995

Ollscoil na hÉireann, Gaillimh

National University of Ireland, Galway

Semester II Examinations 2005

Exam Code(s)	4BG121, 4BM121	
Exam(s)	4^{th} Engineering Mechanical & Biomedical	
Module Code(s)	ME423	
Module(s)	Polymers and Polymer Composites	
Paper No.	1	
Repeat Paper		Special Paper
External Examiner(s)	Professor J. Fitzpatrick	
Internal Examiner(s)	Professor J.F. McNamara Dr. C. O'Bradaigh	

<u>Instructions</u>: Answer 5 questions

All questions will be marked equally.

Duration	3hrs	
No. of Answer Books	1	
Requirements:		
Handout		2 Pages of Supplementary Equations
MCQ		
Statistical Tables		
Graph Paper		
Log Graph Paper		
Other Material		
No. of Pages	13	(including 2 pages of supplementary equations)
Department(s)	Mechanical and Biomedical Engineering	

1 (a) (i) Clearly label and explain the fatigue curves for a typical polymer shown below in Figure 1(a). **(3)**

(ii) Describe all possible failure modes and discuss the effects of frequency, waveform shape and mean stress. **(5)**

(iii) What is mean by R = 1.0, R = - 1.0 and R = 10.0 in the context of fatigue testing? **(2)**

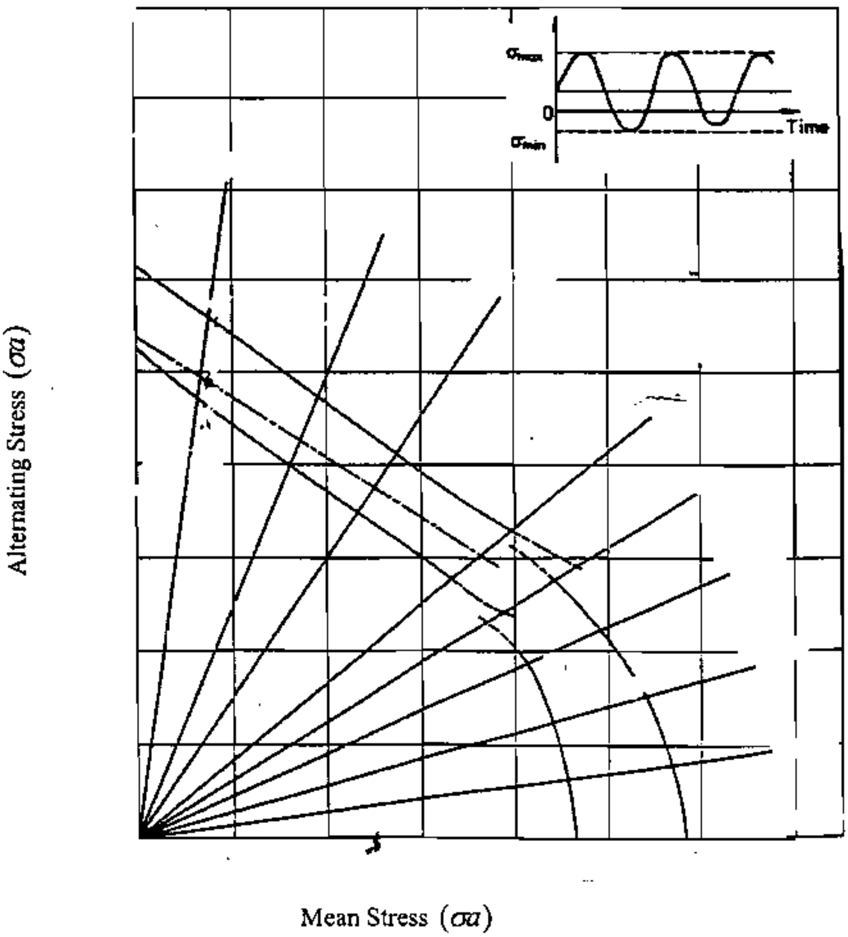
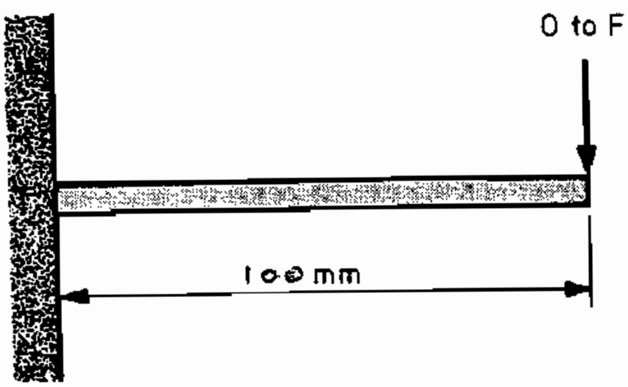


