First Semester Examination
2021/2022 Academic Session

February/March 2022

EMM331 – Solids Mechanics

Duration : 3 hours

Please ensure that this examination paper contains **EIGHT (8)** pages and **FIVE (5)** question before you begin the examination.

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

Answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.

Each question must begin from a new page.

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1. a) With sketches of related diagram, provide answers to the following questions:

    i. Define strain energy density and show it in stress-strain graph.

    ii. Define the benefit of plotting a stress-strain graph instead of a load-displacement graph.

    iii. Define virtual work method and state its benefit in predicting structural deflection.

(30 marks)

b) A curved beam in the shape of a semicircle is illustrated in Figure Q1 (b). The end A is fixed to the ground and the end B is pinned allowing horizontal movement only. A horizontal force F is applied at the free end with F = (300 + XXX) N where XXX is the last three digits of your matric number. Determine the vertical restraining force acting at the beam's end.

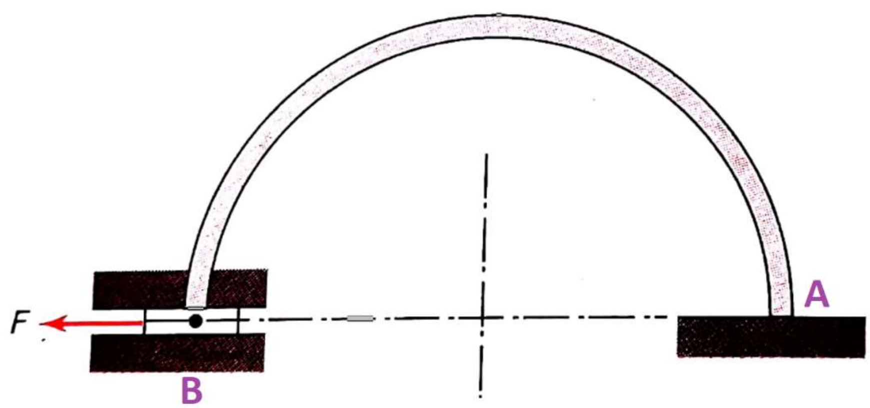

Figure Q1 (b)

(70marks)

2. a) A steel has Young's modulus E and yield point σ_y. With the aid of stress-strain graphs as the responses for strain inputs:

i. compare elastic perfectly plastic and elastic linear hardening deformation model under monotonic loading, and

ii. explain the effect of plastic deformation model to the behavior of the steel when the strain input is removed. Apply elastic perfectly plastic and elastic linear hardening models in separate modelling. Both models have the same value of strain input.

(40 marks)

b) Figure Q2[b] depicts the state of stress acting at a crucial point on a machine element. Determine whether yielding happened for a metal with a yield strength of 130 MPa using both the Tresca and von-Mises criteria. Keep in mind that YY represents the final two digits of your matric number..

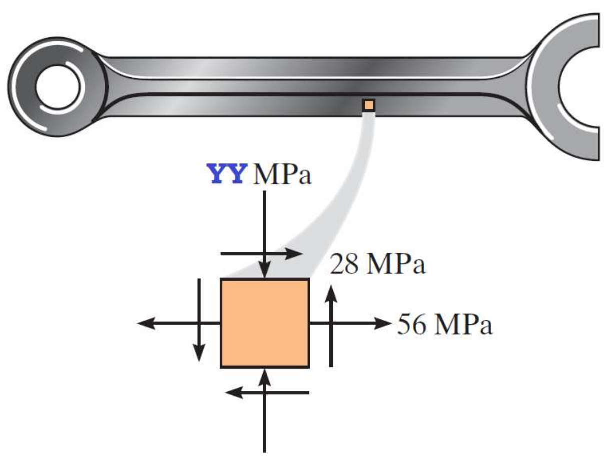

Figure Q2 (b)

(60 marks)

