UNIVERSITY OF BRISTOL
FACULTY OF ENGINEERING

First Year Examination for the Degrees of Bachelor and Master of Engineering

MAY/JUNE 2016　　3 HOURS

STRUCTURES AND MATERIALS 1
AENG 11200

This paper contains *seven* questions, *five* in Section A and *two* in Section B.

Answer *five* questions.

You must answer Q1 and *four* other questions.

At least one question must be chosen from Section B.

All questions carry *20 marks* each.

The maximum for this paper is *100 marks*.

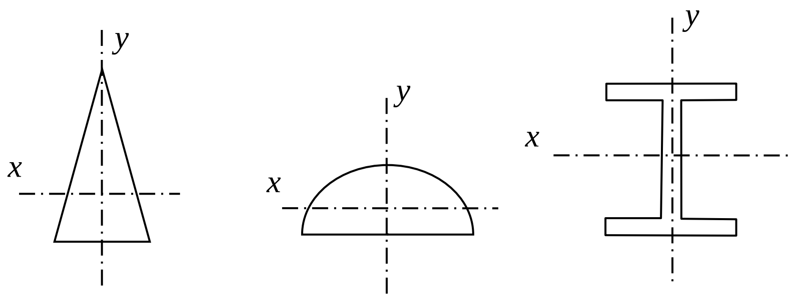
TURN OVER WHEN TOLD TO START WRITING

SECTION A

Q1 This question is compulsory and consists of 20 short answer questions which should all be attempted. Answers should be no more than one or two sentences.

[20 marks, 1 for each short answer question answered correctly]

(a) About which centroidal axis would you expect the largest second moment of area for each of the following cross-section shapes and why?



(*i*) (*ii*) (*iii*)

(b) When does a structure become statically indeterminate?

(c) When would you use the following methods to solve for forces in a truss structure?

i. Method of joints
ii. Method of sections
iii. Method of tension coefficients

(d) Write the 2nd order differential equation of bending which defines the relationship between bending moment and deflection.

(e) Write the Engineer's beam bending relation and define the parameters in it.

(f) Briefly describe (in no more than two sentences) what is the *second moment of area* of a cross-section.

(g) State St Venant's principle.

(h) Write the equations of simple torsion of circular shafts which relate torque to the angle of twist and the shear stresses.

(i) Write a formula for the basic pinned-pinned Euler strut buckling. How would you account for other end conditions?

(j) Which members normally carry the majority of the shear loading in the wing structure of a large transport aircraft?

(k) What is the meaning of the term *load factor* in aircraft structure loading calculations?

(l) Define the term *isotropic* as used to describe material properties.

(m) What are the typical values of Young's modulus for steel, aluminium and titanium alloys?

(n) Name four different types of failure in engineering materials.

(o) What are the advantages of polymers over metals in engineering applications?

(p) Name the three main types of atomic bonding.

(q) Name the process within a crystal structure which is responsible for the disparity between theoretical and experimental strength values.

(r) Why do polycrystalline metals have higher yield strengths than single crystals?

(s) What is meant by the term *polymerisation*?

(t) What is the fundamental chemical/molecular difference between thermosetting and thermoplastic polymers?

Turn over ...

Q2 A uniform horizontal beam $ABCD$ is simply supported at A and C and has vertical loads applied at B and D, as shown in Figure Q2(a). The cross-section of the beam is shown in Figure Q2(b).

(a) Sketch carefully the distribution of bending moments along the length of the beam due to the application of the loads, giving principal values and ensuring that the sketch is reasonably to scale.

[8 marks]

(b) Determine the maximum tensile and compressive stresses in the beam due to the bending moment, giving their values and positions where they occur, both along the beam and across the cross-section.

[12 marks]

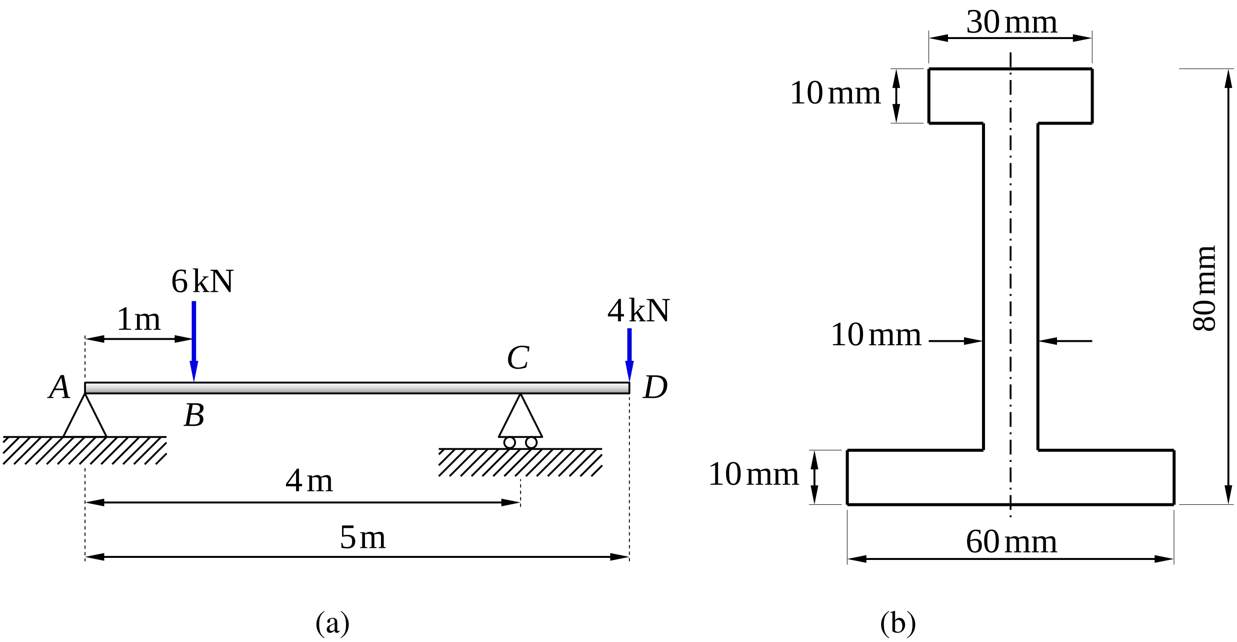


Figure Q2: A simply-supported beam (a) and detail of its cross-section (b).

Q3 A rectangular pin-jointed frame is subjected to a vertical downward load of 10 kN as shown in Figure Q3. The joints A and D are pin-jointed to a rigid wall and the cross-over point at E is not a joint. The structure is statically indeterminate with a degree of redundancy of one.

(a) Taking AC as the redundant member, determine the loads in all other members.

