UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2015/2016

December 2015 / January 2016

EMM 331 – Solid Mechanics
[Mekanik Pepejal]

Duration : 3 hours
Masa : 3 jam

Please check that this paper contains **NINE** printed pages, **THREE** page Appendix and **FIVE** questions before you begin the examination.

*[sila pastikan bahawa kertas soalan ini mengandungi **SEMBILAN** mukasurat beserta **TIGA** mukasurat Lampiran dan **LIMA** soalan yang bercetak sebelum anda memulakan peperiksaan.]*

Appendix/*Lampiran* :

1. Formula for solid mechanics [1 **page**/*mukasurat*]
2. Stress concentration factors for fillets in circular shafts [1 **page**/*mukasurat*]
3. Creep curves for Acetal [1 **page**/*mukasurat*]

INSTRUCTIONS : Answer **ALL** questions.
*[**ARAHAN** : Jawab **SEMUA** 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.]

Q1. [a] Figure Q1[a] shows a cyclic stress-strain graph of a uniaxial cylindrical specimen under push-pull loading with a strain-controlled test condition of ±0.5% strain. X and Y axis represent strain (%) and stress (MPa) respectively.

Rajah S1[a] menunjukkan graf tegasan-terikan berkitar bagi spesimen berbentuk silinder ekapaksi di bawah daya tekan-tarik dalam keadaan ujian terikan-terkawal dengan terikan ±0.5%.

[i] Define strain energy density of a material.
Takrifkan ketumpatan tenaga terikan bagi suatu bahan.

[ii] Calculate the plastic strain energy density of the steel if the push, y_1, and pull, y_2, behavior are given as the following equations:

Kirakan ketumpatan tenaga terikan plastik bagi keluli berkenaan jika kelakuan tekan, y_1, dan kelakuan tarik, y_2, diberikan oleh persamaan berikut:

$$y_1 = -194 + 180x + 467x^2 + 1173x^3 + 1102x^4$$
$$y_2 = 203 + 182x - 553x^2 + 1202x^3 - 958x^4$$

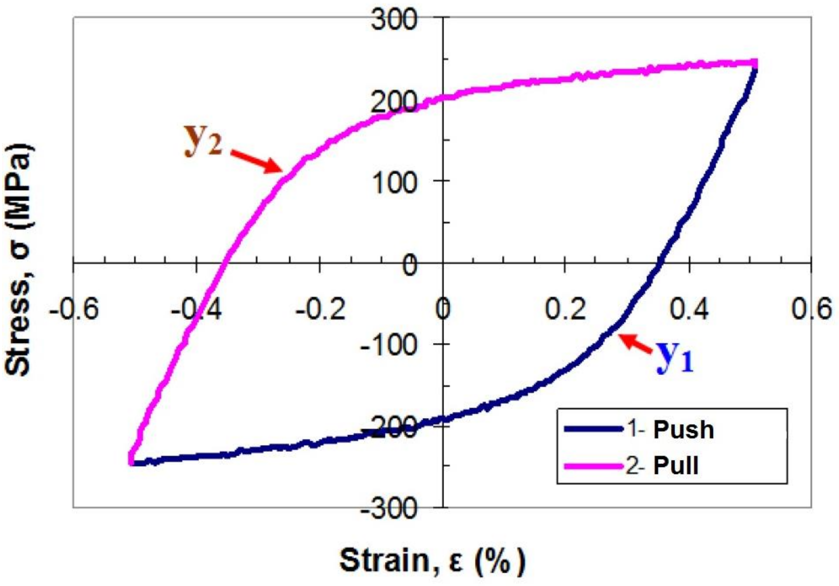

Figure Q1[a]
Rajah S1[a]

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

[b] **Figure Q1[b] shows a truss made of steel. The cross-sectional area of member BC is 800 mm^2 and for all other members the cross-sectional area is 400 mm^2. Using E = 200 GPa, determine the horizontal deflection of point D caused by the 60 kN load.**

Rajah S1[b] menunjukkan kekuda yang diperbuat daripada keluli. Luas keratan rentas bagi anggota BC ialah 800 mm^2 dan luas keratan rentas untuk anggota yang lain ialah 400 mm^2. Dengan menggunakan E =200 GPa, tentukan pesongan mendatar titik D yang disebabkan oleh daya 60 kN.

