GATE 2023

MECHANICAL ENGINEERING

Memory based Questions & Solutions

Exam held on 04th Feb, 2023 Afternoon Session

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SECTION - A GENERAL APTITUDE

Q.1 The minute hand and second hand of a clock cross each other _____ times between 9.15 AM and 9.45 AM in a day.

(a) 30 (b) 31
(c) 29 (d) 15

Ans. (a)

The minute hand and second hand will cross each other 1 time every minute after 9:15 i.e. 1 time each in 9:16, 9:17, 9.18 and so on upto 9:45. Thus, they will cross each other 30 times.

End of Solution

Q.2 Which one of the sentence sequence in the given option creates a coherent narrative?

1. I could not bring myself to knock
2. There was a number of unfamiliar voices coming from the big drawing room and the door was firmly shut.
3. The passage was dark a bit, but then it suddenly opened into a bright kitchen.
4. I decided I would rather wander down the passage.

(a) 3 - 1 - 2 - 4 (b) 2 - 1 - 4 - 3
(c) 1 - 3 - 2 - 4 (d) 4 - 1 - 3 - 2

Ans. (b)

End of Solution

Q.3 In a recently held parents teacher meeting, the teachers had very few complaints about Ravi. After all, Ravi was a hardworking and kind student. Incidentally, almost all of Ravi's friends at school were hard working and kind too. But the teachers drew attention to Ravi's complete lack of interest in sports. The teachers believed that along with some of his friends who shows similar disinterest in sports, Ravi needed to engage in some sports for his overall development. Which of the following can be logically inferred with certainty?

(a) No one who is not a friend of Ravi is hardworking and kind.
(b) None of Ravi's friends are interested in sports.
(c) Some of Ravi's friends are hardworking and kind.
(d) All of Ravi's friends are hardworking and kind.

Ans. (d)

End of Solution

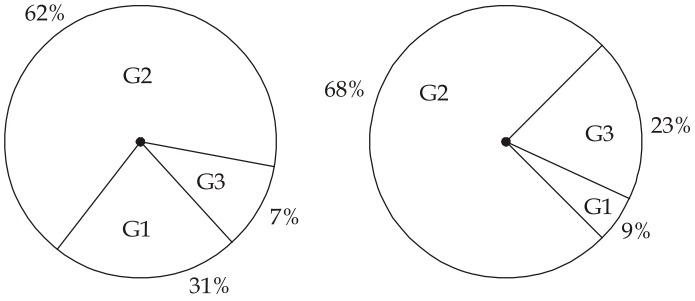
Q.4 He did not manage to fix the car himself, so he _____ in the garage.

(a) got it fixed
(b) gets fixed
(c) got fixed
(d) getting it fixed

Ans. (a)

End of Solution

Q.5 A certain country has 504 universities of 25951 colleges. These are categorised into grade 1, 2 and 3 as shown in the given pie charts. What is the percentage of higher educations insititutions (C & U) that fall into grade 3?



(a) 15.0
(b) 22.7
(c) 23.7
(d) 66.8

Ans. (b)

Given,

Number of colleges, $C = 25951$

Number of universities, $U = 504$

Number of students with grade 3 in colleges

$$G_3(C) = 0.23 \text{ of } 25951 = 0.23 \times 25951$$

$$G_3(C) = 5968.73$$

Number of students with grade 3 in universities

$$G_3(U) = 0.07 \text{ of } 504 = 0.07 \times 504$$

$$G_3(U) = 35.28$$

$$\text{Thus, required percentage} = \frac{\text{Total number of students with Grade 3}}{\text{Total number of students}}$$

$$= \frac{G_3(c) + G_3(u)}{c + u}$$

$$= \frac{35.28 + 5968.73}{25951 + 504}$$

$$= 0.2269 \text{ or } 22.7\%$$

End of Solution

Q.6 Planting : Seed : : Raising : _____?

(a) Height
(b) Temperature
(c) Lift
(d) Child

Ans. (d)

End of Solution

Q.7 The symbol ◯ * △ □ are to be filled one in each box, as shown below.

The rules for filling in the 4 symbols are as follows:

1. Every row and every column must contain each of the 4 symbols.
2. Every 2 × 2 square delineated by bold lines must contain each of the 4 symbols.

Which symbol will occupy the box marked?

	?		△
	◯	*	
		□	*
*		△	◯

(a) □
(b) *
(c) ◯
(d) △

Ans. (b)

□	*	◯	△
△	◯	*	□
◯	△	□	*
*	□	△	◯

End of Solution

Q.8 Consider the following inequalities

$p^2 - 4q < 4$

$3p + 2q < 6$

where, p and q are positive integers.

The value of $(p + q)$ is

(a) 3 (b) 2

(c) 1 (d) 4

Ans. **(b)**

Given inequalities,

$$p^2 - 4q < 4 \quad \text{...(i)}$$

$$3p + 2q < 6 \quad \text{...(ii)}$$

Since p and q are positive integers and satisfy the given inequalities, only possibility is

$$p = q = 1$$

This can be easily verified by putting values of p and q in inequality (ii),

For $p = q = 1$; $3(1) + 2(1) < 6$

For $p = 1$ and $q = 2$; $3(1) + 2(2) > 6$

And, similarly any other value of p and q will not satisfy the inequality.

Hence, $p + q = 1 + 1 = 2$

Alternatively,

Multiplying inequality (ii) with 2,

$$6p + 4q < 12$$

or, $$4q < 12 - 6p \quad \text{...(iii)}$$

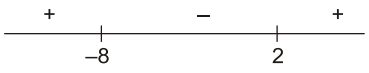
From (i) and (iii),

$$p^2 - 4 < 12 - 6p$$

$$p^2 + 6p - 16 < 0$$

$$(p + 8)(p - 2) < 0$$

Using wavy curve method,



$\therefore$ $p \in (-8, 2)$

But it is given that p is positive integer,

$\therefore$ $p = 1$

From (iii), $4q < 12 - 6(1)$

$4q < 6$

$\Rightarrow$ $q < \frac{3}{2}$

But again q is positive integer,

$\therefore$ $q = 1$

Hence, $p + q = 1 + 1 = 2$

End of Solution

■■■■

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SECTION - B TECHNICAL

ENGINEERING MATHEMATICS

Q.9 The probability of defective component is 0.015 in a box of 200, follows Poisson distribution. Find mean and variance of Poisson's distribution.

(a) $\sqrt{3}, \sqrt{3}$ (b) 3, 3

(c) $\frac{1}{\sqrt{3}}, \frac{1}{\sqrt{3}}$ (d) $\frac{1}{3}, \frac{1}{3}$

Ans. **(b)**

Given, $n = 200$ and $p = 0.015$

For Poisson's distribution,

$$\text{Mean} = \text{Variance} = \lambda = np$$
$$= 200 \times 0.015 = 3$$

End of Solution

Q.10 The inverse Laplace transform of $\frac{1}{s^3 - s}$ is _____.

Ans.

Given, $$F(s) = \frac{1}{s^3 - s} = \frac{1}{s(s^2 - 1)} = \frac{1}{s(s-1)(s+1)}$$

On partial fraction decomposition,

$$F(s) = -\frac{1}{s} + \frac{\frac{1}{2}}{s-1} + \frac{\frac{1}{2}}{s+1}$$

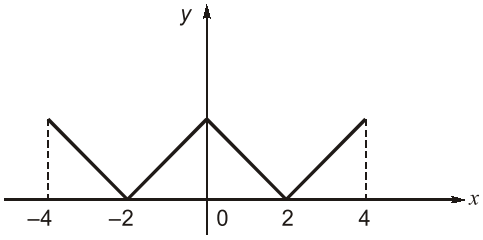
Thus, $$L^{-1}(F(s)) = L^{-1}\left(-\frac{1}{s}\right) + L^{-1}\left(\frac{\frac{1}{2}}{s-1}\right) + L^{-1}\left(\frac{\frac{1}{2}}{s+1}\right)$$

$$= -L^{-1}\left(\frac{1}{s}\right) + \frac{1}{2}L^{-1}\left(\frac{1}{s-1}\right) + \frac{1}{2}L^{-1}\left(\frac{1}{s+1}\right)$$

$$= -1 + \frac{1}{2}e^{t} + \frac{1}{2}e^{-t}$$

End of Solution

Q.11 The figure shows the plot of a function over [–4, 4]. Identify its correct equation.