[12 marks]

(b) Calculate the vertical deflection of joint C.

[8 marks]

The product of Young's modulus and the cross-sectional area, $E \times A$, can be taken as 8×10^6 N for all members.

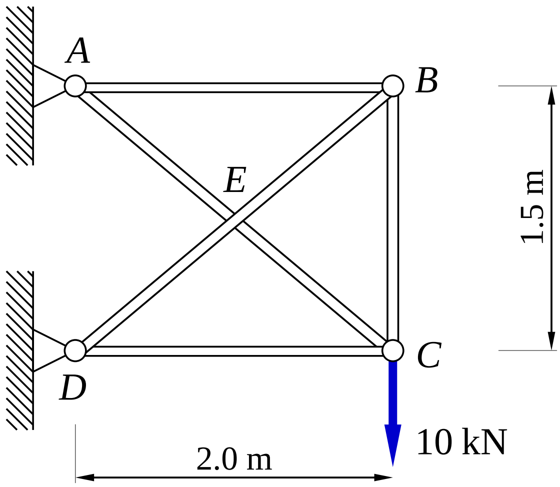


Figure Q3: A plane pin-jointed truss structure.

Q4 An aluminium alloy cylinder is to be designed with a geometric envelope as outlined in Figure Q4. The cylinder is to be bolted to fittings (not shown) using *eight* bolts *at each end*, which are spaced equally around the circumference, to form a single lap joint at each end. Each bolt has a diameter of 8 mm. A limit load of 100 kN (in tension) is to be applied through the end fittings. Given the alloy properties in Table Q4 and assuming an ultimate safety factor of 1.5 perform the following tasks:

(a) Determine a suitable thickness so that the axial deflection of the cylinder is no greater than 0.5 mm at limit load, rounding up to the nearest whole millimetre value.

[4 marks]

(b) Referring to the bolted end joints, calculate the joint stresses at ultimate load for the possible failure modes in the cylinder and quote the ultimate reserve factors. (Use an appropriate edge distance.)

[10 marks]

(c) State any assumptions made in your calculations in (a) and (b) above.

[3 marks]

(d) Comment on your results and suggest possible modifications to the design.

[3 marks]

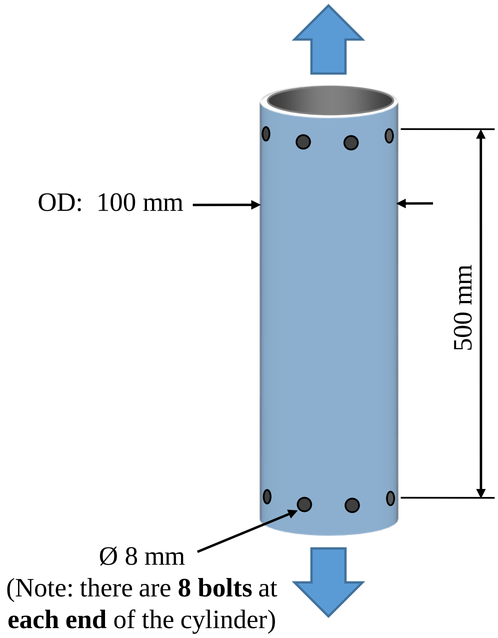


Figure Q4: An aluminium alloy cylinder with bolt holes.

Table Q4: Aluminium alloy properties.

Modulus	E	$= 70$	GPa
Ult. tensile strength	σ^*	$= 400$	N/mm^2
Ult. bearing strength	$\sigma_{br}{}^*$	$= 600$	N/mm^2
Ult. shear strength	τ^*	$= 250$	N/mm^2

Q5 A long range transport aircraft has an all-up mass of 180,000 kg and a wingspan of 52 m. The three engines are mounted on the rear fuselage. The wing structural mass is 12,000 kg and the wing carries 36,000 kg of fuel. Loads from the fuselage can be assumed to act at the wing-to-fuselage joints which are 2.4 m on either side of the fuselage centreline. The distribution of structural mass, lift and fuel mass can be assumed as uniform across the full tip to tip wingspan.

(a) Draw the vertical shear force and bending moment diagrams for a positive symmetric manoeuvre case with a load factor of 2.0, giving the principal values across the full wing span.

[10 marks]

(b) The same aircraft has been fitted with a vertical wingtip structure which gives an effective additional point bending moment at each wingtip of +150 kNm. For simplicity, all-up mass, wing mass and fuel mass all remain the same. Show graphically what effect these additional tip structures will have on the vertical shear force and bending moment distributions of the full wing span, giving principal values of both.

[5 marks]

(c) Sketch a typical cross-section for the wing of this type of aircraft, and label the principal structural components. Explain how the overall wing bending moment, shear force and torsional moment are carried by the structure.

[5 marks]

SECTION B

(In this section you may include **figures** and **equations** in your answers, where appropriate.)

Q6 (a) Describe the nature of hydrogen bonding. Why is it called a secondary bond? How do hydrogen bonds influence the strength of Kevlar fibres?

[4 marks]

(b) From a stress-strain diagram obtained from a tensile test conducted on a given material, describe how you can determine the following:

i. Young's modulus

ii. Toughness

What is the importance of toughness in designing a given engineering product/component? Compare the toughness that would be obtained from a metal, polymer and carbon fibre composite sample.

[6 marks]

(c) Derive the relation between the lattice parameter a_0 and atomic radius r in a FCC crystal lattice. What is the packing factor for a FCC unit cell?

[4 marks]

(d) What is brittle to ductile transition in metals?

[6 marks]

Q7 (a) Glass fibres provide longitudinal reinforcement to a polycarbonate thermoplastic material subject to a tensile load. If the volume fraction (V_f) of glass fibres is 50%, what is the modulus of elasticity of the glass/polycarbonate composite along the direction of alignment of fibres? Assume the moduli $E_{\text{glass}} = 80$ GPa and $E_{\text{polycarbonate}} = 2.1$ GPa.

[4 marks]

(b) Why is dislocation movement easier in the FCC lattice as compared to BCC? How do the FCC and BCC crystal lattices affect the mechanical properties of metals?

[6 marks]

(c) Why is the dislocation movement in ceramic materials more difficult as compared to metals?

[4 marks]

(d) For a polymeric material explain the following two properties:

i. Viscoelasticity

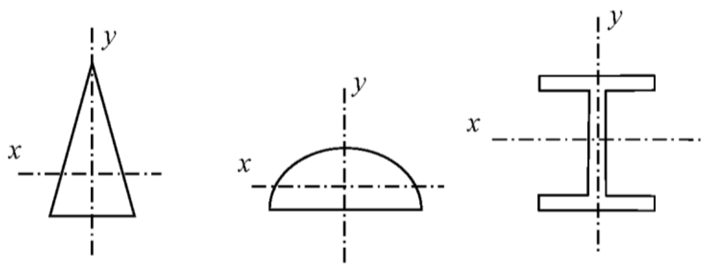
ii. Glass transition temperature

[6 marks]

END OF PAPER

Q1

(a) About which centroidal axis would you expect the largest second moment of area for each of the following cross-section shapes and why?



