UNIVERSITI SAINS MALAYSIA

First Semester Examination
2013/2014 Academic Session

December 2013/January 2014

# EMM 331 – Solid Mechanics
## *[Mekanik Pepejal]*

Duration : 3 hours
*[Masa : 3 jam]*

Please check that this paper contains **SEVEN (7)** printed pages and **FIVE (5)** questions before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **TUJUH (7)** mukasurat bercetak dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.]*

**INSTRUCTIONS :** Answer **ALL** questions. You may answer all questions in **English** OR **Bahasa Malaysia** OR a combination of both.

*[**ARAHAN :** Jawab **SEMUA** soalan. Calon boleh menjawab semua soalan dalam **Bahasa Malaysia** ATAU **Bahasa Inggeris** ATAU kombinasi kedua-duanya.]*

**Appendix**/Lampiran: [2 page/mukasurat]

1. Formulas for Solid Mechanics
2. Stress-concentration factors graphs

Answer to each question must begin from 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] With the help of sketches, provide brief answers to the following questions:**

**(i) Define strain energy and explain the difference between elastic and plastic strain energy in elastic-plastic deformation.**

**(ii) Distinguish between modulus of toughness and modulus of resilience.**

*Dengan bantuan lakaran, berikan jawapan ringkas bagi soalan di bawah:*

*(i) Takrifkan tenaga terikan dan terangkan perbezaan antara tenaga terikan elastik dan plastik dalam perubahan elastik-plastik.*

*(ii) Bezakan antara modulus keliatan dan modulus kebingkasan.*

(**40 marks**/*markah*)

**[b] A cantilever beam supports a uniformly distributed load W and a concentrated load P as shown in Figure Q1[b]. Knowing that L = 2 m, w = 4 kN/m, P = 6 kN and EI = 5 MNm$^2$, determine the deflection at A using Castigliano's theorem.**

*Sebuah rusuk julur menyokong beban teragih sekata W dan beban terpumpun P seperti ditunjuk pada Rajah S1[b]. Sekiranya diketahui L = 2 m, w = 4 kN/m, P = 6 kN dan EI = 5 MNm$^2$, tentukan lenturan pada A menggunakan teorem Castigliano.*

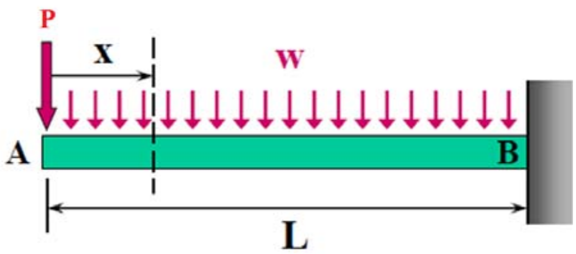



**Figure Q1[b]**
*Rajah S1[b]*

(**60 marks**/markah)

**Q2. [a] A steel has shown a cyclic softening behaviour under a tension-compression test at high temperature. With the aid of stress-strain graphs,**

**(i) explain basic parameters of stress-strain graph, under cyclic plasticity behaviour, such as stress, strain and plastic strain range, and**

**(ii) describe the cyclic softening behaviour of the steel under a strain-controlled and a stress-controlled test.**

*Keluli 9Cr1Mo menunjukkan sifat pelembutan berkitar dalam ujikaji tegangan-mampatan pada suhu tinggi. Dengan bantuan graf terikan-tegasan,*

*(i) terangkan parameter-parameter asas daripada graf terikan-tegasan, yang berada dibawah sifat plastik berkitar, seperti julat tegasan, terikan dan terikan plastik, dan*

*(ii) berikan gambaran sifat pelembutan berkitar bagi keluli berkenaan dalam keadaan ujikaji terikan terkawal dan ujikaji tegasan terkawal.*

(**40 marks**/*markah*)

**[b] A mild steel shaft of 100 mm diameter is subjected to a bending moment of 1.9 kNm. If the yield point of the steel in simple tension is 300 MPa, find the maximum torque that can be applied according to the shear-strain energy theory of yielding (von-Mises criterion).**

*Sebuah aci keluli lembut berdiameter 100 mm dikenakan momen lenturan sebanyak 1.9kNm. Sekiranya titik alah bagi keluli berkenaan dalam keadaan tegangan mudah ialah sebanyak 300 MPa, tentukan tork maksimum yang boleh dikenakan berdasarkan teori alahan tenaga terikan ricih (kriteria von-Mises).*

(**60 marks**/*markah*)