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

(20 marks)

ii. A stepped shaft shown in Figure Q3[a] is to rotate at 900 rpm as it transmits power from a turbine to a generator. The grade of steel specified in the design has an allowable shearing stress of 55 MPa. Determine the maximum power that can be transmitted. Note that X is the last digit of your matric number and please refer to Appendix 1 for related Stress Concentration Factors. (Power, P=2πfT)

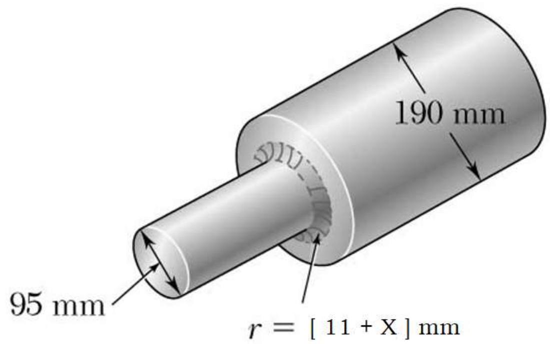

Figure Q3 (a)

(30 marks)

(b) A steel bolt is subjected to an axial load between two rigid plates so the length of the bolt remains constant. The bolt is subjected to an elevated temperature so that creep is produced. What must be the initial stress so that 70% of the stress is retained after ten years, creep constant is 6.0. Reference stress is 7 MPa and steady state creep strain is 4.2×10^{-8}mm/mm per day and elastic modulus is 210 GPa.

Refer to Appendix 2 to develop your answer.

(50 marks)

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4. (a) A riveted plate (304.8 mm and 25.4 mm thick) in a large structure has developed a crack as shown in Figure Q4(a). P is the single force load acting in the centre of the crack having a crack length of $2a$. Use the superposition technique to estimate the stress intensity factor of the crack in the plate.

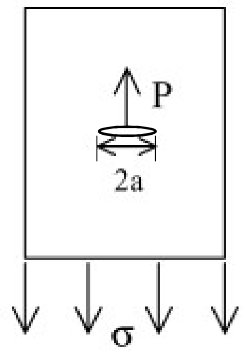

Figure Q4(a)

If the plate is fabricated from maraging steel with a plane strain fracture toughness of 109.0 MPa(m)$^{1/2}$, what is the maximum stress at failure?

Refer to Appendix 2 to develop your answer.

(50 marks)

(b) An engineering structure has been found to contain a crack. To evaluate the effect of crack on the structure, a centre-cracked plate specimen of an identical material to the engineering structure has been used to conduct a structural integrity assessment. The centre-cracked plate has dimensions b = 50 mm, t = 5 mm, and large h; An applied force of P = 50 kN is applied.

i. What is the stress intensity factor K for a half crack length of a = 10 mm?

ii. What is the stress intensity factor K for a half crack length of a = 30 mm?

iii. What is the critical half crack length a_c for fracture if the material is 2014-T651 aluminium with a fracture toughness of 24 MPa (m)$^{1/2}$?

Refer to Appendixes 2 and 3 to develop your answer.

(50 marks)

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5. (a) State the foundation of the S-N approach in fatigue of engineering materials and analyze the Figure Q5 based on these statements:

   i. Endurance limit or fatigue limit is discernibly shown in Steel but not in Aluminium. Explain the mechanics that caused the knee in the Steel curve and the reason of no knee in the Aluminium curve.

   ii. In some cases, structures have been shown to exhibit failure below the endurance limit. Explain the critical condition that may cause failure to occur in materials that have operating stresses below the endurance limit and what can be used to predict failure due to fatigue comprehensively.

