THE UNIVERSITY OF ZAMBIA
SCHOOL OF ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING

UNIVERSITY EXAMINATIONS

FINAL EXAMINATION SEMESTER II 2001/2002
OCTOBER/NOVEMBER 2002

ME 232 - PROPERTIES OF ENGINEERING MATERIALS I

Time Allowed: THREE Hours **CLOSED BOOK**

ANSWER: Five Questions With At Least Two Questions from Each Section

HAND IN: Sections A and B in Separate Answer Books

All Questions Carry Equal Marks

SECTION A - Answer at least two questions from this Section.

Q1.

(a) Assuming that metal crystals can be considered as hard spheres in contact, determine the co-ordination numbers and packing fractions for the following crystal structures:
 (i) Body-centred cubic [4 marks]
 (ii) Face-centred cubic [5 marks]
 (iii) Hexagonal close-packed. [5 marks]
 [**Hint:** Packing fraction = (volume of atoms in unit cell)/(volume of unit cell)]

(b) Draw sketches showing the near neighbours of the atoms in these crystal structures.
 (i) Body-centred cubic [2 marks]
 (ii) Face-centred cubic [2 marks]
 (iii) Hexagonal close-packed. [2 marks]

Q2.

(a) Draw a fully labelled Fe-C phase diagram up to 6.7% Carbon. [12 marks]

(b) With reference to your Fe-C phase diagram, for two plain carbon steels of 0.4% and 1.0% Carbon;
 (i) Calculate the amount of austenite present in each of these steels at 723^{o}C, assuming the transformation is complete. [2 marks]
 (ii) Calculate the amount of pearlite present in each of these steels at 25^{o}C, assuming slow cooling. [2 marks]
 (iii) Suggest a typical application for each steel in its fully hardened and tempered conditions, and justify your choice. [4 marks]

Q3.

(a) What is electrochemical corrosion? [4 marks]

(b) Explain concisely each of the following forms of metallic corrosion
 (i) Pitting [6 marks]
 (ii) Corrosion fatigue [3 marks]
 (iii) Stress corrosion [3 marks]
 (iv) Fretting corrosion n[4 marks]

SECTION B: - Answer <u>at least two questions</u> from this Section.

Q4.
Refer to the plot below (Figure Q4) of the engineering stress-engineering strain curve for stainless steel. E=200GPa, S_O = 750 MPa, Poisson's ratio = 0.3, Sample Diameter = 50 mm and Sample Length = 100 mm.

