Student Number: ________________ Name: ________________________

UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING

Final Examination, April 18, 2001

Third Year - Program 6

CHE 341S – Engineering Materials

Exam Type: A

Examiner: T.W. Coyle

Answer all questions on these pages.
Marks for each question are given in the margin.
Only non-programmable calculators are permitted.

Marks
#1:
#2:
#3:
#4:
Total:

Data & Equations

$$\sigma = \frac{F}{A_o} \qquad \varepsilon = \frac{l_i - l_o}{l_o} \qquad \sigma_T = \frac{F}{A_i} = \sigma(1+\varepsilon) \qquad \varepsilon_T = ln\frac{l_i}{l_o} = ln(1+\varepsilon)$$

$$\frac{da}{dt} = AK^n \qquad \frac{da}{dN} = A\Delta K^m \qquad \sigma_\ell = \frac{Pr}{2t} \qquad \sigma_c = \frac{Pr}{t}$$

$$\tau_{max} = \frac{1}{2}\left[4\tau_{xy}^2 + (\sigma_x - \sigma_y)^2\right]^{1/2} \qquad \sigma_{max} = \frac{1}{2}\left[\sigma_x + \sigma_y + \left(4\tau_{xy}^2 + (\sigma_x - \sigma_y)^2\right)^{1/2}\right]$$

$$I = \int y^2 dA \qquad I = \frac{\pi r^4}{4} \qquad I_{hollow\ circular} = \pi r^3 t \qquad I = \frac{bh^3}{12}$$

$$K = Y\sigma\sqrt{\pi a} \qquad \sigma = \frac{My}{I} \qquad \frac{d^2\delta}{dx^2} = \frac{M}{EI} \qquad U_{el} = \frac{1}{2}\sigma\varepsilon$$

$$N_A = 6.02 \times 10^{23}\ mol^{-1} \qquad c^2 = a^2 + b^2 \qquad \varepsilon_x = \frac{1}{E}(\sigma_x - \nu\sigma_y - \nu\sigma_z)$$

$$I_x = I_{x'} + A \cdot y_c^2 \qquad \Phi_b^e = \frac{4\pi I}{A^2} \qquad \Phi_b^f = \frac{4\sqrt{\pi}\, I}{A^{3/2} y_{max}}$$

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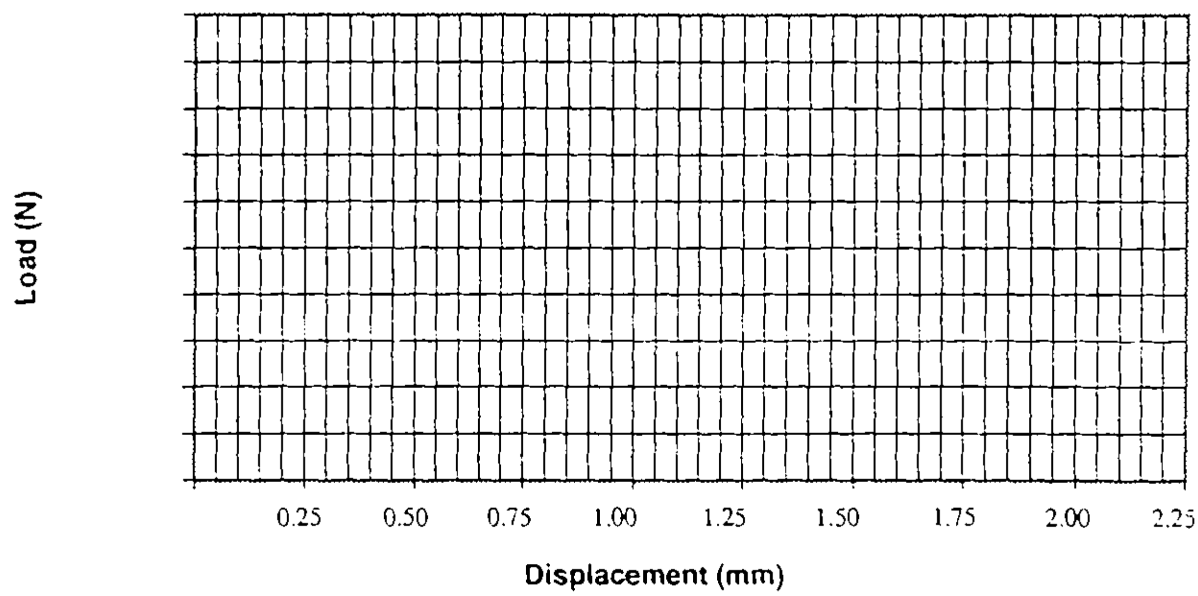
1. Tungsten alloys are used for light bulb filaments because of their high melting points. Tungsten (W) has a BCC crystal structure, a density of 19.3 $^{g}/_{cm^3}$, and a molar mass of 183.8 $^{g}/_{mol}$.

