

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATION, APRIL 2001
MMS 350H1 S - MATERIALS DESIGN & ENGINEERING

EXAMINERS: D. D. PEROVIC AND B.G. YACOBI

[Answer all 5 questions]

[All 5 questions are of equal value]

[Marks for individual questions are as indicated]

Exam Type: A

1. Briefly answer the following questions:

- (a) Explain why covalently bonded materials are generally less dense than ionically or metallically bonded solids. **(4 marks)**
- (b) Explain why the properties of polycrystalline materials are most often isotropic. **(4 marks)**
- (c) Would you expect a material in which the atomic bonding is predominantly ionic in nature to be more or less likely to form a noncrystalline solid upon solidification than a covalent material? **(4 marks)**
- (d) For a face-centred cubic solid, would you expect the surface energy for a (100) plane to be greater or less than that for a (111) plane? Why? **(4 marks)**
- (e) Explain why small-angle grain boundaries are not as effective in increasing the yield stress of a material as are high-angle grain boundaries. **(4 marks)**

- 2.(a) Gaseous hydrogen at a constant pressure of 1.013 MPa (10 atm) is to flow within the interior of a thin-walled cylindrical tube of nickel that has a radius of 0.1 m. The temperature of the tube is to be 300 C and the pressure of hydrogen outside the tube will be maintained at 0.01013 (0.1 atm). Calculate the minimum wall thickness if the diffusion flux is to be no greater than 1×10^{-7} mol/m² sec. The concentration of hydrogen in nickel (C_H), in moles hydrogen per m³ of nickel, is a function of hydrogen pressure, p_{H_2} (in MPa) and absolute temperature (T) according to:

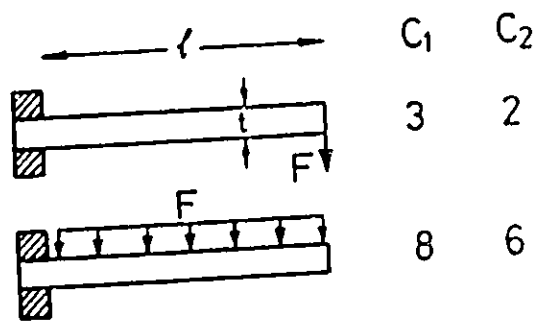
$$C_H = 30.8 (p_{H_2})^{1/2} \exp (-Q_C / RT) \text{ where } Q_C = 12.3 \text{ kJ/mol.}$$

Furthermore, the diffusivity of H in Ni is given by:

$$D_H \text{ (m}^2\text{/sec)} = 4.76 \times 10^{-7} \exp (-Q_D / RT) \text{ where } Q_D = 39.56 \text{ kJ/mol. (5 marks)}$$

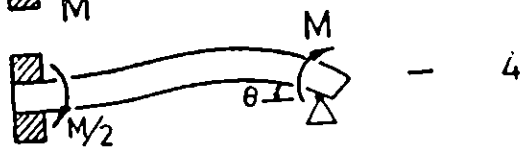
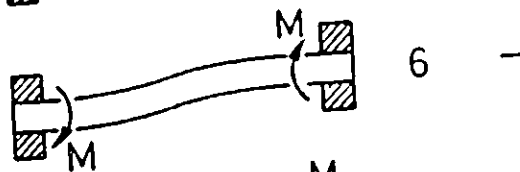
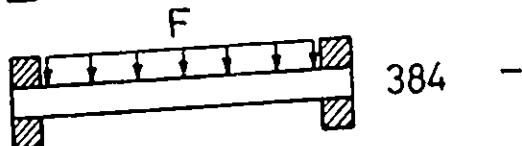
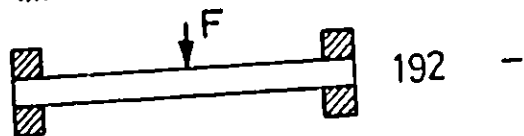
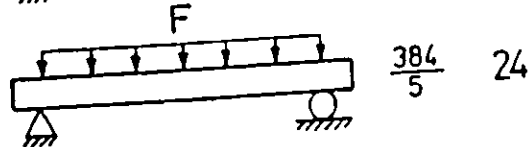
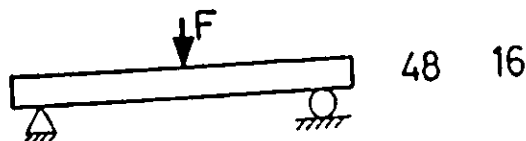
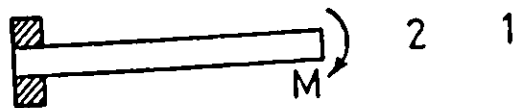
- (b) For thin-walled cylindrical tubes that are pressurized, the circumferential stress (σ) is a function of the pressure difference across the wall (Δp), cylinder radius (r) and tube thickness (Δx) as given by: $\sigma = r(\Delta p)/4(\Delta x)$. Compute the circumferential stress to which the walls of this pressurized cylinder are exposed. (5 marks)
- (c) The room-temperature yield strength (σ_y) of Ni is 100 MPa and decreases about 5 MPa for every 50 C increase in temperature. Would you expect the wall thickness computed in (b) to be suitable for this Ni cylinder at 300 C? Why or why not? (5 marks)
- (d) If this thickness is found to be suitable, compute the minimum thickness that could be used without any deformation of the tube walls. How much would the diffusion flux increase with this reduction in thickness? On the other hand, if the thickness determined in (c) is found to be unsuitable, then specify a minimum thickness that you would use. In this case how much of a reduction in diffusion flux would result? (5 marks)
- 3.(a) Consider a hypothetical phase diagram for a lead-free A-B alloy to be used in microelectronics assembly and packaging. The diagram is similar in form to the Pb-Sn system. Assume that: (i) α and β solid solution phases exist at the A and B extremities of the phase diagram, respectively; (ii) the eutectic composition is 47 wt.%B-53 wt.%A; and (iii) the composition of the β phase at the eutectic temperature is 92.6 wt.%B-7.4 wt.%A. Determine the composition of an alloy that will yield primary α and total α mass fractions of 0.356 and 0.693, respectively. (10 marks)
- (b) A microelectronic component is manufactured from the A-B alloy which has been determined to have a *plane strain* fracture toughness of 35 MPa $\sqrt{\text{m}}$. It is known from thermal cycling tests that fracture results at a stress of 250 MPa when the maximum internal flaw size is 2.0 mm. For this same component and alloy, will fracture occur at a stress level of 325 MPa when the maximum internal flaw size is 1.0 mm? Why or why not? [Recall that: $K_{Ic} = Y\sigma(\pi a)^{1/2}$ where Y is a dimensionless parameter that depends on specimen size, geometry and stress state (e.g. plane strain conditions)]. (10 marks)
4. Outline briefly (i) the changes in the properties at the nanoscale and (ii) the major advantages of nanostructures, as related to:
- (a) Electronic properties (10 marks)
- (b) Mechanical properties (10 marks)
- In your answer, specifically, consider such applications as (i) quantum dot lasers and (ii) high-surface area materials.

