Department of Mechanical Engineering
University of Saskatchewan

ME492.3 Materials in Engineering Design

FINAL EXAMINATION (CLOSED BOOK, GROUP)

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This Group Examination carries one-half (1/2) of the final examination grade.

Instructions

1. Answer ALL Questions **TIME ALLOWED**: 1 HOUR 40 MINUTES
2. FOUR **Help Sheets** are allowed. **Course textbook is also allowed.**
3. Show details of all calculations where required or necessary.
4. All necessary charts, tables, tables are provided. Return all used charts with your script.
5. Attach all CES printouts used to solve the questions
6. Write the name of your group and the names of your group members on all scripts and printouts submitted. Ensure that each member signs off against his/her name.

QUESTION #1: DISPOSABLE COFFEE CUPS (260 Points)

It is increasingly recognized that the use of materials in engineering carries environmental penalties: pollution of water and air, solid waste, consumption of non-renewable resources and more (collectively called *eco-damage*). One response is to adopt, as a design objective, the minimization of this damage.

Consider, as an example, the replacement of an existing disposable cup (**Figure Q1 in the Group Worksheet**) by one which is more environmentally benign. The environmental impact it causes is difficult to quantify. One component of impact relates to the energy content of the material: many aspects of impact (CO_2 emissions, air-borne particulates) are proportional to this. And energy content (H) can be quantified, at least approximately. We shall use it as a measure of environmental impact, to illustrate how it can be balanced against cost.

Disposable cups are not, at present, recycled, so the energy and material they contain are irretrievably lost when they are discarded. To minimize the eco-impact (measured now by energy content), we seek the design which incorporates the least energy to start with. But disposable cups must also be cheap. So we find two conflicting objectives: the environmental goal of minimizing energy content (H), and the economic one of minimizing cost (C). There are constraints which must be met: (i) the stiffness constraint requires that severe ovalization must be avoided when the cup is picked up (or loaded) across a diagonal as shown in the figure. The critical stiffness for onset of unacceptable ovalization is designated S_c. (ii) it would be desirable, too, that it also insulates (**Table Q1 in the Worksheet**).

Questions

(a) Derive the appropriate material indices for selecting materials for the cup based on the specification given above. Follow the method described in class (i.e., describe function(s), objective(s), measure of performance, design variables, constraints and constraint equations, and so on). State any assumption(s) made to simplify your analysis. (80 Points)

(b) Using the material indices obtained in (a), develop an expression for the *penalty function* and *relative penalty function* for this application. (30 Points)

(d) Table Q1-2 (**see Worksheet**) lists three candidate materials for the cup, with the relevant properties. Given that R = 40 mm, Q = 4, C_I = 24 and S_c = 3 kN, use the Analytical Method to make a selection of material for the cup from the listed candidate materials for the following situations (100 Points):

(i) No penalty on energy
(ii) A pollution tax of 0.01 \$/MJ
(iii) A pollution tax of 0.05 \$/MJ

Complete the empty columns in Table Q1-2 as part of your answers.
Show TWO sample calculations. Make sure your units and dimensions are correct.

(d) Use CES Edupack Level 3 and the *relative penalty function* developed in (b) to select suitable polymeric and foam materials for the cup, subject to the following constraints: $E \geq 0.8$ GPa; $\lambda \leq 0.08$ W/m.K, $\rho \leq 1000$ kg/m^3; *Price* ≤ CAN\$5/kg. Exchange constant = 0.01 \$/MJ. Label the materials clearly. Make sure you eliminate all materials that did not qualify from your chart. (50 Points)

QUESTION #2: SELECTING MATERIALS AND SHAPES (205 Points)

A concept for a lightweight display stand is shown in Figure Q2 in the Worksheet. The frame must support a mass of 100 kg (to be placed on its upper surface) at a height h = 1 m without failing by elastic buckling. It is to be made of stock tubing and must be as *light as possible.* The design requirements are given in Table Q2-1 in the Worksheet.

Questions

(a) Derive a material index for the tubular material of the stand which meets these requirements, and which includes the shape of the section, described by the shape factor

$$\phi_B^e = \frac{4\pi I}{A^2}$$

where I is the second moment of area and A is the section area. State any assumptions. Tubing is available from stock in the following materials and sizes (Table Q2_1 in Worksheet). Note that a stand with four legs will just support a centrally-placed load $F = 4F_{crit}$. (60 Points)

(b) Use the *Calculation Method* to rank the candidate materials in Table Q2_1 using the index obtained in (a), tabulating all the results in Table Q2-Answer (Worksheet). (60 Points)

(c) Plot the TWO top ranked stock materials onto the Ashby Chart (see Fig. Q2C, Worksheet) provided to demonstrate that your choice of the BEST TWO shaped stock materials for the stand in (b) is consistent with sound engineering practice. M_o = 6 GPa$^{1/2}$/Mg/m^3. Show all details of how you arrived at your answers. M_o is the material index obtained without shape. M^* is the index with shape. (50 Points)

(d) Check that a stand made of the best material you selected in (b) will actually support the design load without buckling. Assume a safety factor of 4. Will the legs of the table fail by yielding? (35 Points)

QUESTION #3: MANUFACTURING PROCESSES (112 Points)

(a) What is the difference between a cast product and a wrought product? (6 Points)

(b) Name the TWO main corrosion attacks that plague mechanically joined parts. (8 Points)

(c) State FOUR functions of surface treatment processes (12 Points)

(d) Distinguish between soldering and brazing in terms of their operating temperatures (6 Points)

(e) **Selection of Cost-Effective Manufacturing Processes**

A component can be manufactured by *die pressing and sintering*, *powder metal forging* and *cold closed die forging*. Approximate cost data, in units of the material cost of the component, are given in the table below. Advise on the cheapest process for a batch size of (a) 100, (b) 10,000 and (c) 1000,000. Assume that the component is simple enough that it will fall near the bottom of each cost band. Show details and include all pertinent CES printouts. (80 Points)

Parameters	*Die pressing and sintering*	*Powder metal forging*	*Cold closed die forging*
Material cost, C_m (CAN$/kg)	2	2	2
Overhead rate, $\dot{C}_{oh}$ (CAN$/h)	100	100	100
Component mass (kg)	0.4	0.4	0.4
Capital write-off year	5	5	5
Load factor	0.8	0.8	0.8