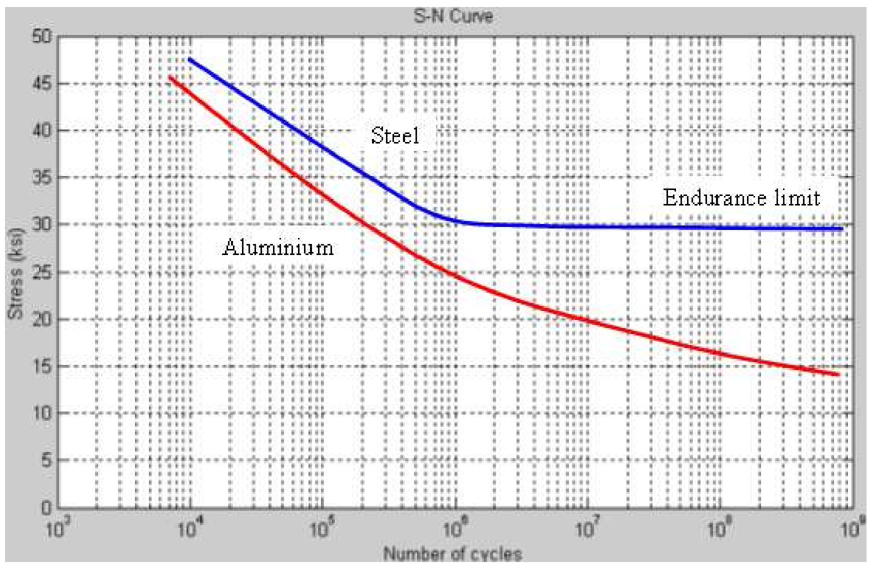


Figure Q5(a)

(50 marks)

(b) A centre-cracked plate of AISI 4340 steel (σ_u = 1296 MPa) has dimensions b = 38 mm and t = 6 mm, and it contains an initial crack of length a_i = 1μmm. The centre-cracked plate is subjected to tension-to-tension cyclic loading between constant values of minimum and maximum force, P_{min} = 40 kN and P_{max} = 120 kN.

   i. At what crack length a_f is failure expected? Is the cause of failure, yielding or brittle fracture?

   ii. How many cycles can be applied before failure occurs? Assume all fatigue crack growth parameters are constants.

Refer to Appendixes 2, 3 and 4 to develop your answer.

(50 marks)

