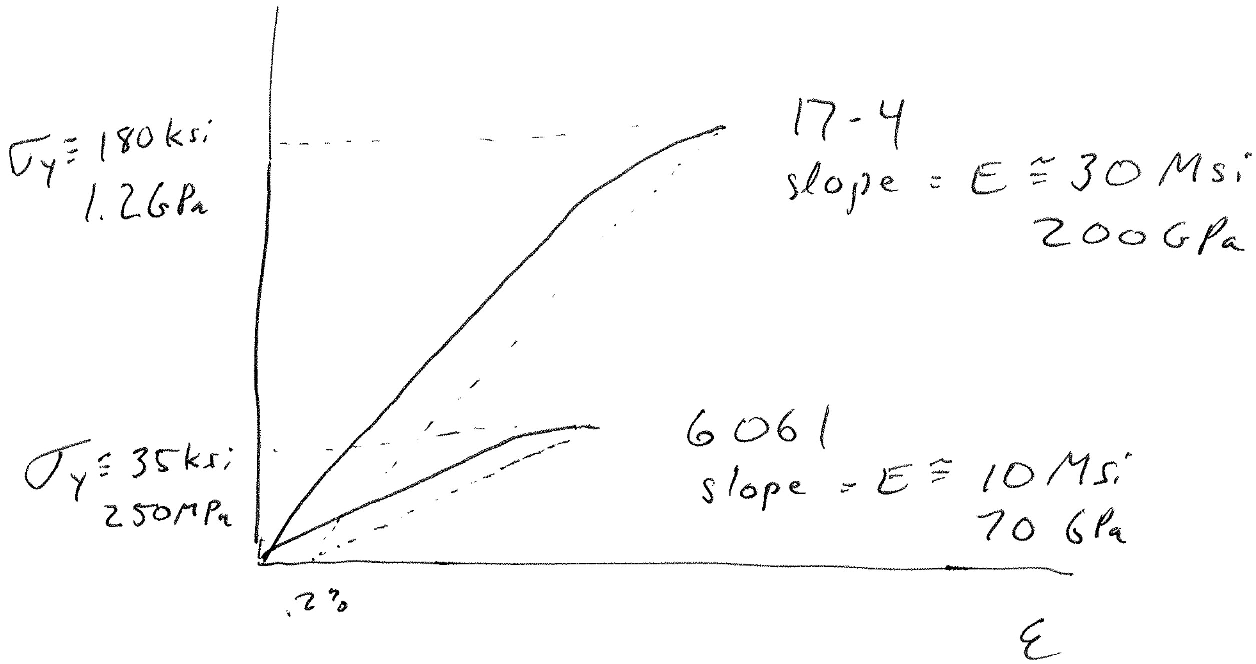
Optical Engineering 421/521 – Fall 2009
Midterm 2 50 minutes, closed book, closed notes, no calculators
November 16, 2009

1.) (10) Draw a plot showing the relationship between stress and strain for 6061 aluminum. Label the axes and give units. On the same plot, provide an approximate curve for 17-4 stainless steel (spring steel). Indicate Young's modulus and the yield strength for both.



2.) (6) Name a metal with exceptionally high specific stiffness. Compare Young's modulus and density for this material with aluminum.

	beryllium		aluminum is
E	42 msi 290 GPa	$\frac{E_{Be}}{E_{Al}} \cong 4$	10 msi 68 GPa (~70)
ρ	.067 lb/in^3 1.85 g/cm^3	$\frac{\rho_{Be}}{\rho_{Al}} \cong 2/3$	0.1 lb/in^3 2.7 g/cm^3

3.) (5) Provide the relationship that describes the change in focal length for a mirror due to a change in temperature.

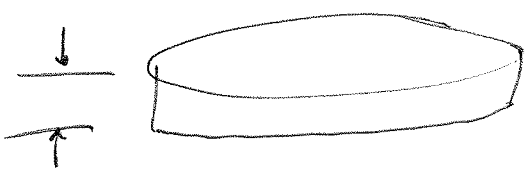
All dimensions scale with CTE α

$$\Delta f = f \cdot \alpha \Delta T$$

4.) (6) List the three basic steps to create a solid model of a cube with a threaded hole in it using Solid Works..

1. Sketch
2. Extrude
3. Use the hole wizard

5.) (5) One side of a 1 cm thick BK7 window is 1°C warmer than the other. If the window has 0.1 m^2 cross sectional area, calculate the power in Watts conducted by the glass.