**Q3. [a] Explain stress concentration concept using flow lines analogy. Also, suggest methods of reducing stress concentration effect for the plate shown in Figure Q3[a].**

*Terangkan konsep penumpuan tegasan dengan menggunakan analogi aliran bendalir. Juga cadangkan kaedah-kaedah bagi pengurangan kesan penumpuan tegasan bagi plat yang ditunjukkan pada Rajah S3[a].*

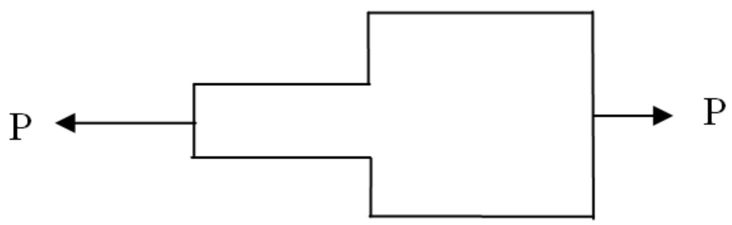



**Figure Q3[a]**
*Rajah S3[a]*

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

**[b] A stepped shaft shown in Figure Q3[b] 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.**

**(i) For the preliminary design as shown in Figure Q3[b], determine the maximum power that can be transmitted.**

**(ii)** **If in the final design the radius of the fillet is increased so that r = 24 mm, what will be the percent change, relative to the preliminary design, in the power that can be transmitted? (Power, P = 2πfT)**

*Sebuah aci berlangkah seperti Rajah S3[b] berputar pada 900 rpm untuk menghantar kuasa dari turbin ke penjana. Gred keluli yang dinyatakan dalam rekabentuk mempunyai tegasan ricih yang dibenarkan sebanyak 55 MPa.*

*(i)* *Bagi rekabentuk permulaan seperti Rajah S3[b], tentukan kuasa maksimum yang boleh dihantar.*

(ii) *Sekiranya jejari kambi bagi rekabentuk akhir ditingkatkan supaya r = 24 mm, apakah peratus perubahan, dinisbahkan kepada rekabentuk permulaan, dalam bentuk kuasa yang dihantar?(Kuasa, P = 2πfT)*

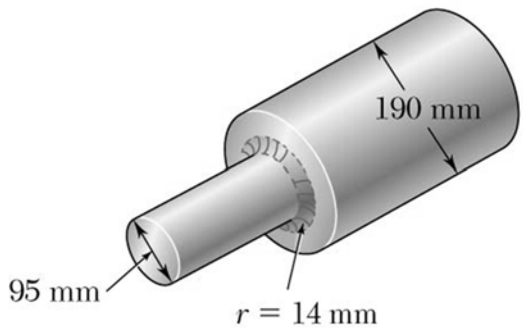



**Figure Q3[b]**
*Rajah S3[b]*

(**70 marks**/markah)

**Q4. [a] Consider the statement:**

**"A series of high-temperature creep failure tests of thin, pressurized tubes is carried out at different stress levels and the time to failure increases linearly, on a logarithmic scale, with decreasing stress levels. *Failure at larger times cannot be predicted reliably from the resulting trend line.*"**

**Answer True or False to the statement <u>made in italics.</u> Explain the reasons for your conclusion.**

*Pertimbangkan kenyataan dibawah:*

*"Suatu siri ujian kegagalan rayapan pada suhu tinggi tiub nipis dibawah tekanan telah dijalankan pada tahap tegasan berbeza. Didapati masa mencapai kegagalan bertambah secara linear pada skala logaritma apabila tegasan berkurangan. <u>Kegagalan pada masa yang lebih lama tidak dapat di ramalkan daripada keputusan ujian yang dijalankan</u>"*

*Jawab Benar atau Salah kepada kenyataan bergaris di atas. Terangkan alasan atas jawapan yang diberikan.*

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

**[b] For a bolted flange to remain rigid in a creeping environment, the total strain must remain the same. Develop a relationship to approximate a stress relaxation time in a bolted system under the effect of creep. Consider that bolt follow a creep law $\left(\frac{d\varepsilon_{cr}}{dt}\right) = B\sigma^n$ whereby $B = \varepsilon_o/\sigma_o$.**

*Bagi bolt berada dalam keadaan tegar pada persekitaran yang membenarkan fenomena rayapan, keseluruhan terikan sistem bolt tersebut mestilah tidak berubah. Tunjukkan perhubungan tegasan mengendur mengikut masa pada sistem berboltan yang mengalami rayapan. Pertimbangkan hukum rayapan mengikut $\left(\frac{d\varepsilon_{cr}}{dt}\right) = B\sigma^n$ pada mana $B = \varepsilon_o/\sigma_o$.*

