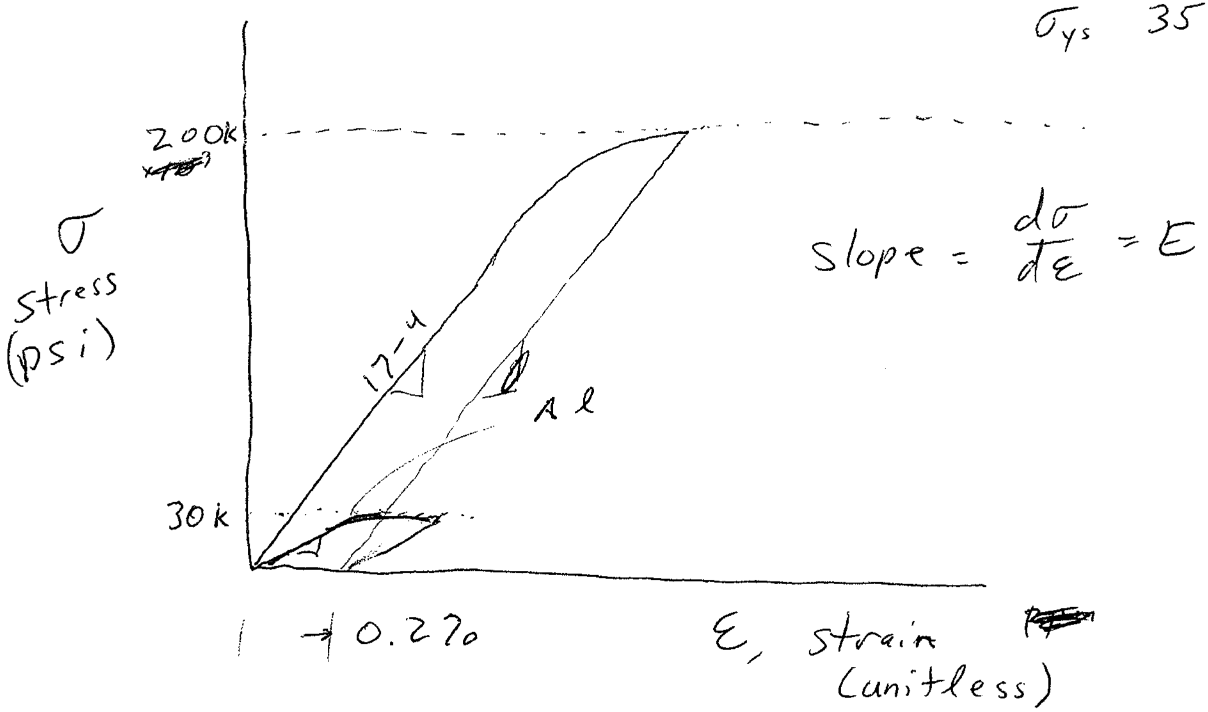
Solution

Optical Engineering 421/521 – Fall 2008
Midterm 2 50 minutes, closed book, closed notes, no calculators
November 17, 2008

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. Indicate Young's modulus and the yield strength for both.

	Al	17-4	
E	10	30	Msi
σ_{ys}	35	200	ksi



2.) (6) SiC is used because of its outstanding specific stiffness and thermal conductivity. Give approximate values for the density, Young's modulus, and thermal conductivity.

$\rho = 3.1\ g/cm^3$

$E \cong 400\ GPa$

$\lambda \cong 150\ W/m \cdot K$

3.) (5) How does the focal length change with temperature for lens made of BK7? (include both dn/dT and CTE effects)

$\frac{dn_r}{dT} = 3$ ppm/°C

$\alpha = 7$ ppm/°C

$$\phi = 1/f, \quad \frac{1}{\phi}\frac{d\phi}{dT} = -\frac{dR}{R} + \frac{dn_r}{n-1}$$

$$\phi = \frac{n-1}{R} \qquad \beta = \frac{1}{f}\frac{df}{dT} = -\frac{1}{\phi}\frac{d\phi}{dT} = \alpha - \frac{dn_r}{n-1} = 7 - \frac{3}{1.5-1}$$

$$= 1 \text{ ppm/°C}$$

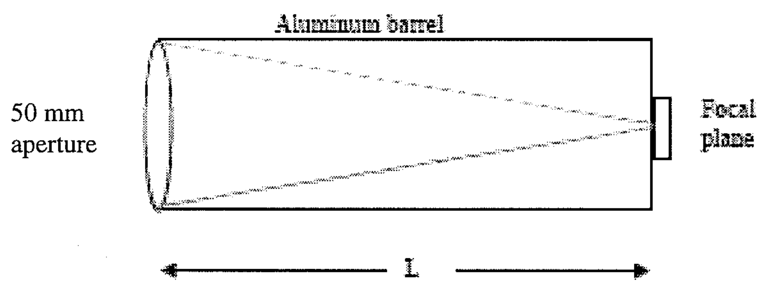
$$\Delta f = f \cdot \Delta T \cdot (1 \text{ ppm/°C})$$

