THE UNIVERSITY OF ADELAIDE
DEPARTMENT OF MECHANICAL ENGINEERING

EXAMINATION FOR THE DEGREE OF B.E.

4024: Materials Selection and Failure Analysis

EXAMINATION - NOVEMBER, 2002

TIME: 3 HOURS & 10 MINUTES

[Students are advised to devote 10 minutes to reading the paper and planning their approach.]

[The use of notes, textbooks and calculating devices with the exception of laptop computers is permitted in the examination room.]

Attempt **ALL THREE** questions.

Question 1

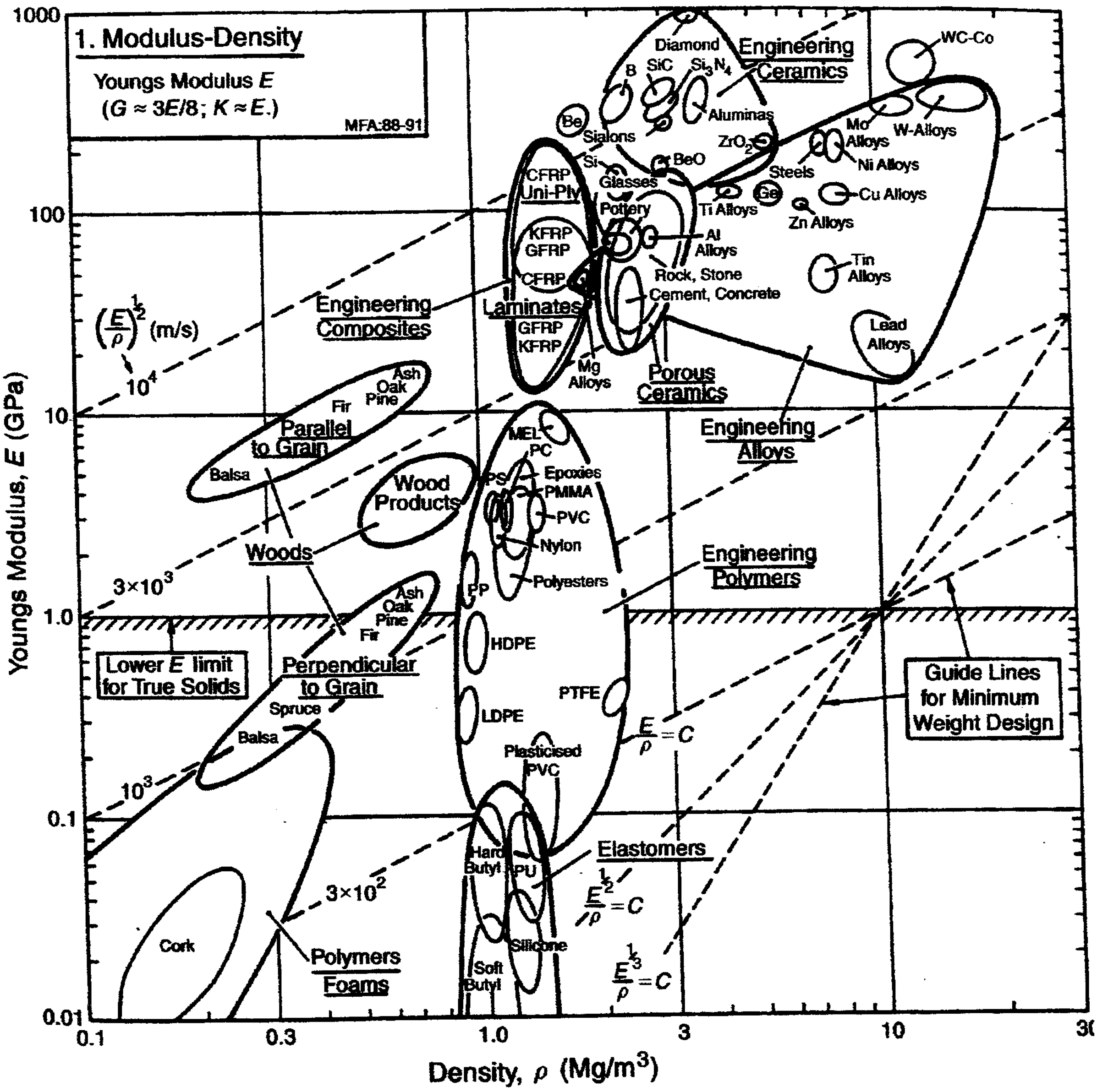
You have been asked to make a recommendation on material selection for the **stand** of a lamp. The lamp is made up of a flat base, a 2m tall stand and a large, heavy glass shade. The stand supports the weight of the light and the shade. Since the shade is so heavy, you should make the stand as light as possible. You have the choice of a solid glass rod, an aluminium solid square section and a stainless steel tube (r_0 = 15mm, r_i = 12.5mm, t = 5mm). Which material would you recommend and why? Show all of your workings, including use of the material selection chart.

