ADELAIDE UNIVERSITY

DEPARTMENT OF MECHANICAL ENGINEERING
FINAL EXAMINATION FOR THE DEGREE OF B.E
#4109: SOLID MECHANICS
NOVEMBER, 2001

TIME ALLOWED: 3 HOURS & 10 MINUTES

- **You are advised to devote the first 10 minutes to read the paper and plan your approach.**
- Answer all FIVE questions.
- All questions carry UNEQUAL marks
- Open books, open notes examinations. The use of lecture notes, textbooks, drawing instruments and programmable calculating devices are permitted in the examination room.
- Appropriate engineering assumptions may be made for inadequate data.

Question #1 (a).
The fatigue behaviour of a specimen under alternating stress conditions with zero mean stress is given by the expression:

$$\sigma_r^{a} \cdot N_f = K$$

where, σ_r is the range of cyclic stress, N_f is the number of cycles to failure; and K and "a" are material constants. It is known that $N_f = 10^6$ when $\sigma_r = 300$ MN/m^2 and $N_f = 10^8$ when $\sigma_r = 200$ MN/m^2. Calculate the constants K and "a" and hence the life of the specimen when subjected to a stress range of $\sigma_r = 100$ MN/m^2.

(12 Marks).

Question # 1(b).
The values of the endurance limits at various stress amplitude levels for low-alloy constructional steel fatigue specimens are given below:

σ_a (MN/m^2)	N_f (Cycles)
550	1,500
510	10,050
480	20,800
450	50,500
410	125,000
380	275,000

A similar specimen is subjected to the following programme of cycles at the stress amplitudes stated as:

> 3,000 at 510 MN / m^2, 12,000 at 450 MN/m^2 and 80,000 at 380MN /m^2, after which the sample remained unbroken.

How many additional cycles would the specimen withstand at 480 MN/m^2 prior to failure? Assume zero mean stress conditions.

(10 Marks)

Question #2.
An external pressure of 10 MN/m^2 is applied to a thick cylinder of internal diameter 160 mm and external diameter 320-mm. If the maximum circumferential (hoop) stress permitted on the inside wall of the cylinder is limited to 30 MN/m^2, determine (a) the maximum internal pressure that can be applied assuming the cylinder has closed ends. (b) What will be the change in outside diameter when this external pressure of 10 MN/ m^2 is applied? Take E =207 GN/m^2 and Poisson's ratio ν = 0.29.

(15 Marks).

Question #3
A U-shaped curved beam with a symmetric channel cross section is shown in the figure below (Figure Q3 –part a & b). The beam is loaded by two opposed forces of magnitude 2 kN. Find the neutral radius R_{NA} associated with this cross section. Also find the maximum tensile stress at the section A-A shown in the figure. The cross section is conveniently regarded as the difference between the solid (30x30) Square and the dotted (20x20) Square and is shown in the Figure Q3- part c.

(17 Marks).

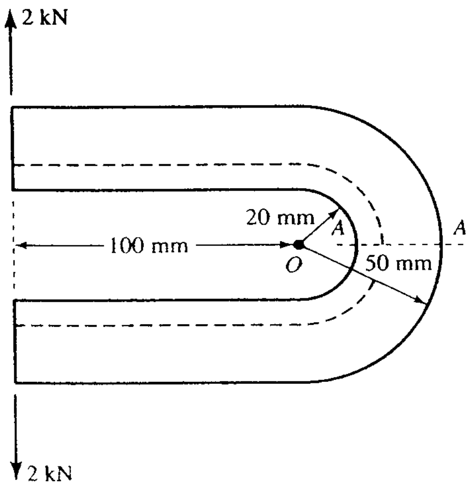


Fig. Q3-part a

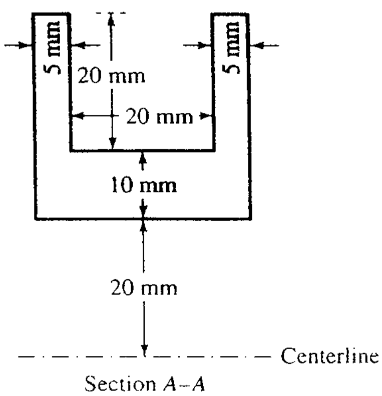


Fig. Q3 – part b

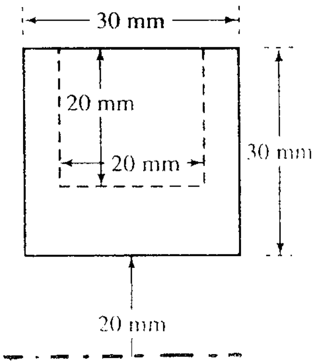


Fig. Q3 – part c

Figure: Q3 – part a, b & c

Question #4.
In a laboratory fatigue test on a CTS (Compact Tension) specimen of an aluminium alloy the following crack length measurements were taken.