Figure 1(a) – Fatigue Failure Curves for Polymer

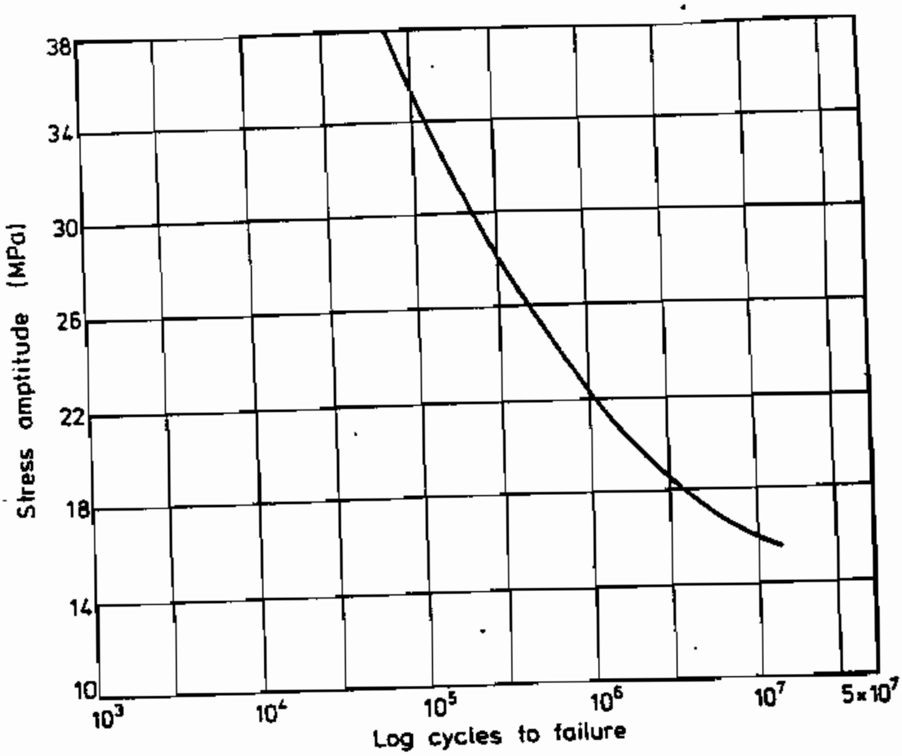
1 (b) In a small timing mechanism, a 150 mm long acetal copolymer beam is loaded in cantilever loading, as shown in Figure 1(b). The end load varies from 0 to F with a frequency of 2.5 Hz. If the beam is required to withstand at least 10 million cycles of load, calculate the permissible value of F, assuming a fatigue strength reduction factor of 2.0. **(10)**

Given: *The surface stress (in MPa) in the beam at the support is given by* ($\sigma = \frac{FL}{60}$) *where F is in Newtons, L is in mm.*
Fatigue and creep fracture data for the acetal copolymer are in Figures 1(c) and 1(d)