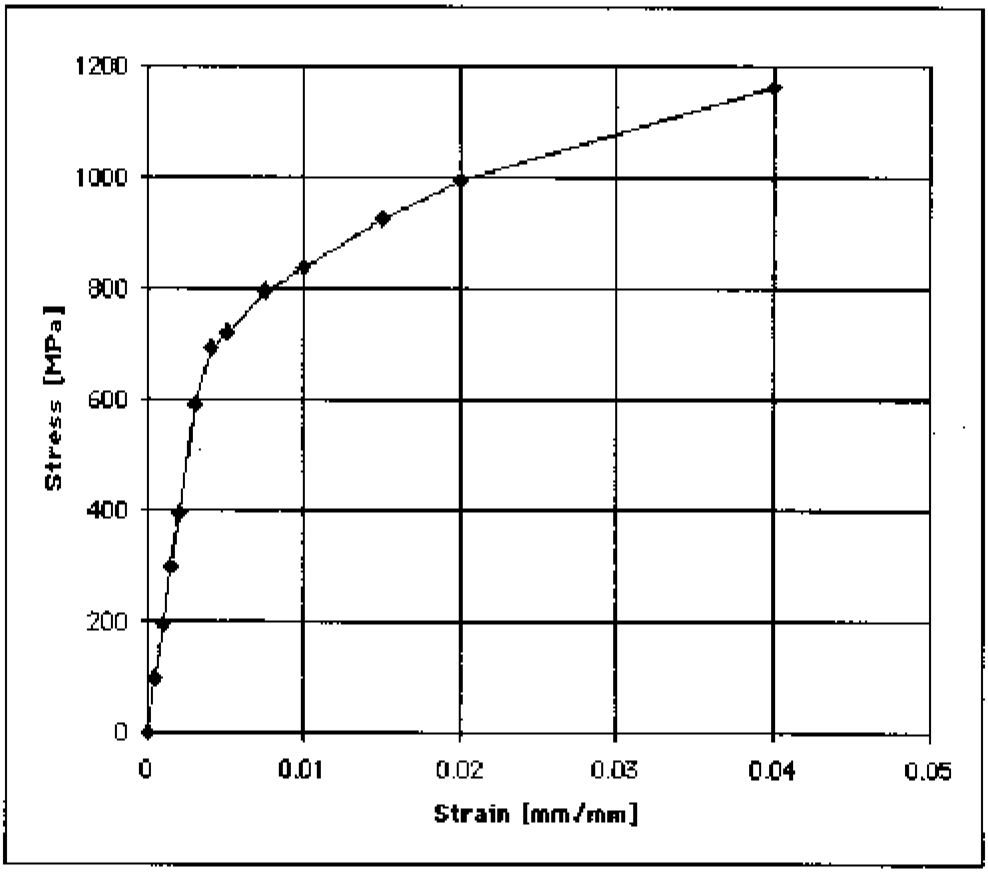

Figure Q4: Stress-Strain Plot

Assume the plot is made for testing the sample in **COMPRESSION**, and that it only undergoes uniform deformation.

(a) How much larger in diameter will the sample get when compressed with a load of P= 800,000 N? [5 marks]

(b) The stainless steel sample is loaded in compression with a load of **P = 1,964,000 N**, and then unloaded to **P = 0 N.** How much larger in diameter will the sample be? [5 marks]

(c) The stainless steel sample is loaded in compression with a load of P = 1,964,000 N, and then unloaded to P = 0 N. How much larger in diameter will the sample be? [5 marks]

(d) What is the modulus of resilience for the stainless steel? [3 marks]

(e) Sketch the strain as a function of time for a sample with significant ANELASTICITY that is loaded and unloaded within the elastic region. [2 marks]

Q5.

(a) What are the three basic categories of polymer [2 marks]

(b) Briefly describe the two main types of polymerisation process [4 marks]

(c) Ceramic materials are generally limited in their tensile mechanical properties due to brittle failure caused by small porosity and surface cracks. Using Griffith's criteria for brittle solids, determine the functional dependence of the failure strength on pore size, and explain your answer in words. [6 marks]

(d) How can the glass transition temperature of polymers influence the properties of the end products in service? [3 marks]

(e) A polystyrene component must not fail when a tensile stress of 1.25 MPa is applied. Determine the maximum allowable surface crack length if the surface energy of polystyrene is 0.50 J/m$^{2.}$ Assume a modulus of elasticity of 3.0 GPa. [5 marks]

$$\sigma_C = \left(\frac{2E\gamma_S}{\pi a}\right)^{1/2} \Rightarrow a = \frac{2E\gamma_S}{\pi {\sigma_C}^2} = \frac{2(3.0[GPa])\left(0.50\left[\frac{J}{m^2}\right]\right)}{\pi(1.25[MPa])^2} \Rightarrow$$

$$a = \frac{2(3.0\times10^9[Pa])\left(0.50\left[\frac{J}{m^2}\right]\right)}{\pi(1.25\times10^6[Pa])^2} = 6.11\times10^{-4}\left[\frac{J}{Pa\cdot m^2}\right] = 6.11\times10^{-4}[m] = 0.611[mm].$$

Q6.

(a) What are the principle reasons for the heat treatment of metals? [2 m arks]

(b) Name three important stages in annealing process. Describe briefly the change of strength and ductility in each stage. [6 marks]

(c) Using the isothermal transformation diagram (Figure Q6 on Page 4) for eutectoid composition shown below, specify the nature of the final microstructure of a specimen that has been subjected to the following time-temperature treatments. In each case assume that the specimen begins at 760^0 C and that it has been held at this temperature long enough to have achieved a complete and homogeneous austenitic structure.

