UNIVERSITI SAINS MALAYSIA

First Semester Examination
2011/2012 Academic Session

January 2012

EMM 331/3 – Solid Mechanics
[Mekanik Pepejal]

Duration : 3 hours
Masa : 3 jam

INSTRUCTIONS TO CANDIDATE:
ARAHAN KEPADA CALON:

Please check that this paper contains **SIX (6)** printed pages, **FOUR (4)** pages appendix and **SIX (6)** questions before you begin the examination.
Sila pastikan bahawa kertas soalan ini mengandungi ***ENAM (6)*** *mukasurat bercetak,* ***EMPAT (4)*** *mukasurat lampiran dan* ***ENAM (6)*** *soalan sebelum anda memulakan peperiksaan.*

Answer **ALL** questions.
Jawab ***SEMUA*** *soalan.*

Appendix/*Lampiran :*

1. Selected Formulas in Solid Mechanics [1 page/mukasurat]
2. Stress Concentration Factor for Shaft [1 page/mukasurat]
3. K-calibration factors [1 page/mukasurat]
4. Isometric Creep Curves for Acetal [1 page/mukasurat]

You may answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.
Calon boleh menjawab semua soalan dalam ***Bahasa Malaysia*** *ATAU* ***Bahasa Inggeris*** *ATAU kombinasi kedua-duanya.*

Answer to each question must begin on a new page.
Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru.

In the event of any discrepancies, the English version shall be used.
Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai.

Q1. [a] Provide BRIEF answers to the following questions:

(i) Define strain energy and explain, with the help of sketches, the difference between elastic and plastic strain energy in elastic and plastic deformation.

(ii) State the limitations of Castigliano's second theorem.

Berikan jawapan-jawapan RINGKAS bagi soalan-soalan berikut:

(i) Takrifkan tenaga terikan dan terangkan dengan bantuan lakaran-lakaran perbezaan di antara tenaga terikan elastik dan plastik di dalam deformasi elastik dan plastik.

(ii) Nyatakan batasan-batasan teorem kedua Castigliano.

(30 marks/*markah*)

[b] Determine the vertical deflection at the point of loading of the curved beam with the fixed supports as depicted in Figure Q1[b]. Assume EI constant and G = 0.4E. State any assumptions that you take in solving the problem.

Tentukan anjakan menegak pada titik beban p bagi rasuk melengkung tetap seperti yang tertera di dalam Rajah S1[b]. Andaikan EI malar dan G = 0.4E. Berikan sebarang andaian lain untuk anda menyelesaikan masalah ini.

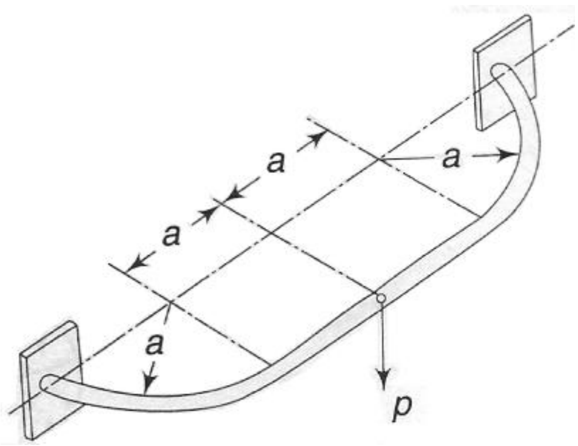

Figure Q1[b]
Rajah S1[b]

(70 marks/*markah*)

Q2. [a] (i) Explain, with the aid of a sketch, why the Tresca criterion is generally considered more conservative than the von Mises criterion.

(ii) State THREE (3) reasons why the Tsai-Hill failure criterion is used to analyze fibre-composite laminates.

(i) Terangkan dengan bantuan lakaran mengapa kriteria Tresca biasanya dianggap lebih konservatif daripada kriteria von Mises.

(ii) Nyatakana TIGA (3) sebab mengapa kriteria kegagalan Tsai-Hill digunakan untuk menganalisa laminat rencam gentian.