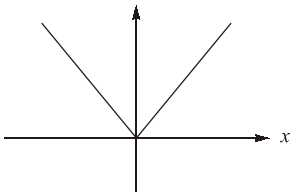


(a) $\big|2-|x|\big|$ (b) $\big|2+|x|\big|$

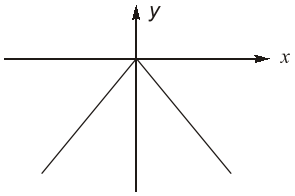
(c) $|2-x|$ (d) $2-|x|$

Ans. **(a)**

We know that the graph of $y = |x|$ is



and the graph of $y = -|x|$ is



It can be observed that the given graph can be obtained by first shifting the graph of $y = -|x|$ up by 2 units and then taking the modulus of resultant function.

Shifting up by 2 units transforms the equation to,

$$y = 2 - |x|$$

and, taking modulus gives the resultant equation as

$$y = |2 - |x||$$

End of Solution

Q.12 The value of k which makes $f(z) = e^{-kx}(\cos 2y - i \sin 2y)$ to be analytic, where $z = x + iy$, is _____.

Ans. **(2)**

Given, $f(z) = u(x, y) + iv(x, y)$

$f(z) = e^{-kx} \cos 2y - ie^{-kx} \sin 2y$

Here, $\dfrac{\partial u}{\partial x} = -ke^{-kx} \cos 2y$

$\dfrac{\partial u}{\partial y} = -2e^{-kx} \sin 2y$

and, $\frac{\partial v}{\partial x} = -ke^{-kx} \sin 2y$

$\frac{\partial v}{\partial y} = -2e^{-kx} \cos 2y$

Since $f(z)$ is analytic, it will satisfy Cauchy–Riemann equation,

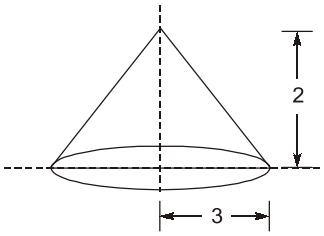
$\frac{\partial u}{\partial x} = \frac{\partial v}{\partial y}$

$\Rightarrow \quad -ke^{kx} \cos 2y = -2e^{-kx} \cos 2y$

$\Rightarrow \quad k = 2$

End of Solution

Q.13 Given vector field $B(x, y, z) = x\hat{i} + y\hat{j} - 2z\hat{k}$ is defined over a conical region having height = 2 and base radius = 3 and axis along z, as shown the base of cone lies in the x - y plane and centred at origin $\int_s B \cdot \hat{n} ds =$ _____.



Ans. (0)

Given, $\bar{B}(x,y,z) = x\hat{i} + y\hat{j} - 2z\hat{k}$

Since surface s is a closed surface, Gauss-divergence theorem can be applied

$\therefore \quad \int_s \bar{B} \cdot \hat{n} ds = \iiint \bar{\nabla} \cdot \bar{B} dv$

where, $\bar{\nabla} \cdot \bar{B} = \frac{\partial}{\partial x} x + \frac{\partial}{\partial y}(y) - \frac{\partial}{\partial z}(2z) = 1 + 1 - 2 = 0$

Thus, $\int_s \bar{B} \cdot \hat{n} ds = 0$

End of Solution

Q.14 For the differential equation $x^2 \frac{d^2y}{dx^2} + x\frac{dy}{dx} - y = 0$, $x \geq 0$ and initial condition $y(x = 1) = 6, \left.\frac{dy}{dx}\right|_{x=1} = 2$, then the value of $y(x = 2)$ = ____.

Ans. **(9)**

It is Euler differential equation

$$\therefore \quad D(D-1)y + Dy - y = 0$$

$$[D(D-1) + (D-1)]y = 0$$

Corresponding auxiliary equation,

$$m^2 - m + m - 1 = 0$$

On solving, $m^2 = 1$

$$m = \pm 1$$

$$\therefore \quad y = C_1 e^{t} + C_1 e^{-t}$$

But, $t = \ln x$

$$\therefore \quad y = C_1 x + \frac{C_2}{x}$$

Also, $$\frac{dy}{dx} = C_1 - \frac{C_2}{x^2}$$

Now applying boundary conditions,

i.e. $y(x = 1) = 6; \quad C_1 + C_2 = 6$ ...(i)

and, $$\left.\frac{dy}{dx}\right|_{x=1} = 2; \quad C_1 - C_2 = 2$$ ...(ii)

On solving (i) and (ii),

$$C_1 = 4; \; C_2 = 2$$

Thus, $$y = 4x + \frac{2}{x}$$

Substituting, x = 2,

$$y = 4(2) + \frac{2}{2} = 9$$

End of Solution

Q.15 A linear transformation maps a point (x, y) in the plane to the point $(\hat{x}, \hat{y})$ as per $\hat{x} = 3y, \hat{y} = 2x$, then the disc $x^2 + y^2 \le 1$ gets transformed to a region with an area of equal to _____.

Ans. **(18.84)**

Given that,

$$\hat{x} = 3y \text{ and } \hat{y} = 2x$$

$$\therefore \quad y = \frac{\hat{x}}{3} \text{ and } x = \frac{\hat{y}}{2}$$

The given region,

$$x^2 + y^2 \le 1$$

or $$\left(\frac{\hat{y}}{2}\right)^2 + \left(\frac{\hat{x}}{3}\right)^2 \le 1$$

$$\frac{(\hat{y})^2}{4}+\frac{(\hat{x})^2}{9} \le 1$$

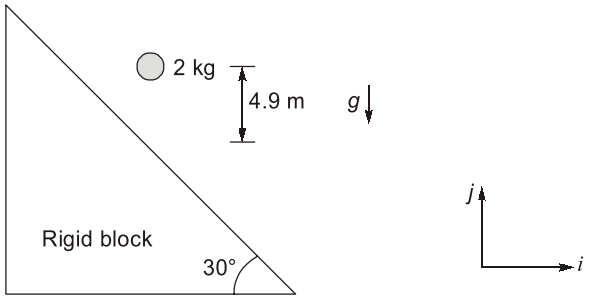
This is equation of an ellipse with semi major axis, $a = 3$ and semi-minor axis, $b = 2$, thus area of transformed region is

$$A = \pi ab = 6\pi \simeq 18.84 \text{ units}$$

End of Solution

ENGINEERING MECHANICS

Q.16 A spherical ball weighing 2 kg is dropped from a height of 4.9 m onto an immovable rigid block as shown in the figure. If the collision is perfectly elastic, what is the momentum vector of the ball (in kg m/s) just after impect?
Take the acceleration due to gravity to be $g = 9.8$ m/s^2; options have been rounded off to one decimal place.



(a) $9.8\hat{i}+17.0\hat{j}$ (b) $19.6\hat{i}$

(c) $17.0\hat{i}+9.8\hat{j}$ (d) $19.6\hat{j}$

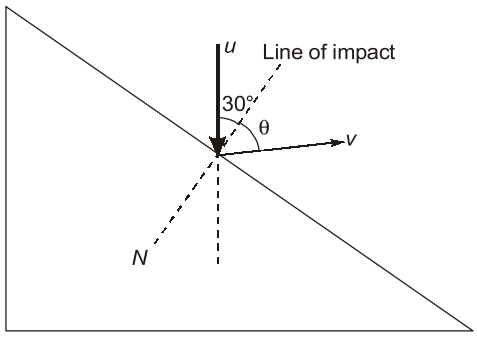
Ans. **(c)**

Velocity of the ball, just before making an impact with the incline

$$u = \sqrt{2gh} = \sqrt{2\times 9.8\times 4.9} = 9.8 \text{m/s}$$

For perfectly elastic collision, along the line of impact,

Velocity of approach = Velocity of separation



$$9.8\cos 30° = v\cos\theta \qquad \text{...(i)}$$

Now, momentum along the inclined plane will remain conserved,

$$P_i = P_f$$

$$\Rightarrow \quad 2u\sin 30° = 2v\sin\theta$$

$$\Rightarrow \qquad v\sin\theta = 9.8\sin 30° = 4.9 \qquad \text{...(ii)}$$

Using equation (i) and (ii), we get

$$v = 9.8\sqrt{\sin^2 30 + \cos^2 30°} = 9.8 \text{ m/s}$$

Therefore, $\theta = 30°$

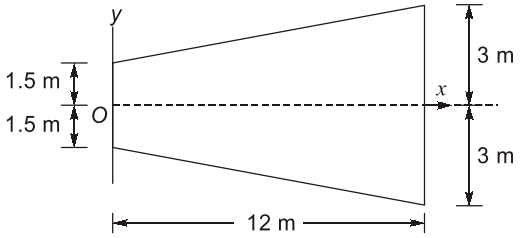
Now, momentum is given by,

$$\vec{P}_f = 2 \times 9.8\sin 60°\,\hat{i} + 2 \times 9.8\cos 60°\,\hat{j}$$

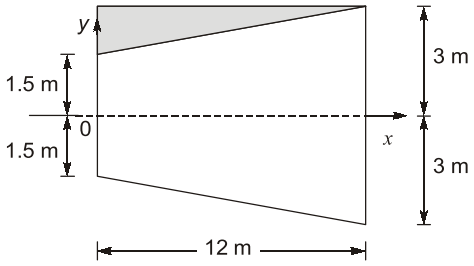
$$= 17\hat{i} + 9.8\hat{j}$$

End of Solution

Q.17 Area moment of inertia about y-axis of a linearly tapered section as shown in figure is_____ m^4.



