UNIVERSITY OF BOLTON

FACULTY OF ADVANCED ENGINEERING & SCIENCES

BENG (HONS) MECHANICAL ENGINEERING

GERMAN COHORT

SEMESTER ONE EXAMINATION 2011/2012

STRUCTURES AND MATERIALS

MODULE NO: DMT3012

Date: Thursday, 19 January 2012 **Time: 10.00 a.m. – 1.00 p.m.**

INSTRUCTIONS TO CANDIDATES:

There are FOUR questions on this paper.

Attempt all FOUR questions.

All questions carry equal marks.

Marks for parts of questions are shown in brackets.

NB: Extra information is supplied with this paper: Formulae sheet

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Q1. Consider part of a closed end cylindrical aluminium container as shown in Figure 1. The container is subjected to an internal pressure of 3 MPa and an external torque applied that imparts a stress of 35.22 MPa in the *x-y* plane. If you use a small element to analyse the stresses within the wall of the container:

a) Calculate the hoop stress and longitudinal stress. (2 marks)

b) Draw the element and show the acting stresses. (2 marks)

c) Show the stress tensor of the small element as indicated in Figure 1. (3 marks)

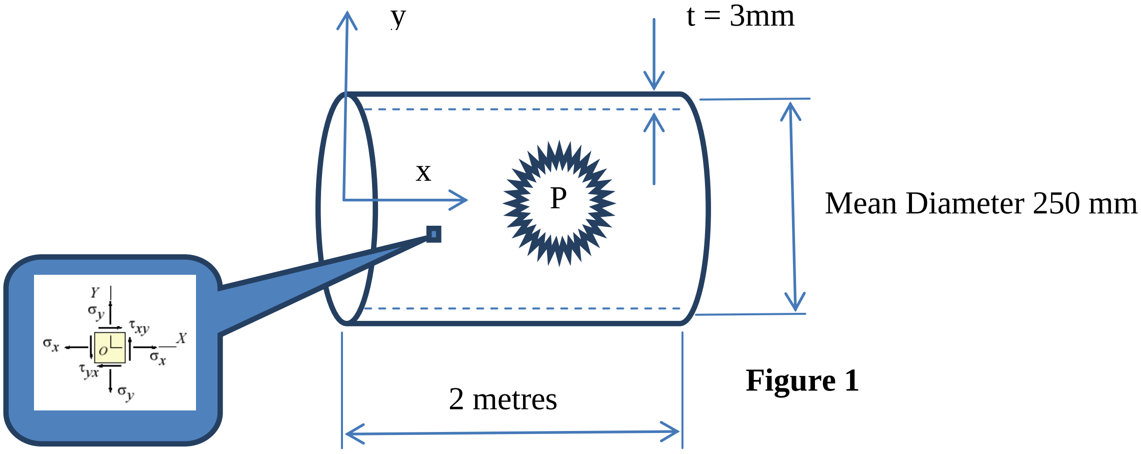

Figure 1

d) Determine the principal stresses and direction cosines by using the eigenvalue method assuming that the stress in the z direction is negligible. (10 marks)

e) Construct Mohr's circle to verify your results. (3 marks)

f) If the yield strength of the material in tension and in shear is 400 MPa and 170 MPa respectively, and you are using a factor of safety of 1.8. Use Tresca and von Mises yield criterion to verify the safety of your design and make recommendations. (5 marks)

Total 25 marks

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Q2. a) What is meant by:

I. The stress concentration factor?
II. The stress intensity factor?
III. The critical stress intensity factor? (3 marks)

b) Describe the effect of yield strength on fracture behaviour. (2 marks)

c) Consider a plate with an edge crack (see figure 2). The plate thickness is such that a plane strain condition is present.

