First Semester Examination
Academic Session 2018/2019

December 2018/January 2019

EMM 331 – Solid Mechanics
[Mekanik Pepejal]

Duration : 3 hours
[Masa : 3 jam]

Please check that this paper contains **SIXTEEN [16]** printed pages including appendix before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **ENAM BELAS [16]** mukasurat bercetak beserta lampiran sebelum anda memulakan peperiksaan.]*

INSTRUCTIONS : Answer **ALL FIVE [5]** questions.
*[**ARAHAN** : Jawab **SEMUA LIMA [5]** soalan.]*

Answer Questions In **English** OR **Bahasa Malaysia**.
*[Jawab soalan dalam **Bahasa Inggeris** ATAU **Bahasa Malaysia**.]*

Answer to each question must begin from a new page.
[Jawapan bagi 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.]

1. [a] **Figure 1[a] shows the stress-strain graph for two materials under tensile test and their Young's modulus are indicated by E_A and E_B in the graph. Also, material 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 energy. Use APPENDIX 7 to answer this question.**

Rajah 1[a] menunjukkan graf tegasan-terikan bagi 2 bahan yang dikenakan ujian tegangan dan modulus Young bahan-bahan itu ditunjukkan sebagai E_A dan E_B dalam graf. Bahan A dan B masing-masing mempunyai had elastik sebanyak 300 N/mm^2 dan 500 N/mm^2. Berdasarkan maklumat yang diberi, tentukan secara kasar modulus keliatan bagi ke dua-dua bahan dan komen tentang kemampuan bahan dalam menyerap tenaga. Gunakan Lampiran 7 untuk menjawab soalan ini.

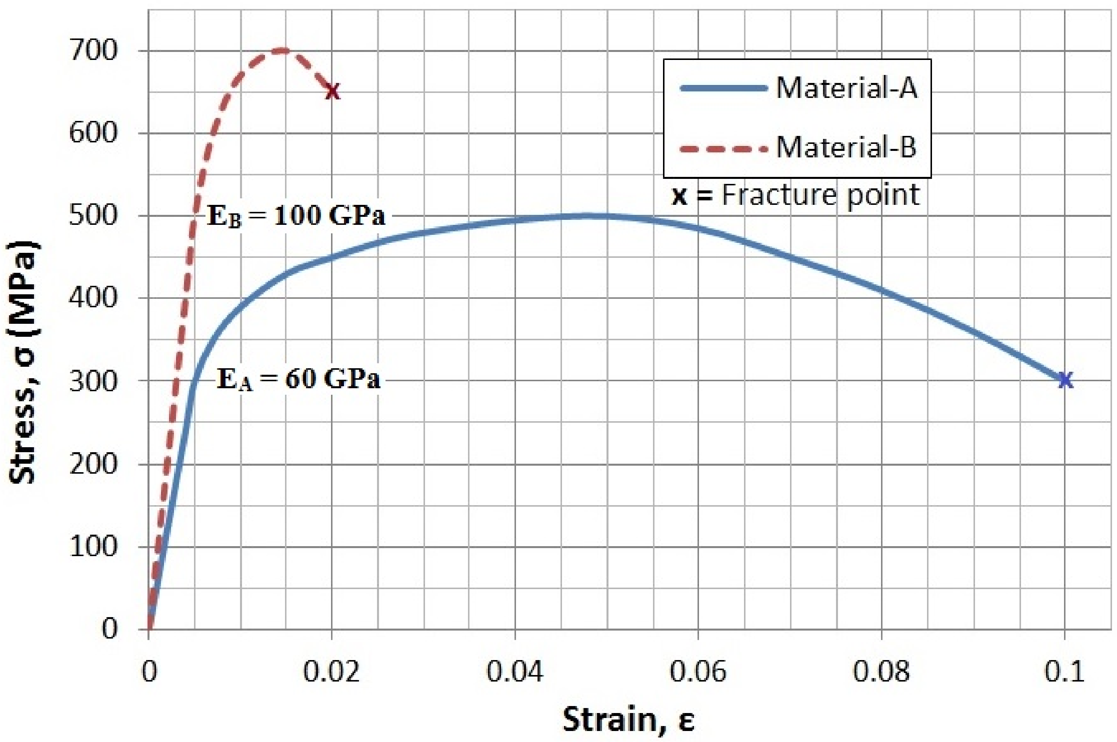

Figure 1[a]
Rajah 1[a]

(**35 marks**/*markah*)

[b] A steel cantilever beam shown in Figure 1[b] is of uniform solid circular cross-section and carries a vertical load F at its free end A. The beam has Young's modulus of 210 GPa and diameter of 20 mm. Determine the deflection caused by force F at the free end using Castigliano's theorem.