7 a) Calculate the radius of a W atom.

10 b) On the axes below sketch the curves that would be obtained during a uniaxial tensile test of specimens of each of the materials described in the following table. Assume the specimens are 1 cm in diameter and have a gage length of L_o = 10 cm. Label the Load axis accordingly.

Material	**E (GPa)**	**σ_{yield} (MPa)**	**σ_{TS} (MPa)**	**ε at $\sigma = \sigma_{TS}$**	**Ductility (%)**
Pure W	400	760	960	0.016	2
W alloy	400	1100	1200	0.009	1



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6 1. c) In the space below, describe 3 strengthening mechanisms that could contribute to the increase in yield strength of the W alloy compared to pure W.

2. Flywheels store energy, and have been suggested as a way to store the energy otherwise lost by vehicles during braking. An efficient flywheel stores as much kinetic energy per unit mass, $\frac{U}{m} = \frac{r^2\omega^2}{4}$, as possible, without failure by yielding or fracture. Failure, if it were to occur, is caused by the centrifugal loading, which results in a maximum principal stress of $\sigma_{max} = \left(\frac{3+\nu}{8}\right)\rho r^2\omega^2$, where $\nu = 0.33$ is Poisson's ratio, r is the radius, ρ is the density, and ω is the angular velocity. We wish to choose the optimum material from which to make a flywheel for a TTC bus. The diameter will be 1.5 m, and each flywheel will be examined using an ultrasonic technique that can reliably detect surface flaws larger than 0.5 mm. For surface cracks of this size we can assume Y = 1.

6 a) State the Objective and Constraints in words and with appropriate equations.

6 b) Derive the Selection Index for each constraint.

4 c) Use the attached charts to select the optimum material.

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2. (continued)

6 2. d) Calculate maximum angular velocity at which your flywheel can safely operate. Obtain the materials property values needed for these calculations from the charts by using the most favourable edge of the "bubble" for your choice of material.