Given: Stress intensity factor $K_I = Y\sigma\sqrt{\pi a}$ where $Y = 1.12$
m = 3, a_o = 2 mm, a_1 = 5 mm, C = 2 x 10^{-31}

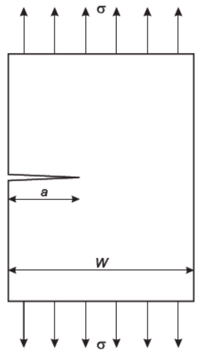

Figure 2

Table 1

Material	yield strength σ_{ys} (N/mm^2)	tensile strength σ_{uts} (N/mm^2)	plane strain fracture toughness K_{Ic} (N/mm$^{3/2}$)
Steel 4340	1470	1820	1500
Maraging steel	1730	1850	2900
Al 7075 -T6	500	560	1040

Answer the next questions given for the three materials in the table 1 above:

I. Does fracture occur at a stress $\sigma = \frac{7}{8}\sigma_{yield}$ and a crack length of $a = 2\ mm$? Show your calculations. (3 marks)

II. What is the critical defect size of a stress $\sigma = \frac{7}{8}\sigma_{yield}$? (3 marks)

III. What is the maximum stress for a crack length $a = 2\ mm$ without permanent consequences? (3 marks)

Question 2 continued over

Question 2 continued

IV. Calculate the number of cycles to extend the crack from a_o to a_1, when the stress applied varies between $\sigma_1 = \frac{7}{8}\sigma_{yield}$ and $\sigma_2 = \frac{1}{2}\sigma_{yield}$

(6 marks)

d) A structural part of about 200 cm thickness is subjected to a tensile load that varies 5 times per minute between 110 and 200 MPa. For the material the following data are known:

- $K_{IC} = 30\ MPa\ m^{\frac{1}{2}}$
- $\Delta K_{th} = 5\ MPa\ m^{\frac{1}{2}}$
- $Paris\ curve\ \frac{da}{dN} = 2\times10^{-11}\left(\Delta K\right)^3$

  $\left(\frac{da}{dN}\ in\ m\ per\ cycle\right)$

I. Based on the data, what can be concluded about the lifetime of the part? (2 marks)

II. Investigations show that after the manufacture of this type of part semi- circular surface cracks may be present. Using NDT techniques it is found that these cracks are at least 2 mm deep. Calculate whether or not there is a risk of crack growth.

(3 marks)

Total 25 marks

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Q3 An extruded aluminium member is shown schematically in figure 3 below. The section is subjected to a torque of 56.5 kNm along its longitudinal axis. For this situation:

a) Determine the maximum stress in the sections and state where this occurs.

(8 marks)

b) Under this torque determine the angle of twist per metre length of section.

(6 marks)

c) Due to a suggested redesign section CD is to be removed from the cross section shown. For this new section determine the maximum shear stress and the percentage increase in the angle of twist per unit length.

(11 marks)

Given:
$t_1 = 0.012$ m, $t_2 = t_3 = 0.006$ m, $t_4 = t_5 = 0.01$ m.

Take G as 28 GPa.