The critical force for buckling F is:

$$F_c = \frac{\pi^2 EI}{l^2}$$

Note: treat this problem as a column in compression. A Young's Modulus vs. density chart for use with this question is provided on the next page. A formulae sheet is provided with the examination paper.

(20 marks)



1. Modulus-Density
Youngs Modulus E
(G ≈ 3E/8; K ≈ E.)
MFA:88-91
Youngs Modulus, E (GPa)
Density, ρ (Mg/m³)
Engineering Ceramics
Diamond
B
SiC
Si3N4
Aluminas
Be
Sialons
ZrO2
BeO
Si
Glasses
Pottery
WC-Co
Mo Alloys
W-Alloys
Ni Alloys
Steels
Ge
Cu Alloys
Ti Alloys
Zn Alloys
Al Alloys
Tin Alloys
Lead Alloys
Rock, Stone
Cement, Concrete
Porous Ceramics
Engineering Alloys
CFRP
Uni-Ply
KFRP
GFRP
CFRP
Laminates
GFRP
KFRP
Mg Alloys
Engineering Composites
(E/ρ)^½ (m/s)
10⁴
3×10³
10³
3×10²
Ash
Oak
Pine
Fir
Parallel to Grain
Balsa
Wood Products
Woods
Perpendicular to Grain
Spruce
Lower E limit for True Solids
MEL
PC
PS
Epoxies
PMMA
PVC
Nylon
Polyesters
PP
HDPE
LDPE
PTFE
Plasticised PVC
Engineering Polymers
Hard Butyl
PU
Silicone
Soft Butyl
Elastomers
Cork
Polymers Foams
E/ρ = C
E^½/ρ = C
E^⅓/ρ = C
Guide Lines for Minimum Weight Design

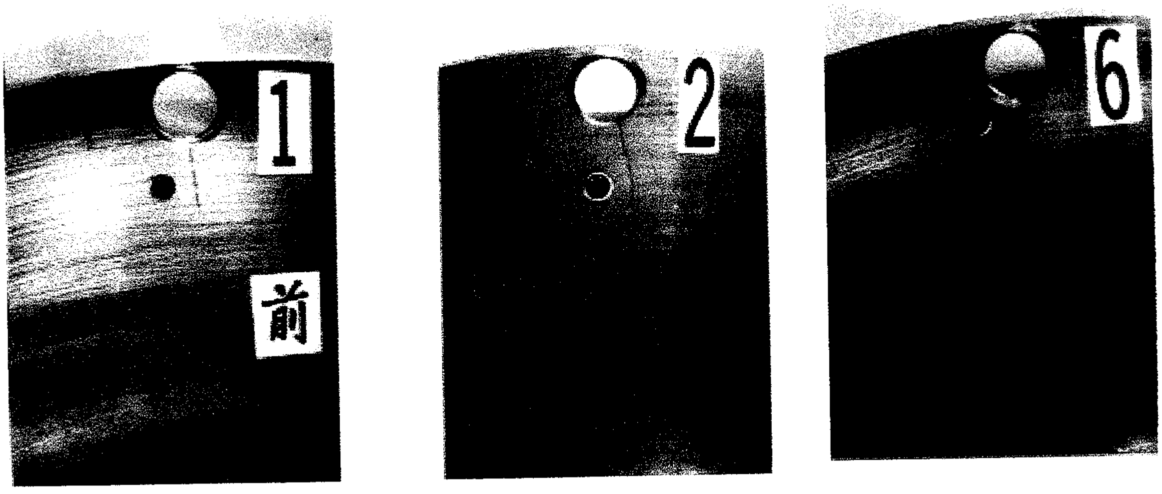
Question 2
Four accidents have occurred as a result of cracks being present in aeroengine compressor discs. These discs have blades fitted to them and spin in service to compress air. The discs are made from 11%Cr martensitic stainless steel. Each disc has 6 holes distributed evenly around the perimeter of the disc. These holes are designed to balance the loads of the aerodynamic force on the blades and the air pressure on the front and back of the disc.