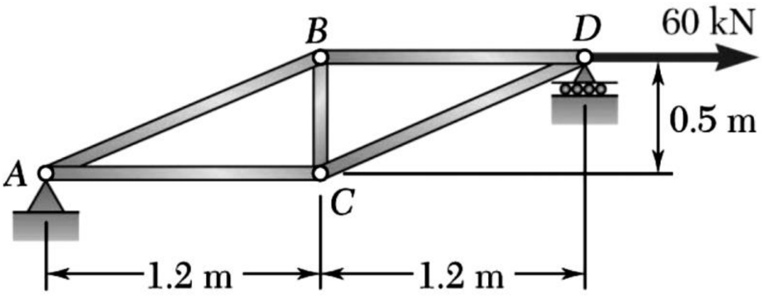

Figure Q1[b]
Rajah S1[b]

(**70 marks**/markah)

Q2. **[a]** **With the help of sketches, provide brief answers to the following questions:**

Dengan bantuan lakaran, berikan jawapan ringkas kepada soalan berikut:

[i] **Define cyclic hardening of a material under strain-controlled test condition.**

Takrifkan pengerasan berkitar bagi suatu bahan di bawah keadan ujian terikan-terkawal.

[ii] **Distinguish between Tresca and von-Mises yield criteria.**

Bezakan antara kriteria alah Tresca dan von-Mises.

(**30 marks**/markah)

[b] A block material is subjected to equal compressive stresses in the x- and y-directions and it is confined by a rigid die so that it cannot deform in the z-direction as shown in Figure Q2[b]. Assume that there is no friction against the die and also that the material behaves in an elastic, perfectly plastic, with yield strength σ_o.

Sebuah bongkah dikenakan tegasan mampatan yang sama nilai pada arah x dan y dan ianya dikekang dengan acuan tegar agar tidak dapat berubah pada arah z seperti ditunjukkan pada Rajah S2[b]. Anggapkan tiada geseran terhadap acuan dan juga bahan berkelakuan elastik, plastik sempurna, dengan tegasan alah σ_o .

[i] Determine the stress $\sigma_x = \sigma_y$ necessary to cause yielding, expressing this as a function of σ_o and elastic constants of the material. Use von-Mises yield criterion to solve this problem.

Tentukan tegasan $\sigma_x = \sigma_y$ yang diperlukan untuk menyebabkan pengalahan, dengan mengungkapkannya sebagai fungsi σ_o dan pekali elastik bahan. Gunakan kriteria alah von-Mises untuk menyelesaikan masalah ini.

[ii] What is the value of σ_y at yielding if the material is an aluminium alloy with yield strength σ_o = 350 MPa, elastic modulus E = 70.3 GPa and Poisson's ratio υ = 0.35.

Apakah nilai σ_y pada alahan jika bahan berkenaan ialah aloi aluminium dengan tegasan alah σ_o = 350 MPa, modulus elastik E = 70.3 GPa dan nisbah Poisson υ = 0.35.

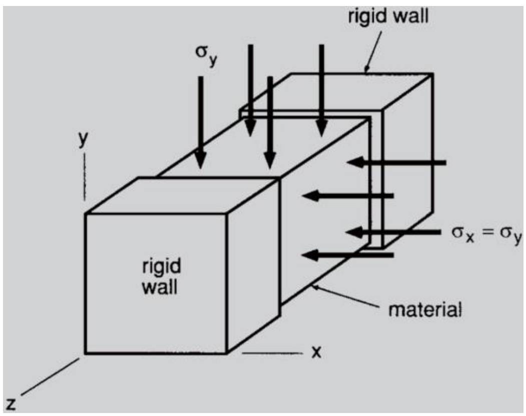

Figure Q2[b]
Rajah S2[b]

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

Q3. [a] Figure Q3[a] shows a stepped shaft which has a quarter–circular fillet. The allowable shearing stress for the shaft is 80 MPa.

Rajah S3[a] menunjukkan aci berlangkah yang mempunyai filet seperempat bulatan. Tegasan ricih yang dibenarkan pada aci ialah 80 MPa.

[i] With the help of Figure Q3[a], explain stress concentration concept using flow lines analogy.

Dengan bantuan Rajah S3[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.