(30 marks/*markah*)

[b] An aluminum alloy tube with 50 mm and 40 mm outside and inside diameters respectively, is being assembled into a structure. Due to misalignment, it is subjected to a torque about the longitudinal axis of 2.5 kNm and a tensile force of 50 kN. It was discovered that the line of application of the tensile force was parallel to the axis of the tube but offset from it by 5 mm as shown in Figure Q2[b] which causes additional stress due to bending moment. Determine whether this offset *e* will cause failure of the tube according to the von Mises criterion. Assume the failure stress of the alloy in simple tension is 310 MN/m^2.

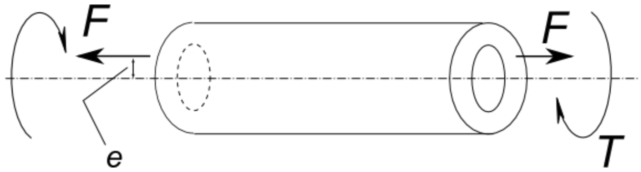

Figure Q2[b]
Rajah S2[b]

Sebatang tiub aloi aluminum yang bergaris pusat luar dan dalam masing-masing 50 mm dan 40 mm dipasang untuk membentuk suatu struktur. Disebabkan oleh salah jajaran, ia mengalami kilasan 2.5 kNm pada paksinya serta daya tegangan 50 kN. Siasatan menunjukkan bahawa garis daya tegangan yang dikenakan adalah selari dengan paksi tiub tetapi terdapat ofset darinya sebanyak 5 mm yang memberi tegasan tambahan akibat daripada momen lentur. Tentukan samada ofset ini akan menyebabkan kegagalan tiub berdasarkan kriteria von Mises. Andaikan tegasan kegagalan aloi itu bagi tegangan ringkas ialah 310 MN/m^2.

(70 marks/*markah*)

Q3. [a] Consider a plate with a hole under axial tension:
(i) indicate the location with the highest tensile stress,
(ii) explain, with the help of a sketch or an equation, why the highest stress concentration develops at this location.

Pertimbangkan plat yang mempunyai lubang dan mengalami tegangan paksi:
(i) tunjukkan lokasi di mana tegasan tegangan paling tinggi,
(ii) terangkan, dengan bantuan lakaran atau persamaan, mengapa tumpuan tegasan tertinggi terbentuk pada lokasi ini.

(30 marks/*markah*)

[b] A shaft is stepped from 50 mm diameter to 40 mm diameter through a fillet of 2.4 mm radius. A gear wheel is keyed to the larger diameter of the shaft. Assume K_{ts} for standard keyways as 2.6 for torsion. Refer to Appendix 2 for the stress concentration data for fillet.

(i) Determine the maximum torque that can be transmitted if the steel has a shear stress limit of 200 MN/m^2.

(ii) Determine the minimum radius of the fillet such that the maximum torque is limited by the shear stress at the keyway.

Sebatang syaf membentuk tingkat dari garis pusat 50 mm kepada 40 mm melalui kambi berjejari 2.4 mm. Sebuah roda gear dikunci pada bahagian syaf paling besar. Andaikan K_{ts} bagi alur kunci adalah 2.6 bagi kilasan. Rujuk Lampiran 2 bagi data tumpuan tegasan bagi kambi.

(i) Tentukan kilasan maksimum yang boleh dikenakan jika had tegasan ricih ialah 200 MN/m^2.

(ii) Tentukan jejari kambi minimum di mana kilasan maksimum adalah dihadkan oleh tegasan ricih pada alur kunci.

(70 marks/*markah*)

Q4. [a] Evaluate the connection between the energetics of crack advance and stress intensity approaches to fracture mechanics in terms of G and K. Based your explanations assuming crack is infinite in all spatial dimensions.

Jelaskan hubungan di antara kaedah tenaga kemaraan rekahan dan keamatan tegasan dalam mekanik kepatahan melalui terma G dan K. Penerangan boleh didasarkan dengan anggapan rekahan adalah tidak terhingga pada semua skala dimensi.