(i) rapidly cool to 250^0 C, hold for 1000 sec and rapidly cool to room temperature; [3 marks]

(ii) rapidly cool to 400^0 C, hold for 1000 sec and rapidly cool to room temperature; [3 marks]

(iii) rapidly cool to 600^0 C, hold for 3 sec, rapidly cool to 400^0 C, hold for 30 sec, and rapidly cool to room temperature; [3 marks]

(iv) rapidly cool to 300^0 C, hold for 30 sec, and rapidly cool to room temperature. [3 marks]

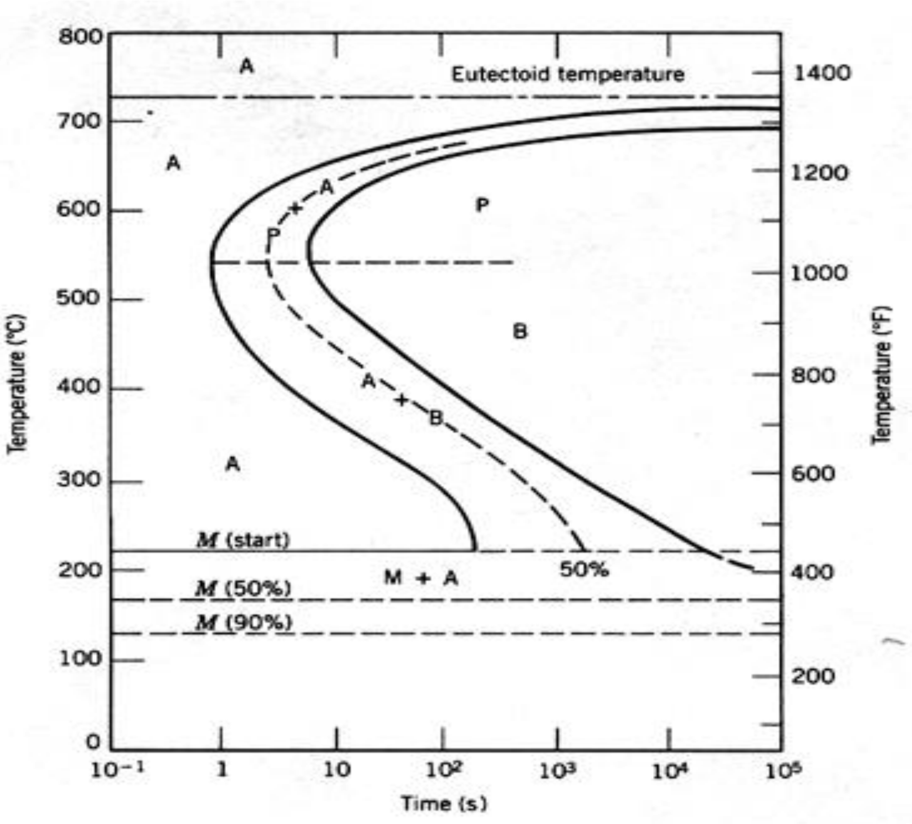

Figure Q6: Isothermal transformation diagram for eutectoid composition

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ENGR322: Midterm One
Winter 1999

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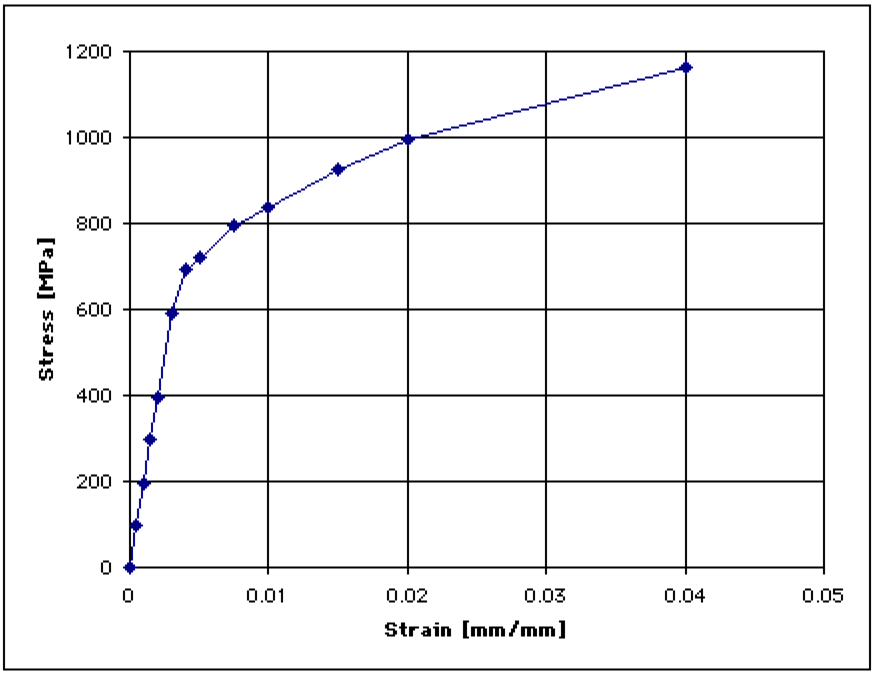
Refer to this plot of engineering stress versus engineering strain for stainless steel and these properties as needed for answering questions.