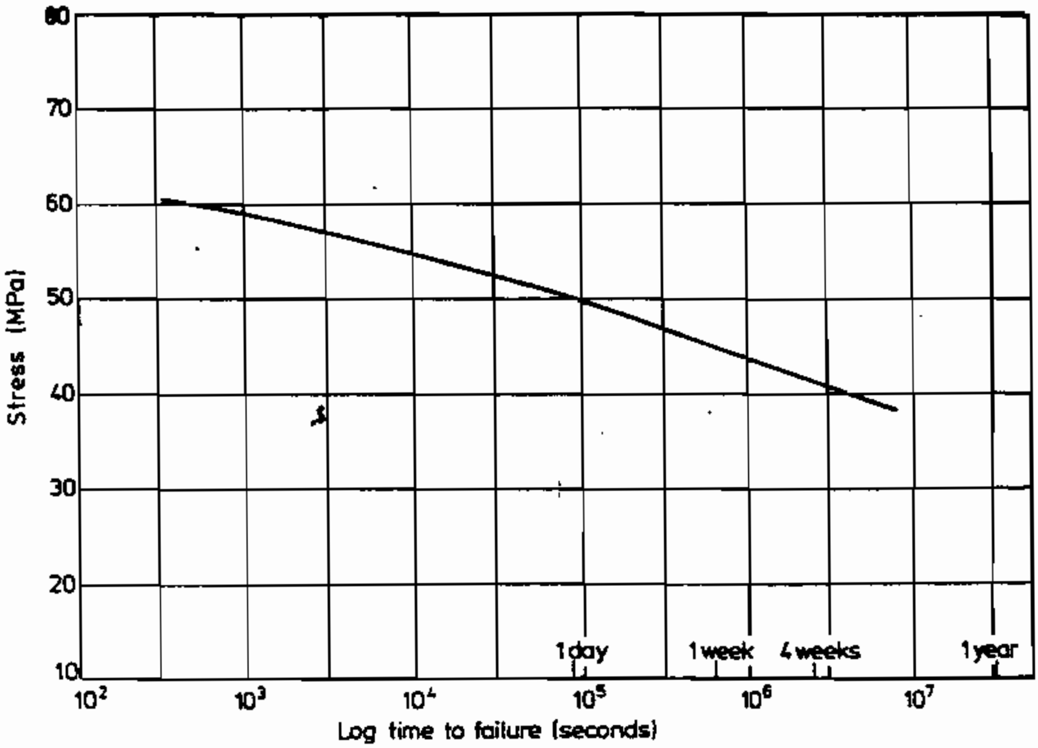
Beam in timing mechanism

Figure 1(b)



Fatigue behaviour of acetal

Figure 1(c)



Creep fracture of acetal

Figure 1(d)

2 (a) (i) Define the following terms in fracture of materials. What are the units of each?

- Stress Intensity Factor
- Critical Stress Intensity Factor
- Critical Strain Energy Release Rate
- Ductility Factor **(3)**

(ii) Discuss the effect of ductility / plastic yielding on the fracture strength of polymers. Explain what is meant by notch-sensitivity and give examples of notch-sensitive and notch-insensitive polymers. **(7)**

2 (b) A series of fatigue crack growth tests on PMMA gave the following results:

da/dN (x 10^{-7} m/cycle)	2.25	4.0	6.2	11.0	17.0	29.0
ΔK ($MPa\sqrt{m}$)	0.42	0.53	0.63	0.79	0.94	1.17

A stress cycle from 0 to 2.0 MPa is applied on a PMMA moulding with an initial defect size of 0.04 mm. Estimate the fatigue life of the moulding, given the crack growth data above and a critical stress intensity factor of 1.9 MPa $\sqrt{m}$. **(10)**

Assume: *An elliptical crack in a large sheet subject to tensile loading in one direction.*