$t = 0.01\ m$

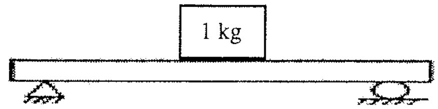
$A = 0.1\ m^2$

BK7 $\lambda \doteq 1\ W/m \cdot K$

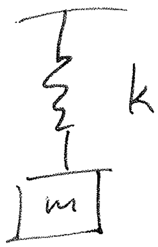
$$\text{Power} = \frac{\lambda A \Delta T}{t} = \frac{1(.1)(1)}{.01}$$

$= 10$ Watts

6) (15) A 1 kg mass is placed in the center of a beam, causing 0.1 mm deflection. Calculate the resonant frequency (ignoring the weigh of the beam). Assuming 2% damping, sketch a plot of the transmissibility T (ratio of motion at the center of the beam to base motion) at as a function of frequency for this system. Label the axes and show the values of T for low frequency and at resonance.



$$g = 9.8\ m/s^2 \doteq 10\ m/s^2$$



$$\omega = \sqrt{k/m}$$

$$\delta = F/k = mg/k \qquad k/m = g/\delta$$

$$\omega = \sqrt{g/\delta} = \sqrt{\frac{10\ m/s^2}{10^{-4}}} = \sqrt{10^{+5}} \doteq 300\ rad/s \doteq 50\ Hz$$

$$Q = \frac{1}{2C_r} = \frac{1}{.04} = 25$$

7) (25) A BK7 beamsplitter cube is bonded to aluminum with 0.2 mm thick RTV elastomeric adhesive. The bond area is circular, 11 mm diameter. (~100 mm^2 area)

$t = .2$ mm

$A = 100$ mm^2

The adhesive has

G 1 MPa shear modulus

E_b 1 GPa bulk modulus

σ_u 5 MPa adhesive strength, shear and normal

a) Calculate the strength of the bond for shear loading. (The shear force in N required to fail the adhesive.)
b) Calculate the lateral (shear) stiffness of the bond. (The force in N per mm lateral displacement.)
c) Calculate the normal (compressive) stiffness of the bond. (The force in N per mm axial displacement.)
d) Calculate the maximum adhesive shear strain for 11°C change in temperature.
e) Calculate the maximum shear stress in the adhesive for the 11°C temperature change.

a. $\sigma_u = F_u/A = 5\ MPA = 5\ N/mm^2$, $A = 100\ mm^2$

$F = 500N$

b. $k_s = \frac{V}{\delta_s}$ $\quad \delta_s = \frac{V \cdot t}{G \cdot A}$ $\quad k_s = \frac{G \cdot A}{t} = \frac{1\ N/mm^2 \cdot 100\ mm^2}{0.2\ mm}$

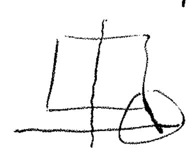
$k_s = 500\ N/mm$

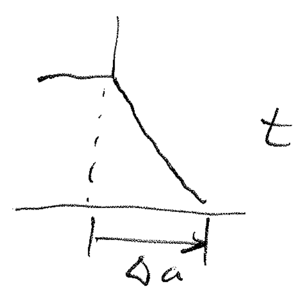
c. $k_N = F/\delta_N$ $\quad \delta_n = \frac{F t}{E_b \cdot A}$ $\quad k_N = \frac{E_b \cdot A}{t}$

$k_N = 500{,}000\ N/mm$

d. Al. $\alpha = 23\ ppm/°C$ $\quad \Delta\alpha = 16\ ppm/°C$

BK7 $\alpha = 7\ ppm/°C$





$\Delta a = \left(\frac{11}{2}\right) \cdot 16\ ppm/°C \cdot 11°$

$= 112.8$ μm

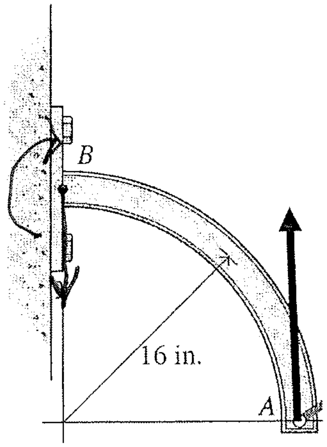
$\cong 121.8 = 1000$ nm

$= 1$ μm

$\gamma = 1\ \mu m / 200\ \mu m = .005$

$\tau = G \cdot \gamma = 0.005\ MPa$

8) (5) Calculate the reactions at B for static equilibrium when a 10 lb vertical force is applied at A.



$F_{By} = 10\ lb$

$F_{Bx} = 0$

$M_B = 10 lb \cdot 16'' = 160\ in \cdot lb$

9) (5) What determines the strength of glass? Critical flaw size

How can you determine allowable stresses for glass, assuming a standard ground finish?

For ground surface, this is statistical.