Crack length, (mm)	21.58	22.64	23.68	24.71	25.72	27.37	28.97	29.75
Cycles	3575	4255	4593	4831	5008	5273	5474	5514

The specimen has an effective width of 50 mm., Load amplitude = 3 kN, and Specimen thickness = 25 mm.

Construct a growth rate curve in order to estimate the constant "C" and "m" in the Paris – Erdogan's equation.

$$da/dN = C(\Delta K)^m.$$

Use the expressions given in Table 1 to evaluate ΔK. Use the three- point method to evaluate da/dN, i.e. at point n:

$$\left(\frac{da}{dN}\right)_n = \left[\frac{a_{n-1} - a_{n+1}}{N_{n+1} - N_{n-1}}\right]$$

Use the following Table shown below to calculate amplitude of stress intensity factor and compliance functions for CTS specimen.

Compliance function $Y = A\left(\frac{a}{W}\right)^{1/2} - B\left(\frac{a}{W}\right)^{3/2} + C\left(\frac{a}{W}\right)^{5/2} - D\left(\frac{a}{W}\right)^{7/2} + E\left(\frac{a}{W}\right)^{9/2}$
with W = uncracked specimen width; a = length of edge crack; b = specimen thickness; P = total load; L = distance between loading points

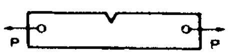
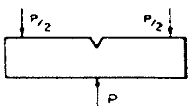
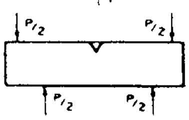
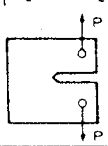
Specimen geometry	Specimen nomenclature	Equation for K	Compliance function constants				
			A	B	C	D	E
	Single edge notched (S.E.N.)	$K = \frac{P}{bW^{1/2}} \cdot Y$	1.99	0.41	18.70	38.48	53.85
	Three-point bend ($L = 4W$)	$K = \frac{3PL}{bW^{3/2}} \cdot Y$	1.93	3.07	14.53	25.11	25.80
	Four-point bend	$K = \frac{3PL}{bW^{3/2}} \cdot Y$	1.99	2.47	12.97	23.17	24.80
	Compact tension (C.T.S.)	$K = \frac{P}{bW^{1/2}} \cdot Y$	29.60	185.50	655.70	1017.0	638.90

Table of compliance functions (Y).

(17 Marks).

PLEASE SEE NEXT PAGE.

Question # 5(a).

The lives of Nimonic 90 turbine blades tested under varying conditions of stress and temperature are set out in the table below:

Stress (MN/m^2)	Temperature °C	Life (hours)
180	750	3,000
180	800	500
300	700	5,235
350	650	23,820

Use the information given to produce a master curve based upon the Larsen – Miller parameter, and thus calculate the expected life of a blade when subjected to a stress of 250 MN/m^2 and a temperature of 750 °C.

(16 Marks)

Question #5(b).

The following table shows the creep data obtained for a metal using a stress of 100 MN/m^2 at a range of temperatures. If the constant "a" in the " Larsen – Miller" parameter is 22, calculate the time to failure at a stress of 100 MN/m^2 when the temperature of the material is 725 °C. (R=8.314 J $mol^{-1}K$)

Tempera -ture °C	100	200	250	300	400	500	600
$d\varepsilon_o / dt$ mm/mm/ hr	2.1 $\times 10^{-23}$	2.77 $\times 10^{-17}$	4.25 $\times 10^{-15}$	2.7 $\times 10^{-13}$	1.72 $\times 10^{-10}$	2.06 $\times 10^{-8}$	8.25 $\times 10^{-7}$

(13 Marks)

END OF EXAMINATION