Ans. (3024)



Considering upper half of the section:

Moment of inertia of rectangular secton about *y*-axis:

$$I_{\text{rectangular sec.}} = \frac{1}{3}\times 3\times (12)^3 = (12)^3$$

Moment of inertia of triangular section about *y*-axis:

$$I_{\text{triangular sec.}} = \frac{1}{12}\times 1.5\times (12)^3 = \frac{1}{8}\times (12)^3$$

$$I = (12)^3 - \frac{(12)^3}{8} = \frac{7}{8}\times (12)^3$$

$\therefore$ Moment of inertia for the whole section

$$= 2\times\frac{7}{8}\times (12)^3 = 3024 \text{ m}^3$$

End of Solution

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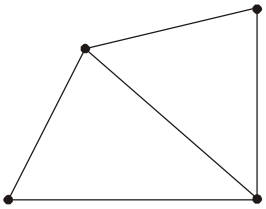
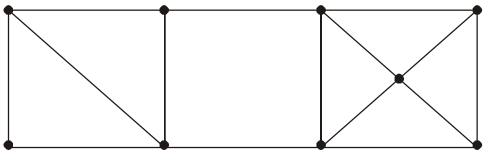
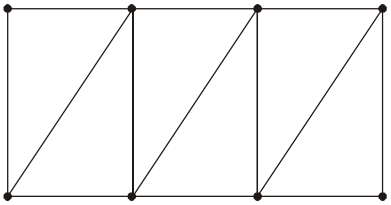
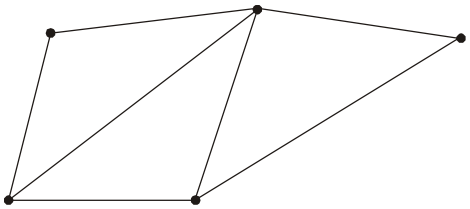
Q.18 Which of the following is not rigid?

(a) 

(b) 

(c) 

(d) 

Ans. (b)

End of Solution

STRENGTH OF MATERIALS

Q.19 A cylindrical transmission shaft of length 1.5 m and diameter 100 mm, is made of a linear elastic material with a shear modulus of 80 GPa. While operating at 500 rpm, the angle of twist across its length is found to be 0.5 degrees. The power transmitted by the shaft at this speed is _____ kW.

Ans. (239.246)

Using the equation $\theta = \frac{TL}{GJ}$

$$\therefore \quad T = \frac{GJ\theta}{L} = \frac{80\times10^3\times\frac{\pi}{32}\times(100)^4\times0.5\times\frac{\pi}{180}}{1500}$$

$$\Rightarrow \quad T = 4569261.297 \text{ N-mm}$$

$$\Rightarrow \quad T = 4569.261 \text{ N-m}$$

$$\therefore \quad P = \frac{2\pi NT}{60}$$

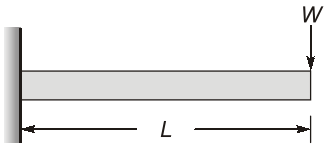
$$\Rightarrow \quad P = \frac{2\pi\times500\times4569.261}{60}$$

$$\Rightarrow \quad P = 239245.96 \text{ W}$$

$$\Rightarrow \quad P = 239.246 \text{ kW}$$

End of Solution

Q.20 The effective stiffness of a cantilever beam of length L and flexural rigidity EI subjected to a transverse tip load W, is



(a) $\frac{3EI}{L^3}$ (b) $\frac{2EI}{L^3}$

(c) $\frac{L^3}{2EI}$ (d) $\frac{L^3}{3EI}$

Ans. **(a)**

The deflection of the beam is given by,

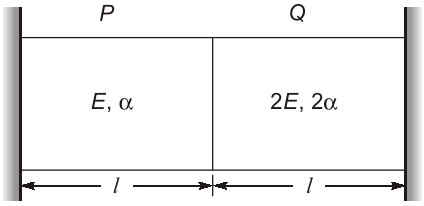
$$\Delta = \frac{WL^3}{3EI}$$

and the stiffness will be given by,

$$K = \frac{W}{\Delta} = \frac{3EI}{L^3}$$

End of Solution

Q.21 Consider the figure below with rods P and Q fixed at both the ends.

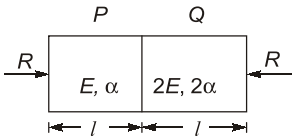


If temperature of the bar increases and $\sigma_1 = \sigma_P$ and $\sigma_2 = \sigma_Q$, then

(a) $\sigma_1 < \sigma_2$ (b) $\sigma_1 = \sigma_2$

(c) Interface moves to left (d) Interface moves to right

Ans. **(b, c)**



As the areas of both the bars are same, therefore, the stress developed in both the bars will remain same.

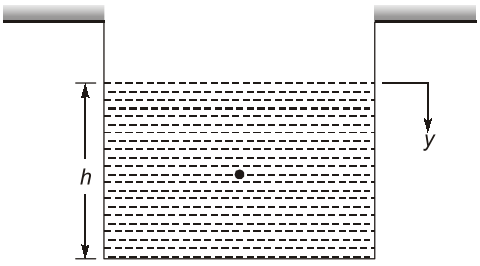
Deflection in rod P, $\Delta_P = l\alpha T - \frac{RL}{AE}$

Deflection in rod Q, $\Delta_Q = l(2\alpha)T - \frac{RL}{A(2E)}$

We can say that $\Delta_Q > \Delta_P$. Therefore, interface will move towards left side.

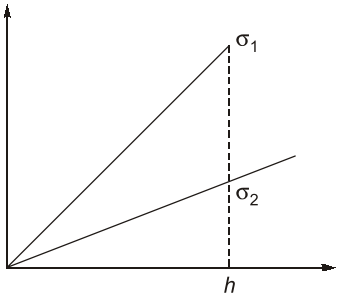
End of Solution

Q.22 A thin cylinder is filled with water as shows in figure below:

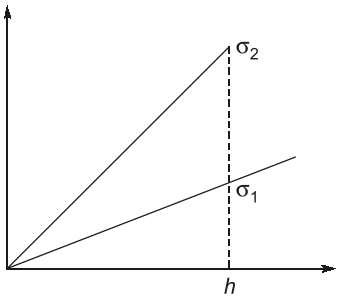


If $\sigma_L = \sigma_1$ and $\sigma_C = \sigma_2$ then, which of the following graph is correct?

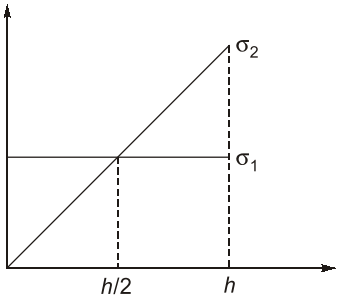
(a)



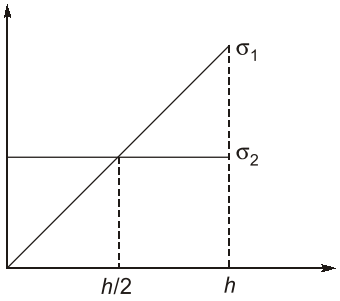
(b)



(c)

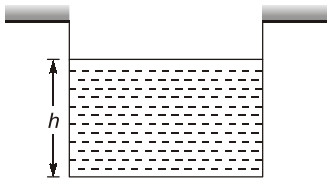


(d)



End of Solution

Ans. (c)



As we move from the free surface towards bottom, the pressure variation can be written as:

$$P = \rho g h$$

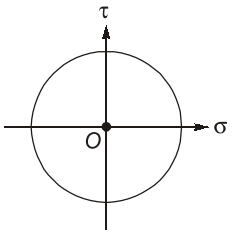
Now, $$\sigma_h = \frac{PD}{2t} = \rho g h\left(\frac{D}{2t}\right)$$

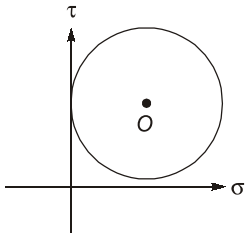
$\therefore$ $$\sigma_h \propto h$$

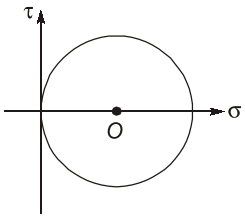
Longitudinal stress will be developed because of the total amount of fluid and since this amount is constant, the longitudinal stress will be constant.