Sebuah rusuk julur keluli seperti ditunjuk pada Rajah 1[b] mempunyai keratan rentas bulatan pejal yang sekata dan dikenakan daya menegak F pada penghujung bebas A. Rusuk berkenaan mempunyai modulus Young 210 MPa dan berdiameter 20mm. Tentukan lenturan yang disebabkan daya F pada penghujung bebas menggunakan teorem Castigliano.

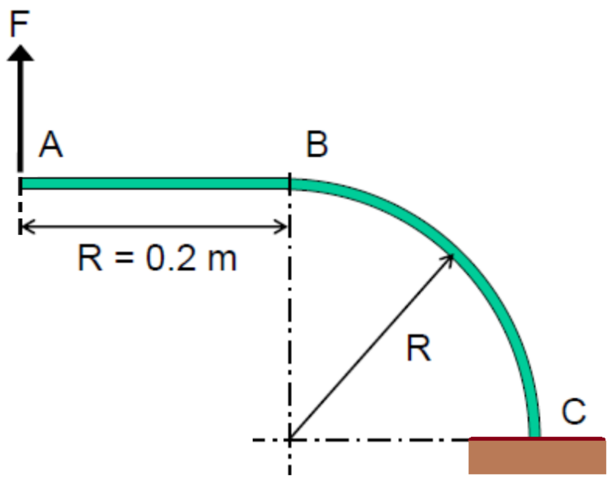

Figure 1[b]
Rajah 1[b]

(**65 marks**/*markah*)

2. [a] A cylindrical aluminium specimen has Young's modulus E = 60 GPa and elastic limit σ_o = 300 MPa. With the aid of stress-strain graphs as the responses for cyclic stress-controlled loading (tension-compression cycle):

Sebuah spesimen aluminium berbentuk silinder mempunyai limit elastik E = 60 GPa dan titik alahan σ_o= 300 MPa. Dengan bantuan graf tegasan-terikan sebagai respon kepada bebanan berkitar tegasan terkawal (kitar tegangan-mampatan):

(i) **explain the meaning of Bauschinger's effect and indicate the onset of yielding conditions on a resultant closed loop stress-strain graph under $\sigma_{max,min}$ = ±500 MPa and $\varepsilon_{max,min}$ = ±0.03 for the first cycle, and**
jelaskan maksud kesan Bauschinger dan tunjukkan permulaan keadaan alah pada graf tegasan-terikan tertutup yang terhasil di bawah $\sigma_{max,min}$ = ±500 MPa and $\varepsilon_{max,min}$ = ±0.03 bagi kitar pertama, dan

(ii) **if the aluminum exhibits a cyclic softening behaviour, sketch a resultant stress-strain graph indicating the change of plastic strain range when the number of cycles increases.**
jika aluminium berkenaan menunjukkan sifat perlembutan kitaran, lakarkan hasil graf tegasan-terikan yang menunjukkan perubahan julat terikan plastik apabila bertambahnya bilangan kitaran.

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

[b] **In an engineering component made of steel, the most severely stressed point is subjected to the following state of stress as shown below where all stresses are in MPa. Analyze the material's yielding condition based on (a) Tresca and (b) von-Mises criteria if the yield strength of the steel is 950 MPa. Also, sketch the 3 dimensional Mohr's circle for this stress state.**

Pada sebuah komponen kejuruteraan yang diperbuat daripada keluli, titik tegasan paling tinggi mempunyai keadaan tegasan seperti ditunjukkan di bawah yang mana semua tegasan dalam unit MPa. Analisa keadaan alahan keluli ini berdasarkan (a) kriteria Tresca dan (b) kriteria von-Mises jika kekuatan alah keluli berkenaan ialah 950 MPa. Juga, lakarkan bulatan Mohr 3 dimensi bagi keadaan tegasan ini.

$$\sigma_{ij} = \begin{pmatrix} 0 & 0 & 300 \\ 0 & 400 & 50 \\ 300 & 50 & 800 \end{pmatrix}$$

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

3. [a] **Figure 3[a] shows a stepped shaft which has a quarter–circular fillet. The allowable shearing stress for the shaft is 80 MPa.**

Rajah 3[a] menunjukkan aci berlangkah yang mempunyai filet seperempat bulatan. Tegasan ricih yang dibenarkan pada aci ialah 80 MPa.