(i) (ii) (iii)

(i) x, (ii) y, (iii) x; since there is more material further from these axes.

(b) When does a structure become statically indeterminate?

When there are more members or supports than needed to prevent rigid body motion.

(c) When would you use the following methods to solve for forces in a truss structure?

i. Method of joints
ii. Method of sections
iii. Method of tension coefficients

(i) when forces in all members are required in a 2D-truss structure; (ii) when only forces in specific members are required in a 2D-truss structure; (iii) when members are at various angles in a 2D-truss structure, and for 3D-truss structures.

(d) Write the 2nd order differential equation of bending which defines the relationship between bending moment and deflection.

$EI\frac{\partial^2 y}{\partial x^2} = M(x)$

(e) Write the Engineer's beam bending relation and define the parameters in it.

$\frac{M}{I} = \frac{E}{R} = \frac{\sigma}{y}$, *where* M =*bending moment,* I =*second moment of area,* E =*Young's modulus,* R =*radius of curvature,* σ =*stress,* y =*distance from neutral axis.*

(f) Briefly describe (in no more than two sentences) what you understand by the term *second moment of area*.

A measure of cross-section area distribution relevant to bending rigidity. The product of area and the square of its distance from the axis.

(g) State St Venant's principle.

Stress fields tend to become uniform away from details and load application points.

Q1 (cont.)

(h) Write the equations of simple torsion of circular shafts which relate torque to the angle of twist and the shear stresses.

$\frac{\tau}{r} = \frac{T}{J} = \frac{G\theta}{L} = T/J = G/L$

(i) Write a formula for the basic pinned-pinned Euler strut buckling. How would you account for other end conditions?

$P_{cr} = \frac{\pi^2 EI}{L^2}$. *For other end conditions: apply factor relating to effective length between points of contraflexure.*

(j) Which members normally carry the *majority* of the shear loading in the wing structure of a large transport aircraft?

Wing skins.

(k) What is the meaning of the term *load factor* in aircraft structure loading calculations?

Acceleration factor applied to $1g$ *static loading to account for changes in aircraft velocity.*

(l) Define the term *isotropic* as used to describe material properties.

Material properties identical in all directions.

(m) What are the typical values of Young's modulus for steel, aluminium and titanium alloys?

Steel: 210 GPa, aluminium: 70 GPa, titanium: 110 GPa.

(n) Name four different types of failure in engineering materials.

Ductile, brittle, fatigue, creep, environmental.

(o) What are the advantages of polymers over metals in engineering applications?

Lightweight, corrosion resistance, ease of manufacture (e.g. injection moulding).

(p) Name the three main types of atomic bonding.

Metallic, ionic and covalent.

(q) Name the process within a crystal structure which is responsible for the disparity between theoretical and experimental strength values.

Dislocation motion or slip.

(r) Why do polycrystalline metals have higher yield strengths than single crystals?

Dislocations cannot move easily from one grain to the next in polycrystalline materials; single crystal materials have no such mechanism to avoid dislocation movement. Hence polycrystalline metals have higher yield strength.

(s) What is meant by the term *polymerisation*?

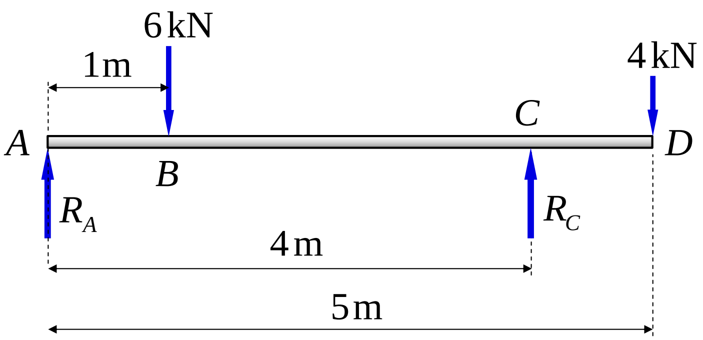
The joining of small molecules to give a long molecular chain.

(t) What is the fundamental structural difference between thermosetting and thermoplastic polymers?

Cross-linking between polymer chains.

Q2

a) The free body diagram is:



$$\sum M_{@C}^{CW} = 0$$

$$R_A(4\,\text{m}) - (6\,\text{kN})(3\,\text{m}) + (4\,\text{kN})(1\,\text{m}) = 0$$

$$R_A = 3.5\,\text{kN}$$

$$\sum F = 0$$

$$R_A + R_C = 6\,\text{kN} + 4\,\text{kN}$$

$$R_C = 6.5\,\text{kN}$$

$$\sum M_{@B}^{CW} = 0$$

$$R_A(1\,\text{m}) - M_B = 0$$

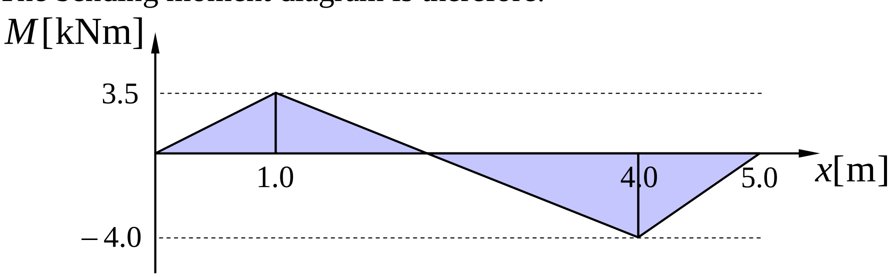
$$M_B = 3.5\,\text{kNm}$$

$$\sum M_{@C}^{CW} = 0$$

$$M_C + (4\,\text{kN})(1\,\text{m}) = 0$$

$$M_C = -4\,\text{kNm}$$

The bending moment diagram is therefore:



Q2 (cont.)