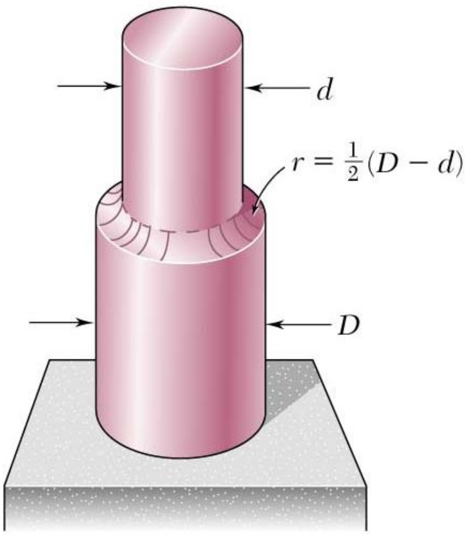

Figure Q3[a]
Rajah S3[a]

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

[b] "***Creep is a deformation mechanism that MAY or MAY NOT lead to catastrophic failure."*** **Based on the underlined statement, DISCUSS the consequences of creep deformation in each of these cases:**

"*Rayapan adalah satu mekanisma ubah bentuk yang BERKEMUNGKINAN atau TIDAK BERKEMUNGKINAN menjadi suatu mod kegagalan."* *Berdasarkan pernyataan bergaris itu, BINCANGKAN akibat daripada ubah bentuk rayapan pada keadaan ini:*

[i] **A steel turbine blade having a melting temperature T_m = 1100°C and a in a gas turbine engine operating at a temperature of 2000°C.**

Bilah turbin keluli yang mempunyai suhu lebur, T_m =1100°C dan berada di dalam injin turbin gas beroperasi pada suhu 2000°C.

[ii] **A nuclear reactor containment structure which include a pressure vessel (T_m = 1500°C) and a steel lined concrete slab ($T_m \approx$ 2000°C) in a meltdown incident (excess temperature of 2930°C).**

Suatu struktur pembendungan reaktor nuclear terdiri daripada kebuk tekanan mempunyai suhu lebur (T_m = 1500°C) dan struktur keluli bersalut konkrit mempunyai suhu lebur (T_m = 2000°C) dalam suatu insiden pencairan (lebihan suhu 2930°C).

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

[c] **A solid circular acetal rod, 0.15 m in length, is clamped horizontally at one end and the free end is subjected to a vertical load of 25N. (Bending-stress relationship is $\frac{M}{I} = \frac{\sigma}{y}$; Second moment inertia is $I = \frac{\pi d^3}{32}$; Maximum deflection of simple cantilever is $\delta = \frac{WL^3}{3EI}$). Refer to Appendix 2 for Acetal Creep curves.**

Suatu rod pepejal Asetal membulat panjang 0.15 m di apit secara horizontal pada satu hujungnya dan di kenakan beban menegak 25N pada hujung bertentangan. (Perkaitan lenturan-tegasan adalah $\frac{M}{I} = \frac{\sigma}{y}$; Inertia momen kedua adalah $I = \frac{\pi d^4}{64}$; Lenturan maksima bagi rasuk adalah $\delta = \frac{WL^3}{3EI}$ boleh digunakan dalam perkiraan anda). Rujuk lampiran 2 untuk data bagi rayapan Asetal.

[i] **Determine a suitable diameter for the rod for a limiting strain of 2% in 1 year.**

Tentukan diameter rod pepejal mengikut terikan had sebanyak 2% setahun.

[ii] **What would be the maximum deflection at this time?**

Apakah lenturan maksima pada masa itu.

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

Q4. [a] **The fatigue crack propagation rate of 'natural' cracks in a flat bar subject to alternating bending is to be investigated by carrying out tests on the same material, but the cracks are grown from a sharp starter slits as shown in Figure Q4[a]. "*Provided that the fatigue cracks are a reasonable length compared with the width of the slits, the stress intensity factors and the propagation rates in both cases should be the same.*" State whether the underlined statement is True or False and give your reasons.**

Perambatan lesu retak 'semulajadi' pada bar yang nipis yang dikenakan lenturan ulangalik hendaklah dikaji menggunakan bahan yang sama tetapi retak dihasilkan daripada celahan tajam seperti Rajah S4[a]. "Sekiranya retak lesu yang dihasilkan mempunyai panjang yang sesuai berbanding dengan ruang celah maka faktor keamatan tegasan dan kadar perambatan retak ialah sama pada kedua-dua keadaan". Tentukan samada kenyataan bergaris itu 'Benar' atau 'Palsu' dan nyatakan alasan anda.

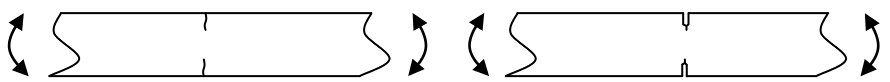

Figure Q4[a]
Rajah S4[a]

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

[b] **Consider the statement 'In a fatigue-loaded structure which may have hidden cracks, small increases in loading on the structure may have large effects on fatigue life' Discuss briefly how the threshold stress intensity value K_{th} and the stress index *m* in the Paris Law are relevant to the statement.**

Pertimbangkan kenyataan "Di dalam struktur yang terbeban lesu yang mempunyai retak yang terlindung; penambahan kecil bebanan akan memberikan kesan yang besar pada hayat lesunya" Bincangkan secara ringkas akan kepentingan parameter nilai keamatan tegasan, K_{th} dan indeks tegasan, m dalam hukum Paris terhadap kenyataan tersebut.