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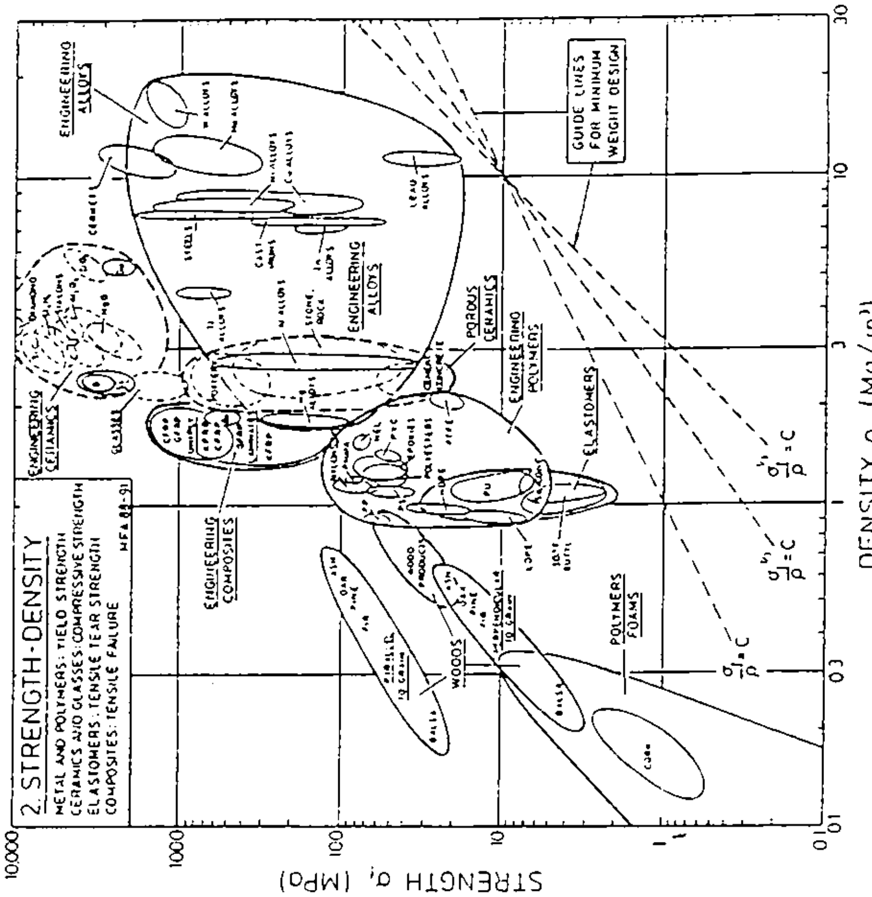

