First Semester Examination
2023/2024 Academic Session

February 2024

EMM 331 – Solid 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 (6) muka surat yang bercetak sebelum anda memulakan peperiksaan ini.]

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

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

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1. (a) With the help of sketches, answer the following:

   (i) Explain the strain energy concept for a rod subjected to a load.

   (ii) Give one example of a strain energy application in an engineering product and explain how the strain energy concept works.

(30 marks)

(b) Figure 1 (b) shows a curved beam subjected to a load of 500 N at A. If the product of Young's modulus and second moment of area for the beam section is given by EI = 26 kNm^2, calculate the vertical deflection at A.

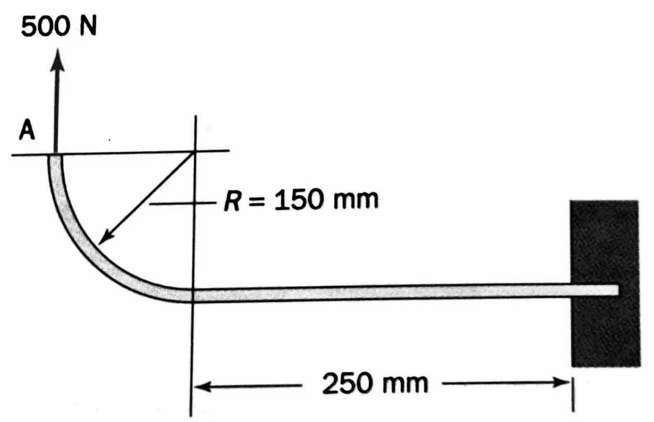

Figure 1 (b)

(70 marks)

2. (a) Two strain-controlled cyclic loading tests were conducted on a metal that has a Young's modulus of 155 GPa and an elastic limit of 200 MPa. The metal is expected to behave in a non-linear plastic deformation, and it will follow the Bauschinger effect behaviour under cyclic loading. The recorded maximum and minimum stress-strain data for the first cycle are given in Table 2 (a).

Table 2 (a)

Test Number	Max.-Min. Strain (%)	Max.-Min. Stress (MPa)
Test 1	± 0.5	± 310
Test 2	± 0.3	± 270

(i) Sketch a closed-loop cyclic stress-strain graph for the first complete cycle of tension-compression-tension loading for each test. Also, indicate the values of the important points of the closed-loop graphs such as the interval points between elastic-plastic deformation and the plastic strain range, $\Delta\varepsilon_{pl}$, of the graph.

...3/-

(ii) If the metal exhibits a low-cycle fatigue behaviour given by the following Coffin-Manson equation:

$$\frac{\Delta\varepsilon_{pl}}{2} = 0.53(2N_f)^{-0.6}$$

calculate the number of cycles to failure N_f, for both tests and briefly comment on the effect of applied strain range values on the predicted N_f.

(50 marks)

(b) In an engineering component, the most severely stressed point is subjected to the following state of stress: σ_x = 14 MPa, σ_y = −56 MPa, σ_z = 70 MPa, and $\tau_{xy} = \tau_{yz} = \tau_{zx}$ = 0 MPa.

(i) Sketch a 3D-Mohr circle to represent the above stress conditions, and

(ii) determine the minimum yield strength required for the material if a safety factor of 2.0 against yielding is required. Employ (a) the maximum shear stress criterion, and (b) the octahedral shear stress criterion.

(50 marks)

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3. (a) Figure 3 (a) shows a steel plate with a hole in the middle of one section of the plate. The plate has two potential areas i.e. at the fillet and at the hole, for failure to initiate due to stress concentration effect.

   (i) Determine the axial force P which can initiate failure at the fillet. (Use Appendix 2 (a) for stress concentration factor K, for a fillet plate section)

   (ii) Analyze the dimension of the steel plate and predict a diameter of the hole which can initiate failure at the hole instead of failure initiation at fillet. (Use Appendix 2 (b) for stress concentration factor K, for a plate with hole section. If the value of 2r/w exceeds 0.5, please assume the value of K between 2.0 and 2.1).

