UNIVERSITY OF GHANA

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FACULTY OF ENGINEERING SCIENCES

BSC. (ENG) MATERIALS SCIENCE AND ENGINEERING

END OF SECOND SEMESTER EXAMINATIONS: 2013/2014

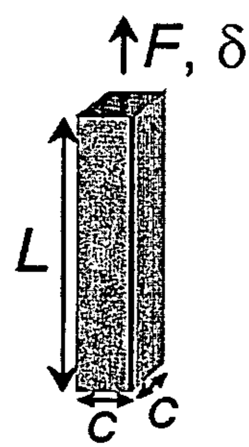
MTEN 412: MATERIALS SELECTION & DESIGN (2 CREDITS)

ANSWER ALL QUESTIONS

TIME ALLOWED: 2 HOURS

1. The selection of a material for engineering designs involves four basic steps. Describe each step in not more than fifteen (15) words.

2. A design calls for a **strong** and **light** tension members as shown in the diagram below.



The bar must carry a force F without failing. The design requirements, translated, are as shown on Page 2:

Design requirements for the strong and light tension member

Function	**Strong and light tension member**
Constraints	∘ **Length L is specified** ∘ **Bar must support axial load without failing**
Objective	**Minimize the mass m of the bar**
Free variables	∘ **Cross-sectional area, A** ∘ **Choice of material**

Develop a ***Performance Metric, P,*** as shown in the equation below for this bar:

$$P = \left[\begin{pmatrix} Functional \\ requirenments, F \end{pmatrix}\right], \begin{pmatrix} Geometric \\ parameters, G \end{pmatrix}, \begin{pmatrix} Material \\ properties, M \end{pmatrix}$$

3. **Materials for oars**

An oar is a beam, loaded in bending. It must be strong enough to carry, without breaking, the bending moment exerted by the oarsman, it must have a stiffness to match the rower's own characteristics and give the right "feel", and very important, it must be as light as possible. Oars are dropped, and therefore the material must be tough enough to survive this, so brittle materials (those with a toughness G_{1C} less than 1 $^{kJ}/_{m^2}$ are not acceptable.

The material index for a light, stiff beam is: $M = \frac{E^{1/2}}{\rho}$

where E is Young's modulus
and ρ is density

The design requirements for the oar are as follows:

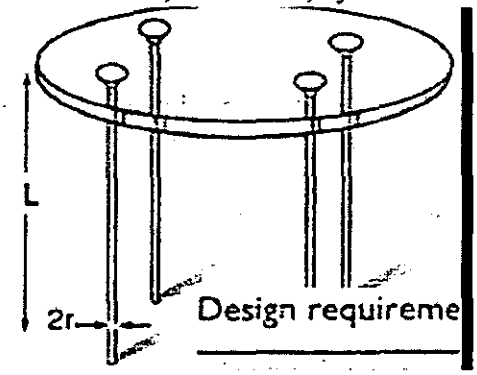
Function	**Oar – light, stiff beam**
Constraints	∘ **Length L is specified** ∘ **Bending stiffness S specified**

	• Toughness $G_{1C} > 1\ {}^{kJ}/_{m^2}$
Objective	**Minimize the mass m of the oar**
Free variables	• **Shaft diameter** • **Choice of material**

Given these requirements and setting $M_1 = 5.5\ GPa^{1/2}/\left({}^{Mg}/_{m^3}\right)$ on the Young's modulus axis, what materials would you choose?
(Use Young's modulus – Density and Fracture toughness – Young's modulus charts attached at the end of the page).

4. **Materials for table legs**

The furniture designer, conceives of a light-weight table of daring simplicity: a flat sheet of toughened glass supported on slender, un-braced, cylindrical legs as shown below:



The legs must be solid (to make them thin) and as light as possible (to make the table easier to move). They must support the table top and whatever is placed upon it without buckling.
This is a problem with two objectives: weight is to be minimized, and slenderness maximized.