b) The second moment of area must be found. The neutral axis is given by:

$$\bar{y}[(60)(10)+(10)(60)+(30)(10)]=(60)(10)(5)+(10)(60)(40)+(30)(10)(75)$$

$$\bar{y}=33\text{ mm}$$

And using the parallel axis theorem:

$$I_{xx}=\left[\frac{1}{12}(60)(10)^3\right]+[5-33]^2[(60)(10)]+\left[\frac{1}{12}(10)(60)^3\right]+[40-33]^2[(10)(60)]+\left[\frac{1}{12}(30)(10)^3\right]+[75-33]^2[(30)(10)]$$

$$I_{xx}=1.2165\times10^6\text{ mm}^4=1.2165\times10^{-6}\text{ m}^4$$

The stresses due to bending are given by: $\sigma=\dfrac{-M\,y}{I}$

At $x=1\text{m}$, $M_{(x)}=3.5\text{kNm}$ and:

$$\sigma_{\text{top}}=\frac{-(3.5\text{kNm})(80-33)\times10^{-3}\text{ m}}{1.2165\times10^{-6}\text{ m}^4}$$

$$\sigma_{\text{top}}=-1.3522\times10^8\frac{\text{N}}{\text{m}^2}=-1.3522\times10^2\frac{\text{N}}{\text{mm}^2}=-135.22\text{MPa}$$

$$\sigma_{\text{bottom}}=\frac{-(3.5\text{kNm})(-33)\times10^{-3}\text{ m}}{1.2165\times10^{-6}\text{ m}^4}$$

$$\sigma_{\text{bottom}}=9.4945\times10^7\frac{\text{N}}{\text{m}^2}=9.4945\times10^1\frac{\text{N}}{\text{mm}^2}=94.94\text{MPa}$$

At $x=4\text{m}$, $M_{(x)}=-4\text{kNm}$ and:

$$\sigma_{\text{top}}=\frac{-(-4\text{kNm})(80-33)\times10^{-3}\text{ m}}{1.2165\times10^{-6}\text{ m}^4}$$

$$\sigma_{\text{top}}=1.5454\times10^8\frac{\text{N}}{\text{m}^2}=1.5454\times10^2\frac{\text{N}}{\text{mm}^2}=154.54\text{MPa}$$

$$\sigma_{\text{bottom}}=\frac{-(-4\text{kNm})(-33)\times10^{-3}\text{ m}}{1.2165\times10^{-6}\text{ m}^4}$$

$$\sigma_{\text{bottom}}=-1.0851\times10^8\frac{\text{N}}{\text{m}^2}=-1.0851\times10^2\frac{\text{N}}{\text{mm}^2}=-108.51\text{MPa}$$

Therefore the maximum tensile stress is 154.54MPa in the upper surface at point *C*, and the maximum compressive stress is -135.22MPa in the upper surface at point *B*.

Q3

a) Let X be the tension in the redundant member AC. From the dimensions of the truss we find the characteristic angle and trigonometric constants:

$$\alpha = \arctan\left(\frac{1.5}{2.0}\right) \cong 36.9^\circ, \qquad \cos\alpha = 0.8, \qquad \sin\alpha = 0.6$$

Using the method of joints, starting at joint C (all forces in kN):

$$F_{BC} = 10 - (0.6)X$$

$$F_{CD} = -(0.8)X$$

Joint B:

$$F_{BD}(0.6) + F_{BC} = 0 \;\therefore\; F_{BD} = X - 16.67$$

$$F_{AB} + F_{BD}(0.8) = 0 \;\therefore\; F_{AB} = -(0.8)X + 13.33$$

We use the Principle of Stationary Potential Energy: $\frac{\partial U}{\partial X} = 0$, where $U = \sum \frac{F^2 L}{2AE}$. Therefore:

$$\frac{\partial U}{\partial X} = \frac{\partial U}{\partial F}\frac{\partial F}{\partial X} = \sum \frac{F\,L}{AE}\frac{\partial F}{\partial X} = 0$$

Since AE is constant: $\sum F\,L\frac{\partial F}{\partial X} = 0$

Tabulating:

Member	F [kN]	$\frac{\partial F}{\partial X}$	L [m]	$F\,L\frac{\partial F}{\partial X}$ [kNm]
AB	$-(0.8)X + 13.33$	-0.8	2.0	$(1.28)X - 21.33$
BC	$-(0.6)X + 10$	-0.6	1.5	$(0.54)X - 9$
CD	$-(0.8)X$	-0.8	2.0	$(1.28)X$
AC	X	1	2.5	$(2.5)X$
BD	$X - 16.67$	1	2.5	$(2.5)X - 41.66$
			$\sum$	$(8.1)X - 72$

$$\sum F\,L\frac{\partial F}{\partial X} = (8.1)X - 72 = 0 \;\therefore\; X = 8.888\,\text{kN}$$

Therefore: $F_{AC} = 8.888\,\text{kN}$, $F_{AB} = 6.220\,\text{kN}$, $F_{BC} = 4.666\,\text{kN}$, $F_{CD} = -7.110\,\text{kN}$, $F_{BD} = -7.778\,\text{kN}$

Q3 (cont.)

b) The displacement can be found by Castigliano's 2nd theorem: $\frac{\partial U_C}{\partial W} = u_W$, where W is the externally applied force. Therefore:

$$u_W = \frac{\partial U_C}{\partial W} = \frac{\partial U}{\partial F}\frac{\partial F}{\partial W} = \sum \frac{F\,L}{AE}\frac{\partial F}{\partial W} = \frac{1}{AE}\sum F\,L\frac{\partial F}{\partial W}$$

The term $\frac{\partial F}{\partial W}$ is found by dividing the member forces F by the applied load $W = 10\,\text{kN}$.

Tabulating:

Member	F [kN]	$\frac{\partial F}{\partial W}$	L [m]	$F\,L\frac{\partial F}{\partial W}$ [kNm]
AB	6.220	0.622	2.0	7.738
BC	4.666	0.466	1.5	3.268
CD	-7.110	-0.711	2.0	10.110
AC	8.888	0.888	2.5	19.749
BD	-7.778	-0.777	2.5	15.124
			$\sum$	55.990

This gives: $u_W = \frac{1}{AE}\sum F\,L\frac{\partial F}{\partial W} = \frac{1}{8\times10^3\,\text{kN}}(55.990\,\text{kNm})$

Therefore $u_W = 0.007\text{ m} = 7\text{ mm}$, i.e. joint C is displaced downwards by 7 mm.