(50 marks/*markah*)

[b] Suppose that a compact tension specimen is used to measure the fracture toughness of steel. The specimen has dimensions W = 40 mm and B = 20 mm. The crack length was 18.5 mm and the fracture load was 15 kN. Refer to Appendix 3 for K-calibration factors.

(i) Calculate the fracture toughness of the steel
(ii) If the steel has yield stress of 800 MPa, was this a valid measurement assuming LEFM conditions applies.

Andaikan suatu spesimen tegangan kompak digunakan untuk mengukur keliatan kepatahan bahan keluli. Spesimen tersebut berukuran W = 40 mm dan B = 20 mm. Panjang rekahan adalah 18.5 mm dan beban kepatahan adalah 15 kN. Rujuk Lampiran 3 untuk faktor kalibrasi-K.

(i) Hitungkan keliatan kepatahan keluli tersebut
(ii) Sekiranya keluli itu mempunyai tegasan alah 800 MPa, adakah keliatan kepatahan yang diukur adalah sah sekiranya keadaan LEFM digunakan.

(50 marks/*markah*)

Q5. [a] Consider the statement:
"The S-N curves, Miners rule and Paris's Law are approaches that can be used to infer integrity of structures under the influence of fatigue failures". Briefly explain each approach and rank the conservatism of each approach base on quantification of failure.

Pertimbangkan kenyataan:
"Lengkung S-N, peraturan Miners dan hukum Paris adalah kaedah yang boleh digunakan dalam mengkaji kewibawaan struktur di bawah pengaruh kegagalan lesu". Terangkan setiap kaedah dan susun kedudukan setiap kaedah mengikut perkiraan kegagalan yang konservatif.

(30 marks/*markah*)

[b] Consider a body, large enough to be considered infinite in lateral dimension, containing a central through-thickness crack initially of length 2a_o and subjected to a cyclic stress of amplitude Δσ. Using the Paris Law, show that the number of cycles N_f needed for the crack to grow to a length 2a_f is given by the relation

$$\ln\left(\frac{a_f}{a_o}\right) = A(\Delta\sigma)^2\,\pi\,N_f$$

when m = 2, and for other values of m

$$\left|{a_f}^{1-\frac{m}{2}} - a_o^{1-m/2}\right| = \left(2 - \frac{m}{2m}\right) A(\Delta\sigma)^m \pi^{\frac{m}{2}} N_f$$

Use the expression developed above to compute the number of cycles a steel component can sustain before failure, where the initial crack half length is 0.1 mm and the critical crack half length to cause fracture is 2.5 mm. The stress amplitude per cycle is 950 MPa. Take the crack to be that of a central crack in an infinite plate and m is 4 and *A* is 0.15e-11.

Pertimbangkan suatu badan yang cukup besar untuk dianggap infiniti pada arah dimensi sisi mengandungi suatu rekahan tembus sepanjang 2a_o dikenakan beban tegasan beramplitud Δσ. Menggunakan hukum Paris, tunjukkan hubungan bilangan kitar yang diperlukan untuk panjang rekahan membesar menjadi 2a_f di beri oleh:

$$ln\left(\frac{a_f}{a_o}\right) = A(\Delta\sigma)^2\,\pi\,N_f$$

untuk m = 2 dan untuk lain-lain nilai m:

$$\left|{a_f}^{1-\frac{m}{2}} - a_o^{1-m/2}\right| = \left(2 - \frac{m}{2m}\right) A(\Delta\sigma)^m \pi^{\frac{m}{2}} N_f$$

Gunakan perkaitan di atas untuk mencari jumlah kitar beban suatu komponen keluli dapat menampung sebelum mengalami kegagalan. Panjang setengah rekahan awal ialah 0.1 mm dan panjang setengah rekahan akhir ketika gagal ialah 2.5 mm. Amplitud beban tegasan per kitar ialah 950 MPa. Andaikan rekahan adalah rekahan pada plat infiniti and m ialah 4 dan A ialah 0.15e-11.

(70 marks/*markah*)

Q6. [a] In each of the following cases, answer 'True' or 'False'. Explain the reasons for your conclusion in each case.

(i) Creep rupture strength is the most desirable property for bolts which are required to operate at high temperature.