3 (a) Derive the governing equation of the standard linear solid viscoelastic model shown in Figure 3(a) below and show that the creep compliance J(t) of the model is given as:

$$J(t) = \left(\frac{1}{\xi_1 + \xi_2} - \frac{1}{\xi_2}\right).e^{-t/\tau} + \frac{1}{\xi_2}$$

where $\tau = \dfrac{\eta_3(\xi_1 + \xi_2)}{\xi_1 \xi_2}$ characteristic time (secs)

<u>Note</u>: *Solutions to Ordinary Differential Equations attached*

(10)

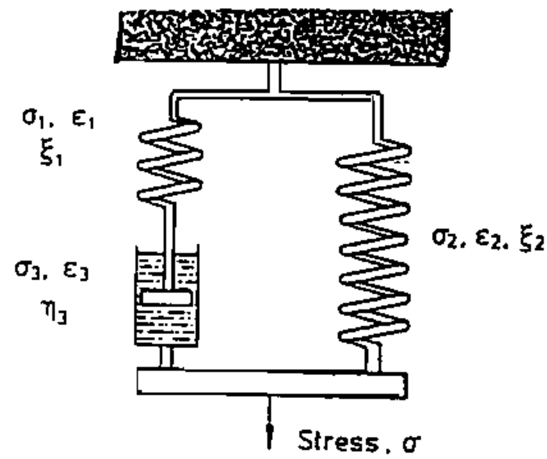


Figure 3(a)

3 (b) A polymer whose creep response is represented by a standard linear solid model is subjected to the stress history shown in Figure 3(b) below.

Given the following material properties:

ξ_1 = 70 GPa; ξ_2 = 50 GPa

η_3 = 900 GPa secs

Plot the strain history in the material up to 40 seconds. **(10)**

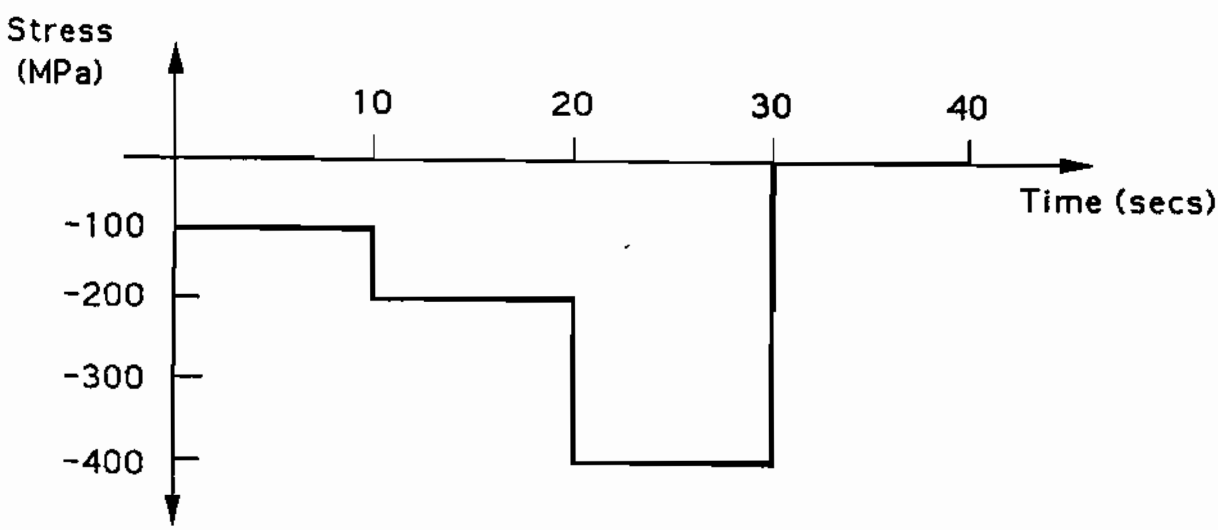


Figure 3(b)

4 (a) Discuss the growth and projected growth of advanced composites in large aircraft structure. Compare the properties and processing methods of these materials to their metal counterparts. **(10)**