Use Weibull statistics to relate probability of failure to tensile stress at surface

$$P = 1 - e^{-(\sigma/\sigma_0)^m}$$

σ = characteristic strength

m = Weibull modulus

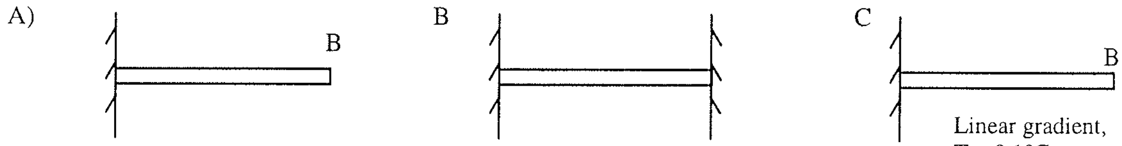
10) (5) What is a Belleville washer? Why are these used?

Conic shaped washer.

Used as spring for assembly

11 (13) Consider a bar made of aluminum 10 cm long, 1 cm x 1 cm cross section. Determine the following:

A) Motion of point B if the bar is heated 1°C, and allowed to expand
B) stress in the material if the bar is heated 1°C while constrained.
C) motion of point B for the case where a thermal gradient is applied, with the top of the bar 0.1°C warmer than the bottom.



$\Delta T = 1°C$ $\Delta T = 1°C$ Linear gradient, T = 0.1°C warmer on top than on bottom

$\alpha = 23$ ppm /°C $E \doteq 70$ GPa $= 70{,}000$ N/mm²

$l = 100$ mm $A = 100$ mm²

a) $\Delta l = l \alpha \Delta T = 2300\,\mu$mm $= 2.3\,\mu$m →

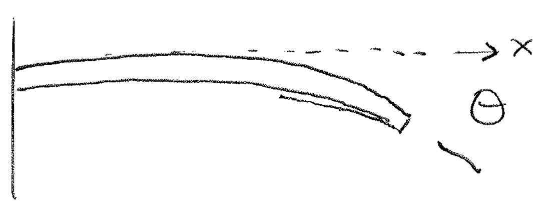
b) Superposition $\Delta l = \frac{Fl}{EA} = \frac{\sigma l}{E}$

$\sigma = \frac{\Delta l}{l} \cdot E = E \alpha \Delta T$

$= 70$ GPa $\cdot$ 23 ppm

or 10 Msi $\cdot$ 23 ppm

$= 230$ psi

c. 

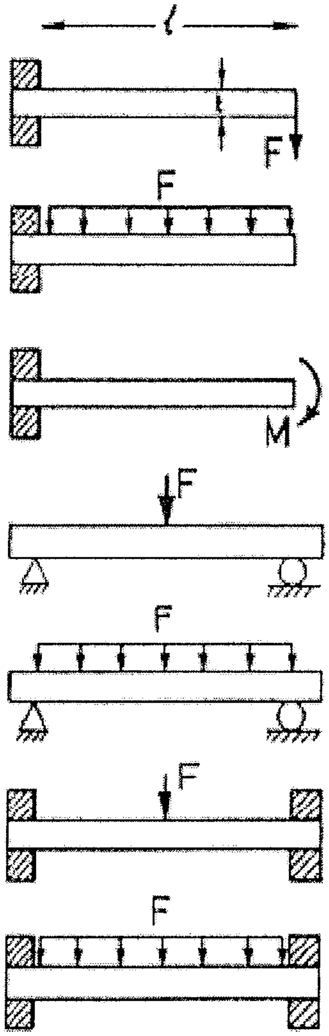
$\theta = \frac{\alpha L \Delta T}{t} = \frac{23\,\text{ppm} \cdot 100\,\text{mm} \cdot 1°C}{10\,\text{mm}}$

$= 230\,\mu$rad

$\theta(x) = \frac{\alpha \Delta T}{t} \cdot x + \cancel{C}^{\,0}$

$\delta(x) = \int \theta\, dx = \frac{1}{2} \frac{\alpha \Delta T}{t} x^2 + \cancel{C}^{\,0} = \frac{230\,\mu\text{rad}}{2} \cdot 100$ mm

$= 115$ ~~rad~~ $\cdot\ 0.1$ μm $= 11.5$ μm



C_1	C_2
3	2
8	6
2	1
48	16
$\frac{384}{5}$	24
192	–
384	–

$$\delta = \frac{F\ell^3}{C_1 E I} = \frac{M\ell^2}{C_1 E I}$$

$$\theta = \frac{F\ell^2}{C_2 E I} = \frac{M\ell}{C_2 E I}$$

E = YOUNGS MODULUS (N/m^2)

δ = DEFLECTION (m)

F = FORCE (N)

M = MOMENT (N m)

ℓ = LENGTH (m)

b = WIDTH (m)

t = DEPTH (m)

θ = END SLOPE (-)

I = SEE TABLE 2 (m^4)