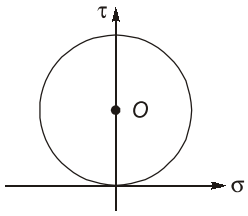
End of Solution

Q.23 Which of the following is the correct representation of plane stress state in a material?

(a) 

(b) 

(c) 

(d) 

Ans. **(a)**

Since the question mentions plane stress state condition, it implies biaxial stress state and hence option (a) is correct.

End of Solution

Q.24 Given a bar with,

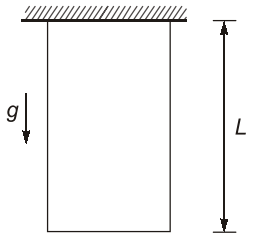
L = 5 m

A = 10 m^2

E = 70 GPa

ρ = 2700 kg/m^3

What is elastic strain energy due to self weight?



Ans. **(2.09)**

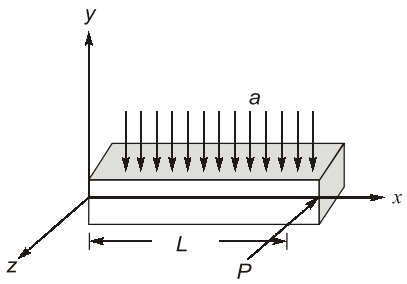
The strain energy is given by:

$$U = \frac{W^2 L}{6AE} = \frac{\gamma^2 A L^3}{6E}$$

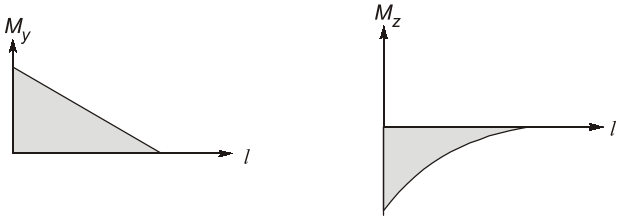
$$\Rightarrow \quad U = \frac{(2700 \times 9.81)^2 \times 10 \times 5^3}{6 \times 70 \times 10^9} = 2.09 \text{ N-m}$$

End of Solution

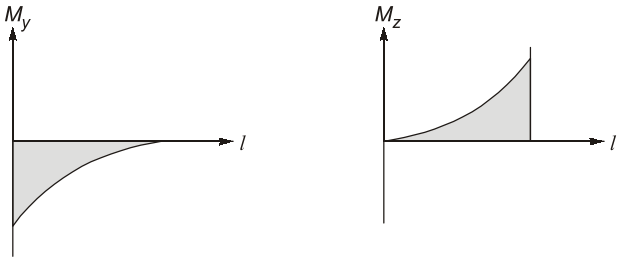
Q.25 For the given figure below which of the following option is correct for bending moment about y and z-axis?



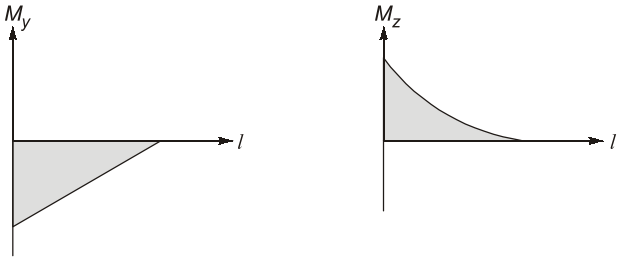
(a)



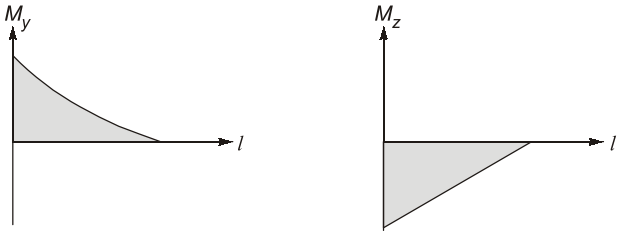
(b)



(c)



(d)



Ans. (a)

The vertical bending moment diagram in x-y plane due to uniformly distributed load is given as:

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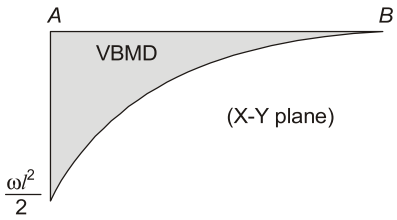
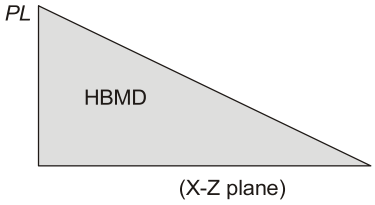


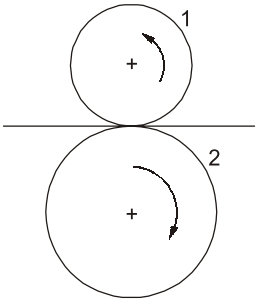
The horizontal bending moment diagram due to horizontal point load is given as:



End of Solution

THEORY OF MACHINES

Q.26 Two meshing spur gear with diametrical pitch 8 teeth/mm and $\frac{|\omega_2|}{|\omega_1|} = \frac{1}{4}$, centre distance 30 mm apart, the number of teeth on driver gear (1) is_____.



Ans. (96)

Given:

$$\text{Diametrical pitch, } P_d = \frac{8 \text{ teeth}}{\text{mm}} = \frac{T}{D}$$

$$\Rightarrow \quad \text{module } (m) = \frac{D(\text{mm})}{T} = \frac{1}{P_d}$$

$$\therefore \quad m = \frac{1}{8}\text{mm}$$

$$\frac{\omega_2}{\omega_1} = \frac{1}{4} = \frac{T_1}{T_2}$$

$$\Rightarrow \quad T_2 = 4T_1$$

$$\because \quad R + r = 30$$

$$\Rightarrow \quad \frac{mT_2}{2} + \frac{mT_1}{2} = 30 \qquad \left\{ m = \frac{D}{T} = \frac{2R}{T} \right\} \quad \therefore \quad R = \frac{mT}{2}$$

$$\Rightarrow \quad \frac{m}{2}(T_2 + T_1) = 30$$

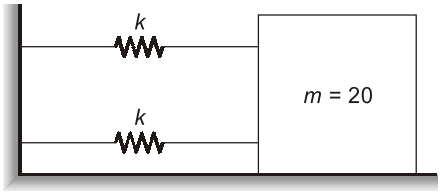
$$\Rightarrow \quad \frac{1}{8 \times 2}(4T_1 + T_1) = 30$$

$$\Rightarrow \quad 5T_1 = 30 \times 16$$

$$\therefore \quad T_1 = \frac{30 \times 16}{5} = 96$$ x

End of Solution

Q.27 The figure shows a block of mass, $m = 20$ kg attached to a pair of identical linear springs, each having spring constant $k = 1000$ N/m. The block oscillates on a frictionless horizontal surface. Assuming free vibration, the time taken by the block to complete 10 oscillations is _____ sec.