The ***Performance Metric*** for the mass of the legs is:

$$m \geq \left(\frac{4F}{\pi}\right)^{1/2} (L)^2 \left[\frac{\rho}{E^{1/2}}\right]$$

which gives a material index of: $M_1 = \frac{E^{1/2}}{\rho}$

The ***Performance metric*** for the thinnest leg that will not buckle is:

$$r \geq \left(\frac{4F}{\pi^3}\right)^{1/4} (L)^{1/2} \left[\frac{1}{E}\right]^{1/4}$$

which gives material index of: $M_2 = E$

The design requirements for the table are as follows:

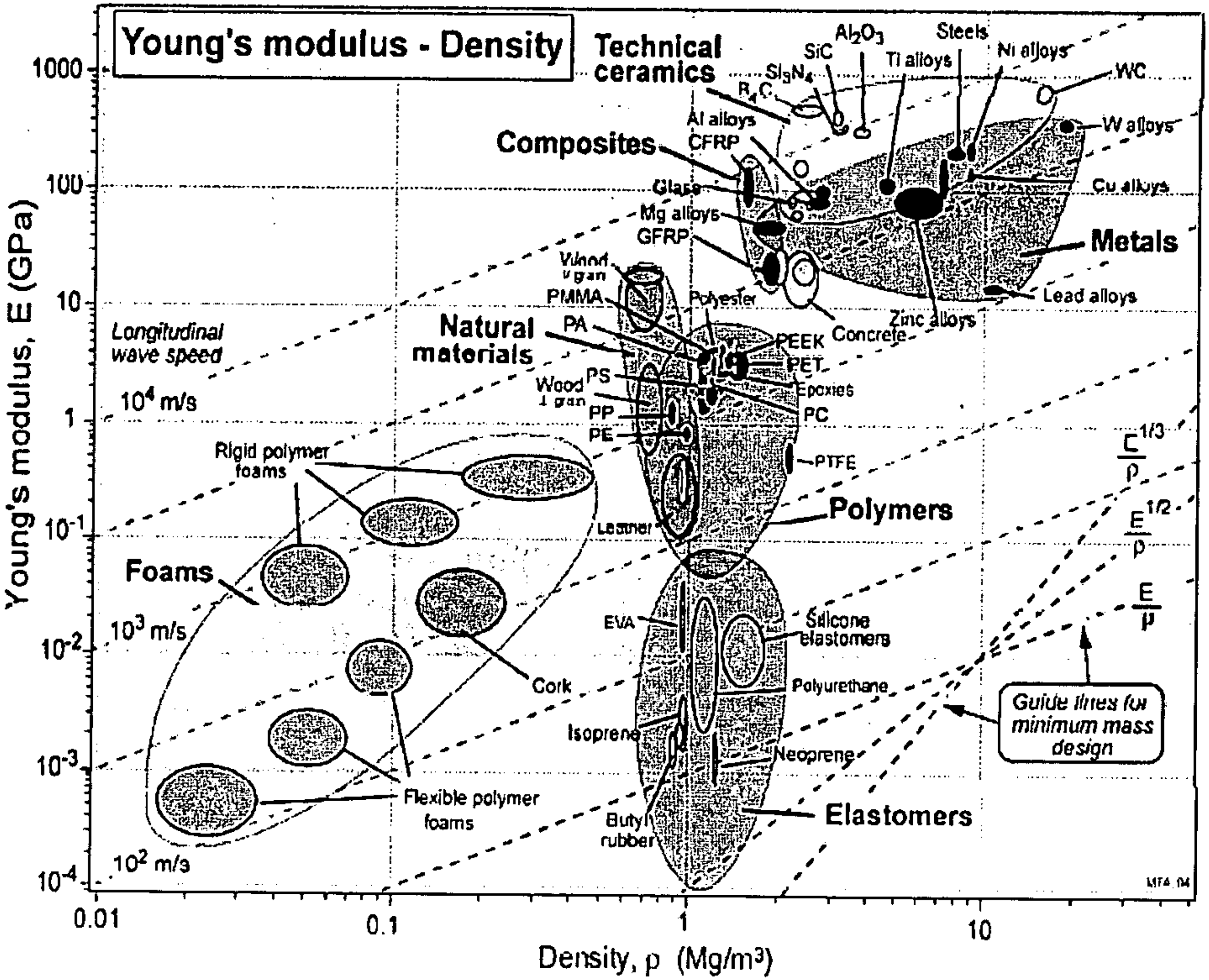
Function	**Column (supporting compressive loads)**
Constraints	**• Length L is specified** **• Must not buckle under design loads** **• Must not fracture if accidentally struck**
Objective	**• Minimize the mass, m** **• Maximize slenderness**
Free variables	**• Diameter of legs, 2r** **• Choice of material**

