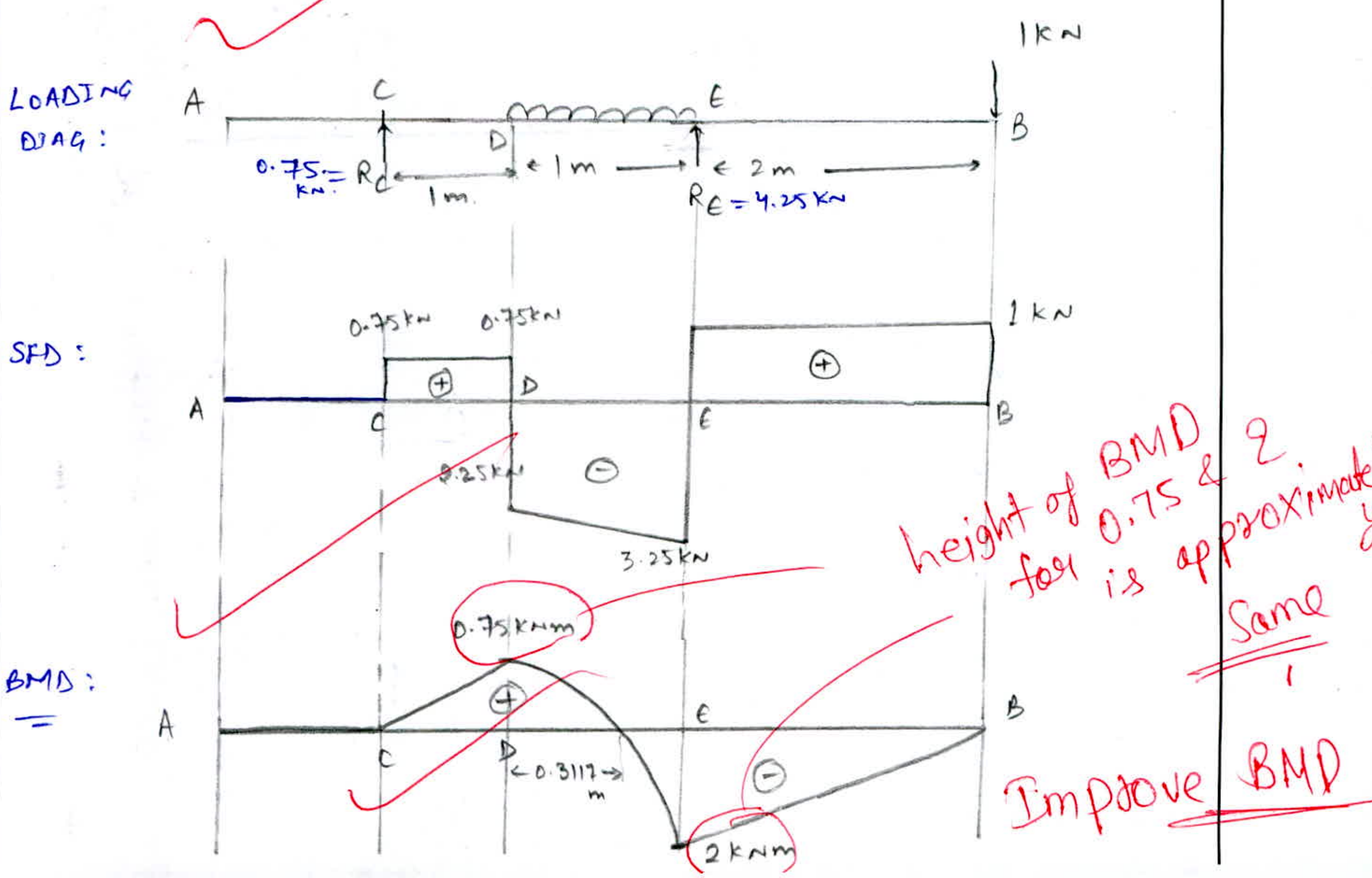
08

Temp. rise = 111.6 °C

**.8 (c)** A beam is loaded as shown in figure. Determine the distance of point of contraflexure from point *A* and maximum moment and its location.




