First Semester Examination
2022/2023 Academic Session

February 2023

EMM 331 – Solids Mechanics
(Mekanik Pepejal)

Duration: 3 hours
(Masa: 3 Jam)

Please check that this examination paper consists of EIGHT (8) pages of printed material before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi LAPAN (8) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

Instructions: Answer ALL **FIVE (5)** questions.

*[**Arahan**: Jawab **LIMA (5)** soalan]*

...2/-

1. (a) Figure Q1 (a) shows the stress-strain graph for two materials under tensile test. Their Young's moduli are indicated by E_A and E_B in the graph. Also, materials A and B have elastic limit of 300 N/mm^2 and 500 N/mm^2 respectively. Based on the given data, briefly predict modulus of toughness for both materials and comment on the materials' ability to absorb impact.

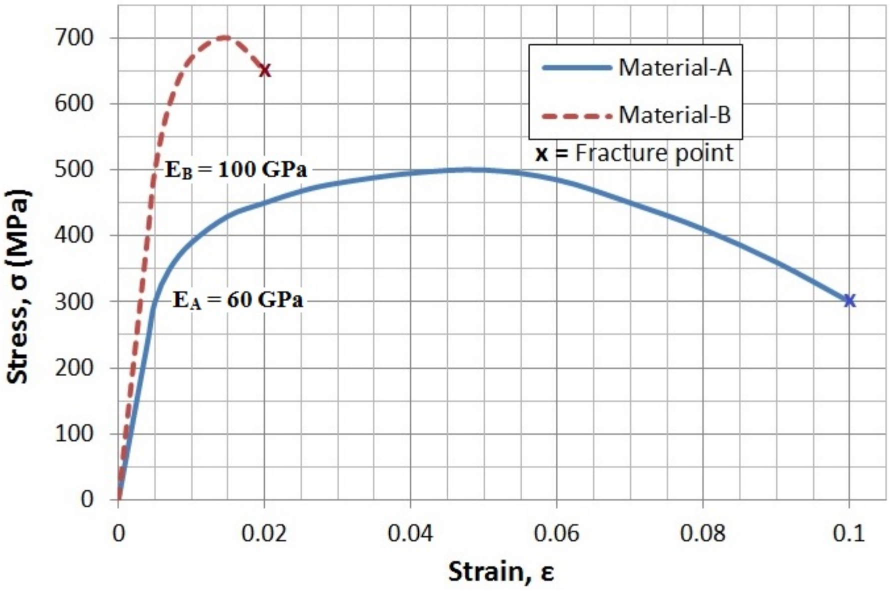

Figure Q1 (a)

(35 marks)

(b) Figure Q1 (b) shows a truss made of steel with E = 200 GPa. The cross-sectional area of member BC is 800 mm^2 and for all other members the cross-sectional area is 400 mm^2. Sketch the necessary free body diagram and determine the horizontal deflection of point D caused by the 60 kN horizontal load.

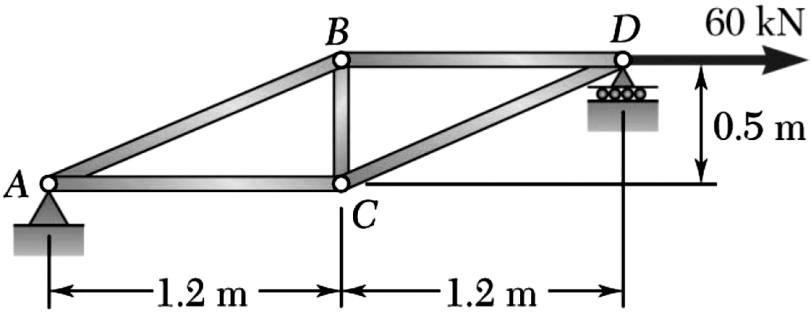

Figure Q1 (b)

(65 marks)

...3/-

2. (a) A cylindrical steel specimen has a Young's modulus of E = 60 GPa and yield stress of σ_o = 300 MPa. The specimen is under stress-controlled test of tension-compression cycle.

(i) Briefly sketch a closed loop stress-strain graph under $\sigma_{max,min} = \pm 500$ MPa and $\varepsilon_{max,min} = \pm 0.03$ for the first cycle, and

(ii) if the steel exhibits a cyclic softening behaviour, briefly sketch a resultant stress-strain graph indicating the change of plastic strain range when the number of cycle increases.

(35 marks)

(b) A block material is subjected to equal compressive stresses in the x- and y-directions and it is confined by a rigid die so that it cannot deform in the z-direction as shown in Figure Q2[b]. Assume that there is no friction against the die and also that the material behaves in an elastic-perfectly plastic with yield stress σ_o.