**Using the relationship developed above, work out a problem given below:**

**The bolts of a flanged joint in steam piping are tightened to an initial stress of 400MN/m$^2$. Determine the relaxed stress after 10000 hours. E = 200 GN/m$^2$, n = 3 and B = 4.8x10$^{-34}$ per hour per N/m$^2$.**

*Melalui perhubungan yang telah dibina, selesaikan masalah dibawah;*

*Bolt yang memegang bebibir dalam paip stim diketatkan kepada tegasan awal 400 MN/m2. Tentukan tegasan mengendur selepas 10000 jam. E = 200 GN/m$^2$, n = 3 and B = 4.8x10$^{-34}$ per jam per N/m$^2$*

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

**Q5. [a] Consider the statement:**

**An I-shaped cross-section is not the best form for a load-carrying beam made from a brittle material such as cast iron or glass.**

**Answer TRUE or FALSE to the above statement. Explain clearly the reasons for your conclusion in each case.**

*Pertimbangkan kenyataan ini:*

*Keratan rentas berbentuk-I bukanlah bentuk terbaik untuk rasuk membawa beban yang diperbuat daripada bahan rapuh seperti besi tuang atau kaca.*

*Jawab Benar atau Salah kepada kenyataan di atas. Terangkan alasan atas jawapan yang diberikan.*

**(20 marks/*markah*)**

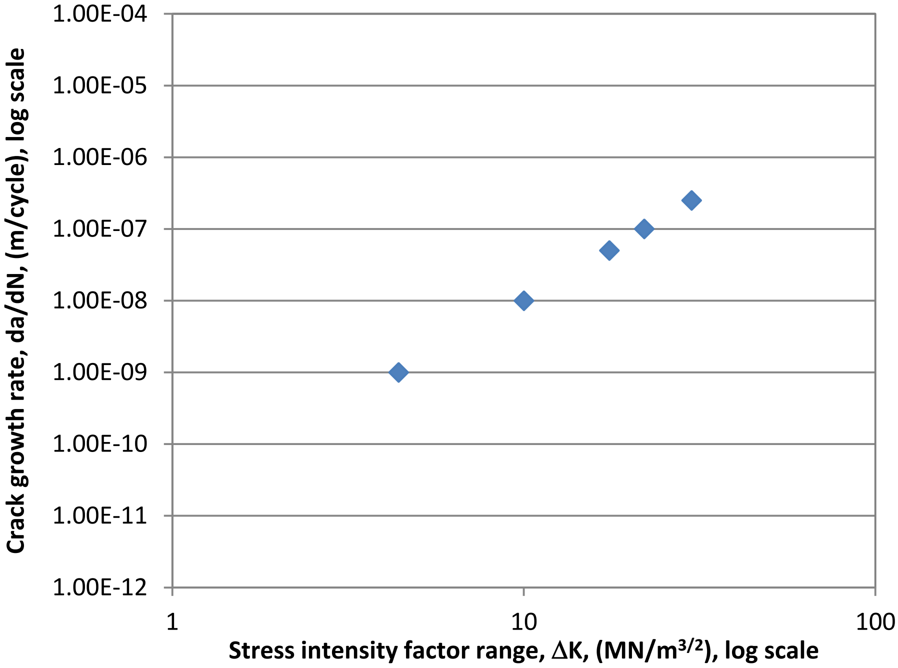
**[b] Cracks are found on the inside surface of a spherical pressure vessel which contains a hazardous liquefied gas at pressure. The largest cracks are estimated to be 1 mm deep and 100 mm long on the surface. In normal operation, the pressure fluctuates between 1 and 3 MN/m$^2$ once per hour, in a continuous process. The vessel has a 3 m mean diameter and is 10 mm thick.**

**Crack propagation tests that measure stress intensity fluctuations, $\Delta K$, and crack growth rate, $da/dN$, which are carried out in an appropriate environment, at R = 0.33, give the following results as represented in the table and graph below:**

*Retak telah dijumpai pada permukaan dalam kebuk tekanan berbentuk sfera yang mengandungi gas cecair dibawah tekanan. Retak terbesar dianggarkan 1 mm dalam dan 100 mm panjang di permukaan dalam kebuk sfera. Pada keadaan normal, tekanan kebuk berkitar diantara 1 dan 3 MN/m2 sejam sekali secara berterusan. Kebuk berdiameter purata 3 m dan tebal 10 mm.*