(i) **With the help of Figure 3[a], explain stress concentration concept using flow lines analogy.**
Dengan bantuan Rajah 3[a], terangkan konsep penumpuan tegasan dengan menggunakan analogi aliran bendalir.

(ii) **Knowing that D = 30 mm, determine the largest allowable torque that can be applied to the shaft if d = 26 mm. Please refer APPENDIX 2 for stress concentration factor value.**
Diketahui bahawa D = 30 mm, tentukan kilas tertinggi yang dibenarkan untuk dikenakan pada aci jika d = 26 mm. Sila rujuk LAMPIRAN 2 untuk nilai faktor penumpuan tegasan.

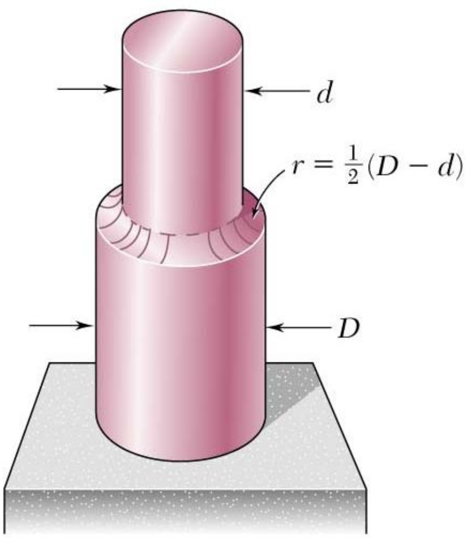

Figure 3[a]
Rajah 3[a]

(**50 marks**/*markah*)

[b] **An Acetal plastic snap-fit connection is shown in Figure 3[b] and the normal deflection is 2 mm. If the pin will slip out when the transverse clamping force exerted by the clasp is 33 N, calculate:**

Suatu sambungan tekan-padan Asetal ditunjukkan pada Rajah 3[b]. Sambungan pin akan terkeluar jika daya pengapit oleh pengancing adalah 33 N, kirakan:

(i) **the clamping force when the pin is first inserted**
daya pengapit pada mana pin dimasukkan pada kali pertama

(ii) **the elapsed time before the pin would slip out**
masa yang diperlukan untuk pin terkeluar dengan sendiri

Assume the deflection of the plastic snap-fit is similar to a cantilever subjected to a vertical load at the tip-end of the plastic snap fit, the deflection, δ, is given as:

Andaikan pesongan pada tekan-padan menyerupai suatu rasuk julur yang dikenakan beban pada hujungnya, maka pesongan maksima, δ, diberikan oleh:

$$\delta = \frac{WL^3}{3EI}$$

Choose the appropriate moment of inertia formula given in Appendix 3. Assume the geometry of the deformation causes a strain of about 1%, use the 1% strain modulus for Acetal in Appendix 4 in your calculations.

Gunakan formula momen inersia yang sesuai seperti yang diberikan dalam Lampiran 3. Anggapkan geometri mengalami terikan sebanyak 1%, gunakan graf modulus terikan 1% yang diberikan dalam Lampiran 4 dalam pengiraan anda.

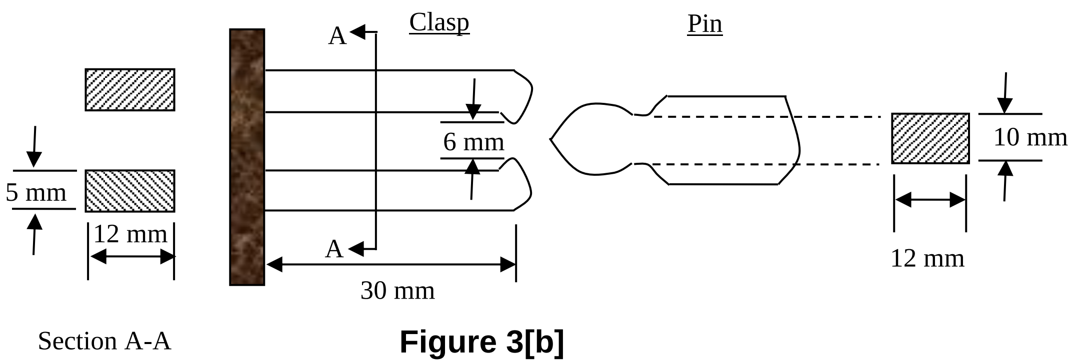

Figure 3[b]
Rajah 3[b]

(**50 marks/***markah*)

4. [a] **Calculate the critical defect size for each of the following steels assuming they are each subjected to a stress of $\frac{1}{2}\sigma_Y$.**

Tentukan saiz kritikal retak bagi setiap keluli di bawah ini sekiranya tegasan sebanyak $\frac{1}{2}\sigma_Y$ dikenakan.