E = 200 GPa, So = 750 MPa, Poisson's ratio = 0.3,

Sample Diameter = 50 mm, Sample Length = 100 mm.



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1) (50 points TOTAL) Assume the plot is made for testing the sample in COMPRESSION, and that it only undergoes uniform deformation.

a) (25 points) How much larger in diameter will the sample get when compressed with a load of P = 800,000 N?

b) (25 points) The stainless steel sample is loaded in compression with a load of P = 1,964,000 N, and then unloaded to P = 0 N. How much larger in diameter will the sample be?

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2) (20 points) For an applied load of P = 1,500,000 N, what are the true stress and true strain values?

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3) (25 points) The stainless steel sample being tested is a single crystal. If the plastic deformation in compression is found to produce slip on planes at 45 degrees to the applied load, and in a slip direction that is at an angle of 40 degrees to the applied load, what is the CRITICAL RESOLVED SHEAR STRESS needed for plastic deformation?

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4) (20 points) Sketch the strain as a function of time for a sample with significant ANELASTICITY that is loaded and unloaded within the elastic region.

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5) (15 points) What is the modulus of resilience for the stainless steel shown on the first page?

6) (20 points)

T F Plastic deformation conserves volume.

T F The burger's vector is parallel to the line of an edge dislocation.

T F True strain is usually larger than engineering strain.

T F The elastic modulus get smaller as the temperature increases.

T F At the maximum load, the strain hardening exponent is equal to the true strain.

T F The elastic modulus of a material is determined by the strength of the atomic bonds.

T F The strain hardening exponent is between about 1.0 and 2.0 for most metals.

T F The energy required to form a dislocation gets smaller as the amount of slip gets bigger.

T F Edge dislocations move in the direction of their burger's vector.

T F The stress field around an edge dislocation is always compressive.

SOLUTIONS

1) a) We know that the stress is given by S = P / A:

$$A = \frac{\pi d^2}{4} = \frac{\pi\left(50\times10^{-3}\ \mathrm{m}\right)^2}{4} = 1.96\times10^{-3}\ \mathrm{m}^2.$$

$$S = \frac{P}{A} = \frac{8\times10^5\ \mathrm{N}}{1.96\times10^{-3}\ \mathrm{m}^2} = 407\ \mathrm{MPa}.$$

Since this stress is less than the yield strength of So = 750 MPa, the load is in the elastic region. We can use the elastic relation to find the amount of elastic strain for this load:

$$e = \frac{S}{E} = \frac{407\ \mathrm{MPa}}{200\ \mathrm{GPa}} = -2.04\times10^{-3} = \text{ length change (negative since this is a compressive load).}$$

This is related to the change in diameter by the Poisson's ratio :

$$\frac{\Delta d}{d_o} = e_\perp = -\nu e_\| \Longrightarrow \Delta d = -\nu e_\| d_o = -(0.3)\left(-2.04\times10^{-3}\right)(50\ \mathrm{mm}) = 0.031\ \mathrm{mm}$$

or $d_f = 50.031$ mm.

b) In this case, the stress, S = P / A = 1,000 MPa, a stress well into the plastic deformation area. We know that, at S = 1,000 MPa, the total strain contains BOTH elastic and plastic strain. When the load is released, the elastic strain is recovered, and we are left with the plastic (permanent) strain:

From the plot, $e_{total} = e_{el} + e_{pl} = 0.02$. We know the elastic strain is given by:

$$e_{el} = \frac{S}{E} = \frac{1000 \text{ MPa}}{200 \text{ GPa}} = 5 \times 10^{-3}, \text{ which gives the plastic strain as } e_{pl} = 0.02 - 0.005 = 1.5 \times 10^{-2}.$$