Q4

Solution

IRF
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Q#

$D_o = 100$

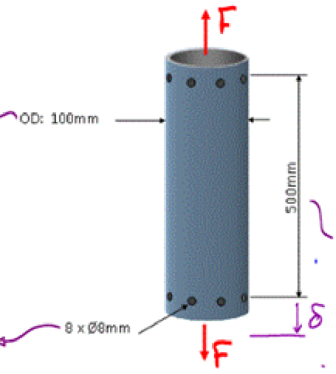


Figure Q#

$L = 500\,mm$

δ

$n = 8$, $d = 8\,mm$

$E = 70'000\ N/mm^2$

$\sigma^* = 400\ N/mm^2$

$\sigma_{br}^* = 600\ N/mm^2$

$\tau^* = 250\ N/mm^2$

D_o = outer dia.
D_i = inner dia.

$$A = \frac{\pi(D_o^2 - D_i^2)}{4} \approx \pi D_o t$$

a) Thickness for $\delta < 0.5\,mm$

$$F = k\delta \quad \text{where} \quad k = \frac{AE}{L}$$

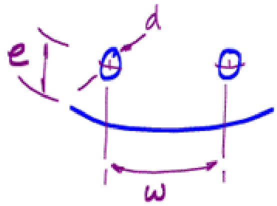
[Could start from $\sigma = \frac{F}{A} = E\varepsilon$ and $\varepsilon = \frac{\delta}{L}$ etc.]

$$\hookrightarrow \quad A = \frac{FL}{\delta E} = \frac{100'000 \times 500}{70'000 \times 0.5} = 1429\ mm^2$$

$$\hookrightarrow \quad \frac{\pi(100^2 - D_i^2)}{4} = 1429 \quad \rightarrow \quad D_i = \sqrt{100^2 - \frac{4 \times 1429}{\pi}} = 90.4\,mm$$

$$\hookrightarrow \quad t = (100 - 90.4)/2 = 4.8\,mm \rightarrow \underline{\underline{5\,mm}}$$

b) Bolted joint – cylinder failure mode check.



$$w \simeq \frac{\pi D_o}{8} = \frac{\pi \times 100}{8} = 39.3\,mm$$

And from typical guidelines:

$$e = 2d = 2 \times 8 = 16\,mm$$

Tension: $\sigma_T = \frac{F/n}{(w-d)t} = \frac{100'000/8}{(39.3-8) \times 5} = 79.9\ N/mm^2$; $\boxed{RF = \frac{400}{79.9} = 5.0}$

Bearing: $\sigma_{br} = \frac{F/n}{dt} = \frac{100'000/8}{8 \times 5} = 312.5\ N/mm^2$; $\boxed{RF = \frac{600}{312.5} = 1.9}$

Shear: $\tau = \frac{F/n}{2et} = \frac{100'000/8}{2 \times 16 \times 5} = 78.1\ N/mm^2$; $\boxed{RF = \frac{250}{78.1} = 3.2}$

c) Assumptions

Concentric uniform loading; Effective length between fitting attachments;
Alloy ductility allowing neglect of stress concentrations at ultimate.

Q4 (cont.)

d) Comments.

lowest RF is bearing and this is desirable as initial failure because it results in hole elongation and slackness giving some warning before catastrophic failure. Adjustments to RF's could be made by increasing local cylinder thickness at the ends of the joint. An increased number of smaller bolts could be an option but increasing the bolt size would result in spacing less than the typical recommended 4d and increased stress interactions.

Q5

a) Aero loading on the wing = 180,000 * 9.81 * 2 = 3532 kN

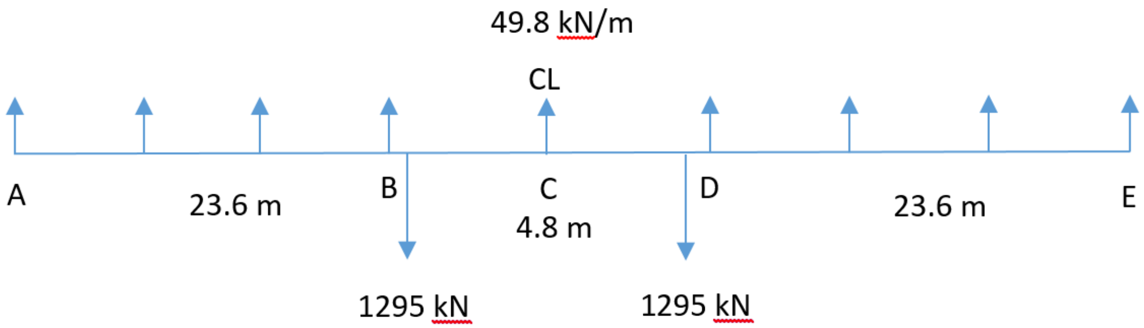
Wing fuel and structure interia loading = (12,000 + 36,000) * 9.81 * 2 = 942 kN

Net loading in fuselage = 3532 – 942 = 2590 kN

Therefore fuselage loading per side = 2590 / 2 = 1295 kN

Net distributed wing loading = 2590 / 52 = 49.8 kN/m

Therefore loading diagram can be shown as follows :



Shear forces can be calculated as follows :

Point A : SF = 0

Point B : SF = (-49.8 * 23.6) = -1176 kN

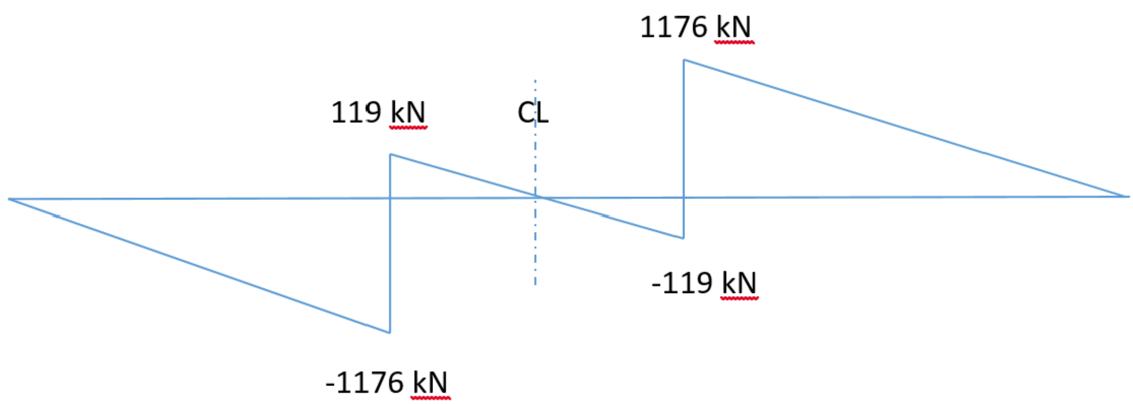
Point B': SF = -1176 + 1295 = 119 kN

Point C : SF = (-49.8 * 26) + 1295 = 0

Point D : SF = (-49.8 * 28.4) + 1295 = -119 kN

Point D': SF = -119 + 1295 = 1176 kN

Point E : SF = 0



Shear force diagram with principal values

Q5 (cont.)