APPENDIX 1

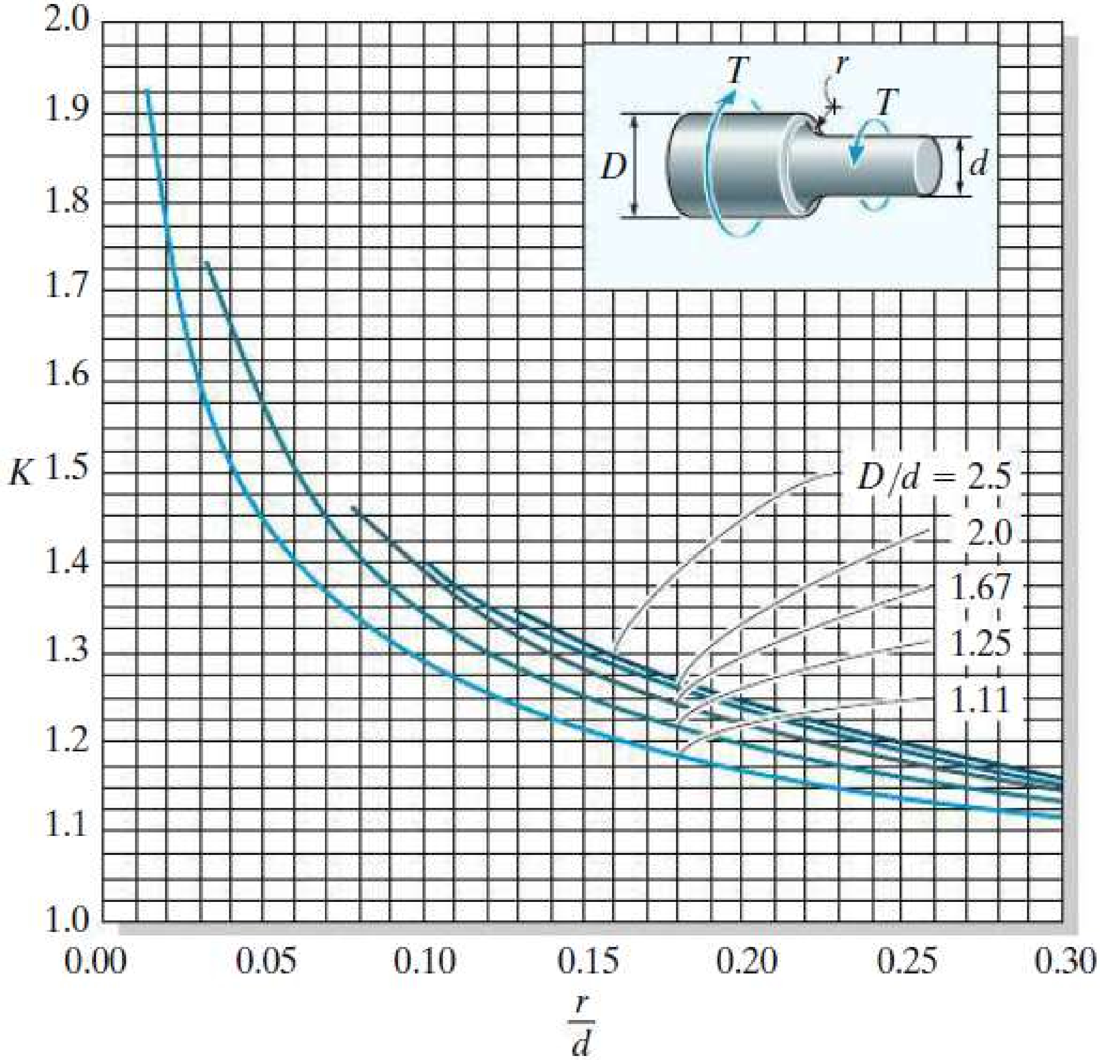


Figure A1 : Stress Concentration factors for fillets in circular shafts.

Selected formulas

Selected theories of failure

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

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

Stress Invariants:

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

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

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

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

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

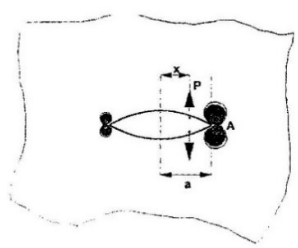
APPENDIX 2

Some basic formulas

(i)	**Steady state creep relationship**
(ii)	**Irwin equation:** $K_I = FS\sqrt{\pi a}$ **for** $F \propto \frac{a}{b}$
(iii)	**Paris' law:** $\frac{da}{dN} = C\Delta K^m$
(iv)	**Walker equation:** $C = C_0/(1-R)^{m(1-\gamma)}$

Stress intensity factor formula for selected geometries

Cracks with surface forces in infinite plate



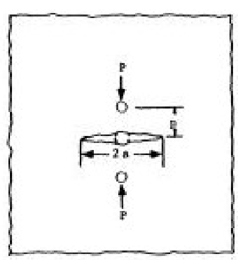
For a single force pair

$$K_{IA} = \frac{P}{\sqrt{\pi a}}\sqrt{\frac{a+x}{a-x}}$$

and for two symmetrical pairs of forces

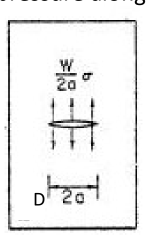
$$K_{IA} = 2P\sqrt{\frac{a}{\pi}}\sqrt{\frac{1}{(a^2-x^2)}}$$