**[20 marks]**



Applying $\Sigma V = 0$

$$R_C + R_E = 3 + (1 \times 1) + 1$$

$$R_C + R_E = 5 \quad \text{—— (i)}$$

Taking moment about C;

$$2R_E - (1 \times 4) - (1 \times 1 \times 1.5) - 3 \times 1 = 0$$

$$2R_E = 4 + 3 + 1.5$$

$$\boxed{R_E = 4.25 \text{ kN}}$$

$$\boxed{R_C = 0.75 \text{ kN.}}$$

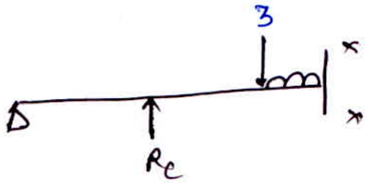
**Shear force Diagram:**

Section AC: $S_{xx} = 0 \Rightarrow \boxed{S_A = 0}$ ; $\boxed{S_C = 0}$

CD: $S_{xx} = R_C = 0.75 \text{ kN} \Rightarrow \boxed{S_C = 0.}75$

$S_D = 0.75$ kN.

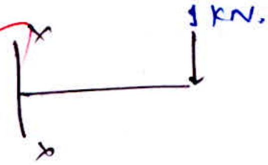
DE: $S_{xx} = R_C - 3 - (1 \times x)$




$\boxed{x = 0}$ $S_D = 0.75 - 3 - 0$

$S_D = -2.25$ kN

BE: $S_{xx} = +1$ kN

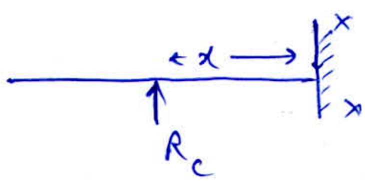



**Moment Diagram:**

Section AC:


$M_{xx} = 0$

Section CD:

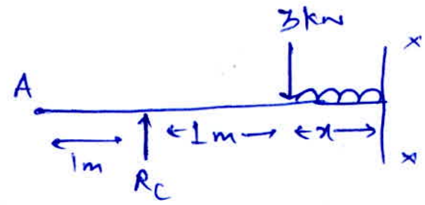



$M_{xx} = R_C \cdot x$.

at $x = 0$ $\quad M_C = 0$

at $x = 1$ m $\quad M_C = R_C \times 1 = 0.75$ kNm

**Section DE:**



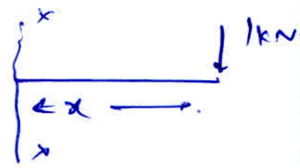

$M_{xx} = R_C.(x+1) - 3x - \frac{1(x)^2}{2}$

$M_{xx} = 0.75(x+1) - 3x - \frac{x^2}{2}$

at $x = 0$ $\quad M_D = 0.75$ kNm

at $x = 1m$ $\quad M_E = 0.75(2) - 3(1) - \frac{(1)^2}{2} = -2$ kNm

**Section BE:**




$M_{xx} = 1 . x$

at B; $x = 0$ $\quad M_B = 0$

$x = 2m$; $\quad M_E = 2$ kNm

**Point of Contraflexure:** ($M_{xx} = 0$) (B.M. changes sign).

Section DE:

$M_{xx} = 0.75(x+1) - 3x - \frac{x^2}{2} = 0$

$0.75x + 0.75 - 3x - \frac{x^2}{2} = 0$

$\frac{x^2}{2} + 3x - 0.75x - 0.75 = 0$

$\frac{x^2}{2} + 2.25x - 0.75 = 0$

18

$\boxed{x = 0.3117 m}$

P.O.C. lies at a distance of 2.3117 m from A.

**Maximum Bending Moment:**

$\boxed{M_{max.} = 2 \text{ kNm}}$ at ($x = 3m$ from A.)

## Space for Rough Work