On closer examination of the discs, the cracks were found to have initiated from the front edge of the holes in the discs and propagated towards the centre of the disc. A summary of the cracking is given in table 1.

Disc	Service time before failure	Number of cracks	Crack length, mm
1	45 hours, 13 mins	3	31.8, 7.5, 14
2	99 hours, 13 mins	1	29
3	99 hours, 19 mins	3	25, 15, 12
4	99 hours 11 mins	1	38

Table 1: Summary of cracking

Disc 1 was examined further. The three cracks in this disc are shown in figure 1. The crack at hole 2 (the longest crack) ran through the full thickness of the disc.



Crack at 1# hole

Crack at 2# hole

Crack at 6# hole

Figure 1: Cracking seen in disc 1. The numbers indicate the hole number. The small circles in the pictures indicate the location of the crack – the circle is just to the left hand side of the crack.

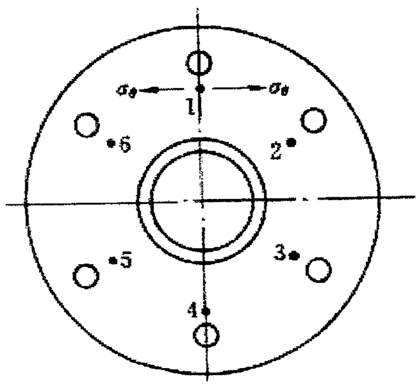
The chemical composition of disc 1 was found to be 0.1%C, 11%Cr, 2%Ni, 2%W, 0.5%Mo, 0.3%V.

The results of mechanical testing of disc 1 are shown in table 2.

Sample	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Hardness, HB
1	1029	1270	10.9	3730
2	1017	1248	10.7	3780
3	1022	1246	10.7	3830
Standard requirements	>850	>1030	>8	3110-3880

Table 2: Results of mechanical testing on disc 1.

Residual stress measurements were made on disc 1 at the six holes. The results of the testing are shown in table 3.



Test location	#1 hole	#2 hole	#3 hole	#4 hole	#5 hole	#6 hole
Front surface	-275	-353	-510	-510	-391	-510
Back surface	-235	-196	-392	-391	-353	-275

Table 3: Results of residual stress testing on disc 1. Stresses are in MPa.

The inside of one of the holes in disc 1 is shown in figure 2. This was typical of all of the holes.

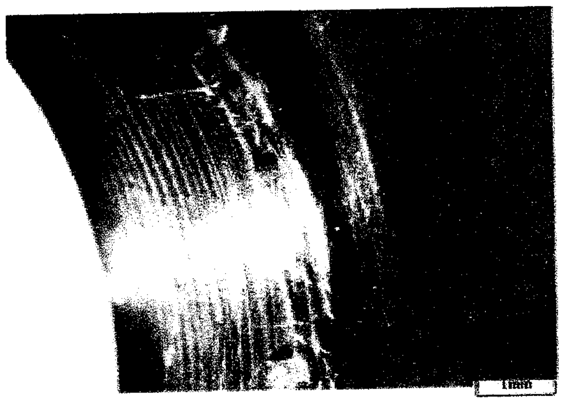


Figure 3: Looking into one of the holes in disc 1.

One of the cracks was opened up and figures 4 and 5 show the crack fracture surface.

