MASSACHUSETTS INSTITUTE OF TECHNOLOGY
DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
CAMBRIDGE, MASSACHUSETTS 02139

3.22 MECHANICAL PROPERTIES OF MATERIALS
PROBLEM SET 3

Due in 8 days from its assigned date

Reading
Hertzberg, *Deformation and Fracture Mechanics of Engineering Materials* (John Wiley& Sons, Inc.)
Chapter I, sections 1 – 2.
Ashby, M.F., *Mechanical Behaviour of Materials* (Course Notes). Section 3.

1. (Hertzberg 1.7) In class we have discussed the relation between the modulus of elasticity of a group of crystalline solids and their respective melting points. Relate the modulus of elasticity to the respective coefficients of thermal expansion. (The coefficient of thermal expansion increases with temperature for most materials.)

2. For a solid-solid equilibrium phase transformation of a crystalline material, comment on the value of the modulus before and after the phase transformation.

3. As temperature increases, explain how the elastic modulus changes for crystalline materials and rubbers. Relate each type of behavior to fundamental properties of each class of material.

4. (a) Explain why aluminum and magnesium have similar melting temperatures ($T_m = 650^\circ \mathrm{C}$) and dissimilar elastic moduli ($E_{Al} = 70$ GPa, $E_{Mg} = 45$ GPa)?
   (b) Aluminum 7075 T6 is an aluminum alloy with 1.6% Copper, 2.5% Magnesium, 5.6% Zinc, 0.23% Chromium by weight. Explain why the modulus of aluminum 7075 T6 ($E_{Al\,7075} = 70.7$ GPa) and pure aluminum ($E_{Al} = 70$ GPa) are nearly the same. Explain why the modulus of the alloy is slightly higher than the pure material.
   (c) Cobalt is a magnetorestrictive and contracts upon exposure to a magnetic field. Explain the effect of a magnetic field on the elastic modulus of cobalt.

5. (Hertzberg 1.19) You are given a 135 cm long length of high-strength wire with a circular cross-sectional diameter of 0.5 cm. The wire has the following properties: E=216 GPa; ε_f= 0.02. You are to manufacture a composite rod 15 cm long and having a cross-sectional area of 6.5 cm^2. The 135 cm long high-strength wire is to be used as the high-strength constituent of the composite. The matrix phase will consist of a polymer resin that is to be cured after the high-strength wires have been positioned. Ignoring the strength contribution of the polymer resin matrix and any residual thermal shrinkage stresses, and assuming an ideal bond between the matrix and the reinforcing phase, calculate the modulus of the strongest composite that can be made from the resin and the length of wire provided.

6. (Hertzberg 1.23) From Table 1.9, we see that the stiffness of Nylon 66 + 25v/o (volume fraction) carbon fibers is 14 GPa, whereas the stiffness of an epoxy resin + 60v/o carbon fibers is 220 GPa. If the elastic modulus of carbon fibers is 390 GPa, speculate on the nature of the two composites in question in tems of fiber length and fiber orientation. Also, calculate the lower bound modulus for the Nylon 66 + 25v/o carbon fiber composite.

7. Thermostatic bimetals: A thermostatic bimetal consists of two metals layers with different coefficients of thermal expansion bonded together. When subjected to a temperature change, the bimetal undergoes a change of shape that is mechanically exploited for control of temperature or some other function. To design a bimetal, it is advantageous to bond a low expansivity alloy with a high expansivity alloy. Guillaume (1898) discovered that an iron alloy with 35.4 wt% of nickel yielded a material with a very low thermal expansion coefficient over a useful range from 0°C to 100°C of $1.3\times10^{-6}\ (^{\circ}\mathrm{C})^{-1}$. This alloy was named *invar* to reflect its invariant dimensions over most atmospheric temperatures.
   (a) Explain why lead, aside from environmental concerns, cannot be used as one of the two metals in the bimetallic strip in thermostats.
   (b) Derive an expression for the variation of curvature of a brass (90% Cu–10% Zn)–Invar thermostatic bimetal as a function of temperature change, ΔT. Assume that the brass and Invar layers have the same thickness.
   ($\alpha_{\text{Cu-Zn}} = 20\times10^{-6}(^{\circ}\mathrm{C})^{-1}$, $E_{\text{Invar}} = 141$ GPA, $E_{\text{Cu-Zn}} = 117$ GPa)
   (c) If the temperature is increased, identify the direction in which the bimetal curves.
   (d) Discuss why rapid fluctuations in temperature would affect the ability of the thermostatic bimetal to provide accurate measures of instantaneous temperature.