UNIVERSITY OF GHANA

BSc. (ENG) MATERIALS SCIENCE AND ENGINEERING

END OF SECOND SEMESTER EXAMINATIONS: 2015/2016

SCHOOL OF ENGINEERING SCIENCES

DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING

MTEN 412: MATERIALS SELECTION AND DESIGN (2 CREDITS)

TIME ALLOWED: TWO (2) HOURS

Answer ALL Questions

Question 1

a) Provide answers to the following questions:

   i. Define design.

   ii. With the help of a flow chart, outline the design process and provide brief descriptions of the activities that occur at each stage in the process.

   iii. The interaction between function, material, shape, and process lies at the heart of the material selection process. Use a diagram to illustrate this interaction.

b) Describe the following design types:

   i. Original design

   ii. Adaptive or developmental design and

   iii. Variant design.

c) A metal pipe of radius *r* and wall thickness *t* carry an internal pressure *p*. The pressure generates a circumferential wall stress of σ_1 = pr/t, an axial wall stress σ_2 = pr/2t. At what pressure will the pipe first yield?

Hint:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 = 2\sigma_f^2 \qquad \text{Equation 1}$$

d) The four (4) steps outlined below (i – iv) are followed to tackle materials selection in design. Describe the activities that are performed in each step:

i. Translation
ii. Screening
iii. Ranking
iv. Documentation

25 Marks

Question 2

a) A design calls for a tie like the one shown in figure one (1) below. It must carry a tensile force F* without failure and be as light as possible. The length L is specified but the cross-sectional area A is not. Here, "maximising performance" means "minimising the mass while still carrying the load F* safely".

i. Provide a translation of the design requirement in the problem above
ii. Write an objective function for the performance criterion
iii. Express your objective function in the form: $P \leq f_1(F) \cdot f_2(G) \cdot f_3(M)$, where P is performance metric, F is functional requirements, G is geometry, and M is material properties.
iv. Write an expression for the material index of the problem from your answer to iii above

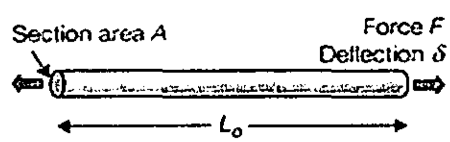
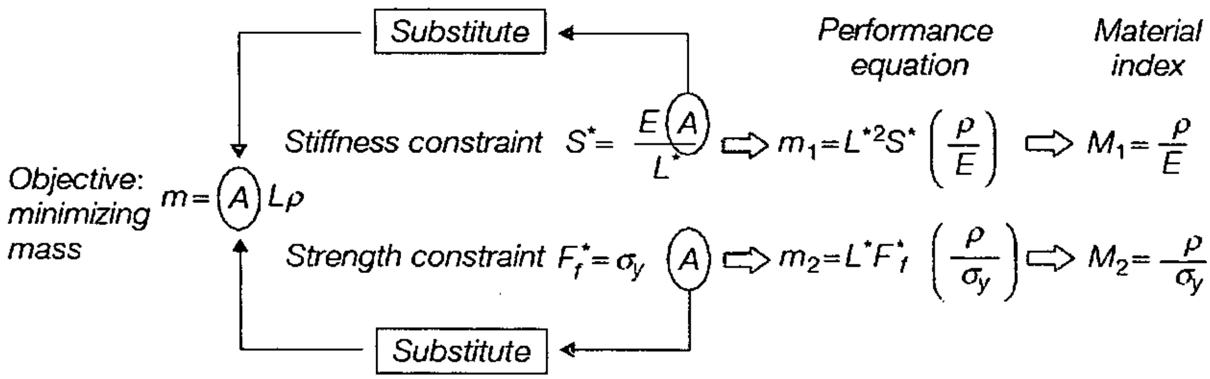


Figure 1: a tie

b) Figure two (2) shows the chain of reasoning for the design of a tie-rod that satisfies both stiffness and strength constraints. The objective of the design is one (here, to minimise mass), with the two constraints (stiffness and strength) leading to two performance equations. A material is required for a light tie of specified length L, stiffness S, and collapse load F_f.



The symbols have their usual meanings: A=area, L^*=length, ρ=density, S^*=stiffness, E=Young's modulus, F_f^*=collapse load, σ_y=yield strength or elastic limit

Figure 2: One objective (here, minimising mass) with two constraints leads to two performance equations, each with its own value of M.

i. Given that $L^* = 1$ m, $S^* = 3 \times 10^7$ N/m and $F_f^* = 10^4$ N. Rank the materials shown in table one (1) in order of lightest to heaviest design material. Show all work (reasoning) leading to your order of the materials. Which material gives the lightest design?

ii. If the constraints are now changed to $L^* = 3$ m, $S^* = 10^8$ N/m and $F_f^* = 3 \times 10^4$ N, which of the materials in table one (1) will give the lightest tie that satisfies all the constraints. Show all work (reasoning) leading to your choice of material.

Table 1: Selection of a material for a light, stiff, strong tie

Material	ρ Kg/m^3	E GPa	σ_y MPa
1020 Steel	7,850	200	320
6061 Al	2,700	70	120
Ti-6-4	4,400	115	950

25 Marks

Question 3

A material is needed that can best be used to make a light pressure vessel. The radius of the pressure vessel R is prescribed. The pressure vessel must contain a pressure p without failing by yield or by fast fracture and it must be as light as possible. Given that: the mass of a thin-walled spherical pressure vessel is $m = 4\pi R^2 t\rho$ where t is the wall thickness and ρ is the density of the material it is made; the stress (σ) in the wall of the pressure vessel is $\sigma = pR/2t$; the failure stress (σ_f) may be calculated from $\sigma_f = \frac{K_{Ic}}{C\sqrt{\pi a_c^*}}$ with the constant C taken to be one (1), with K_{Ic} being the plane-strain fracture toughness and $2a_c^*$ being the diameter of the largest crack or flaw contained in the wall of the pressure vessel.

i. Provide a table of the design requirements for the problem above in terms of function, constraints, objectives and free variables

ii. Write an expression for the objective function of the problem above and subsequently express it in terms of the constraints

iii. Determine the equation of the coupling line and write an expression for the coupling constant.