4.) Consider a 50 mm diameter BK7 lens mounted in an aluminum barrel. Assume the focal length $f = L = 100$ mm:

Al $\alpha = 24$ ppm/°C

BK7 $\beta = 1$ ppm/°C

$\Delta = 23$ ppm/°C



a) (10) Calculate the focus error that would be caused by a 10° C temperature change? (include both the change in the lens focal length and the change in the aluminum tube length.

$$\Delta L = L\alpha\Delta T \qquad L = f = 100$$

$$\Delta f = f\beta\Delta T$$

$$\text{defocus} = \Delta L - \Delta f = L(\alpha - \beta)\Delta T = (100\text{ mm})(23 \text{ ppm/°C})(10\text{°C})$$

$$= 23\,\mu m$$

b) (10) Determine the wavefront error due to the defocus above. Assume 500 nm wavelength

$$f^{\#} = f/D = \frac{100}{50} = 2$$

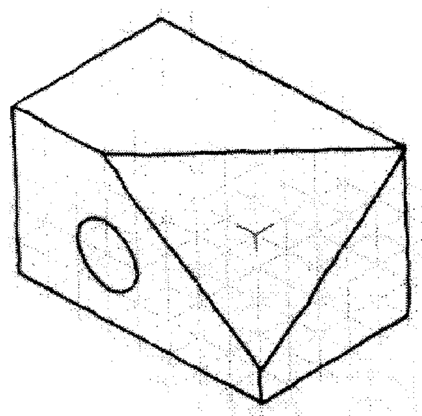
$$\Delta W = \frac{1}{8F_n^2}\Delta f = \frac{1}{8(2^2)} 23\,\mu m = \frac{23\,\mu m}{32} \approx \frac{2}{3}\,\mu m$$

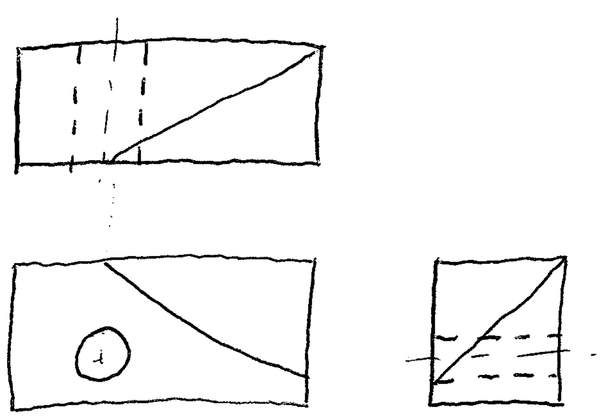
$$\lambda = 0.5\,\mu m \qquad \Delta W = \frac{2/3}{0.5} \approx 1.3\,\lambda$$

5.) (5) Name an optical material that has good UV transmission. List one difficulty or limitation for using this material.

CaF_2: cost, high CTE, soft, fragile
NaCl: cost, soft,
MgF_2: birefringent
Fused Silica: high dn/dT

6.) (5) Sketch a 3-view orthographic projection of the following part. (**<u>You do not need to add dimensions</u>**)





7) (10) Consider a fused silica prism bonded to aluminum with 300 µm ~~mm~~ thick 2216. The bond is circular, 10 mm diameter. (shear modulus G =~ 300 MPa,)
A =~80 mm^2

strength $\cong$ 2ksi = 14MPa

a) Calculate the shear strength of the bond

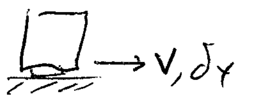
Stress = F/A

for 2ksi stress = adhesive strength

$F = A \cdot \sigma = 80\,mm^2 \cdot 14\,N/mm^2$

$= 1120\,N$

b) Calculate the shear stiffness for the bond (ratio of shear force to shear displacement).

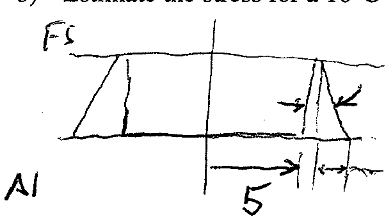


$\delta_Y = \frac{Vt}{GA} =$

$k = V/\delta_Y = \frac{GA}{t} = \frac{(300\,N/mm^2)(80\,mm^2)}{0.3\,mm}$

$= 80{,}000\,N/mm$

b) Estimate the stress for a 10°C temperature change $\Delta\alpha = \alpha_{AL} - \alpha_{FS} = 24 - 1 = 23\,ppm/°C$



γ : shear strain

$\Delta Y = 5\,mm \cdot \Delta\alpha \cdot \Delta T = 5\,mm \cdot 23\,ppm/°C \cdot 10°C$