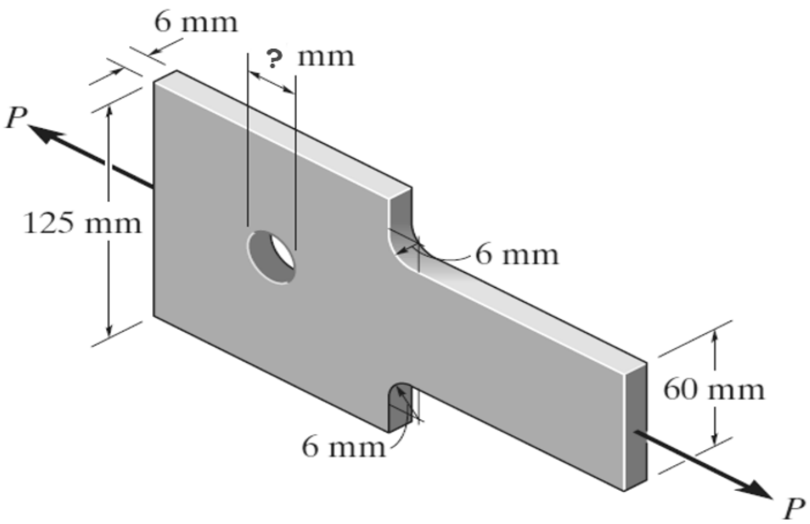

Figure 3 (a)

(50 marks)

(b) Explain the concept of pseudo-elastic design method in creep analysis?

(20 marks)

(c) A long thin-walled pipe constrained by end fittings made of polyvinylchloride is subjected to a steady internal pressure of 700 kN/m^2 at 20^{o}C. If a tensile stress of 17.5 MN/m^2 is not to be exceeded and the internal radius is 100 mm, determine a suitable wall thickness.

What will be the increase in diameter after 1000 hrs?

The mean creep contraction ratio, ν, is 0.45 and the tensile creep curve provides the following values at 1000 hrs.

σ (MN/m^2)	6.9	13.8	20.7	27.6	34.5
ε (%)	0.2	0.48	0.97	1.72	3.38

(30 marks)

4. (a) An elastic stress ahead of a crack as a function of distance from the tip can be graphically represented in Figure 4 (a):

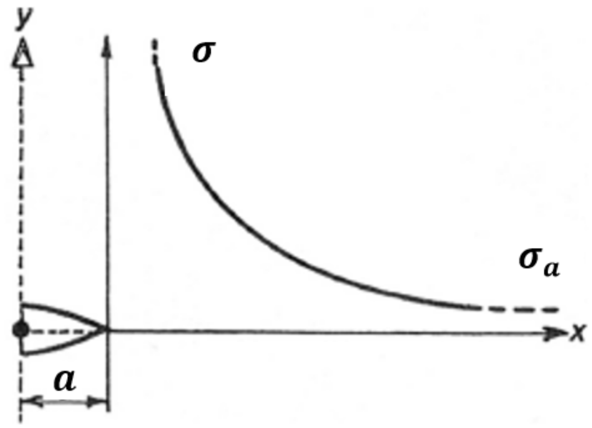

Figure 4 (a)

where a represents a crack that has manifested in an infinite geometry and the curve show a distribution of stress with distance from the tip. Based on a stress distribution in the vicinity of the crack:

$$\sigma = \frac{\sigma_a}{\sqrt{1 - \frac{a^2}{x^2}}}$$

Prove that the stress intensity factor K, is given by:

$$K = \sigma\sqrt{2\pi r}$$

(50 marks)

(b) Suppose that a compact tension specimen is used to measure the fracture toughness of a steel. The specimen has ligament of 100 mm and thickness of 50 mm. The crack length is 53 mm and the fracture load is 59.1 kN. The crack calibration factor is given in the Table 4 (b):

Table 4 (b)

a/W	0.50	0.51	0.52	0.53	0.54
Y	9.60	9.90	10.21	10.54	10.89

(i) Calculate the fracture toughness of the steel if the stress intensity for the compact tension specimen is:

$$K_I = \frac{P}{B\sqrt{W}}Y$$

(ii) If the steel has yield stress of 400 MN/m^2, is the fracture toughness determined in (i) above a valid measurement under LEFM conditions?

(50 marks)

5. (a) A stress-life (S-N) and a micromechanics of fatigue (Paris Law) methods can be used in a fatigue analysis. Discuss the limitation of each method in terms of:

1. Ease of applicability
2. Data availability
3. Life estimates of structures

Suggest a general consensus to the application of the methods in fatigue analysis.

(30 marks)

(b) A series of crack growth tests on a moulding grade polymethyl methacrylate gave the following results as shown in Table 5 (b):

Table 5 (b)

da/dN (x10^{-7})	2.25	4	6.2	11	17	29
ΔK	0.42	0.53	0.63	0.79	0.94	1.17

If the material has a critical stress intensity factor of 1.8 MN/m$^{3/2}$ and yield strength of 70 MN/m^2 and it is known that the moulding process produces defects of 40 μm long (assume it is akin to a crack in an infinite geometrical condition), estimate the maximum repeated tensile stress which could be applied to this material for at least 1x10^6 cycles without causing fatigue failure.