Bending moments can be calculated as follows :

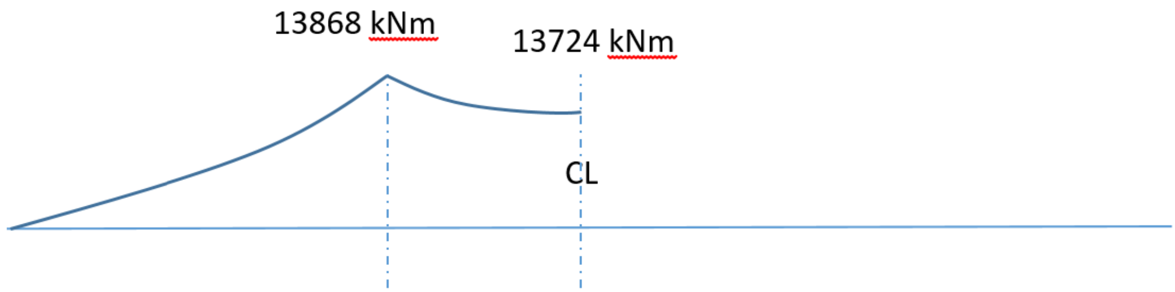
Point A : BM = 0

Point B : BM = (23.6 * 49.8) * (23.6 / 2) = 13868 kNm

Point C : BM = [(26 * 49.8) * (26 / 2)] – (1295 * 2.4) = 13724 kNm

Point D : BM = [(28.4 * 49.8) * (28.4 / 2)] – (1295 * 4.8) = 13868 kNm

Point E : BM = 0



Bending moment diagram with principal values

b) Wingtip device gives an additional + 150 kNm point bending moment ONLY at each wingtip. Therefore the vertical shear force diagram remains the same as before with the same principal values.

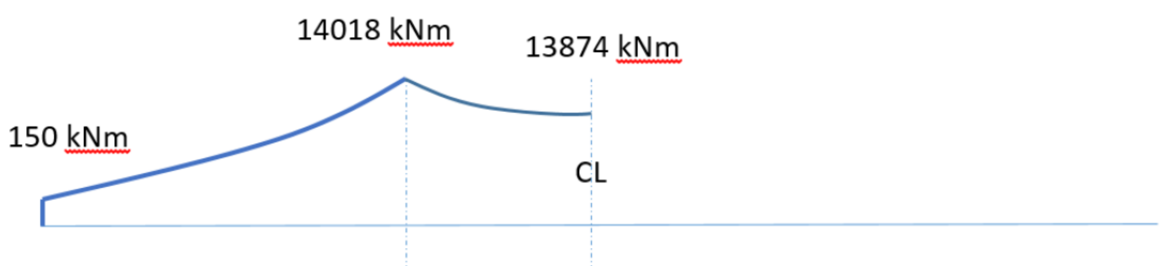
Additional positive bending moment at each wingtip will result in + 150 kNm being added to the two principal values plus the tip point (which was previously zero).

Bending moments can be calculated as follows :

Point A : BM = 150 kNm

Point B : BM = 13868 + 150 = 14018 kNm

Point C : BM = 13724 + 150 = 13874 kNm



Bending moment diagram with principal values for wing with tip devices

Q5 (cont.)

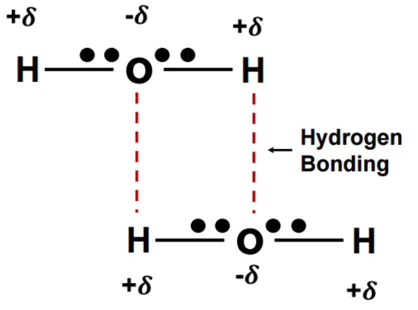
c) *Q. Sketch a typical cross-section for the wing of this type of aircraft, and label the principal structural components. Explain how the overall wing bending moment, shear force and torsional moment are carried by the structure.*

- Vertical shear force, carried mainly by the spars
- Vertical bending moment, carried principally by skin and stringers as tension/ compression at top and bottom of box, with ribs providing support against buckling
- Torsional moment due to offset of vertical load from centre of box, carried mainly by shear in the skin and spar webs around the closed box, with ribs and stringers providing support against buckling.

Q6

a)

Hydrogen bonding is caused by secondary effect which takes place in a covalently bonded molecules. This effect takes place due to difference in ability of atoms to pull electrons towards itself (electro--negativity). Some atoms have higher ability to pull electrons towards itself. This causes partial shift of shared electrons in a covalent bond towards more electronegative atom. In water, oxygen can pull the electrons more towards itself than hydrogen. The shifted electron cloud towards oxygen results in partial negative change on oxygen and partial positive charge on hydrogen.

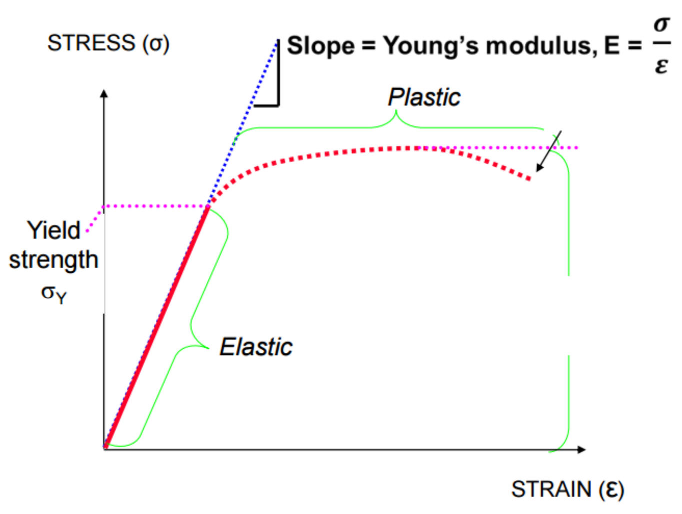


(*2 marks*)

It is referred as secondary boding as it does not involve direct transfer or sharing of electrons. The polymer chains in Kevlar form a large number of H-bonds between their neighbouring chains. Due to the cross-chain (inter-chain) hydrogen bonding overall strength of the Kevlar is increased significantly. Hence hydrogen bonding in Kevlar helps to achieve high strength & high impact resistance.

(*2 marks*)

b)



(*1 mark*)

The stress strain curve obtained from tensile testing of a metallic sample is shown in the figure above. The Young's modulus can be determined by measuring slot of the linear portion of the stress strain curve as shown in the above diagram [Young's Modulus (E) = Stress (σ)/Strain(ε)].