(ii) High work hardening materials are much better suited for design of structures that undergo creep loading compared to low work hardening materials.

Bagi setiap kes yang dikemukakan, jawab 'Benar' atau 'Salah'. Terangkan alasan bagi setiap kesimpulan.

(i) Kekuatan rayapan pecah ialah sifat yang amat penting bagi bolt yang beroperasi pada suhu tinggi.

(ii) Bahan yang mempunyai peliatan kerja yang tinggi adalah lebih baik untuk rekabentuk struktur yang mengalami beban rayapan berbanding bahan peliatan kerja rendah.

(30 marks/*markah***)**

[b] A pressure vessel is subjected to an internal pressure of 0.7 MN/m^2. Suppose the inner and outer diameter of the vessel is 60 mm and 61 mm respectively. Assuming a failure criterion based on von Mises, calculate how long the vessel may be regarded as serviceable. Assume the vessel is Acetal and creep curves for Acetal is given in the Appendix 4 and the applied equivalent strain is not to exceed 2% .

Suatu kebuk tekanan dikenakan tekanan dalaman sebanyak 0.7 MN/m^2. Andaikan garispusat dalaman dan luaran kebuk adalah 60 mm dan 61 mm. Andaikan kriteria kegagalan didasarkan kepada von Mises, hitungkan masa kebuk dapat berfungsi. Andaikan kebuk dibuat daripada Asetal dan lengkung rayapan Asetal diberikan dalam Lampiran 4 dan terikan setara yang dikenakan tidak melebihi 2%.

(70 marks/*markah***)**

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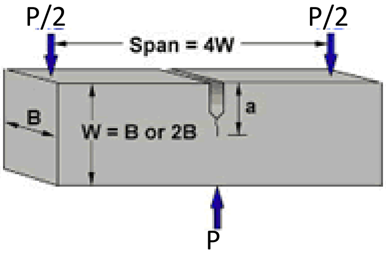
APPENDIX 3/*LAMPIRAN 3*

K-calibration factors

Nondimensional K_I solutions for through thickness-thickness cracks based on general formulation:

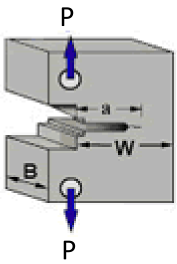
$$f\left(\frac{a}{W}\right) = \frac{K_I B\sqrt{W}}{P}$$

Bend bar in bending



$$\frac{3\left(\frac{S}{W}\right)\sqrt{\frac{a}{W}}}{2\left(1+2\left(\frac{a}{W}\right)\right)\left(1-\frac{a}{W}\right)^{1.5}} \left[1.99 - \left(\frac{a}{W}\right)\left(1-\frac{a}{W}\right)\left\{2.15 - 3.93\left(\frac{a}{W}\right) + 2.7\left(\frac{a}{W}\right)^2\right\}\right]$$

Compact tension specimen



$$\frac{2+\frac{a}{W}}{\left(1-\frac{a}{W}\right)^{\frac{3}{2}}}\left[0.886 + 4.64\left(\frac{a}{w}\right) - 13.32\left(\frac{a}{W}\right)^2 + 14.72\left(\frac{a}{W}\right)^3 - 5.60\left(\frac{a}{W}\right)^4\right]$$

