FINAL EXAMINATION

9:30 AM to 12 :00 PM, April 20, 2001, MMS319S

<<FRACTURE MECHANISMS AND FRACTURE MECHANICS>>

Note: *(i) This is a close-book, 150 min. examination.*
(ii) Only non-programmable calculators are allowed.
(iii) No aid sheet.
(iv) No further explanation is needed for all the problems.

I. Answer "Yes" or "No" to the following statements. If you consider the given statement is correct, mark "Y" for yes; otherwise, mark "N".

(2.5 marks each)

(1) A typical ductile metallic material, such as an annealed low-C steel, may also fail in a brittle way.

(Y—N)

(2) For a metallic material, if a failure is known to have been caused by a fatigue process, there are always striations on the fracture surface.

(Y—N)

(3) Ceramic materials generally show brittle fracture behavior through the cleavage mechanism. This is due to the fact that there are no any dislocations in ceramic materials.

(Y—N)

(4) If the temperature for Charpy impact-testing Al specimens is decreased to below -183°c, the reading for the Charpy impact energy will be drastically decreased as well. This is because this testing temperature is well below the DBTT (Ductile-to-Brittle Transition Temperature) of Al alloy.

(Y—N)

(4) The resistance to crack extension, i.e. the R behavior, of an engineering material is usually provided by the increase in the elastic deformation energy in the test piece.

(Y—N)

(5) All engineering structural materials have a well-defined fatigue endurance limit by nature.

(Y—N)

(6) In Stage II of fatigue crack propagation, the direction of crack development is parallel to the direction of the major applied stress.

(Y—N)

(7) All transgranular fractures in metals are caused by cleavage fracture.

(Y—N)

(8) For steels, generally speaking, the smaller the grain size, the higher the yield strength and the higher the DBTT.

(Y—N)

(9) If the applied stress amplitude is high enough, plastic deformation may be obtained in each and every cycle during the cyclic deformation of a Cu alloy. As a result, cyclic stress-strain hysteresis loops may be obtained and, hence, elastic deformation is no longer involved in the deformation process.

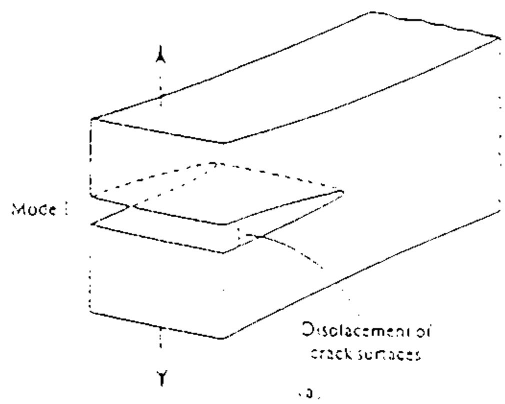
(Y—N)

(10) A block of low C steel was first annealed to give a UTS value of 500 Mpa. A test bar was then machined from this steel and was further deformed to a maximum stress of 450 Mpa in tension before unloading. As a result, a 20% plastic strain was accommodated by the specimen. It is believed that the same specimen may demonstrate softening behavior if cycled at a relatively high peak stress (Assuming that $\sigma_m = 0$).

(Y—N)

II. Using the figure below and employing the miniaturized sample approach, show that a three-dimensional stress field will develop at and near to the crack tip.

(15 marks)



III. For characterizing the mechanical strength of ceramic materials, three point bending test is frequently employed. The result of such test is usually expressed as the Modulus Of Rupture (MOR or σ_r). It has been found that for the same material the value of σ_r is usually higher than that of σ_f, the fracture stress measured in tension. Sometimes σ_r can even be as high as 1.5 times of σ_f. Explain the reason behind this difference in strength from different testing methods.

(10 marks)

IV. Consider a brittle material with its $\gamma = 1\ J/m^2$ and E = 100 Gpa.

(a) What is the theoretical breaking strength of this material by energy consideration if it contains a crack-like defect of 1 mm long?

(10 marks)

(b) Should it be possible to increase the γ value to 1,000 J/m^2, what would be the breaking strength for a 1 mm long crack?

(5 marks)

Note: Choose the equation you need from the following:

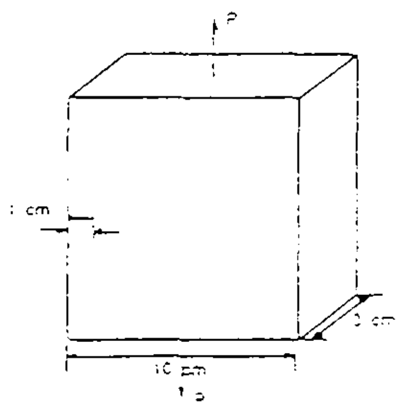
$\sigma_f = [(\gamma E \rho)/(4a_o c)]^{1/2}$, $\sigma_f = [(2\gamma E)/(\pi c)]^{1/2}$,

$K_{Ic} = 1.12\sigma_f(\pi a)^{1/2}$, $G_c = (\sigma_f^2 \pi a)/E$.

V. Establish the maximum load that the component shown in the figure below can withstand. The component is made of Ti-6Al-4V with its σ_y = 900 Mpa and K_{Ic} = 100 Mpa $(m)^{1/2}$.

Note: $K_I = Y\sigma(\pi a)^{1/2}$,

Where $Y = 1.12-0.231(a/W) + 10.55(a/W)^2$. (10 marks)



VI. You are given with three very large identical plates with an identical crack "a" in each. It is also known that these plates are made of an identical material.

(a) In a single plot, draw first the R curve for each of the three plates.

(5 marks)

(b) Now that these three plates are under three different applied stresses, σ_1, σ_2 and σ_3, respectively. Draw the G curves for these three stress conditions, assuming that the application of σ_1 would cause an immediate catastrophic fracture; the application of σ_2 would create a critical condition for the crack propagation; whereas the application of σ_3 would never cause the crack to propagate in a unstable way.

(5 marks)

Note: All the parameters in your plot must be marked clearly.

VII. The size of the Tresca plastic zone at the crack tip in the general plane-stress and plane-strain condition is given by the following two expressions, respectively:

$$r_y = (K_I^2/2\pi\sigma_y^2)\,\{\cos(\theta/2)[1+\sin(\theta/2)]\}^2 \qquad \text{for plane stress,}$$

$$r_y = (K_I^2/2\pi\sigma_y^2)\,\cos^2(\theta/2)[1-2\nu+\sin(\theta/2)]^2 \qquad \text{for plane strain.}$$

(a) Assuming that for a specific metal, the value of ν is 0.3, determine the ratio of the plastic zone size for the plane stress condition to that for the plane strain condition along the crack extension line. (All other conditions are kept the same.)

(5 marks)

(b) From your own result in (a), explain why the plane strain K_{Ic} is usually employed for industrial application instead of plane stress K_{Ic}.

(10 marks)

© Determine the angle at which the plastic zone is the largest for the plane stress condition.

(*5 bonus marks*)