(*1 mark*)

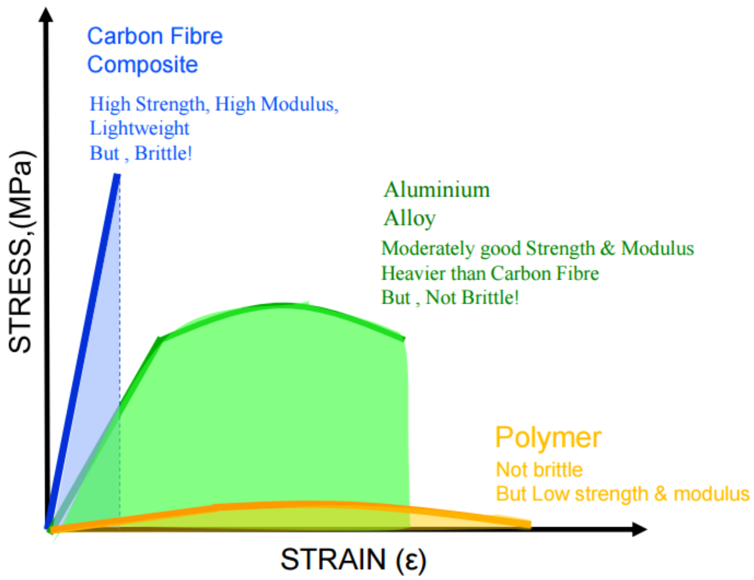
The toughness of the material can be obtained by measuring the area under the curve from the stress strain diagram. The toughness of a material is directly proportional to the energy absorbed by the material before its fails.

(*1 mark*)

Q6 (cont.)

Importance of Toughness:

Ideally, material used for an engineering product/component design should have combination of high strength high modulus as well as good toughness. If the material shows brittle failure (without any or little plastic deformation) then the toughness of that material is low (area under the stress strain curve will be small). Such material is not ideal for engineering design. If a material shows ductile response then it can show high toughness.



Toughness: It is ability of a material to absorb energy and plastically deform before fracture

Toughness of a material can be calculated by measuring the area under the stress strain curve.

Toughness
Aluminium > Carbon Fibre Composite > Polymer

(3 marks)

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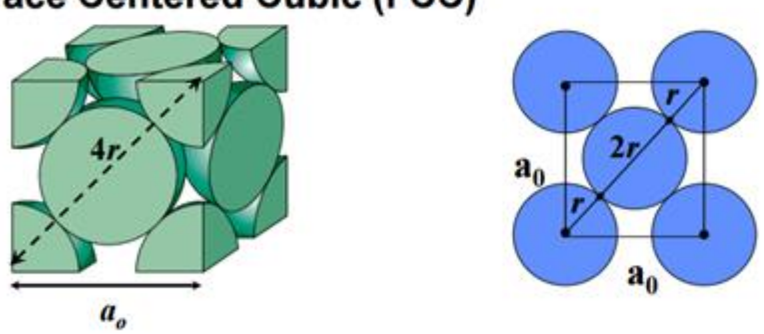
c)

Face Centered Cubic (FCC)



Relation between the lattice parameter a_o and atomic radius

$$(4r)^2 = (a_o)^2 + (a_o)^2$$

$$(4r)^2 = 2\,(a_o)^2 \qquad 4r = \sqrt{2}\,(a_o) \qquad a_o = \frac{4}{\sqrt{2}}\,r$$

(2 marks)

Q6 (cont.)

$$\text{Packing Factor} = \frac{\text{(no. of atoms per unit cell) . (vol. of atom)}}{\text{(vol. of unit cell)}}$$

Number of atoms per unit cell = 4

$$\text{Packing Factor} = \frac{(4)\,.\,(4/3\pi r^3)}{(a_o)^3} = \frac{(4)\,.\,(4/3\pi r^3)}{(\frac{4}{\sqrt{2}}r)^3} = 0.74$$

(*2 marks*)

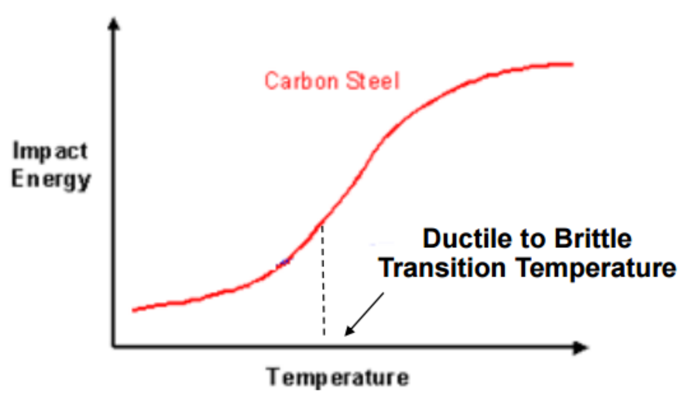
---

d)

Below a critical temperature certain types of metals do not have sufficient energy to deform plastically. ➡ **Brittle failure**

Above this critical temperature the metal get sufficient energy to deform in a plastic manner. ➡ **Ductile Failure**

(*3 marks*)



(*3 marks*)

Q7

a)

<u>Data:</u>

E_{glass} = 80 GPa

$E_{\text{polycarbonate}}$ = 2.1 GPa

Volume fraction of glass fibres (V_f) = 0.5

Volume fraction of polycarbonate (V_m) = 0.5

Rule of mixture for predicting the modulus of modulus of elasticity of the glass/polycarbonate composite along the direction of alignment of glass fibres will be:

$$E_c = v_f E_f + (1 - v_f) E_m$$

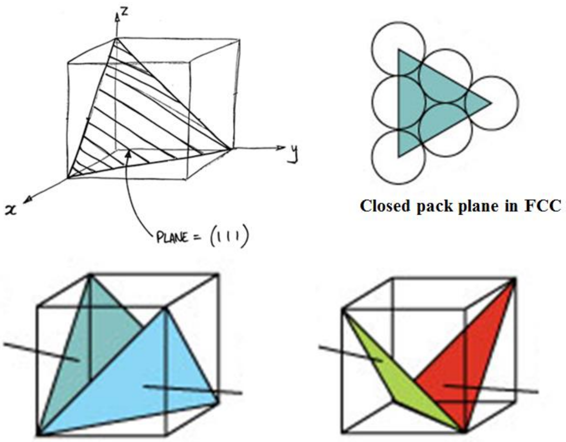
(2 marks)

$$E_c = (0.5)(80\,\text{GPa}) + (1 - 0.5)(2.1\,\text{GPa})$$

$$E_c = 41.05\,\text{GPa}$$

(2 marks)

b) FCC crystals have higher packing density than BCC. The FCC crystal unit cell has four closed pack planes as shown in figure below

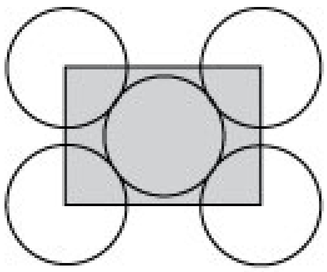


4 closed pack plane and 3 closed pack direction

Dislocation movement on closed pack plane is easier. Hence FCC can easily undergo large dislocation movement t relatively low external stress. This is why FCC metals are ductile but not very strong.