Ans. (6.28)

Equivalent stiffness: $k_{eq} = k + k$

$= 2s$

$= 2 \times 1000$

$\therefore \quad k_{eq} = 2000$ N/m

$m = 20$ kg

Natural frequency: $\omega_n = \sqrt{\frac{k_{eq}}{m}} = \sqrt{\frac{2000}{20}} = 10$ rad/s

Time period of oscillation:

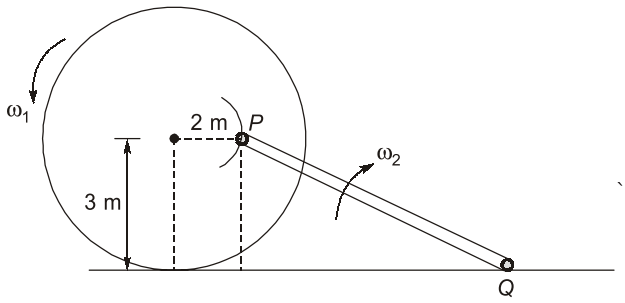
$$T_n = \frac{2\pi}{\omega_n}$$

Time taken to complete 10 oscillations $= 10T_n$

$$= 10 \times \frac{2\pi}{\omega_n} = 10 \times \frac{2\pi}{10} = 2\pi = 2 \times 3.14 = 6.28 \text{ sec}$$

End of Solution

Q.28 A disc rolls without slipping on a flat surface as shown below. A rod PQ is attached to the disc. One end of rod is sliding on the surface. If the angular velocity of disc is ω_1 and that of rod is ω_2 then



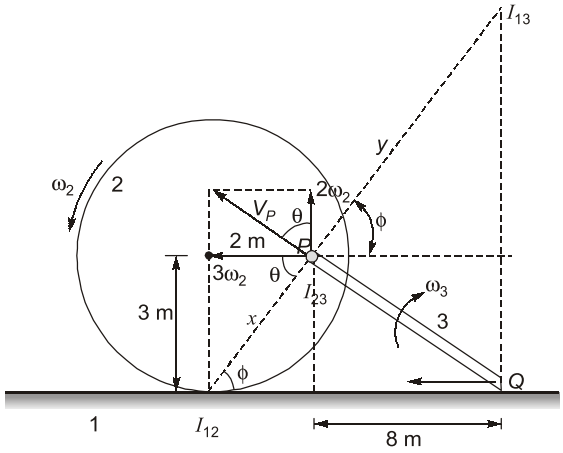
(a) $\omega_2 = 2\omega_1$

(b) $\omega_2 = \dfrac{\omega_1}{2}$

(c) $\omega_1 = \omega_2$

(d) $\omega_2 = 0.25\ \omega_1$

Ans. (d)



Let us assume fixed link as 1, disc as link 2 and rod as link 3.

Applying Kennedy theorem:

$$\omega_2(I_{12}I_{23}) = \omega_3(I_{13}I_{23}) \quad \ldots(1)$$

$$\tan\theta = \frac{3}{2}$$

$$\tan\phi = \frac{3}{2}$$

$$\Rightarrow \quad \theta = \phi$$

$$\therefore \quad x\cos\phi = 2$$

$$y\cos\phi = 8$$

From equation (1),

$$\omega_1\left(\frac{2}{\cos\phi}\right) = \omega_2\left(\frac{8}{\cos\phi}\right)$$

(∵ According to the question, ω_1 is the angular velocity of disc and ω_2 is the angular velocity of rod.)

$\Rightarrow \quad \omega_1 = 4\omega_2$

$\Rightarrow \quad \omega_2 = 0.25\omega_1$

End of Solution

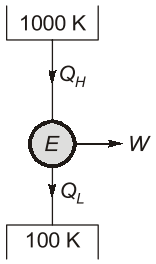
THERMODYNAMICS

Q.29 A heat engine extracts Q_H from a source at 1000 K and rejects Q_L to sink at 100 K while producing W work. Which combination of Q_H, Q_L and W is allowed?

Ans. ()

Using conservation of energy, we get,

$$Q_H = Q_L + W \qquad ...(1)$$



Now, using efficiency relation

$$\eta = 1 - \frac{T_L}{T_H} = 1 - \frac{100}{1000}$$

$$\eta = 0.9 = \frac{W}{Q_H}$$

$$\therefore \quad W = 0.9Q_H \qquad ...(2)$$

From equations (1) and (2), we get

$$\therefore \quad Q_H = Q_L + 0.9Q_H$$

$$\therefore \quad 0.1Q_H = Q_L$$

$$Q_H = 10Q_L$$

End of Solution

Q.30 Consider a mixture of two ideal gases x and y with molar masses M_x = 10 kg/kmol and M_y = 20 kg/kmol, contained at 100 kPa in a container having volume of 10 m^3 at 300 K. If mass of gas x is 2 kg then mass of gas y is _____ kg.

Ans. (4)

We are given with two gases:

P_t = 100 kPa
V = 10 m^3
T = 300 K

X	Y
M_x : 10 kg/k-mol	
M_y : 20 kg/k-mol	

Using the equation, $PV = n\bar{R}T$

$\Rightarrow \quad 100 \times 10 = n \times 8.314 \times 300$

$\Rightarrow \quad n = 0.4$

Now, $\quad n = n_x + n_y$

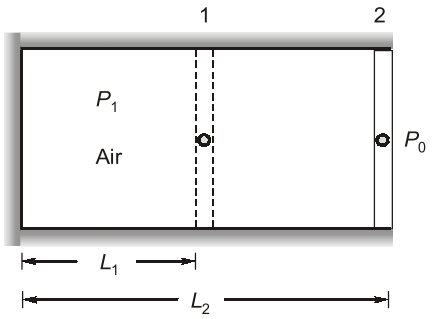
$$n = \frac{m_x}{M_x} + \frac{m_y}{M_y}$$

$$\Rightarrow \quad 0.4 = \frac{2}{10} + \frac{m_y}{20}$$

$$\Rightarrow \quad m_y = 4 \text{ kg}$$

End of Solution

Q.31 A massless piston of cross-section area A, is initially fixed by a stopper. The stopper is now removed and the ideal gas expands adiabatically so that the piston moves outward and is again stopped by a stopper. If P_1 is the initial pressure, P_2 is the final pressure and P_0 is the atmospheric pressure, then the work done on the atmosphere by the piston is
[Given $P_1 > P_0$ and $P_2 > P_0$]



(a) $P_1AL_1 \ln\frac{L_1}{L_2}$

(b) 0

(c) $\frac{(P_2L_2 - P_1L_1)A}{1-\gamma}$

(d) $P_0A(L_2 - L_1)$

Ans. **(d)**

From the given data, $V_1 = L_1 \times A$

$V_2 = L_2 \times A$

$W_{atm} = P_0(V_2 - V_1)$

$= P_0(L_2A - L_1A)$

$= P_0A(L_2 - L_1)$

End of Solution

Q.32 Which of the following statement is false?

(a) For an ideal gas undergoing $PV^{1.5} = C$. The equation connecting the P, V, T of gas at any two points is given by $\frac{P}{R} = \frac{MT}{V}$.

(b) Any real gas behaves as an ideal gas at sufficiently low pressure and high temperature.

(c) For a real gas going through an adiabatic reversible process, $PV^{\gamma} = C$ is applicable.

(d) For an ideal gas, the enthalpy is independent of pressure.

Ans. **(c)**

The process $PV^{\gamma} = C$ is applicable for an ideal gas going through an adiabatic reversible process.

End of Solution

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HEAT TRANSFER

Q.33 A cylindrical rod of length h and diameter d is placed inside the cubic enclosure of side length L. If S denotes the inner surface of the cube, the view factor $F_{S\text{-}S}$ is

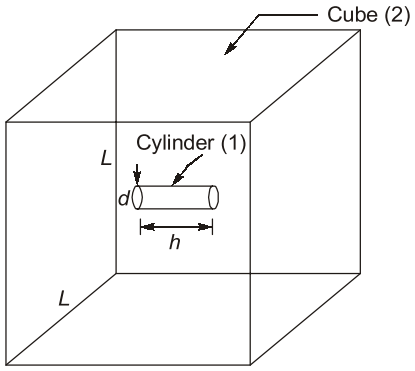
(a) $\dfrac{\pi dh+\dfrac{\pi d^2}{2}}{6L^2}$

(b) $1-\dfrac{\left(\pi dh+\dfrac{\pi d^2}{2}\right)}{6L^2}$

(c) 0

(d) 1

Ans. (b)



$$A_1 = \pi dh+\frac{\pi}{4}d^2+\frac{\pi}{4}d^2$$

$$A_1 = \left(\pi dh+\frac{\pi d^2}{2}\right)$$

$$A_2 = 6L^2$$

Summation rule (for surface 1)

$$F_{11} + F_{12} = 1$$

$$F_{12} = 1 \qquad \{F_{11} = 0\}$$

Reciprocity rule (1, 2):

$$A_1F_{12} = A_2F_{21}$$

$$A_1 = A_2F_{21}$$

$$F_{21} = \frac{A_1}{A_2}$$

Summation rule (for surface 2)

$$F_{21} + F_{22} = 1$$

$$F_{22} \text{ or } F_{ss} = 1-F_{21} = 1-\frac{A_1}{A_2}$$

$$F_{22} = 1-\frac{\left(\pi dh+\dfrac{\pi d^2}{2}\right)}{6L^2}$$

End of Solution

Q.34 Consider incompressible laminar flow of a constant property Newtonian fluid in an isothermal circular tube. The flow is steady with fully developed temperature and velocity profiles. The Nusselt number for this flow depends on

(a) Neither the Reynolds number nor the Prandtl number
(b) The Prandtl number but not the Reynolds number
(c) Both the Reynolds number and the Prandtl number
(d) The Reynolds number but not the Prandtl number

Ans. (a)

For isothermal fully developed laminar flow,

$$\bar{N}u_D = 3.66$$

So, it does not depend on Reynolds and Prandtl number.