Comment on the results obtained in relation to Linear elastic fracture mechanics (LEFM) conditions.

Komen tentang keputusan yang di dapati merujuk kepada penggunaan kaedah mekanik retak linear elastik.

Test	Steel	Yield strength, σ_Y (MN/m^2)	Fracture toughness (MN/m$^{3/2}$)
1.	**Mild steel**	**207**	**200**
2.	**Low-alloy steel**	**500**	**160**
3.	**Medium-carbon steel**	**1000**	**280**
4.	**High-carbon steel**	**1450**	**70**
5.	**18% Ni (maraging) steel**	**1900**	**75**
6.	**Tool steel**	**1750**	**30**

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

[b] **The accident report of a steel pressure vessel which fractured in a brittle manner when an internal pressure of 19 MN/m^2 had been applied to it shows that the vessel had a longitudinal surface crack 8 mm long and 3.2 mm deep. A subsequent fracture mechanics test on a sample of the steel showed that it had a K_{Ic} value of 75 MN/m$^{3/2}$. If the vessel diameter was 1000 mm and its wall thickness was 10 mm, propose whether the data reported are consistent with the observed failure. The crack calibration factor ϕ for a longitudinal surface crack is given in Appendix 5.**

Suatu laporan kemalangan retak kebuk tekanan yang diperbuat daripada keluli yang gagal pada tekanan dalam 19 MN/m^2 menunjukkan kebuk mempunyai retak permukaan sepanjang 8 mm dan kedalaman 3.2 mm. Ujian daripada bahan kebuk yang gagal itu menunjukkan kelulinya mempunyai keliatan patah K_{Ic} iaitu 75 MN/m$^{3/2}$. Sekiranya garispusat kebuk ialah 1000 mm dan kebuk berketebalan 10 mm, cadangkan samada data keliatan patah adalah konsisten dengan kegagalan yang dialami. Faktor kalibrasi retak ϕ bagi suatu retak permukaan memanjang diberikan dalam Lampiran 5.

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

5. [a] **A series of crack growth tests on a moulding grade of polymethyl methacylate (PMMA) gave the following results:**

Suatu siri ujian perambatan retak terhadap bahan polimetil metaakrilate (PMMA) memberikan keputusan yang berikut.

da/dN (m/cycle)x10^{-7}	**2.25**	**4**	**6.2**	**11**	**17**	**29**
ΔK (MN/$m^{3/2}$)	**0.42**	**0.53**	**0.63**	**0.79**	**0.94**	**1.17**

The result has also been plotted as shown in Appendix 6.

Keputusan itu juga diberikan dalam gambarajah seperti ditunjukkan dalam Lampiran 6.

If the material has a critical stress intensity factor of 1.8 MN/$m^{3/2}$ and it is known that the moulding process produces defects 40 μm long, estimate the maximum repeated tensile stress which could be applied to this material for at least 10^6 cycles without causing fatigue failure.

Jika bahan itu mempunyai faktor keamatan tegasan kritikal 1.8 MN/$m^{3/2}$ dan di ketahui juga bahawa proses pengacuan menghasilkan kecacatan seperti retak sepanjang 40 μm panjang. Anggarkan tegangan berkitar maksimum yang boleh dikenakan pada bahan bagi sekurang-kurangnya 10^6 kitaran tanpa bahan mengalami kegagalan.

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

[b] **Explain the concepts of stress based approach (S-N curves) and the concept of fatigue crack growth approach for metallic materials. Evaluate which approach is applicable for high endurance fatigue problems.**

Jelaskan konsep pendekatan tegasan (lengkung S-N) dan konsep perambatan retak lesu bagi bahan logam. Pendekatan manakah yang paling sesuai untuk masalah lesu bagi struktur yang mengalami ketahanan tinggi lesu.