(b) Using the distortion energy yielding criterion

$$\sigma_{ys}^{2} = \sigma_{1}^{2} - \sigma_{1}\sigma_{2} + \sigma_{2}^{2}$$

and the attached table of stresses, show that the radius of the plastic zone at the tip of an infinitely sharp crack under plane stress conditions is given as:

$$r_y = \frac{K_I^{2}}{2\pi\sigma_{ys}^{2}} = \cos^2\frac{\theta}{2}\ (1+3\sin^2\frac{\theta}{2})$$

(10)

5 (a) Describe a capillary rheometer and a melt flow indexer and discuss the important differences between them. **(8)**

(b) The Rabinowitch correction factor (4n/ 3n+ 1) is used to correct for non-Newtonian effects in capillary rheometers.

(10)

$$\eta = \eta_a\left(\frac{4n}{3n+1}\right)$$

where η = true viscosity

and η_a = apparent viscosity

From the basic flow equations below, derive the Rabinowitch correction factor.

(12)

Apparent Viscosity: $\eta_a = \dfrac{\pi P R^4}{8LQ}$

Velocity profile = $V = \left(\dfrac{n}{n+1}\right)\gamma_o^{\left(\frac{n+1}{n}\right)}\left[\dfrac{dp/dz}{2\eta_o}\right]^{\frac{1}{n}}\left[r^{\left(\frac{n+1}{n}\right)} - R^{\left(\frac{n+1}{n}\right)}\right]$

Wall shear stress = $\tau_W = \dfrac{PR}{2L}$

6 (a) Define the terms: shear viscosity and extensional viscosity. Give three examples of shearing and extensional flows in polymer processing. **(6)**

(b) A sliding-plate viscometer, as shown in Figure 6 below, is used to measure the viscosity of a polymer melt.

Clearly stating all assumptions made, derive an expression for the viscosity of the melt.

What are the disadvantages of such an apparatus in comparison to rotational viscometers?

(6)

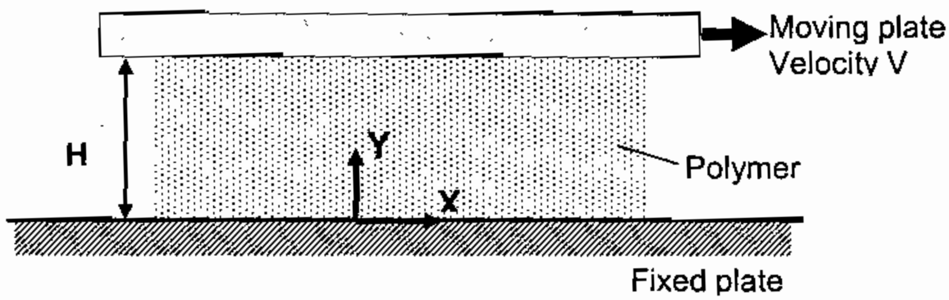


Figure 6

(c) The following readings of force and plate velocity are taken from a sliding plate viscometer, where the wetted surface dimensions are 100 mm x 50 mm, and the plates are kept at 3 mm separation.

Force (N)	0.446	0.817	1.985	3.152	7.228
Velocity (mm / sec)	0.846	1.74	4.74	9.48	27.36

Plot viscosity against shear rate for the polymer and find the power-law constants C & n. **(8)**

7. A Kevlar / Epoxy laminate with layup [0° / ± 30° / 90°] is manufactured, using pre-impregnated tape and standard processing techniques.

(a) Briefly describe how such a laminate would be manufactured? **(5)**

(b) Calculate the effective modulii of the laminate in the x and y directions: Ex*, Ey*. **(15)**

Given: Properties of Kevlar / epoxy preimpregnated tape:

E_L = 76 GPa; E_T = 5.5 GPa
G_{LT} = 2.3 GPa, ν_{LT} = 0.34

Note: Laminate transformulation equations are given on attached sheets.

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