(*3 marks*)

BCC metals have low packing density than FCC; they do not have any closed pack planes; the dislocation must move along nearly closed pack planes as shown below

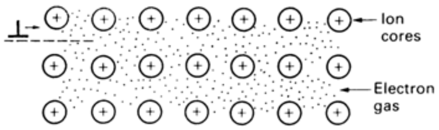


The dislocation movement on this nearly close pack plan is not very smooth and hence the dislocations cannot travel easily in BCC metals. Hence the BCC metals are not as ductile but they are stronger than FCC metals.

(*3 marks*)

Q7 (cont.)

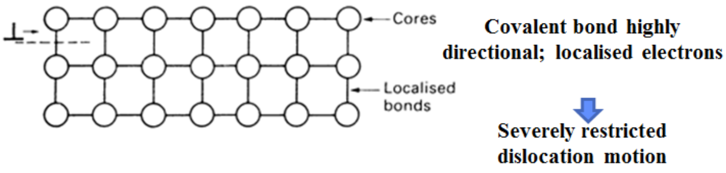
c)

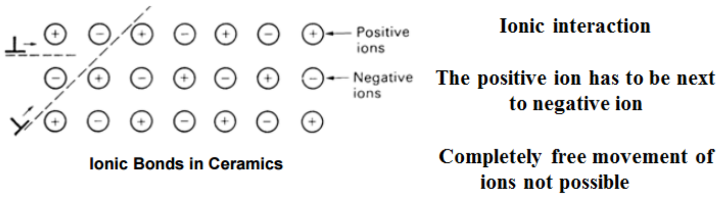


Metallic bond.

Metallic bonds are not directional so it is easy for dislocations to move in metallic crystal; this results in high ductility. The covalent bonds in certain ceramic materials are highly directional which makes motion of dislocation difficult. Similar in ionic bonded ceramic the dislocations movement is restricted due to constrain that the same charge ion cannot come next to each other during the dislocation movement. Hence ceramics materials which mainly have ionic or covalent bond are brittle due to restriction of dislocation movement

(2 marks)



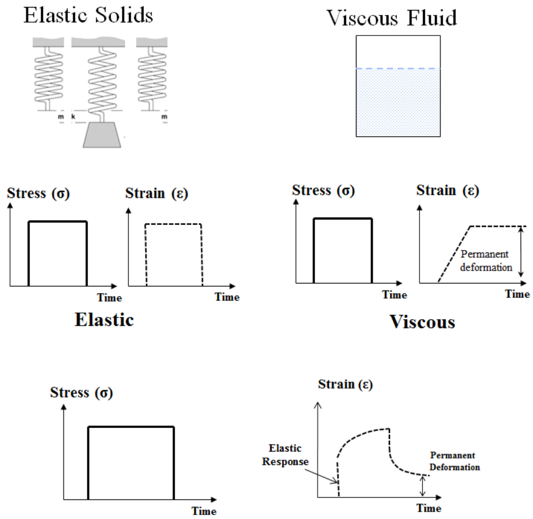


(2 marks)

d)

Viscoelasticity:

Viscoelastic materials are the class of materials which show combination of both solid like as well as liquid like behaviour. When a load is applied viscoelastic material will show an instantaneous deformation (solid like character) followed by a long term deformation as a function of time (liquid like character). After removal of load it will show partly instantaneous recovery followed by slow recovery and there will be a small part of deformation which may not be completely recovered at all. Please refer to the diagram below.



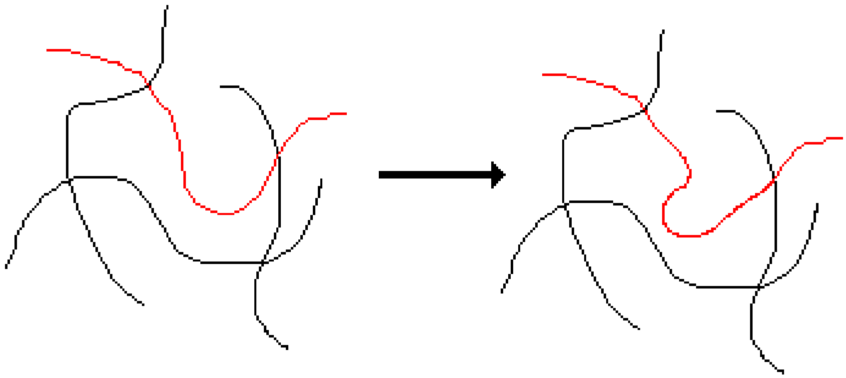
Viscoelastic

(3 marks)

Q7 (cont.)

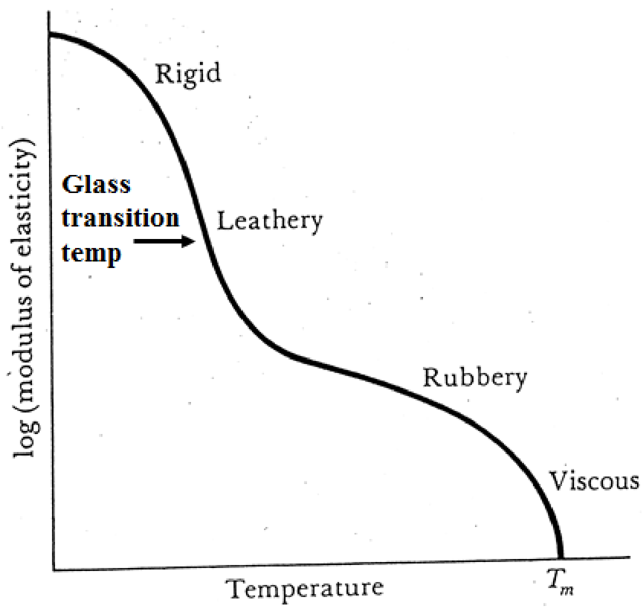
Glass Transition temperature:

Above a critical temperature called glass transition temperature (T_g) the polymer chain gets enough energy for large scale rotational motion as shown by the diagram below.



Below T_g Above T_g

This ability of rotation of polymer chain above a critical temperature results in significant reduction in the mechanical properties of polymer. Hence above the glass transition temperature of a polymer there is a significant reduction in the modulus of the polymer as shown in figure below



The effect of temperature on the modulus of elasticity for an amorphous thermoplastic polymer.

(3 marks)