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

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

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	$\int \frac{F^2}{2AE}dx$	$\frac{F^2 L}{2AE}$	$\frac{\sigma^2}{2E}$
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

APPENDIX 1
LAMPIRAN 1

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 2
LAMPIRAN 2

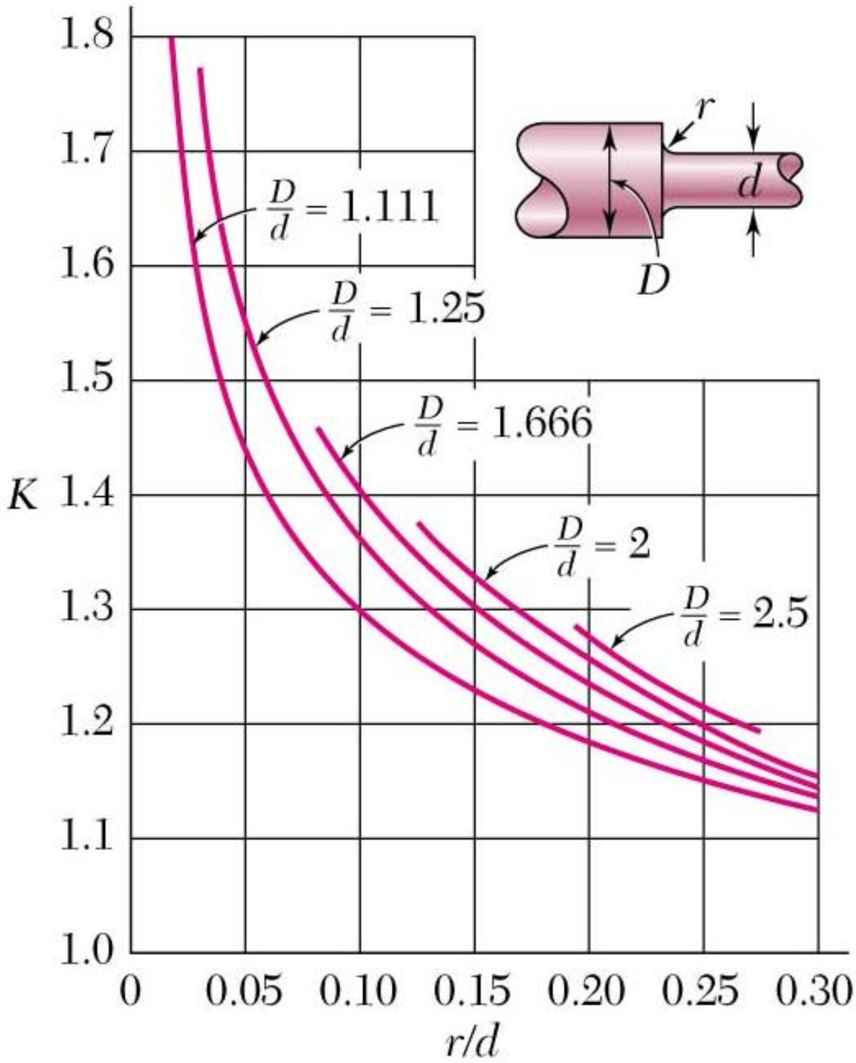
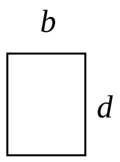
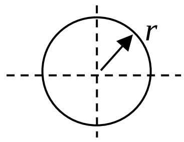


Figure A1: Stress Concentration factors for fillets in circular shafts.