Total 25 marks

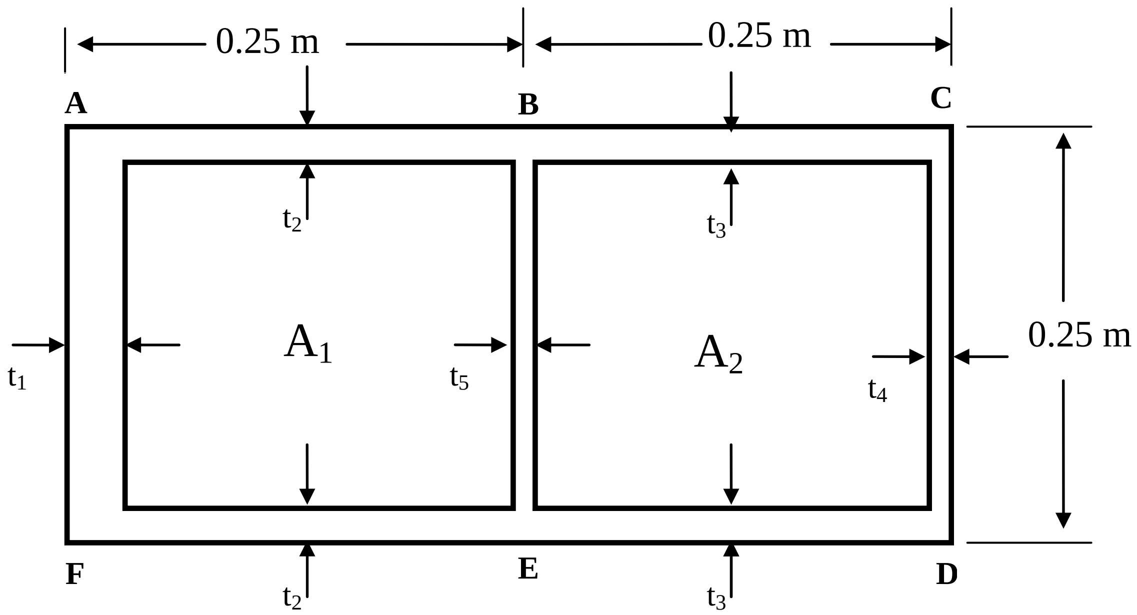

Figure 3

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Q4 A portable military bridge has its main support beams manufactured from glass reinforced plastics with cross section as detailed below in Fig 4.

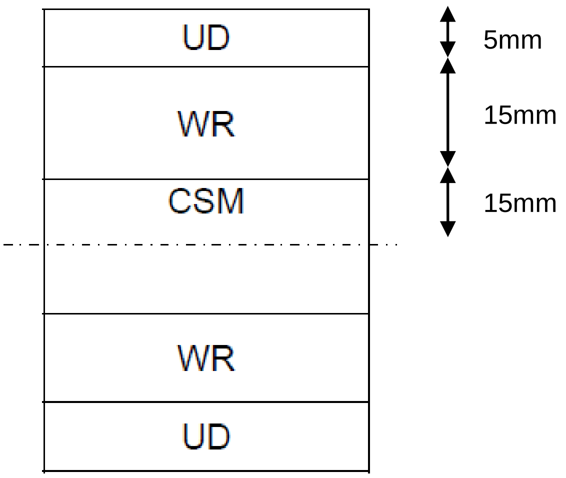


Figure 4

(i) If the bridge must support 6 tonnes over a 1.8m span and each beam is assumed to be 30mm wide and simply supported with the load evenly distributed along its length. Determine for this situation the number of support beams needed if each beam takes the same load. Use the material properties given below in Table 4. (12 marks)

Type	Volume Fraction %	Efficiency Factor	Design Strain %
UD	60	0.9	0.5
Woven Roving(WR)	45	0.5	0.5
CSM (Random Mat)	30	0.2	0.3

Reinforcement (E Glass) with a modulus of 70 GPa and matrix (Polyester) with a modulus of 3 GPa.

Table 4

(ii) Sketch the strain and stress distribution through the beam thickness indicating the salient values. (6 marks)

(iii) If alternatively the Woven roving and CSM part of the beam section is replace by a lightweight core determine the new thickness required for the UD part of the beam assuming the same number of beams are to be used. (7 marks)

Total 25 marks

END OF QUESTIONS

Formulae used in Structures and Materials Module

Elasticity – finding the direction vectors

$$\begin{bmatrix} S_x \\ S_y \\ S_z \end{bmatrix} = \begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix} \begin{pmatrix} l \\ m \\ n \end{pmatrix}$$

$$k = \frac{1}{\sqrt{a^2 + b^2 + c^2}}$$

Where a, b and c are the co-factors of the eigenvalue stress tensor.

$$l = ak \qquad l = \cos\alpha,$$
$$m = bk \qquad m = \cos\theta,$$
$$n = ck \qquad n = \cos\varphi.$$

Principal stresses and Mohr's Circle

$$\tau_{12} = \frac{\sigma_1 - \sigma_2}{2}$$

$$\tau_{13} = \frac{\sigma_1 - \sigma_3}{2}$$

$$\tau_{23} = \frac{\sigma_2 - \sigma_3}{2}$$

Yield Criterion

Von Mises

$$\sigma_{von\ Mises} = \frac{1}{\sqrt{2}}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]^{1/2}$$