(i) Determine the stress $\sigma_x = \sigma_y$ necessary to cause yielding, expressing this as a function of σ_o and elastic constants of the material. Use von-Mises yield criterion to solve this problem.

(ii) What is the value of σ_y at yielding if the material is an aluminium alloy with yield strength σ_o = 350 MPa, elastic modulus E = 70.3 GPa and Poisson's ratio υ = 0.35.

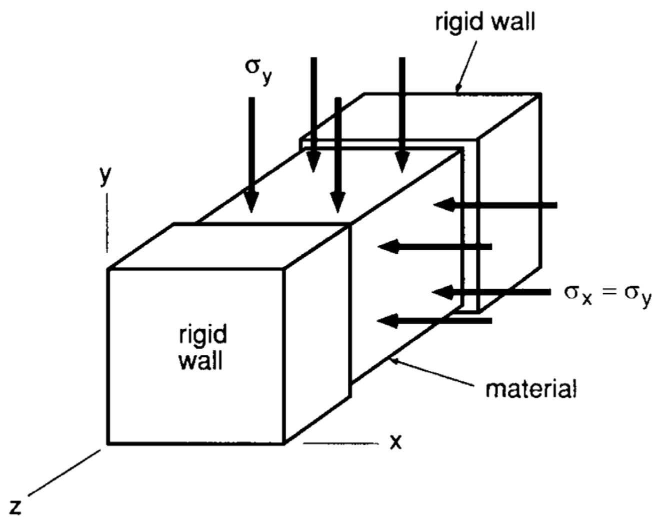

Figure Q2 (b)

(65 marks)

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3. (a) (i) Explain stress concentration concept using flow lines analogy. Also, suggest methods of reducing stress concentration effect for the plate shown in Figure Q3 (a). Please support your answer with sketches.

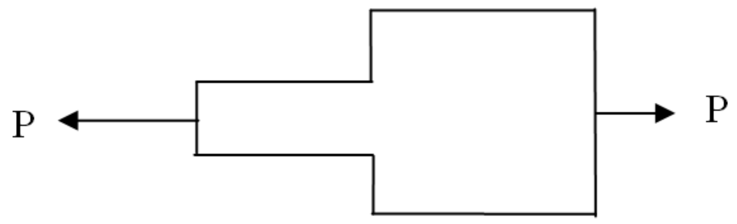

Figure Q3 (a)

(25marks)

(ii) With the help of sketches, give two real examples of structural failures in engineering field and explain their relationship with stress concentration effect.

(25 marks)

(b) Creep tests conducted on an alloy steel at 600 °C produced the following data:

Stress (kN/m^2)	Minimum creep rate (% / 10 000 h)
10.2	0.4
13.8	1.2
25.5	10.0

A rod, 150 mm long and 625 mm^2 in cross-section, made of a similar steel, and operating at 600 °C, is not to creep more than 3.2 mm in 10,000 hours. Determine the maximum axial load which can be applied onto the rod.

(50 marks)

...5/-

4. (a) An unreinforced polymeric pressure vessel is constructed with a diameter d = 0.44 m and a length L = 2 m. The vessel is designed to withstand an internal pressure of P = 7 MPa at a nominal hoop stress of 70 MPa. However, in service the vessel bursts at an internal pressure of only 3.5 MPa, and a failure investigation reveals that the fracture was initiated by a manufacturing-induced semi-circular internal crack 2.5 mm in radius.

(i) Based on the original design criteria, what is the wall thickness of this pressure vessel? Assume that it is a thin-walled vessel for this calculation.

(ii) Calculate the fracture toughness (K_{Ic}) of the material used, given that the semi-circular surface crack has the geometric factor $Y = 1.12\left(\frac{2}{\pi}\right)$.

(iii) Given the following materials to choose among, is it possible for this pressure vessel to meet a leak-before-break criterion at the original design stress without reinforcing the polymer or changing the vessel dimensions?

Material	PMMA	PS	PC	PET	PVC	PP
K_{IC} (MN/m$^{-3/2}$)	1.65	1.1	3.2	5.0	3.8	4.3

(60 marks)

(b) Suppose that a wing component of an aircraft is fabricated from an aluminium alloy that has a fracture toughness of 35 MN/m$^{-3/2}$. It has been determined that the fracture occurs at a stress of 250 MPa when the critical internal crack length is 2.0 mm. For the same component but is made from a different alloy with fracture toughness of 57.5 MN/m$^{-3/2}$ and has an internal crack of 1.5 mm, determine whether fracture will occur at a stress level of 325 MPa. Explain your answer.

(40 marks)

5. (a) A thin cylinder has a diameter of 1.5 m and a wall thickness of 100 mm. The working internal pressure of the cylinder is 15 MPa and K_{IC} for the material is 38 MN/m$^{-3/2}$. Estimate the size of the largest flaw that the cylinder can contain. (Assume that for this physical configuration

$K = \sigma\sqrt{\pi a}$).