APPENDIX 3
LAMPIRAN 3

Selected moment of inertia for geometries

Rectangle		$I = \dfrac{bd^3}{12}$
Circular		$I = \dfrac{\pi r^4}{4}$

APPENDIX 4
LAMPIRAN 4

Acetal 1% strain modulus graph

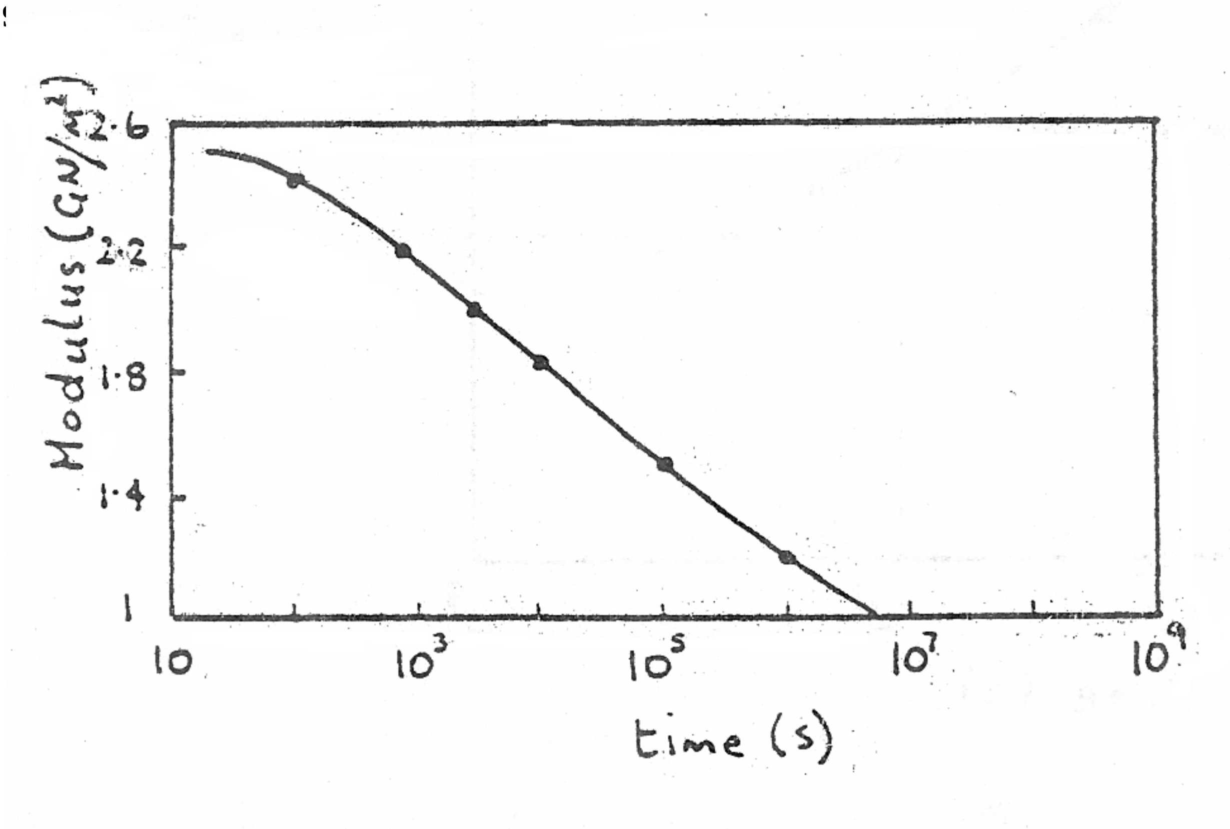


Fig A2: The 1% strain modulus graph.