Tresca

$$\sigma_3 \geq \sigma_2 \geq \sigma_1$$

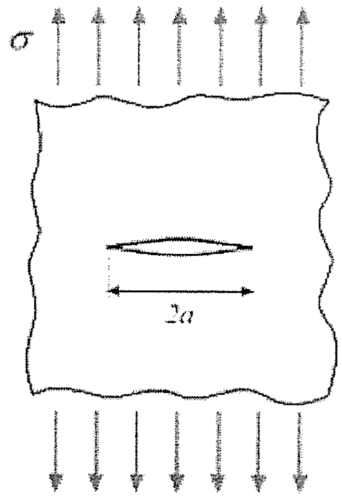
$$\sigma_{tresca} = 2 \cdot \tau_{\max}$$

$$\tau_{\max} = \max\left(\frac{|\sigma_1 - \sigma_2|}{2}; \frac{|\sigma_1 - \sigma_3|}{2}; \frac{|\sigma_3 - \sigma_2|}{2}\right)$$

$$\frac{\sigma_{von\ Mises}}{\sigma_{Tresca}} = \frac{\sqrt{3}}{2}$$

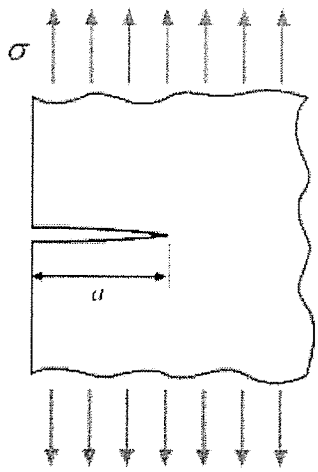
Fracture mechanics

Infinite Plate with a Center Through Crack under Tension



$$K_I = \sigma\sqrt{\pi a}$$

Semi-infinite Plate with an Edge Through Crack under Tension



$$K_I = 1.12\sigma\sqrt{\pi a}$$

Life Calculations

$$\frac{da}{dN} = C\left(\Delta K\right)^m$$

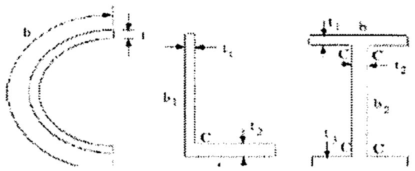
$$N = \frac{1}{CY^m \Delta\sigma^m \pi^{\frac{m}{2}}} \int_{a_0}^{a_1} \frac{da}{a^{\frac{m}{2}}}$$

Composite materials

$$E_{composite} = E_{fibre}V_{fibre} + E_{matrix}\left(1 - V_{fibre}\right)$$

Torsion

Open Section



Shear stress

$$\tau_{max} = \frac{Tt_{max}}{J_\alpha}, \quad J_\alpha = \sum_{i=1}^{n} J_{\alpha,i} = \sum_{i=1}^{n} \alpha b_i t_i^3$$

Twist angle

$$\varphi = \frac{LT}{GJ_\beta}, \quad J_\beta = \sum_{i=1}^{n} J_{\beta,i} = \sum_{i=1}^{n} \beta b_i t_i^3$$

b/t	α	β
1.0	0.208	0.1406
1.2	0.219	0.1661
1.5	0.231	0.1958
2.0	0.246	0.229
2.5	0.258	0.249
3.0	0.267	0.263
4.0	0.282	0.281
5.0	0.291	0.291
10.0	0.312	0.312
∞	0.333	0.333

If $\frac{b}{t} \geq 10$ then $\alpha = \beta = \frac{1}{3}$

and $J_\alpha = J_\beta = J = \sum_{i=1}^{n} \frac{1}{3} b_i t_i^3$

J : torsion constant

n: is the number of branch of the shape.

Shear stress

$$\tau_{max} = \frac{Tt_{max}}{J}$$

Twist angle

$$\varphi = \frac{LT}{GJ}$$

Closed Section

$$\text{shear flow} = q = \tau t$$

$$T = \sum_{i=1}^{N} T_i$$

$$\theta = \frac{1}{2GA_i} \oint_{C_i} \frac{q_i - q'}{t(s)} ds$$