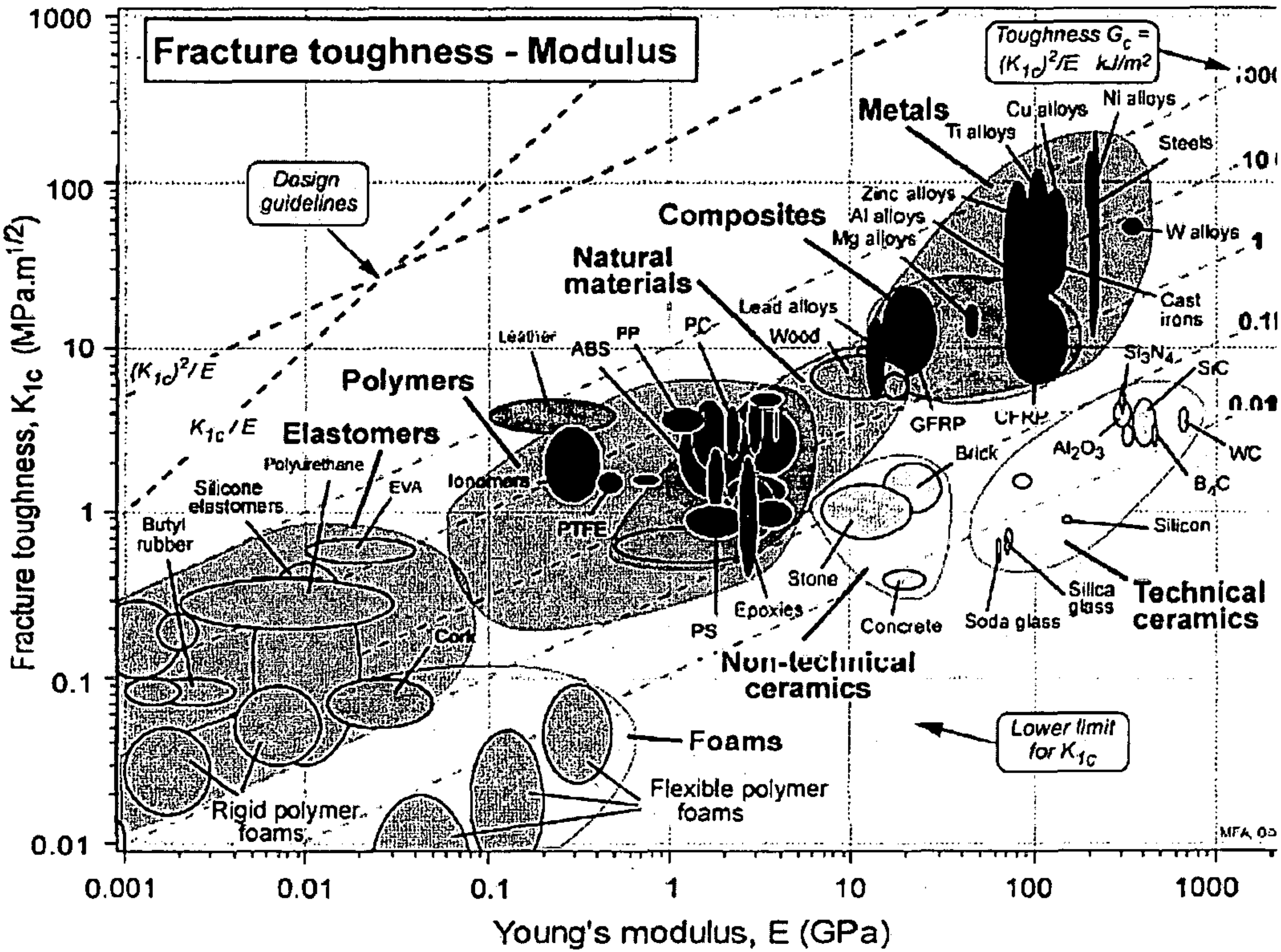
Given these requirements and setting $M_1 = 5.5\ GPa^{1/2}/\left({Mg}/{m^3}\right)$ and $M_2 > 100$ GPa on the Young's modulus axis, what materials would you choose? Eliminate polymers (not stiff enough), metals (too heavy) and ceramics (too brittle).
(Use Young's modulus – Density chart).

