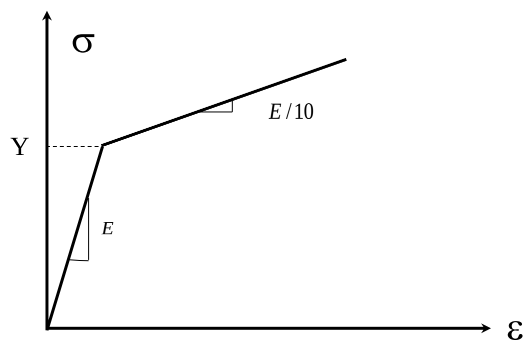
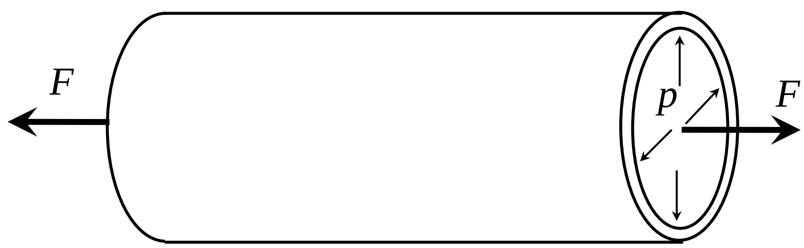
Spring 2011 Mechanics of Materials PhD Qualifying Exam
Written Part

NOTE: Choose any 3 of the 4 problems. You must write explicitly on the first page which 3 problems you have chosen. Otherwise, the 3 lowest scores will be used.

PROBLEM 1

A closed-end, thin-walled tube of thickness *t* and mean radius r is made of a material whose uniaxial stress-strain relation is shown below.



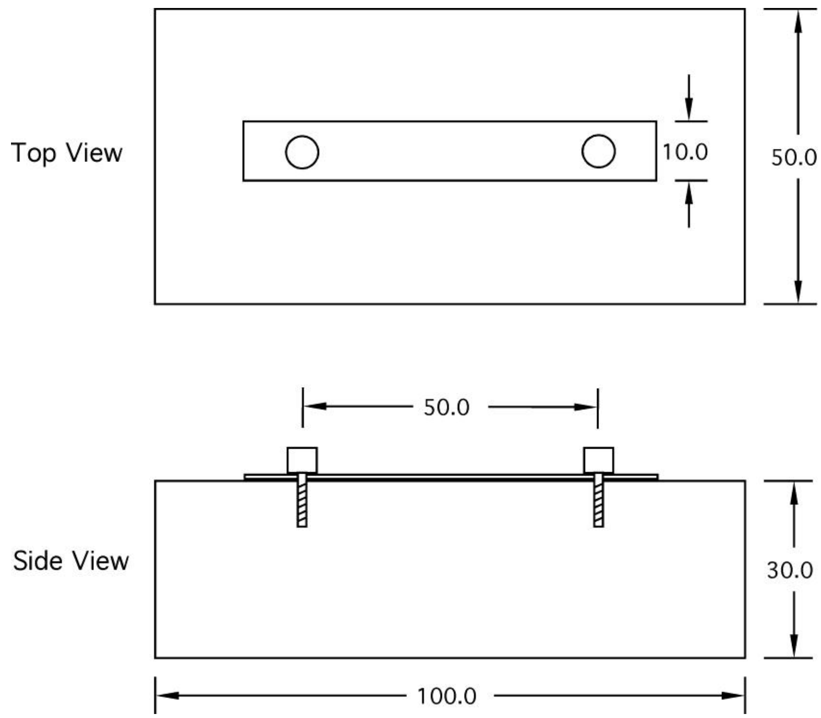


(1) The tube is first subjected to an axial tensile force F which is less than the critical value F_0 necessary to cause yielding in the tube by the force alone. If subsequently F is held constant and a gradually increasing internal pressure p is applied, find the pressure p at which the tube will yield according to the Tresca criterion;

(2) Let p_0 be the internal pressure required to cause yielding in the absence of F. Assume two identical tubes experience each a different process:
(a) F is increased from zero to $1.1F_0$ and then reduced to zero without p;
(b) p is increased from zero to $1.1p_0$ and then reduced to zero without F.
How does the final thickness of the tubes compare? If you can, find the final thickness values.

PROBLEM 2

A 301 austenitic stainless steel sheet (in fully hardened condition) is attached to a block of 4340 steel (quenched and tempered) using two screws spaced 50 *mm* apart as shown in the drawing with dimensions given in *mm*. The steel sheet is 10 *mm* wide and 0.20 *mm* thick. Properties of the two materials are given in the table.