*Ujian perambatan retak dijalankan pada persekitaran yang sesuai pada R = 0.33,menghasilkan data keamatan retak naik turun, $\Delta K$, dan kadar pertambahan retak, $da/dN$, ditunjukkan dalam jadual dan graf seperti dibawah:*

| | | | | | |
|---|---|---|---|---|---|
| $\Delta K(MN/m^{3/2})$ | 4.4 | 10.0 | 17.5 | 22.0 | 30.0 |
| $da/dN\ (m/cycle)$ | 1x10$^{-9}$ | 1x10$^{-8}$ | 5x0$^{-8}$ | 1x10$^{-7}$ | 2.5x10$^{-7}$ |



**In other material property tests, yield strength was found to be 550 MN/m$^2$, $\Delta K_{threshold}$=3.9MN/m$^{3/2}$, and $K_{Ic}$ = 51MN/m$^{3/2}$.**

**(i) Will the crack propagate in service?**
**(ii) Find appropriate constants to fit Paris Law's growth equation**
**(iii) Estimate the life of the vessel in years.**

*Ciri-ciri lain bahan yang diuji mendapati tegasan alah adalah 550 MN/m$^2$, $\Delta K_{ambang}$=3.9MN/m$^{3/2}$, and $K_{Ic}$ = 51MN/m$^{3/2}$.*

*(i) Adakah panjang retak akan bertambah semasa kebuk beroperasi?*
*(ii) Tentukan pemalar yang sesuai untuk persamaan Hukum Perambatan Paris*
*(iii) Anggarkan berapa tahun hayat kebuk tekanan*

**(80 marks/***markah)*

**-oooOOooo-**

**APPENDIX 1/*LAMPIRAN 1***

# Formulas for Solid Mechanics

**Selected theories of failure**

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

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

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

**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 | $K = Y\sigma\sqrt{\pi a}$ |
| Paris' Law | $\frac{da}{dN} = C(\Delta K)^m$ |

**APPENDIX II**/*LAMPIRAN 1I*

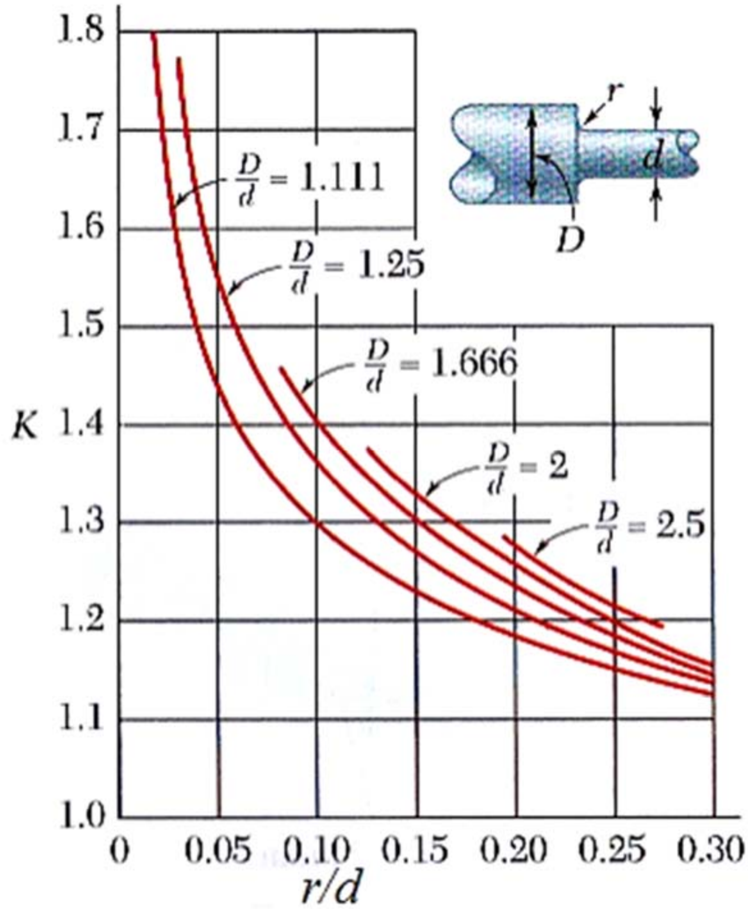



***Figure: Stress-concentration factors for fillets in circular shafts.***