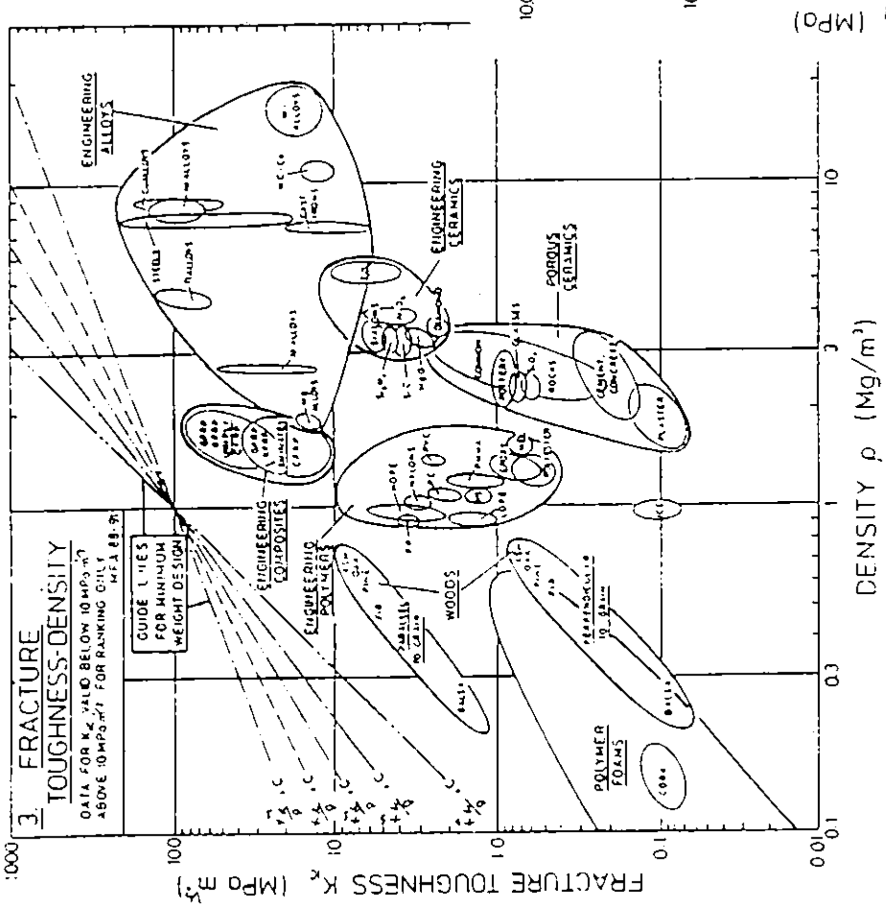

12 3. The flywheel described in Question #2 is subjected to a loading-unloading cycle each time the bus stops and then accelerates, so fatigue failure is also a concern. Assume the component is made from a low carbon steel for which $K_c = 55$ MPa(m)$^{1/2}$, $A = 6\times10^{-13}$ (MPa(m)$^{1/2}$)$^{-4}$m^{-1}, $m = 4$, and the density is 7.85 $^{g}/_{cm^3}$. Recall that the ultrasonic inspection will detect any initial surface flaw larger than 0.5 mm. The maximum angular velocity (which is attained during hard braking) is limited by a governor to ½ the velocity that would cause fracture from a 0.5 mm flaw. Assuming that the minimum angular velocity is zero, calculate the minimum number of cycles to failure.

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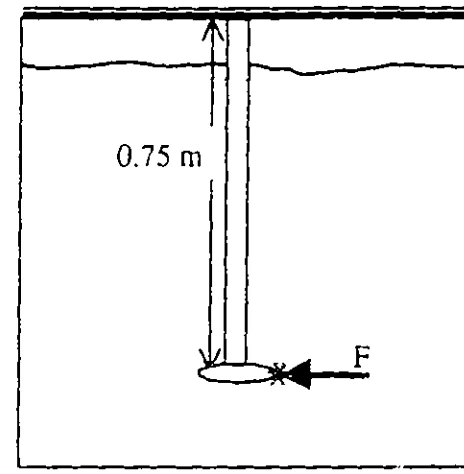
4. An impeller used for stirring a large reactor is suspended on a strut 0.75 m long. The tensile force along the length of the strut due to the mass of the impeller is 100 N. When running at full speed the impeller exerts a force of 100 N perpendicular to the strut.



6 a) The initial design for the strut was a solid circular cross section with a radius of 5 mm. Calculate the maximum tensile stress in the strut:
   (i) when the impeller is off (F = 0) and
   (ii) when the impeller is running at full speed (F = 100 N)

6 b) Show that the maximum deflection of a strut of length L is given by: $\delta_{max} = \dfrac{FL^3}{3EI}$

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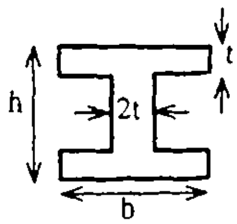
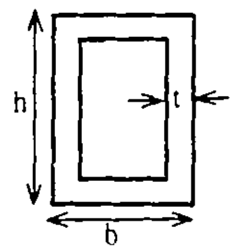
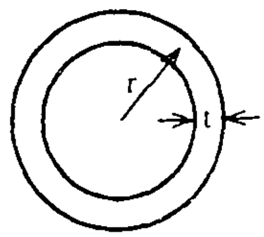
c) You are asked to select the lowest cost strut from among the available stock, as described in the Table below. The strut must not fail by yielding and can not deflect more than 10 cm when the impeller is running at full speed.

6 (i) Derive equations for the two constraints in terms of the appropriate shape factor.

6 (ii) Derive the Selection Indices (M_1, M_2) associated with each constraint.

15 (iii) Fill in the empty spaces in the Table, and select the best choice strut.

4 (iv) Show by calculation that your selection satisfies both constraints.

Material	**Steel**	**Al alloy**	**GFRC**
Shape			
Dimensions (mm)	h = 12 b = 12 t = 3	h = 10 b = 10 t = 2	r = 6 t = 1
Cost ($^{\$}/_{Kg}$)	1.30	6.10	22.00
Density ($^{g}/_{cm^3}$)	7.8	2.8	2.1
E (GPa)	207	72	45
σ_{yield} (MPa)	350	300	1020
I			
Φ_b^e			
Φ_b^f			
M_1			
M_2			

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4. c) (continued)

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4. c) (continued)