5. You have been asked to design the ultimate airplane wing. The wing section is assumed to be hollow (variable wall thickness= t) and ellipsoidal is cross-section. The wing is loaded as a cantilever beam with a uniformly distributed force along the length (l) of the wing. Using the information attached answer the following questions:
- (a) Select the best engineering material to achieve the maximum stiffness for least weight if cost is no object. **(5 marks)**
 - (b) Does your conclusion in (a) change if material cost is a constraint? **(2 marks)**
 - (c) Would your conclusion in (a) change if the wing were to be constructed from a solid ellipsoidal section where the minor axis dimension (b) is variable? **(5 marks)**
 - (d) Select the ultimate material for maximum resistance to full plasticity, where a "plastic hinge" develops prior to plastic collapse, at minimum weight. (N.B. For simplicity assume the wing has a rectangular cross-section with a variable thickness (b)). **(5 marks)**
 - (e) Is the material selected in case (d) ideal for resistance to catastrophic fracture? If not, select the best material for fracture resistance. **(3 marks)**



$$\delta = \frac{Fl^3}{C_1EI} = \frac{Ml^2}{C_1EI}$$

$$\theta = \frac{Fl^2}{C_2EI} = \frac{Ml}{C_2EI}$$



E = YOUNGS MODULUS (N/m²)

δ = DEFLECTION (m)

F = FORCE (N)

M = MOMENT (Nm)

l = LENGTH (m)

b = WIDTH (m)

t = DEPTH (m)

θ = END SLOPE (-)

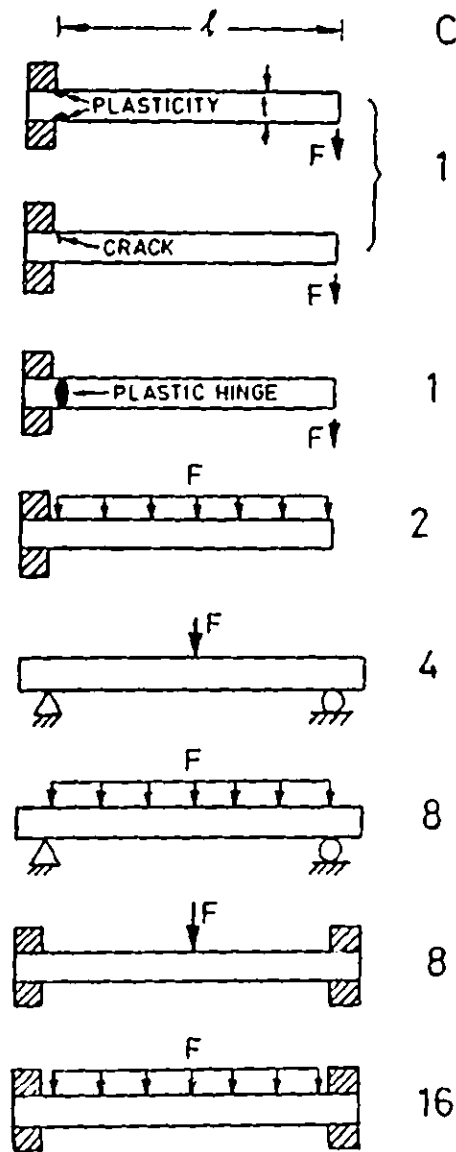
I = SEE TABLE 2 (m⁴)

y = DISTANCE FROM N.A.(m)