5. Use the Young's modulus – density chart (see end of the page) to identify materials with both E > 100 GPa and ${E^{1/3}}/{\rho} > 3\ (GPa)^{1/3}/\left({Mg}/{m^3}\right)$. Remember that, on taking logs, the index
$M = {E^{1/3}}/{\rho}$ becomes $Log\ (E) = 3\ Log(\rho) + 3\ Log(M)$

and that this plots as a line of slope 3 on the chart, passing through the point $\rho = \frac{1}{3} = 0.33$ at E = 1 in the units on the chart.

6. A component is at present made from brass, a copper alloy. Use the Young's modulus – density chart to suggest three other metals that, in the same shape, would be stiffer. "Stiffer" means a higher value of Young's modulus.


Young's modulus - Density
Technical ceramics
Al2O3
SiC
Si3N4
B4C
Steels
Ti alloys
Ni alloys
WC
W alloys
Cu alloys
Metals
Lead alloys
Zinc alloys
Concrete
Composites
Al alloys
CFRP
Glass
Mg alloys
GFRP
Wood
PMMA
PA
Natural materials
Wood
PS
PP
PE
Polyester
PEEK
PET
Epoxies
PC
PTFE
Polymers
Leather
Longitudinal wave speed
10^4 m/s
10^3 m/s
10^2 m/s
Rigid polymer foams
Foams
Cork
Flexible polymer foams
EVA
Isoprene
Butyl rubber
Silicone elastomers
Polyurethane
Neoprene
Elastomers
Guide lines for minimum mass design
E^1/3/ρ
E^1/2/ρ
E/ρ
Young's modulus, E (GPa)
1000
100
10
1
10-1
10-2
10-3
10-4
0.01
0.1
1
10
Density, ρ (Mg/m3)



Fracture toughness - Modulus
Toughness $G_c = (K_{1c})^2/E$ kJ/m²
Design guidelines
Metals
Ti alloys
Cu alloys
Ni alloys
Steels
Zinc alloys
Al alloys
Mg alloys
W alloys
Cast irons
Composites
Natural materials
Lead alloys
Wood
GFRP
CFRP
Leather
PP
ABS
PC
Polymers
Ionomers
PTFE
Elastomers
Polyurethane
Silicone elastomers
EVA
Butyl rubber
Cork
Epoxies
PS
Brick
Stone
Concrete
Non-technical ceramics
Si_3N_4
SiC
Al_2O_3
WC
B_4C
Silicon
Silica glass
Soda glass
Technical ceramics
Foams
Flexible polymer foams
Rigid polymer foams
Lower limit for K_{1c}
$(K_{1c})^2/E$
K_{1c}/E
Fracture toughness, K_{1c} (MPa.m$^{1/2}$)
Young's modulus, E (GPa)
1000
100
10
1
0.1
0.01
0.001
0.01
0.1
1
10
100
1000
MFA, 09