End of Solution

Q.35 A counter-flow heat exchanger having two fluids whose inlet temperature is 300 K and another fluid's inlet temperature is 350 K. C_1 and C_2 for both fluids are 400 W/K and 1000 W/K. The effectiveness of the heat exchanger is 0.5. Find the actual heat exchanged between the fluid.

Ans. (10)

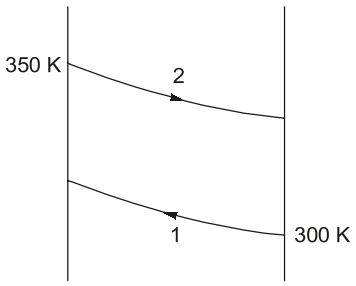
Given: $C_1 = 400$ W/K $= C_{min}$

$C_2 = 1000$ W/K

$$\text{Effectiveness, } \in = \frac{\dot{q}_{actual}}{\dot{q}_{max}}$$

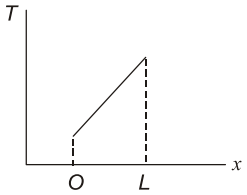
$$\in = \frac{\dot{q}_{actual}}{C_{min}\left(T_{h_i} - T_{c_i}\right)} = 0.5$$

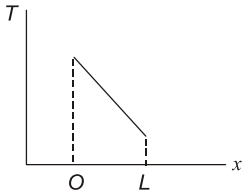
$$q_{actual} = 0.5 \times 400\ (350 - 300)$$
$$= 10000 \text{ Watt} = 10 \text{ kW}$$

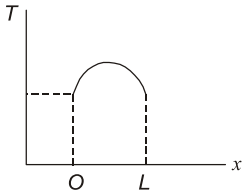


End of Solution

Q.36 The lateral surface of a rod is insulated (k = constant) for steady heat flow and without heat generation, which of the following temperature graphs are possible?

(a)


(b)


(c)


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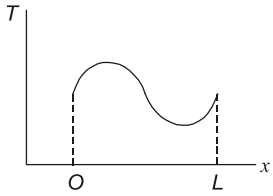
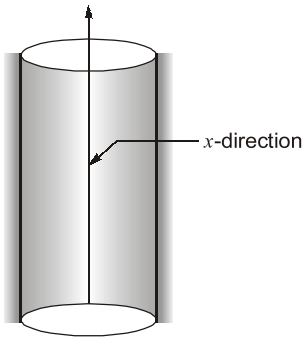


Ans. **(a, b)**

Governing equation for 1-D steady state with no internal heat generation



$$\frac{d^2T}{dx^2} = 0$$

Integrating both sides,

$$\frac{dT}{dx} = c_1$$

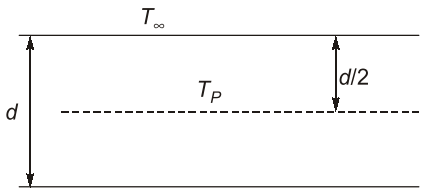
Again integrating both sides,

$$T = c_1 x + c_2$$

This shows that the temperature varies linearly with x which is given in option (a) and (b).

End of Solution

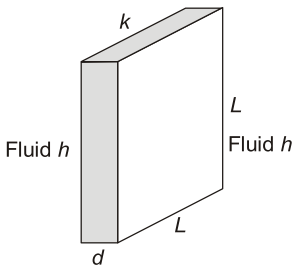
Q.37 A very large metal plate of thickness (d) and thermal conductivity (k) is cooled by a stream of air (T = 300 K). If T_P denotes center line temperature, in which case lumped parameter model is used to study the heat transfer in metal plate?



(a) h = 100, k = 1000, d = 1 mm, T_P = 325 K
(b) h = 100, k = 100, d = 1 m, T_P = 325 K
(c) h = 1000, k = 1, d = 1 m, T_P = 350 K
(d) h = 100, k = 1000, d = 1 mm, T_P = 350 K

Ans. **(a, d)**

To apply lumped heat analysis Biot number (Bi) ≤ 0.1
Characteristic length,



$$L_C = \frac{\text{Volume}}{\text{Surface area}}$$

$$= \frac{d \times L \times L}{(L \times L) + (L \times L)} = \frac{d}{2}$$

Now, we need to check all the options and calculate Biot number.

(a) $$\text{Bi} = \frac{hL_C}{k}$$

$$\text{Bi} = \frac{100 \times 0.5 \times 10^{-3}}{1000} = 0.5 \times 10^{-4}$$

(b) $$\text{Bi} = \frac{100 \times 0.5}{100} = 0.5$$

(c) $\text{Bi} = \dfrac{1000 \times 0.5}{1} = 500$

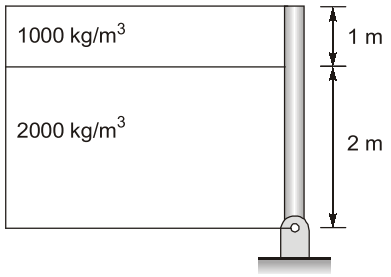
(d) $\text{Bi} = \dfrac{100 \times 0.5 \times 10^{-3}}{1000} = 0.5 \times 10^{-4}$

Option (a) and (d) having biot number less than 0.1.

End of Solution

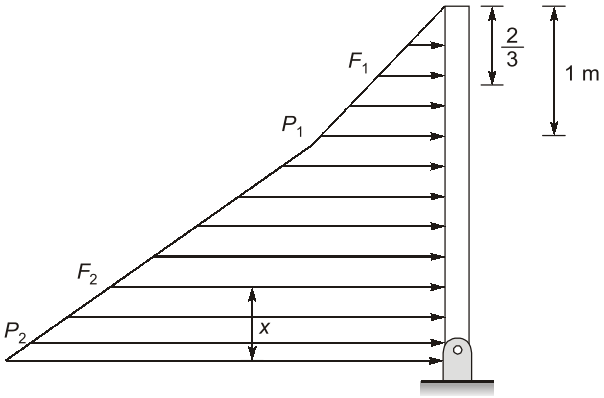
FLUID MECHANICS

Q.38 For the following fluid system as shown in figure, the moment about the bottom hinge point due to the force by the fluids is _____ kN-m.
(Atmosphere pressure P_o = 100 kPa.)



Ans. (57.225)

Making the pressure prism for the system.



$P_1 = 10^3 \times 9.81 \times 1$

$P_1 = 9.81$ kN

$P_2 = P_1 + [2000 \times 9.81 \times 2]$

$P_2 = 49.05$ kN

The resultant forces F_1 and F_2 due to pressure P_1 and P_2 respectively are given as:

F_1 = Volume of triangular pressure prism

$= \dfrac{1}{2} \times P_1 \times 1 \times 1 = 4.9\text{kN}$

F_2 = Volume of trapezoidal pressure prism

$$= \frac{1}{2} \times [P_1 + P_2] \times 2 \times 1 = 58.86 \text{ kN}$$

Now, the moment due to forces is given as

$$M = F_1 \times \left[2 + \frac{1}{3}\right] + F_2 \times \left[\frac{2P_1 + P_2}{P_1 + P_2}\right] \times \frac{2}{3}$$

Putting the values, we get

$$M = 57.225 \text{ kNm}$$

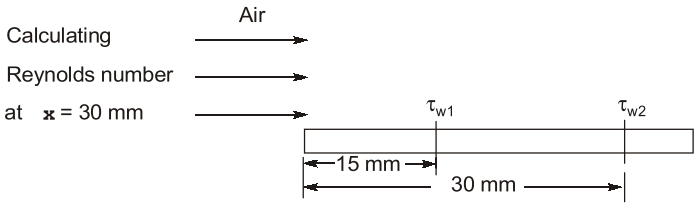
End of Solution

Q.39 Air (density = 1.2 kg/m^3, kinematic viscosity = 1.5 × 10^{-3} m^2/s) flows over a flat plate with free stream velocity of 2 m/s. The wall shear stress at a location 15 mm from leading edge is τ_w. The wall shear stress at a location 30 mm from the leading edge is

(a) $\frac{\tau_w}{\sqrt{2}}$ (b) $2\tau_w$

(c) $\frac{\tau_w}{2}$ (d) $\sqrt{2}\tau_w$

Ans. (a)



$$\text{Re} = \frac{U_\infty x}{\nu} = \frac{2 \times 30 \times 10^{-3}}{1.5 \times 10^{-3}} < 5 \times 10^5$$

For laminar boundary layer,

$$\tau_w \propto \frac{1}{\sqrt{x}}$$

$$\therefore \quad \frac{\tau_{w1}}{\tau_{w2}} = \sqrt{\frac{x_2}{x_1}} = \sqrt{\frac{30}{15}} = \sqrt{2}$$

$$\tau_{w2} = \frac{\tau_{w1}}{\sqrt{2}}$$

End of Solution

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MATERIAL SCIENCE

Q.40 The atomic radius of a hypothetical face-centered cubic (FCC) metal is $\left(\frac{\sqrt{2}}{10}\right)$ nm.