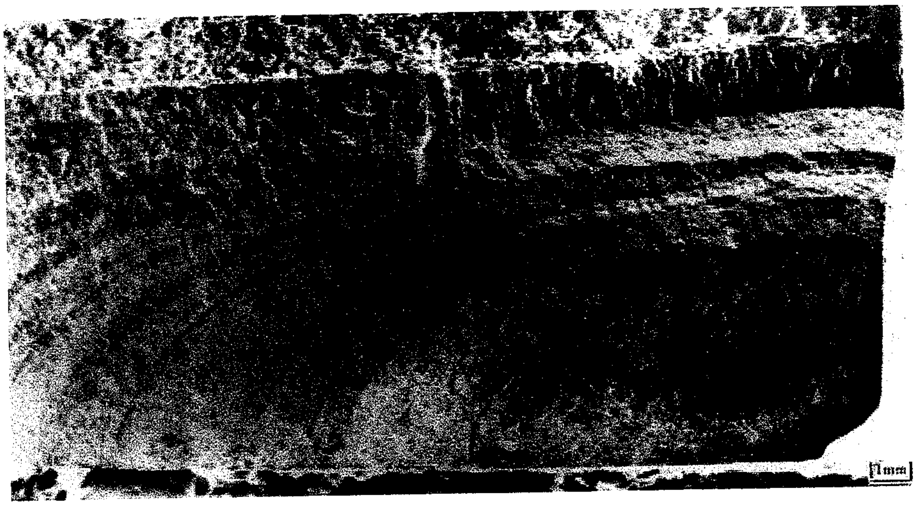


Figure 4: Fracture surface of one of the cracks in disc 1. The inside surface of the hole is shown vertically on the right hand side of the picture. The bottom edge of the picture is the front surface of the disc with the centre of the disc towards the left hand side of the picture.

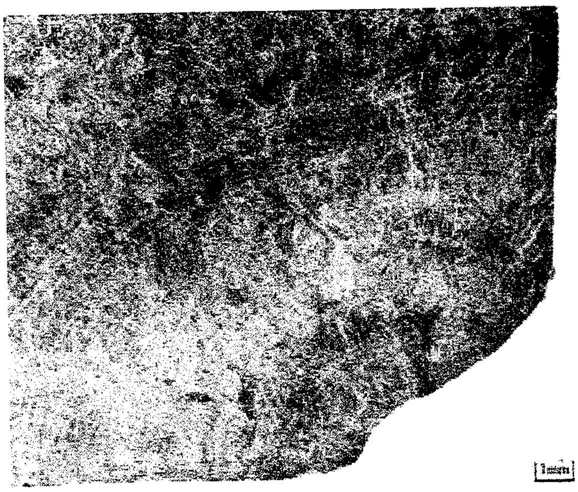


Figure 5: Close up of the bottom right hand corner of figure 4.

Examination of the disc surface showed that there were some corrosion pits on the surface of the disc. The fracture surfaces had a thin layer of oxide on them, the fracture surface of the crack at hole 2 having the thickest oxide layer. Some corrosion products were associated with the crack at hole 6, but no corrosion products were found on the fracture surfaces of the cracks at holes 1 and 2.

Question: Perform a failure analysis on disc 1 using the information presented above.

a) Summarise the service history
b) Summarise the relevant evidence
c) Discuss the evidence
d) Propose some theories of failure
e) Indicate the most likely theory
f) Make some recommendations on preventing similar failures happening in future.

(50 marks)

Question 3

You have been asked to design a new garden fork designed for digging a garden. The fork is approximately 1m long, has 4 prongs at one end and a handle at the other end.

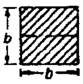
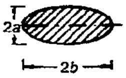
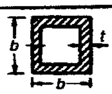
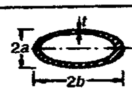
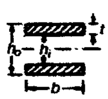
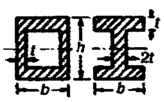
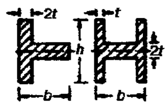
Discuss:

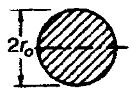
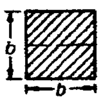
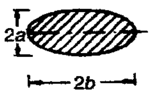
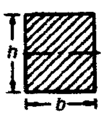
a) The material properties (intrinsic and attributive) the fork should possess
b) The material index you would use to assist you in choosing a material for the fork shaft
c) The shape factors you would use to assist you in choosing a material for the fork shaft
d) Issues relating to fabrication of the fork
e) Cost issues
f) Potential failure modes of the fork
g) Two possible concepts for the fork.

Note: this is a discussion question only – you do **not** have to determine material and shape selection from materials selection charts.

(30 marks)

