Mechanical Engineering Ph.D. Qualifying Exam

ENGINEERING MATERIALS

Fall 2009

IDENTIFICATION NUMBER:______________________________

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Please use a ball point pen, not a pencil.
Write legibly. Illegible writing will not be read

Department of Mechanical Engineering - Clemson University
Ph.D. Qualifying Examination - ENGINEERING MATERIALS

1) (a) Clearly define the concepts of a “slip plane” and a “slip direction”.

(b) Briefly describe the main crystallographic characteristics of the slip planes and the slip directions.

(c) Draw an FCC and a BCC unit cell; identify one of the slip planes in each structure, and one of the slip directions in each of the chosen slip planes.

(d) Explain how the number of slip planes in a material affects its strain-hardening behavior.

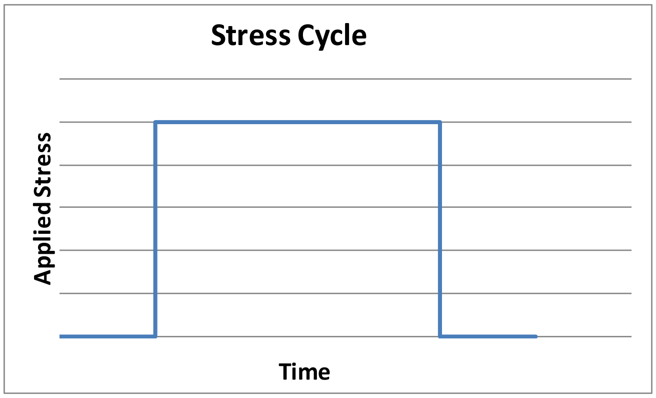
(e) Explain how the number of slip planes in a material affects its ductility.

2) Some ceramic materials like yttria-stabilized zirconia have relatively good toughness.

(a) What is the main underlying mechanism responsible for the enhanced toughness in this material?

(b) The same toughening mechanism is present in steels. Identify the class of steels in which this mechanism is exploited the most.

3) The following stress profile is applied to a sample:



a. CASE 1: Assume a viscoelastic material. Draw the strain response plot.

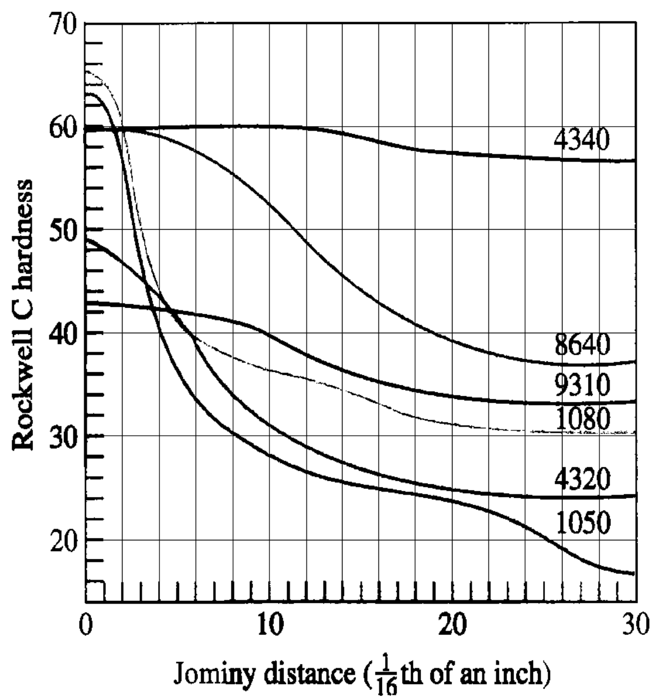
b. CASE 2: Assume that significant creep deformation occurs. Draw the strain response plot.

c. The creep phenomenon occurs in three distinct stages. Describe each, compare the *creep rate* for each stage, and describe how temperature and stress level affect the creep rate.