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

[c] **A pressure vessel support bracket is to be designed so that it can withstand a tensile loading cycle of 10-500 MN/m^2 once every day for 20 years. Which of the following steels would have the greater tolerance to intrinsic defects in this application:**

Reka bentuk suatu bekas tekanan hendaklah ditetapkan supaya berupaya mengalami kitar tegangan diantara 10-500 MN/m^2 setiap hari selama 20 tahun. Menggunakan data yang diberikan, nyatakan keluli yang lebih baik berupaya menahan kecacatan dalaman.

[i] **A maraging steel (Mar_S) ;**
Keluli penuaan-martensit (Mar_S) ;

[ii] **A medium-strength steel (Med_S).**
Keluli kekuatan mediuml (Med_S).

Assuming linear elasticity applies.
Anggapkan keadaan kekenyalan linear digunakan.

Alloy	Young's Modulus (GPa)	Poisson's ratio	Ultimate tensile strength (MPa)	Critical fracture toughness (MN/m$^{3/2}$)	Paris's constants	Paris's exponent
Mar_S	**210**	**0.3**	**2000**	**82**	**0.15e-11**	**4.1**
Med_S	**193**	**0.29**	**1800**	**50**	**0.24e-11**	**3.3**

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

Q5. [a] Assess two ADVANTAGES and DISADVANTAGES of using plane strain and plane stress approximation technique to develop a fracture toughness framework for structural integrity assessment. You may use facts relating to the effect of specimen thickness on fracture toughness to support your explanations.

Nilaikan dua KELEBIHAN dan KEKURANGAN menggunakan kaedah penghampiran terikan satah dan tegasan satah untuk menghasilkan rangka kerja keliatan patah bagi penilaian integriti bagi struktur. Gunakan fakta berkenaan kesan ketebalan specimen pada keliatan retak untuk menyokong penjelasan anda.

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

[b] A compact pressurized containment is constructed with a diameter d = 460 mm and a length of L = 1.830 m. The vessel is to be capable of withstanding an internal pressure of p = 7 MPa, and the wall thickness is such as to keep the nominal hoop stress under 17 MPa. However, the vessel bursts at an internal pressure of only 3.5 MPa. A micrographic investigation reveals the fracture to have been initiated by an internal longitudinal crack of 2.5 mm in length.

Sebuah kebuk tekanan mempunyai diameter, d = 460 mm dan panjang L = 1.830 m. Kebuk tekanan berkeupayaan beroperasi dengan tekanan dalaman, p = 7 MPa manakala ketebalan dinding kebuk berkeupayaan menahan tegasan gegelung nominal, p = 17 MPa. Akan tetapi, kebuk tekanan telah pecah mendadak pada tekanan dalaman hanya 3.5 MPa. Penyiasatan mikrografik mendapati pecah mendadak berpunca daripada retak pada dinding dalam kebuk yang bersaiz 2.5 mm pada arah memanjang kebuk.

[i] Calculate the fracture toughness, K_{Ic} of the material.
Tentukan keliatan patah kritikal, K_{Ic} bahan tersebut.

[ii] If a fracture toughness of $K_c = 2K_{Ic}$ is used, what is the new limit of crack length permissible for the pressure container.

Sekiranya keliatan patah $K_c = 2K_{Ic}$ digunakan, apakah had baru panjang retak yang dibenarkan pada kebuk tekanan tersebut.

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

-oooOooo-

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

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	$K = Y\sigma\sqrt{\pi a}$; Y = 1 for infinite problems
Paris' Law	$\frac{da}{dN} = C(\Delta K)^m$
Life estimates from Paris's Law	$N_f = \int_{a_i}^{a_f} \frac{da}{C(\Delta K)^m}$