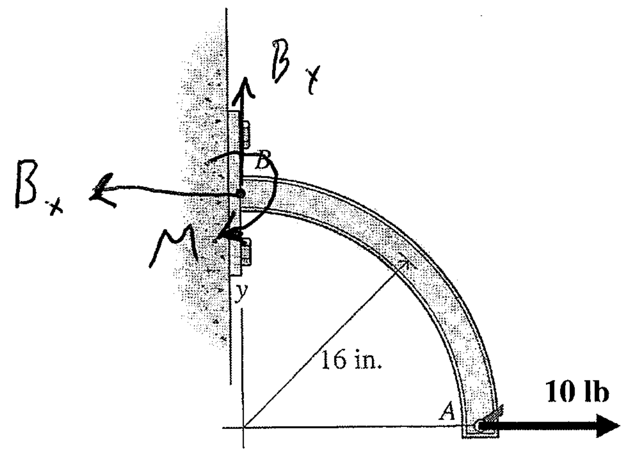
$= 1150 \times 10^{-6}\,mm$

$= 1.15\,\mu m$

$\gamma = \frac{\Delta Y}{t} \cong \frac{1\,\mu m}{300\,\mu m} = 0.0033$

$\tau = G \cdot \gamma = (300\,N/mm^2)(\frac{1}{300}) = 1\,N/mm^2$

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



$B_y = 0$

$B_x = 10$ lb

$M = 160$ in·lb

8.) (6) Name 3 materials with near-zero coefficient of thermal expansion. Give approximate values for the density of each material.

Zerodur	2.5 g/cm^3
ULE	2.2 g/cm^3
Invar	8 g/cm^3
CFRP	2 g/cm^3

9.) (8) What determines the strength of glass? How can you determine allowable stresses for glass?

Strength is limited by critical flaws.

Allowable stresses are determine statistically using Weibull statistics.

$$\text{Probability of Failure} = 1 - \exp\left(-\left(\sigma/\sigma_0\right)^{\lambda}\right)$$

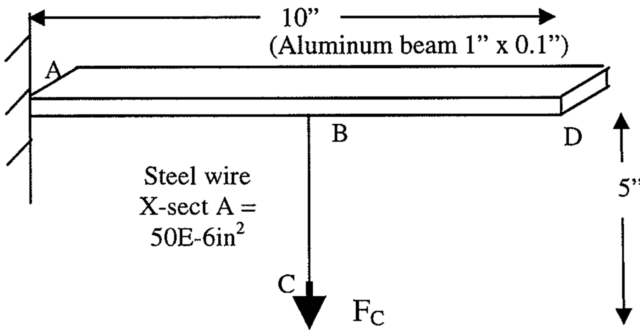
σ_0 = characteristic strength } from data
λ = Weibull factor

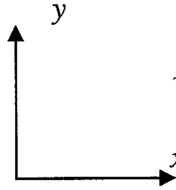
Must compensate for area under stress, stress corrosion (fatigue factor)

10). (20) Consider a 10" cantilevered aluminum bar. A 304 stainless wire with 50E-6 in^2 cross sectional area is attached at the center and a load of 1 lb is applied at the end of the wire. The bar has 0.1" x 1" cross section. (The 1" dimension is into the page as shown.)

Al $E = 10\,Msi$

304 $E = 30\,Msi$

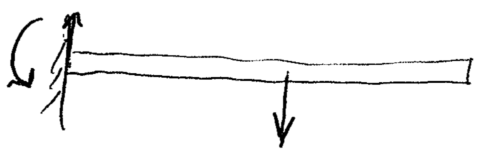




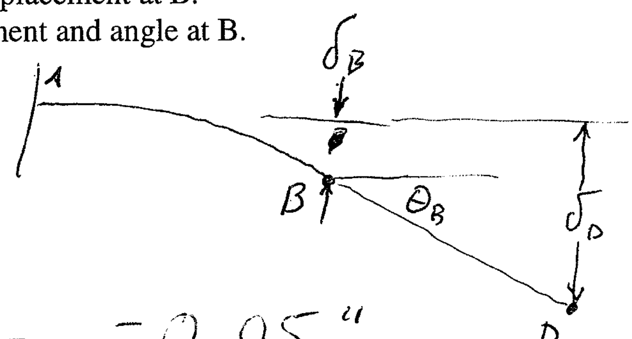
$I = \frac{1}{12} b h^3 = \frac{1}{12}(1)(.1)^3 = \frac{1}{12000}\ in^4$

You need to calculate the motion of point D as the force F_C = 1 lbs applied as shown at point C. Follow the four easy four steps below:

a) Use the free body diagram and find the forces and moment exerted on the beam at point B due to force F_C.
b) Determine the bending of section AB due to the force and moment at B
c) Use superposition to determine the angle and displacement at B.
d) Calculate the displacement at D due to displacement and angle at B.



$F_c = 1\,lb$



$$\delta_B = \frac{F l^3}{3EI} = \frac{(1\,lb)(5'')^3}{3(10E6\ \frac{lb}{in^2})(\frac{1}{12000})in^4} = 0.05''$$

$$\theta_B = \frac{F l^2}{2EI} = \frac{(1\,lb)(5'')^2}{2(10E6\ \frac{lb}{in^2})(\frac{1}{12000} in^4)} = 15\,mrad$$

$$\delta_D = \delta_B + \theta_B \cdot 5'' = \frac{5}{6} \cdot \frac{5^3}{2(10E6)} \cdot 12E3 = \frac{5^3}{1E3} = \frac{125}{1000} = 1/8''$$