APPENDIX 5
LAMPIRAN 5

Semi-elliptical surface flaw

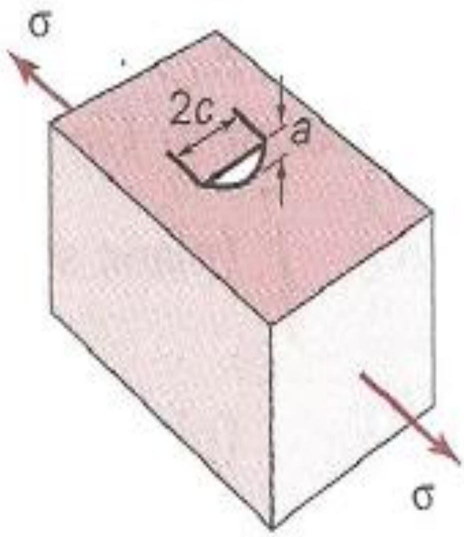


Fig A3: Semi-elliptical surface crack

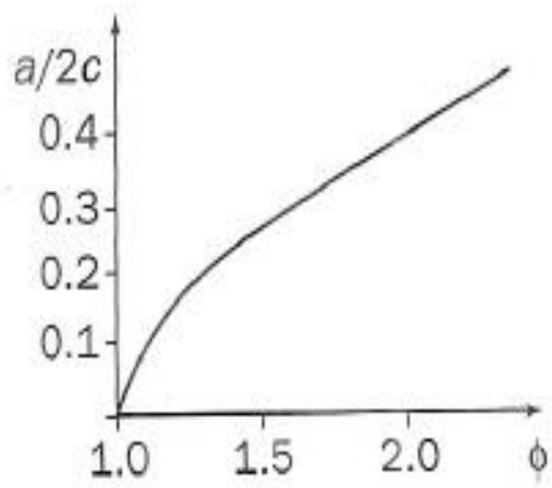


Fig A4: Crack calibration factor for semi-elliptical surface crack

$$K = \sigma(\pi a)^{\frac{1}{2}}\left(\frac{1.12}{\phi^{\frac{1}{2}}}\right)$$

APPENDIX 6
LAMPIRAN 6

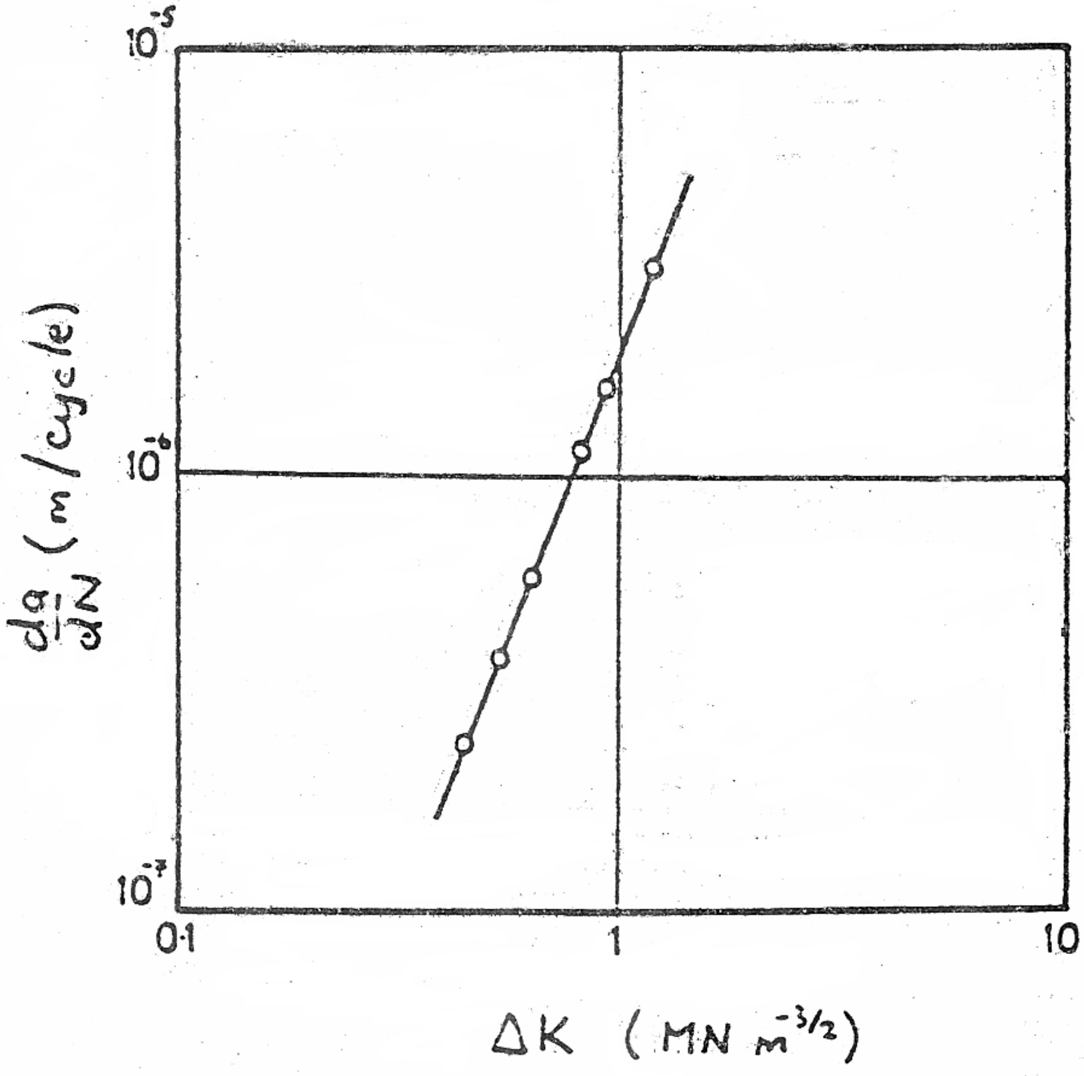


Fig A5: Crack growth of PMMA material

APPENDIX 7
LAMPIRAN 7

Fig A6: Stress – strain curve of material A and B