R = RADIUS OF CURVATURE (m)

$$\frac{\sigma}{y} = \frac{M}{I} = \frac{E}{R}$$

FIG. A3 Deflection of beams.



$$M_f = \left(\frac{I}{y_m} \right) \sigma^* \text{ (ONSET)}$$

$$M_f = H \sigma_y \text{ (FULL PLASTICITY)}$$

$$F_f = C \left(\frac{I}{y_m} \right) \frac{\sigma^*}{l} \text{ (ONSET)}$$

$$F_f = \frac{CH \sigma_y}{l} \text{ (FULL PLASTICITY)}$$

M_f = FAILURE MOMENT (Nm)

F_f = FORCE AT FAILURE (N)

l = LENGTH (m)

t = DEPTH (m)

b = WIDTH (m)

I = SEE TABLE 2 (m^4)

$\frac{I}{y_m}$ = SEE TABLE 2 (m^3)

H = SEE TABLE 2 (m^3)

σ_y = YIELD STRENGTH (N/m^2)

σ_f = MODULUS OF RUPTURE (N/m^2)

σ^* = σ_y (PLASTIC MATERIAL)

= σ_f (BRITTLE MATERIAL)

FIG. A4 Failure of beams.

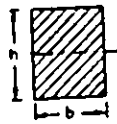
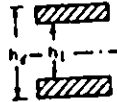



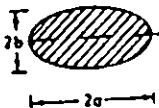
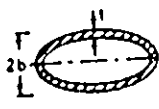
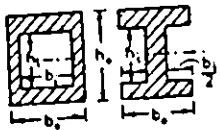
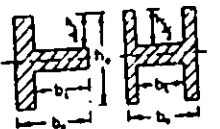

SECTION	$A(m^2)$	$I(m^4)$	$K(m^4)$	$I/y_m(m^2)$	$H(m^3)$
	bh	$\frac{bh^3}{12}$	$\frac{16}{3}hb^3(1-0.58\frac{b}{h})$	$\frac{bh^2}{6}$	$\frac{bh^2}{4}$
	$b(h_0 + h_1)$	$\frac{b}{12}(h_0^3 + h_1^3)$	—	$\frac{b}{12h_0}(h_0^3 + h_1^3)$	$\frac{b}{4}(h_0^2 + h_1^2)$
	$\frac{\sqrt{3}}{4}a^2$	$\frac{a^4}{32\sqrt{3}}$	$\frac{a^4\sqrt{3}}{80}$	$\frac{a^3}{32}$	—
	$\frac{\pi d^2}{4}$	$\frac{\pi}{64}d^4$	$\frac{\pi}{32}d^4$	$\frac{\pi}{32}d^3$	$\frac{1}{6}d^3$
	$\frac{\pi}{4}(d_0^2 - d_1^2)$	$\frac{\pi}{64}(d_0^4 - d_1^4)$	$\frac{\pi}{32}(d_0^4 - d_1^4)$	$\frac{\pi}{32d_0}(d_0^4 - d_1^4)$	$\frac{1}{6}(d_0^3 - d_1^3)$
	πab	$\frac{\pi}{4}ab^3$	$\frac{\pi a^3 b^3}{a^2 + b^2}$	$\frac{\pi}{2}ab^2$	—
	$2\pi(ab)^{1/2}$	$\frac{\pi}{4}ab^3(1 + \frac{1}{2}\frac{a}{b})$	$\frac{4\pi a^2 b^2}{(a+b)}$	$\frac{\pi ab^2}{2}(1 + \frac{1}{2}\frac{a}{b})$	—
	$b_0 h_0 + b_1 h_1$	$\frac{1}{12}(b_0 h_0^3 + b_1 h_1^3)$	—	$\frac{1}{12h_0}(b_0 h_0^3 + b_1 h_1^3)$	$\frac{1}{4}(b_0 h_0^2 + b_1 h_1^2)$
	$b_0 h_0 + b_1 h_1$	$\frac{1}{12}(b_1 h_0^3 + b_0 h_1^3)$	—	$\frac{1}{12h_0}(b_1 h_0^3 + b_0 h_1^3)$	$\frac{1}{4}(b_0 h_0^2 + b_1 h_1^2 - 2b_1 h_1 h_0)$
	$t\lambda(1 + (\frac{\pi d}{2\lambda})^2)$	$\frac{t\lambda d^2}{8}(1 - \frac{0.61}{1 + 2.5(\frac{d}{\lambda})^2})$	—	—	—

FIG. A2 Moments of sections.