Material	E (GPa)	ν	α (1/°C)	σ_o (MPa)	σ_u (MPa)
4340 Steel	210	0.29	12.0×10^{-6}	1380	1500
301 Stainless Steel	185	0.28	17.0×10^{-6}	950	1300

(a) What happens when all components are cooled uniformly from room temperature (20°C) to -80°C? Please justify with calculations. If possible, give the stress state in the middle of the 301 stainless steel sheet after cooling.

(b) What happens when all components are heated uniformly from room temperature (20°C) to 120°C? Please justify with calculations.

PROBLEM 3

Answer the following questions pertaining to fatigue of materials:

a) Two specimens are subjected to a cyclic axial fatigue loading with everything being the same, including the maximum applied stress. The only difference is specimen 1 is subjected to a stress ratio, R, of 0.1 and specimen 2 is subjected to an R of 0.4. Which specimen would be expected to have the longer life?

b) In another set of fatigue tests, 3 specimens are fatigued at identical cyclic conditions except for the surface finish of each specimen: specimen 1 was left as machined, specimen 2 was polished and specimen 3 was shot-peened. Which specimen would be expected to have the longer fatigue life? Which would have the shortest?

c) If the fatigue tests were conducted in an aggressive environment, such as salt water, would a higher frequency or lower frequency test be expected to last a larger number of cycles?

d) In designing for fatigue one has to be very aware of the stress concentration factors, $\mathbf{k_t}$. Define $\mathbf{k_t}$ and show an example with a sketch.

e) If two specimens were fatigued under identical conditions except one had a $\mathbf{k_t}$ of 2.0 and the other had a $\mathbf{k_t}$ of 3.3, which would be expected to fail sooner?

f) You have a choice to design a structural part that would be either cyclic displacement-controlled or cyclic load-controlled and in either case you start with the same maximum applied stress. Which would you choose to get a longer total fatigue life? Why is that?

g) Suppose you have a cast actuator rod made of 7050 aluminum alloy. The rod controls the position of one of the horizontal stabilizers on the F-22 aircraft. The loading is axial. Estimate the life in terms of number of flights if a typical flight had the following loading history (in terms of stress):

# of cycles	max stress(ksi)	stress ratio
20	42	0.5
1500	34	0.5
4	35	-1.0
54	42	0.0

(For this problem just assume the best fit line is good enough. Use Miner's Rule)

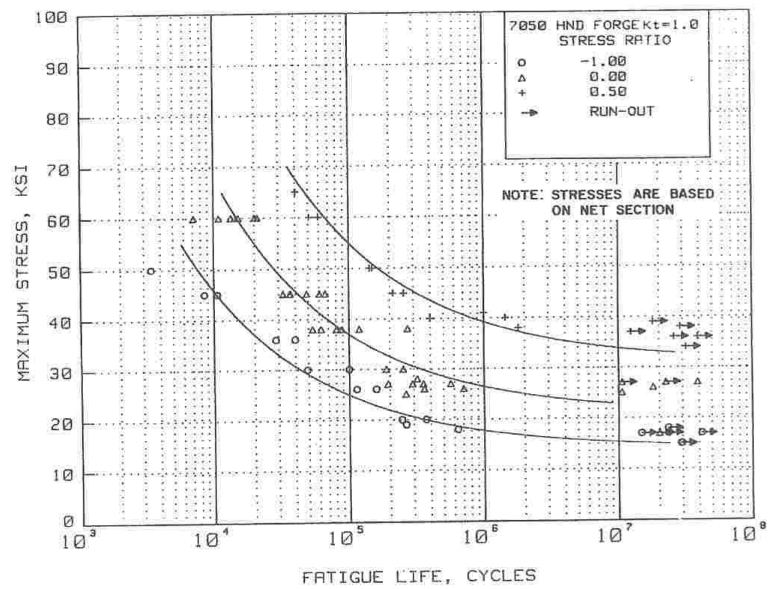


FIGURE 3.7.3.2.8(f). *Best-fit S/N curves for unnotched 7050-T7452 hand forgings, long transverse and short transverse directions.*

PROBLEM 4

The rigid bar *AB* is supported by a pin at *A* and two members *CE* and *DF* as shown in the figure. The bar *CE* is made of steel, with a cross section of $A = 0.004\ m^2$ and length, $L = 1.8\ m$. The bar *DF* is made of aluminum, with a cross section of $A = 0.002\ m^2$ and length, $L = 1.3\ m$.

1) Find the small angular clockwise rotation of *AB* about *A* when the *5 kN* force is applied as shown.

2) Determine the angular rotation change if the structure is cooled by the amount $\Delta T = -20°C$ with the *5 kN* force acting as shown.

Material	Young's modulus, E (MPa)	Coefficient of Thermal expansion, $\alpha \times 10^6$ (1/°C)
Structural steel	210,000	11.7
Aluminum alloy	69,000	23.4