APPENDIX 2/*LAMPIRAN 2*

Stress Concentration for the torsion in a shaft with a shoulder fillet

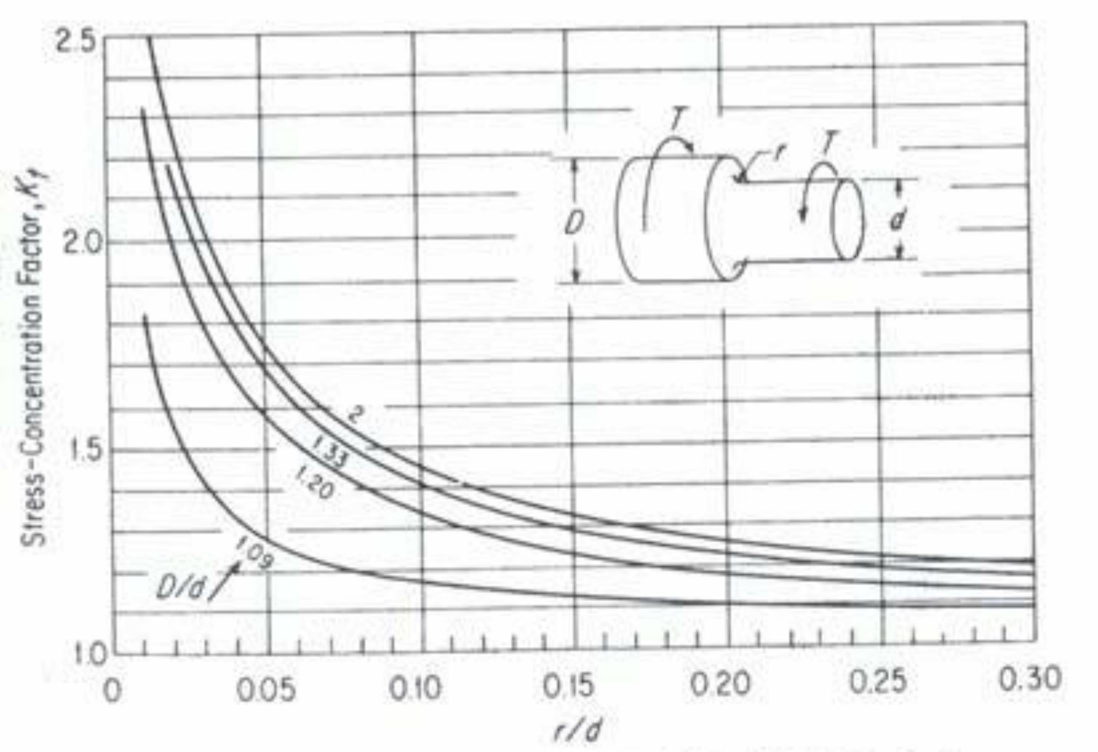


Fig. 4. Stress-concentration factor, K_t, for a filleted shaft in torsion*

APPENDIX 1/*LAMPIRAN 1*

Selected Formulas in Solid Mechanics

Theories of failures:

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

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

Principal stresses:

$$\sigma_1 = \frac{\sigma_x + \sigma_y}{2} + \left[\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2\right]^{1/2}$$

$$\sigma_2 = \frac{\sigma_x + \sigma_y}{2} - \left[\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2\right]^{1/2}$$

Strain energy *U* due to bending to moment *M*:

$$U = \int_0^L \frac{M^2}{2EI} dx$$

Castigliano's Theorem -- Deflection of beam due to load *P*:

$$\Delta_v = \int_0^L \frac{M}{EI} \frac{\partial M}{\partial P} dx$$

Integral of $\sin^2\theta$ and $\cos^2\theta$:

$$\int \sin^2 \theta d\theta = \frac{\theta}{2} - \frac{1}{4}\sin 2\theta + C \qquad \int \cos^2 \theta d\theta = \frac{\theta}{2} + \frac{1}{4}\sin 2\theta + C$$

$$\int_0^{\pi/2} \sin^2 \theta d\theta = \int_0^{\pi/2} \cos^2 \theta d\theta = \frac{\pi}{4}$$

Other useful Integral:

$$\int \frac{1}{x}\, dx = \log_e x + C$$

Shear stress in shaft:

$$\tau = \frac{16T}{\pi d^3}$$

Shear stress in hollow cylinder:

$$\tau_{tx} = \frac{T}{2\pi r_{avg}^2 t}$$

Hoop and longitudinal stresses for thin wall pressure vessels:

$$\sigma_{\theta\theta} = \frac{Pd}{2t} \approx \sigma_2$$

$$\sigma_{rr} = \frac{Pd}{4t} \approx \sigma_1$$

Area moment of inertia for cylinder: $I = \pi r^4/4$

Polar moment of inertia for cyliner: $J = \pi r^4/2$

APPENDIX 4/*LAMPIRAN 4*

Isometric Creep Curves for Acetal