(70 marks)

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APPENDIX 1

Selected formulas
Selected theories of failure

Tresca: $\sigma_1 - \sigma_3 = \sigma_Y$

von Mises: $(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_Y^2$

Stress Invariants:

$$\sigma^3 - \sigma^2 I_1 + \sigma I_2 - I_3 = 0$$

$$I_1 = \sigma_x + \sigma_y + \sigma_z$$

$$I_2 = \sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}^2 - \tau_{yz}^2 - \tau_{zx}^2$$

$$I_3 = \sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{yz}\tau_{zx} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{zx}^2 - \sigma_z\tau_{xy}^2$$

Basic strain energy formulas

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

Selected trigonometric applications

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

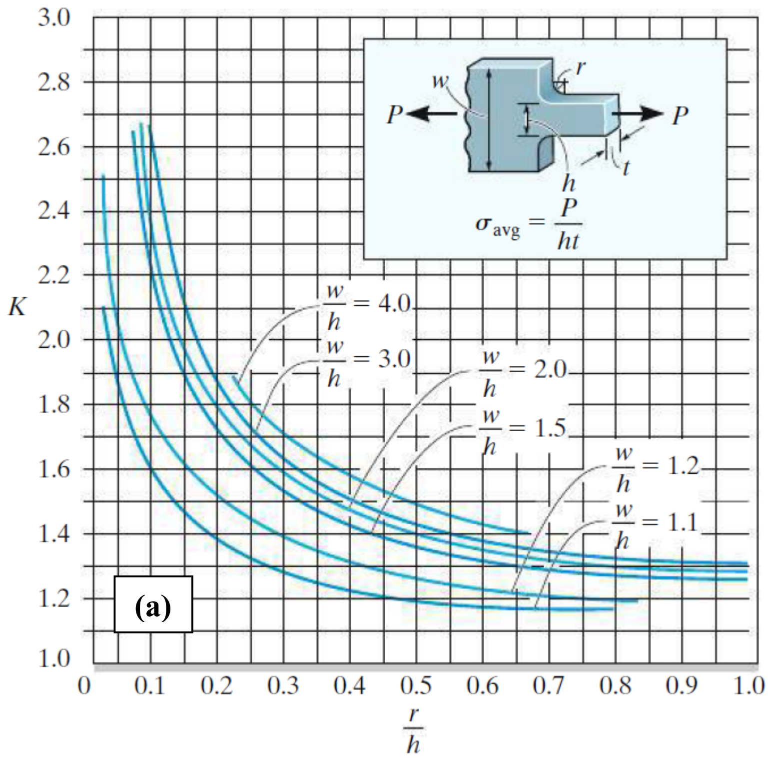
Selected formulas for stresses for pressurized systems

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

APPENDIX 2



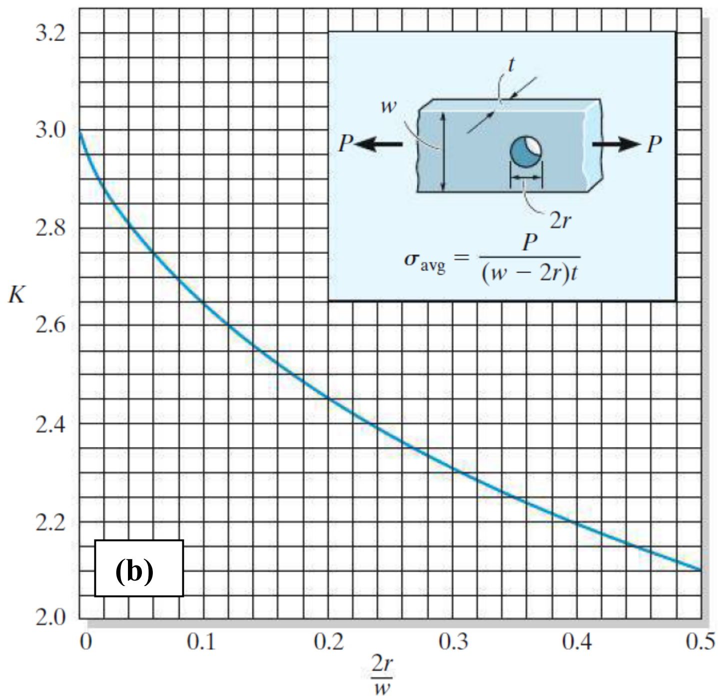


Figure A2 Stress concentration factors for (a) a fillet plate and (b) a plate with a hole.