Since the load is compressive, we can find the change in the sample length to be

$$e_{pl} = -1.5 \times 10^{-2} = \frac{\Delta L}{L} \Longrightarrow \Delta L = \left(-1.5 \times 10^{-2}\right)(100 \text{ mm}) = -1.5 \text{ mm}.$$

We also know that during plastic deformation the volume is conserved, so that

$$V_0 = V_f \Longrightarrow L_o A_o = L_f A_o \text{ , or}$$

$$A_f = \frac{\pi d_f^{\,2}}{4} = \frac{L_o}{L_f} \frac{\pi d_o^{\,2}}{4} \Longrightarrow d_f = d_o \sqrt{\frac{L_o}{L_f}} = (50 \text{ mm}) \sqrt{\frac{100 \text{ mm}}{100 \text{ mm} - 1.5 \text{ mm}}} = 50.38 \text{ mm}.$$

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2) For the load of P = 1.5 MN, we get an engineering stress of S = P / A = 764 MPa. Since this is less than the maximum load point (which we don't see on the chart), we can use our conversion equations to convert to true stress and strain. From the chart, for a stress S = 764 MPa, the engineering strain is about 0.006.

$$\sigma = S(1 + e) = (764 \text{ MPa})(1 + 0.006) = 769 \text{ MPa}.$$

$$\varepsilon = \ln(1 + e) = \ln(1.006) = 0.00598.$$

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3) We know that the resolved shear stress due to the applied compressive stress is given by $\tau_r = \sigma \cos\lambda \cos\phi$.

The critical shear stress is the stress needed for plastic deformation to occur. This is the resolved shear stress on the slip plane when the applied stress is the yield strength:

$$\tau_{crit} = \sigma_o \cos\lambda \cos\phi = (750 \text{ MPa})(\cos 40)(\cos 45) = 406 \text{ MPa}.$$

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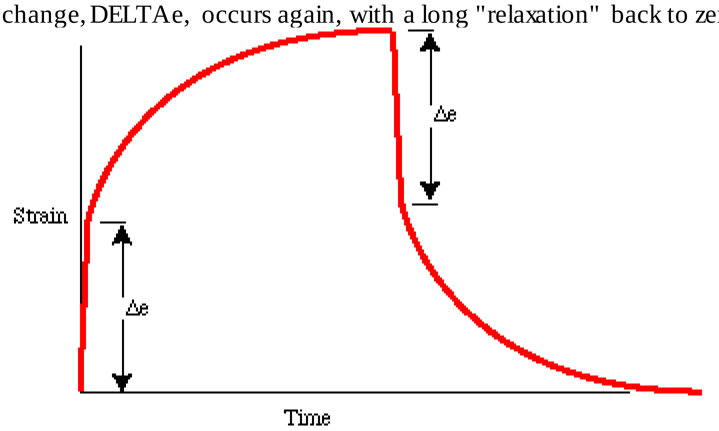
4) Anelastic strain is time dependent strain. On first applying the load there is an "instantaneous" increase in the strain by DELTAe. The strain then increases over some time period to a plateau value. On release of the load, the instantaneous strain change, DELTAe, occurs again, with a long "relaxation" back to zero strain.



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5) $$\text{MOR} = U_R = \frac{1}{2}\frac{S_o^{\,2}}{E} = \frac{1}{2}\frac{(750 \text{ MPa})^2}{(200 \text{ GPa})} = 1.4 \times 10^6 \text{ Pa} = 1.4 \times 10^6 \ \frac{\text{J}}{\text{m}^3}.$$

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6)

True Plastic deformation conserves volume.

False The burger's vector is parallel to the line of an edge dislocation.

False True strain is usually larger than engineering strain.

True The elastic modulus get smaller as the temperature increases.

True At the maximum load, the strain hardening exponent is equal to the true strain.

True The elastic modulus of a material is determined by the strength of the atomic bonds.

False The strain hardening exponent is between about 1.0 and 2.0 for most metals.

False The energy required to form a dislocation gets smaller as the amount of slip gets bigger.

True Edge dislocations move in the direction of their burger's vector.

False The stress field around an edge dislocation is always compressive.

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END OF EXAMINATION
Mr G M Munakaampe / Dr J Phiri