Non-destructive testing reveals that no flaw above 10 mm exists in the cylinder. If, in the Paris-Erdogan formula, C = 3 x 10^{-12} (for K in MN/m$^{-3/2}$) and m = 3.8, estimate the number of pressurisation cycles that the cylinder can safely withstand.

(50 marks)

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(b) Figure Q5 (b) shows the S-N curve for 1045 steel and 2024-T6 aluminium. Explain the foundation of the S-N approach in fatigue for metallic materials. Your explanation should include:

(i) Some metals like steel exhibit endurance limit, but some non-ferrous metal such as aluminium do not have endurance limit.

(ii) In some cases, the failure occurs below the endurance limit. Based on your understanding of fracture and material properties, explain the parameter that may cause the failure.

(iii) Present your strategy on how to predict failure due to fatigue load.

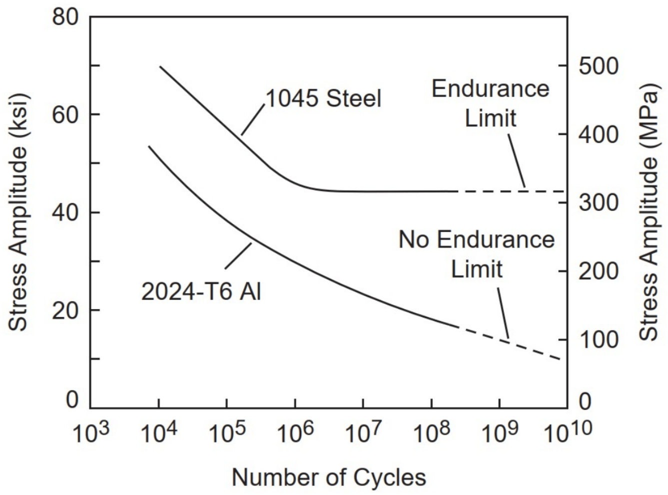

Figure Q5 (b)

(50 marks)

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APPENDIX 1

Selected formulas

Selected theories of failure

Tresca: $\sigma_o = MAX(|\sigma_1 - \sigma_2|, |\sigma_2 - \sigma_3|, |\sigma_3 - \sigma_1|)$

von Mises: $\sigma_o = \frac{1}{\sqrt{2}}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$

Hooke's law for three dimensional strain :

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \nu(\sigma_y + \sigma_z)\right]$$

$$\varepsilon_y = \frac{1}{E}\left[\sigma_y - \nu(\sigma_x + \sigma_z)\right]$$

$$\varepsilon_z = \frac{1}{E}\left[\sigma_z - \nu(\sigma_x + \sigma_y)\right]$$

Basic strain energy formulas

Load category	General Expression for strain energy	Particular case for constant load and geometry	Strain Energy per unit volume
Tension	$\int \frac{F^2}{2AE} dx$	$\frac{F^2 L}{2AE}$	$\frac{\sigma^2}{2E}$
Simple shear	$\int \frac{Q^2}{2AG} dx$	$\frac{Q^2 L}{2AG}$	$\frac{\tau^2}{2G}$
Torsion	$\int \frac{T^2}{2GJ} dx$	$\frac{T^2 L}{2GJ}$	$\frac{\tau_m^2}{4G}$ for circular section
Bending	$\int \frac{M^2}{2EI} dx$	$\frac{M^2 L}{2EI}$	$\frac{\sigma_m^2}{6E}$ for rectangular section

Selected trigonometric applications

Selected Trigonometric identities	Selected Trigonometric integrals
$sin^2\theta = \frac{1}{2}(1 - cos\ 2\theta)$	$\int sin\ x\ dx = -cos\ x + c$
$cos^2\theta = \frac{1}{2}(1 + cos2\theta)$	$\int cos\ x\ dx = sin\ x + c$
$sin\ \theta\ cos\ \theta = \frac{1}{2}\ sin\ 2\theta$	

Selected formulas for stresses for pressurized systems

Hoop stress:	$\sigma_H = \frac{pr}{t}$	for relatively thin wall vessel
Longitudinal stress:	$\sigma_L = \frac{pr}{2t}$	for relatively thin wall vessel
Hoop and Longitudinal stress	$\sigma_H = \sigma_L = \frac{pr}{t}$	for relatively thin spherical vessel

Selected basic formula for fracture and fatigue problems

Stress intensity	$K = Y\sigma\sqrt{\pi a}$; **Y = 1 for infinite problems**
Paris' Law	$\frac{da}{dN} = C(\Delta K)^m$
Life estimates from Paris's Law	$N_f = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m}$

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