END OF EXAMINATION

Section Shape	$A(m^2)$	$I_{xx}(m^4)$	$K(m^4)$	$Z(m^3)$	$Q(m^3)$
	πr^2	$\frac{\pi}{4} r^4$	$\frac{\pi}{2} r^4$	$\frac{\pi}{4} r^3$	$\frac{\pi}{2} r^3$
	b^2	$\frac{b^4}{12}$	$0.14b^4$	$\frac{b^3}{6}$	$0.21b^3$
	πab	$\frac{\pi}{4} a^3 b$	$\frac{\pi a^3 b^3}{(a^2+b^2)}$	$\frac{\pi}{4} a^2 b$	$\frac{\pi a^2 b}{2}$ $(a < b)$
	bh	$\frac{bh^3}{12}$	$\frac{b^3 h}{3}\left(1 - 0.58\frac{b}{h}\right)$ $(h > b)$	$\frac{bh^2}{6}$	$\frac{b^2h^2}{3h + 1.8b}$ $(h > b)$
	$\frac{\sqrt{3}}{4} a^2$	$\frac{a^4}{32\sqrt{3}}$	$\frac{a^4\sqrt{3}}{80}$	$\frac{a^3}{32}$	$\frac{a^3}{20}$
	$\pi(r_o^2 - r_i^2)$ $\approx 2\pi rt$	$\frac{\pi}{4}(r_o^4 - r_i^4)$ $\approx \pi r^3 t$	$\frac{\pi}{2}(r_o^4 - r_i^4)$ $\approx 2\pi r^3 t$	$\frac{\pi}{4r_o}(r_o^4 - r_i^4)$ $\approx \pi r^2 t$	$\frac{\pi}{2r_o}(r_o^4 - r_i^4)$ $\approx 2\pi r^2 t$
	$4bt$	$\frac{2}{3} b^3 t$	$b^3 t\left(1 - \frac{t}{b}\right)^4$	$\frac{4}{3} b^2 t$	$2b^2 t\left(1 - \frac{t}{b}\right)^2$
	$\pi(a+b)t$	$\frac{\pi}{4} a^3 t\left(1 + \frac{3b}{a}\right)$	$\frac{4\pi(ab)^{5/2} t}{(a^2+b^2)}$	$\frac{\pi a^2 t}{4}\left(1 + \frac{3b}{a}\right)$	$2\pi t(a^3 b)^{1/2}$ $(b > a)$
	$b(h_o - h_i)$ $\approx 2bt$	$\frac{b}{12}(h_o^3 - h_i^3)$ $\approx \frac{1}{2} bth_o^2$	—	$\frac{b}{6h_o}(h_o^3 - h_i^3)$ $\approx bth_o$	—
	$2t(h+b)$	$\frac{1}{6} h^3 t\left(1 + \frac{3b}{h}\right)$	I: $\approx \frac{2tb^2h^2}{h+b}$; □: $\frac{2}{3} bt^3\left(1 + \frac{4h}{b}\right)$	$\frac{h^2 t}{3}\left(1 + \frac{3b}{h}\right)$	I: $2tbh$; □: $\frac{2}{3} bt^2\left(1 + \frac{4h}{b}\right)$
	$2t(h+b)$	$\frac{t}{6}(h^3 + 4bt^2)$	H: $\frac{t^3}{3}(8b+h)$; ⊢: $\frac{2}{3} ht^3\left(1 + \frac{4b}{h}\right)$	$\frac{t}{3h}(h^3 + 4bt^2)$	H: $\frac{t^2}{3}(8b+h)$; ⊢: $\frac{2}{3} ht^2\left(1 + \frac{4b}{h}\right)$
	$t\lambda\left(1 + \frac{\pi^2 d^2}{4\lambda^2}\right)$	$\frac{t\lambda d^2}{8}$	—	$\frac{t\lambda d}{4}$	—

Section shape	Stiffness ϕ_B^e	ϕ_T^e	Strength ϕ_B^f	ϕ_T^f
	1	1	1	1
	$\frac{\pi}{3} = 1.05$	0.88	$\frac{2}{3}\sqrt{\pi} = 1.18$	0.74
	$\frac{a}{b}$	$\frac{2ab}{(a^2+b^2)}$	$\sqrt{\frac{a}{b}}$	$\sqrt{\frac{a}{b}}$ $(a < b)$
	$\frac{\pi}{3}\frac{h}{b}$	$\frac{2\pi}{3}\frac{b}{h}\left(1 - 0.58\frac{h}{b}\right)$ $(h > b)$	$\frac{2}{3}\sqrt{\pi}\left(\frac{h}{b}\right)^{1/2}$	$\frac{2}{3}\sqrt{\pi}\frac{(b/h)^{1/2}}{(1 + 0.6b/h)}$ $(h > b)$
	$\frac{2\pi}{3\sqrt{3}} = 1.21$	$\frac{2\pi}{5\sqrt{3}} = 0.73$	0.77	0.62
	$\frac{r}{t}$	$\frac{r}{t}$	$\left(\frac{2r}{t}\right)^{1/2}$	$\left(\frac{2r}{t}\right)^{1/2}$