4) The Jominy quench bar test is designed to assess hardenability.

   a. Define hardenability. Include in your explanation the relevant materials, response of the material to cooling rate, and specific microstructure(s) formed.

The hardenability curves for several materials are given below. A shaft is made from 1050 steel, and quenched such that hardness in a critical area is 30 HR_C.



b. What does the Jominy distance represent?

c. What is the carbon content of the shaft material?

d. Is the shaft material hardenable? Explain.

The critical area is found to wear too quickly. By testing, a hardness of at least 40 HR_C is required in this area.

e. Identify the potential process constraints to improving hardness of the shaft.

f. Identify two potential and feasible solutions, and what changes to the process would be required to implement them.

5) Unidirectional and continuous glass fibers reinforce a nylon matrix.

   a. Draw the stress-strain diagram for the composite; assume loading is parallel to the fiber direction (defined as *0° orientation*), and strain extends beyond the point where the matrix deforms, causing the reinforcement to carry the entire load. Label the matrix deformation point.

b. Assuming the load is applied in this direction and fibers are rigidly bonded to the matrix (no relative slip), the composite strain ε_c, the fiber strain ε_f, and the matrix strain ε_m can be considered equal. Derive an expression for the composite modulus of elasticity $E_{c,0°}$ as a function of the individual fiber and matrix moduli E_f and E_m and their respective volume fractions f_f and f_m, where $f_f + f_m = 1$. Begin by expressing the force in the composite as a sum of loads carried by the fiber and matrix:

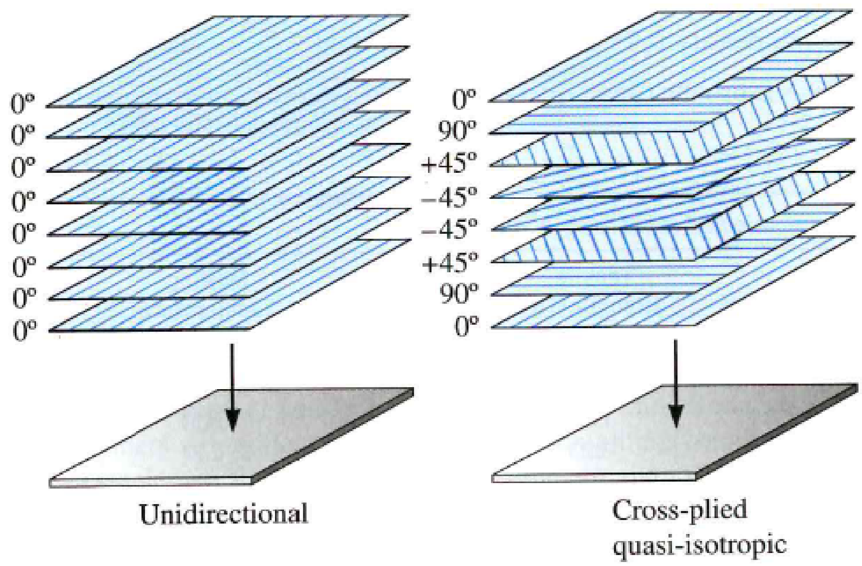
$$F_c = F_f + F_m$$

c. Now consider the case where the composite is loaded perpendicular to the fiber direction (defined as *90° orientation*). Here it can be assumed that the stresses in the composite, fiber and matrix are equal ($\sigma_c = \sigma_f = \sigma_m$).

Derive an expression for the composite modulus of elasticity $E_{c,90°}$ as a function of the individual fiber and matrix moduli E_f and E_m and their respective volume fractions f_f and f_m.

d. If the assumption of rigid bonding at the interface is relaxed, how is the composite elastic modulus affected in each case (0° and 90°)?

e. Sheets of such unidirectional composite can be layered for improved strength. Consider two such layering strategies, unidirectional and quasi-isotropic, as shown:



Give the main benefit and a potential application for each.