APPENDIX 2
LAMPIRAN 2

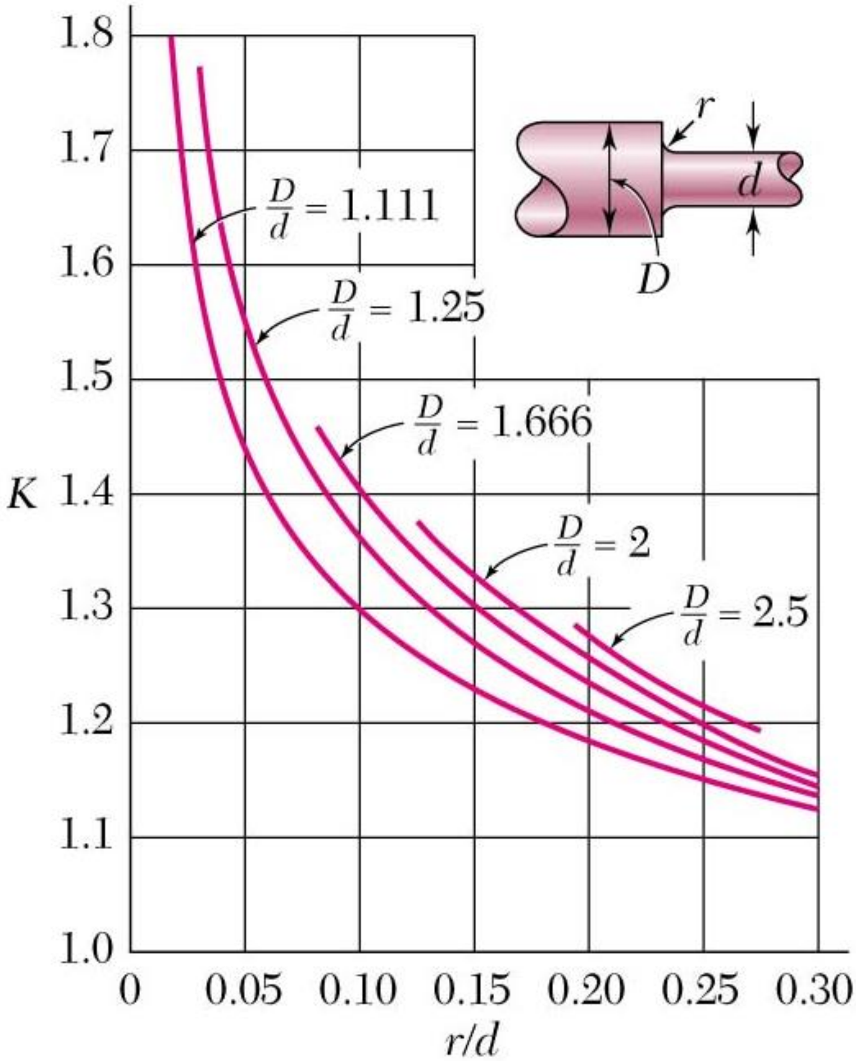

Figure A2: Stress Concentration factors for fillets in circular shafts.

APPENDIX 3
LAMPIRAN 3

Creep strain curves for Acetal

Fig 1: Creep curves for Acetal at 20^{o}C.

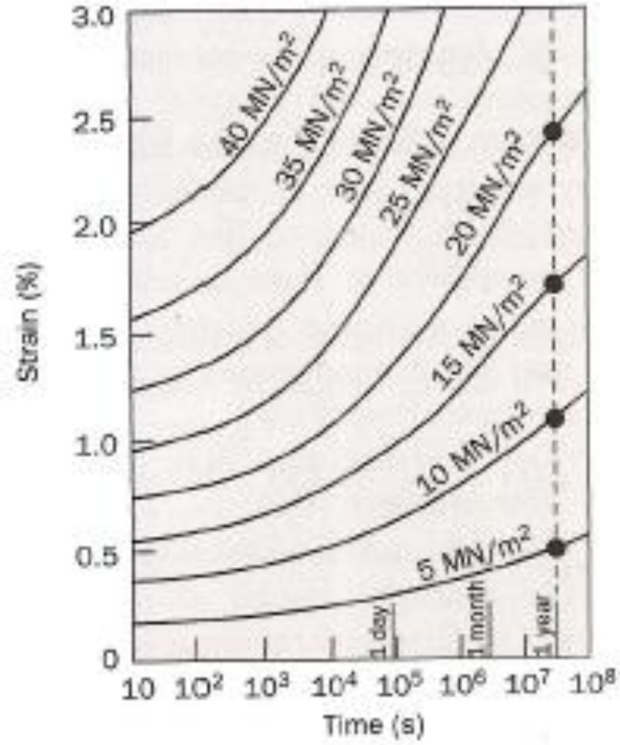

Fig 2: A 1 year isochronous curve for Acetal at 20^{o}C.