Concentrated Force



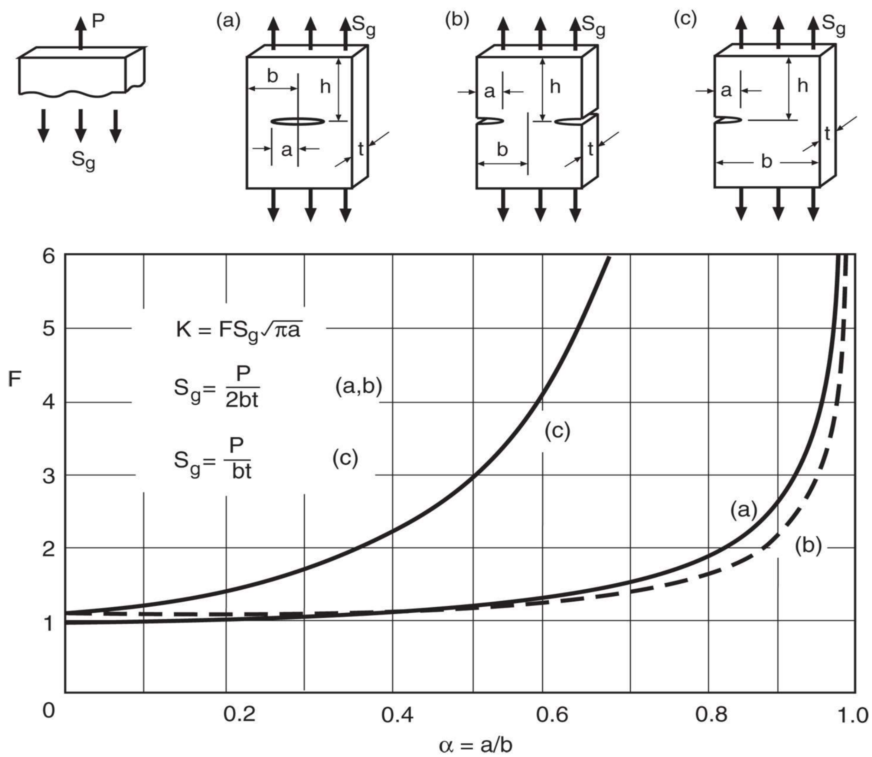
$$K_P\left(\frac{-P\sqrt{\pi a}}{2\pi B}\frac{(3+v)p^2+2a^2}{(a^2+p^2)^{3/2}}\right)$$

Surface pressure along crack flanks



$$K_D = \frac{W}{2a}\sigma\sqrt{\pi a}$$

APPENDIX 3



Expression for K-Calibration factors for geometries shown above.

(a)	$F = \dfrac{1 - 0.5\alpha + 0.326\alpha^2}{\sqrt{1-\alpha}}$	$\left(\dfrac{h}{b} \geq 1.5\right)$
(b)	$F = \left(1 + 0.122\cos^4\dfrac{\pi\alpha}{2}\right)\sqrt{\left(\dfrac{2}{\pi\alpha}\tan\left(\dfrac{\pi\alpha}{2}\right)\right.}$	$\left(\dfrac{h}{b} \geq 2\right)$
(c)	$F = 0.265(1-\alpha)^4 + \dfrac{0.857 + 0.265\alpha}{(1-\alpha)^{3/2}}$	$\left(\dfrac{h}{b} \geq 1\right)$

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APPENDIX 4

Constants for the Walker Equation for Several Metals

Material	Yield	Toughness	Walker Equation				
	σ_o	K_{Ic}	C_0	C_0	m	γ	γ
	MPa (ksi)	MPa $\sqrt{m}$ (ksi$\sqrt{in}$)	$\frac{mm/cycle}{(MPa\sqrt{m})^m}$	$\frac{in/cycle}{(ksi\sqrt{in})^m}$		$(R \geq 0)$	$(R < 0)$
Man-Ten steel	363 (52.6)	200[1] (182)	3.28×10^{-9}	1.74×10^{-10}	3.13	0.928	0.220
RQC-100 steel	778 (113)	150[1] (136)	8.01×10^{-11}	4.71×10^{-12}	4.24	0.719	0
AISI 4340 steel ($\sigma_u = 1296$ MPa)	1255 (182)	130 (118)	5.11×10^{-10}	2.73×10^{-11}	3.24	0.420	0
17-4 PH steel (H1050, vac. melt)	1059 (154)	120[1] (109)	3.29×10^{-8}	1.63×10^{-9}	2.44	0.790	—