The atomic weight of the metal is 24.092 g/mol. Taking Avagardo's number to be 6.023×10^{23} atoms/mol, the density of the metal is_____ kg/m^3.

Ans. (2500)

Given:

$$\text{radius of atom, } r = \left(\frac{\sqrt{2}}{10}\right)\text{nm}$$

Atomic weight of metal, $m =$ 24.092 g/mol

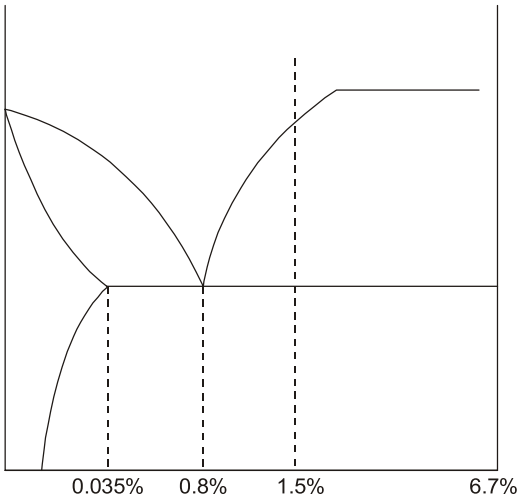
Avogadro's number, $A = 6.023 \times 10^{23}$ atoms/mol

$$\text{Volume of unit cell, } a^3 = \left(\frac{4r}{\sqrt{2}}\right)^3 = \left(\frac{4}{\sqrt{2}} \times \frac{\sqrt{2}}{10}\right)^3 = 0.064 \text{ nm}^3$$

$$\text{Density of metal } \rho = \frac{4 \times 24.092 \times (10^9)^3}{6.023 \times 10^{23} \times 1000 \times 0.064} = 2500 \text{ kg/m}^3$$

End of Solution

Q.41 The iron carbon phase diagram for an alloy with 1.5%C is shown in the figure.



The ratio of proeutectoid cementite to total cementite is _____.

Ans. (0.54)

Mass fraction of preoeutectiod cementite,

$$m_1 = \frac{1.5 - 0.8}{6.7 - 0.8} = 0.1186$$

Mass fraction of total cementite,

$$m_2 = \frac{1.5 - 0.035}{6.7 - 0.035} = 0.2198$$

$$\frac{m_1}{m_2} = \frac{0.1186}{0.2198} = 0.54$$

End of Solution

INDUSTRIAL ENGINEERING

Q.42 Consider the following objective function

$$Z_{max} = 45x_1 + 60x_2$$

Subjected to constraints:

$$x_1 \le 45$$
$$x_2 \le 50$$
$$10x_1 + 10x_2 \ge 600$$
$$25x_1 + 5x_2 \le 750$$

What would be the feasible region satisfying all the constraints?

Ans.

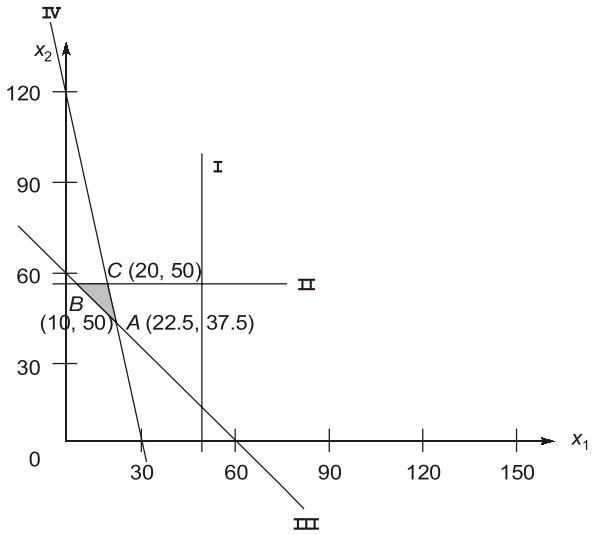
Converting the equation, we get

$$\frac{x_1}{45} = 1 \quad \text{...(i)}$$

$$\frac{x_2}{90} = 1 \quad \text{...(ii)}$$

$$\frac{x_1}{60} + \frac{x_2}{60} = 1 \quad \text{...(iii)}$$

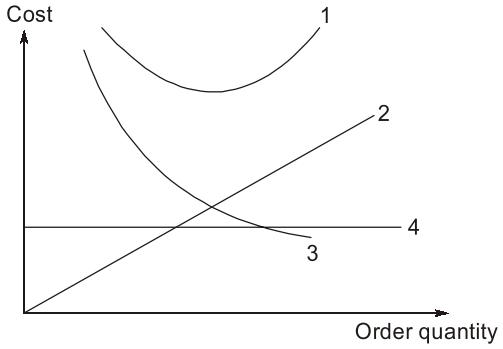
$$\frac{x_1}{30} + \frac{x_2}{150} = 1 \quad \text{...(iv)}$$



We are getting the maximum value of the function at (20, 50) which is 3900.

End of Solution

Q.43 Match curve with corresponding cost:

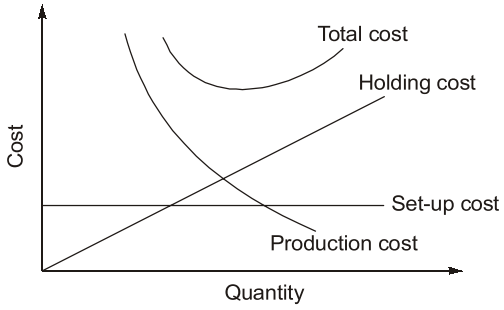


(A) Total cost
(B) Setup cost
(C) Production cost
(D) Holding cost

Codes:

	A	B	C	D
(a)	1	4	3	2
(b)	4	1	3	2
(c)	1	4	2	3
(d)	4	1	2	3

Ans. (a)



End of Solution

MANUFACTURING ENGINEERING

Q.44 In which of the following kind of welding, no melting of two surfaces is required for creating joint?

(a) Arc welding
(b) Braze welding
(c) Adhesive bonding
(d) Spot welding

Ans. (b, c)

In braze welding and adhesive bonding, no melting of two surfaces is required. So option b, c are correct.

End of Solution

Q.45 Ignoring the small elastic region, the true stress (σ) - true strain (ε) variation of a material beyond yielding follows the equation $\sigma = 400\,\varepsilon^{0.3}$ MPa. The engineering ultimate tensile strength value of this material is_____ MPa.

Ans. (206.55)

Given: $\sigma_T = 400\varepsilon_T^{0.3}$

At ultimate tensile strength

$n = \varepsilon_T = 0.3$

So, true stress at ultimate tensile strength

$\sigma_T = 400 \times 0.3^{0.3} = 278.74$ MPa

True strain, $\varepsilon_T = \ln(1 + \varepsilon)$

$\Rightarrow \quad 1 + \varepsilon = e^{0.3} = 1.35$

Engineering ultimate tensile strength

$$\sigma = \frac{\sigma_T}{1+\varepsilon} = \frac{278.74}{1.35} = 206.55\text{MPa}$$

End of Solution

Q.46 Which of the following is correct statement?

(a) Mould is used to make pattern.

(b) Pattern is used to make mould cavity.

(c) Molten metal is in contact with mould cavity.

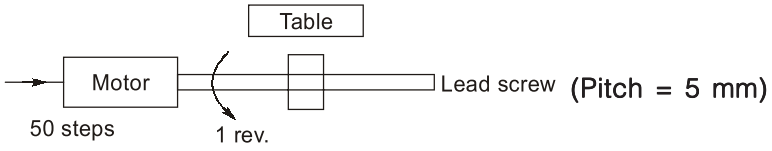
(d) Molten metal come in contact with pattern.

Ans. (b, c)

In casting pattern is used to make mould and in mould liquid metal is poured, so molten metal is in contact with mould cavity.