25 Marks

Question 4

a) A tube has a radius r = 10mm and a wall thickness t = 1mm. How much stiffer is it in bending than a solid cylinder of the same mass per unit length m_l?

b) A beam has a square-box section with a height h = 100 mm, a width b = 100 mm, and a wall thickness t = 5 mm. What is the value of its shape factor ϕ_B^f? Comment on the strength of the square-box section beam in comparison to a solid-square section beam of the same mass per unit length.

c) A slender, solid cylindrical column of height L supports a load F. If overloaded, the column fails by elastic buckling. By how much is the load-bearing capacity increased if the solid cylinder is replaced by a hollow circular tube of the same cross-section A?

Hint (refer to the next page):

$$F_c = \frac{n^2\pi^2 EI_{min}}{L^2}$$ Equation 2 (Euler load)

$$\phi_B^e = \frac{12I}{A^2}$$ Equation 3

d) A hollow tubular aluminum extrusion of complex ribbed shape has a mass per unit length m_l = 0.3 kg/m. A length L = 1 m of the extrusion, loaded in 3-point bending by a central load of W = 10 kg suffers a mid-point deflection δ = 2 mm. What is the shape factor ϕ_B^e of the section?

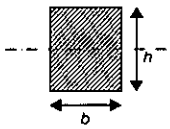
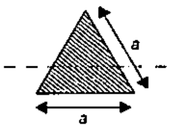
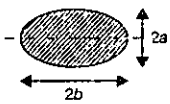
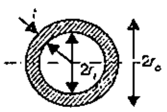
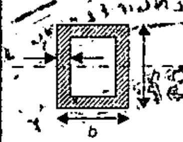
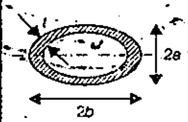
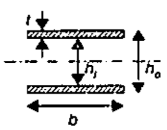
(For aluminum E = 70 GPa and ρ = 2,700 kg/m^3. For 3-point bending, C_1 = 48 in equation 4 below)

$$\phi_B^e = \frac{12 S_B}{C_1}\frac{L^5}{m^2}\left[\frac{\rho^2}{E}\right]$$ Equation 4

where S_B is the bending stiffness

25 Marks

Table 9.3 Shape-efficiency Factors

Section Shape	Bending Factor ϕ_B^e	Torsional Factor ϕ_T^e	Bending Factor ϕ_B^f	Torsional Factor ϕ_T^f
	$\frac{h}{b}$	$2.38\frac{h}{b}\left(1-0.58\frac{b}{h}\right)(h>b)$	$\left(\frac{h}{b}\right)^{0.5}$	$1.6\sqrt{\frac{b}{h}}\frac{1}{\left(1+0.6\frac{b}{h}\right)}$ $(h>b)$
	$\frac{2}{\sqrt{3}}=1.15$	0.832	$\frac{3^{1/4}}{2}=0.658$	0.83
	$\frac{3}{\pi}=0.955$	1.14	$\frac{3}{2\sqrt{\pi}}=0.846$	1.35
	$\frac{3}{\pi}\frac{a}{b}$	$\frac{2.28\,a\,b}{(a^2+b^2)}$	$\frac{3}{2\sqrt{\pi}}\sqrt{\frac{a}{b}}$	$1.35\sqrt{\frac{a}{b}}(a<b)$
	$\frac{3}{\pi}\left(\frac{r}{t}\right)(r>>t)$	$1.14\left(\frac{r}{t}\right)$	$\frac{3}{\sqrt{2\pi}}\sqrt{\frac{r}{t}}$	$1.91\sqrt{\frac{r}{t}}$
	$\frac{1}{2}\frac{h}{t}\frac{(1+3b/h)}{(1+b/h)^2}$ $(h,b>>t)$	$\frac{3.57b^2\left(1-\frac{t}{h}\right)^4}{t\,h\left(1+\frac{b}{h}\right)^3}$	$\frac{1}{\sqrt{2}}\sqrt{\frac{h}{t}}\frac{\left(1+\frac{3b}{h}\right)}{\left(1+\frac{b}{h}\right)^{3/2}}$	$3.39\sqrt{\frac{h^2}{b\,t}}\frac{1}{\left(1+\frac{h}{b}\right)^{3/2}}$
	$\frac{3}{\pi}\frac{a}{t}\frac{(1+3b/a)}{(1+b/a)^2}$ $(a,b>>t)$	$\frac{9.12\,(a\,b)^{5/2}}{t(a^2+b^2)(a+b)^2}$	$\frac{3}{2\sqrt{\pi}}\sqrt{\frac{a}{t}}\frac{\left(1+\frac{3b}{a}\right)}{\left(1+\frac{b}{a}\right)^{3/2}}$	$5.41\sqrt{\frac{a}{t}}\frac{1}{\left(1+\frac{a}{b}\right)^{3/2}}$
	$\frac{3}{2}\frac{h_o^2}{b\,t}(h,b>>t)$	–	$\frac{3}{\sqrt{2}}\frac{h_o}{\sqrt{b\,t}}$	–