End of Solution

Q.47 For 100 mm movement of table, the number of steps required is_____.



Ans. (1000)

Given,

Steps per revolution = 50

Total table movement = 100 mm

Pitch of lead screw = 5 mm

So, In 50 steps lead screw moves 5 mm

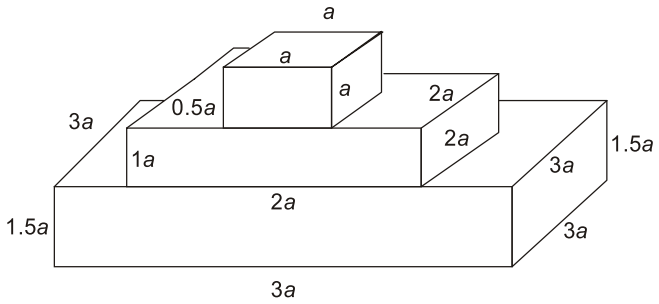
50 steps = 5 mm

hence 10 steps are required to move 1 mm.

So, number of steps required are = $100 \times 10 = 1000$

End of Solution

Q.48 A part is produced as given below by additive manufacturing and nozzle diameter is given $\frac{a}{10}$ mm and feed rate through nozzle is $\frac{a}{5}$ mm/min then find the time taken to produce this part.



Ans. (11465)

$$\text{Given nozzle diameter} = \frac{a}{10}$$

$$\text{Feed rate} = \frac{a}{5}$$

$$\text{Total volume of part} = V_1 + V_2 + V_3$$

$$V_1 = 9a^2 \times 1.5a = 13.5a^3$$

$$V_2 = 4a^2 \times a = 4a^3$$

$$V_3 = 0.5a^2 \times a = 0.5a^3$$

$$\text{Volume flow rate} = \frac{\pi}{4}d^2 \times f = \frac{\pi}{4} \times \left(\frac{a}{10}\right)^2 \times \frac{a}{5}$$

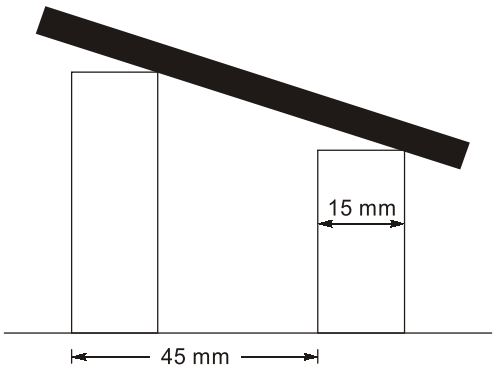
$$= 1.57 \times 10^{-3}a^3 \text{ mm}^3/\text{min}$$

$$\text{Time required} = \frac{V_1 + V_2 + V_3}{\text{Volume flow rate}}$$

$$= \frac{13.5a^3 + 4a^3 + 0.5a^3}{1.57 \times 10^{-3}a^3} = 11465 \text{ min}$$

End of Solution

Q.49 Number of fringes 15 mm gauge are 12 and wavelength is 0.5 μm. The distance between the gauges is 45 mm. The height difference of the slip gauges is



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Ans. (9)

Given

Number of fringes = 12 per 15 mm

Wave length = 0.5 μm

Distance between gauges = 45 mm

Height difference between gauges,

$$h = \frac{h\lambda}{2}$$

$$= \frac{12}{15} \times \frac{0.5}{2} \times 45 = 9\ \mu m$$

End of Solution

Q.50 In orthogonal machining rake angle is 5, shear plane angle is 45°, thickness of shear plane is 25 μm and cutting velocity is 1 m/s. The shear strain rate is _____.

Ans. (5.2×10^4)

Given,

$\alpha = 5°$

$\phi = 45°$

$\delta = 25\ \mu m$

$V = 1$ m/s

$$\dot{\gamma} = \frac{V_s}{\delta} = \frac{V\cos\alpha}{\delta\cos(\phi-\alpha)} = \frac{1\times\cos 5}{25\times10^{-6}\times\cos 40}$$

$= 5.2 \times 10^4 s^{-1}$

End of Solution

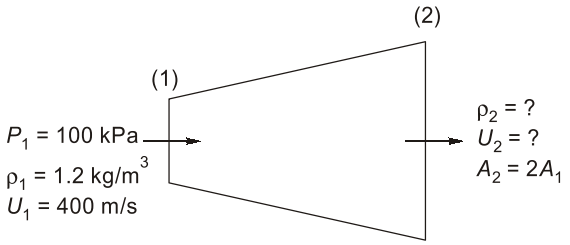
POWER PLANT ENGINEERING

Q.51 Consider an isentropic flow of air (ratio of specific heats = 1.4) through a duct as shown in the figure.

The variations in the flow across the cross-section are negligible. The flow condition at location 1 are given as follows:

P_1 = 100 kPa, ρ = 1.2 kg/m^3, U_2 = 400 m/s.

The duct cross-sectional area at location 2 is given by $A_2 = 2A_1$, where A_1 denotes the duct cross-sectional area at location 1. Which one of the given statements about the velocity U_2 and pressure P_2 at location 2 is TRUE?



(a) $U_2 < U_1,\ P_2 < P_1$

(b) $U_2 < U_1,\ P_2 > P_1$

(c) $U_2 > U_1,\ P_2 > P_1$

(d) $U_2 > U_1,\ P_2 < P_1$

Ans. (d)

First, we need to find the Mach number to know the nature of fluid at entry and exit.

$$M = \frac{V}{\sqrt{\gamma R T_1}} \qquad ...(1)$$

Now, from equation

$$P_1 = \rho R T_1$$

$$\Rightarrow \quad T_1 = \frac{P_1}{\rho R} = 290.6\,\text{K}$$

Putting value of T_1 in equation (1)

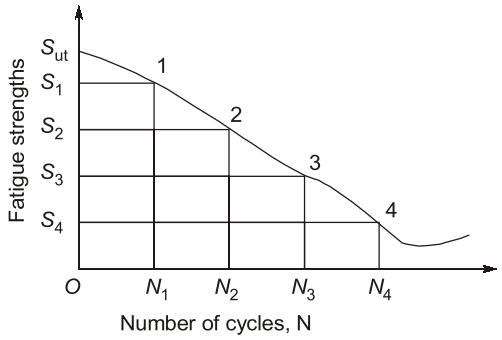
$$M = 1.17 \text{ (flow is supersonic)}$$

Therefore, it will work as a nozzle, therfore velocity will increase and pressure will decrease.

End of Solution

MACHINE DESIGN

Q.52 The S-N curve from a fatigue test for steel is shown, which one of the following options gives the endurance limit?



(a) S_2
(b) S_3
(c) S_{ut}
(d) S_4

Ans. (d)

We know that the curve becomes asymptotic for infinte life, so that is called as endurance limit. S_4 will be the answer.

End of Solution

Q.53 The principal stress at a point *P* in a solid are 70 MPa, –70 MPa, and 0. The yield strength of material in tension is 100 MPa. Which prediction about material failure at P is/are correct?

(a) Maximum normal stress theory predicts that material does not fail.
(b) MSST predicts material does not fail.
(c) Maximum normal stress theory predicts material fail.
(d) MSST predicts material fail.

Ans. (a, d)

Given, $\sigma_1 = 70$ MPa. $\sigma_2 = -70$ MPa

If, $S_{yt} = 100$ MPa

Maximum shear stress,

$\tau_{max} = 100$ MPa

As per MPST, $(\sigma_1 = 70 \text{ MPa}) < (S_{yt} = 100)$

It is safe.

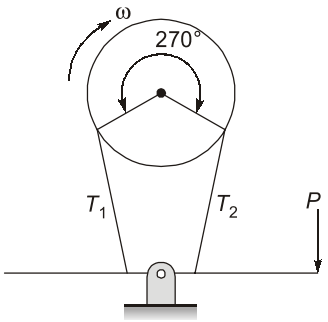
As per MSST, $(\tau_{max} = 70 \text{ MPa}) > \left(S_{ys} = \frac{S_{yt}}{2} = 50\right)$

It is unsafe.

Answer will be (a) and (d)

End of Solution

Q.54 In the band brake shown above, the angle of contact is 270°, and coefficient of friction is 0.3. What will be the ratio of tight side tension to slack side tension?



Ans. (4.1)

Using the equation,

$$\frac{T_1}{T_2} = e^{\mu\theta} = e^{0.3 \times \frac{3\pi}{2}}$$

$$\Rightarrow \quad \frac{T_1}{T_2} = 4.1$$

End of Solution

■■■■