**ME 461 – Exam 1**
**Feb. 25, 2009**

1. List four types of mechanical failures. *(3 pts.)*

- large deformations
- ductile fracture
- brittle fracture
- impact / dynamic loading
- creep
- wear
- buckling
- corrosion
- stress corrosion cracking
- fatigue

2. What are the input variables in a fatigue design process? *(3 pts.)*

- geometry
- loading history
- environment
- design criteria
- material properties
- processing effects (i.e. residual stresses, etc.)

3. List the four fatigue design criteria. *(3 pts.)*

- infinite life design
- safe-life design
- fail-safe design
- damage tolerant design

4. What causes cyclic hardening/softening in a material? *(3 pts.)*

Dislocation movement through the microstructure. Dislocations structuring in cells is also very effective in creating a hardening/softening behavior.

5. List three microstructural factors that lead to fatigue crack nucleation in metals. *(3 pts.)*

- inclusions
- voids
- persistent slip bands
- grain boundaries
- hydrogen trapped in the microstructure
- corossion pits
- impurities
- local stresses (residual)

6. Are grain boundaries beneficial or detrimental to fatigue crack growth? Explain why. *(3 pts.)*

Grain boundaries are in general beneficial for the fatigue lives that involve small crack growth. In this case, grain boundaries represent obstacles against crack propagation.
Grain boundaries are detrimental for long fatigue cracks because cracks propagate along them.
Cracks can grow along grain boundaries at high temps.

7. List at least three methods to boost fatigue life of a metallic component. *(3 pts.)*

- polish outer surfaces
- induce compresive residual strenes
- smooth geometries (reduce stress concentration factors)
- paint outer surfaces (reduces corrosion cracking)
- use ductile materials with higher strength.
- engineer microstructures (finer grain size, single crystals)

8. The strain based approach is most successful for high cycle fatigue (HCF) predictions. True or false? *(3 pts.)*

False. The strain based approach is most succesful for loading situations that involve large local strains and, thus, lead to a low cycle fatigue life.

9. Using the strain life approach, calculate the factor of safety for infinite fatigue life for a shaft loaded with a cyclic load with $R = -1$. The measured local alternating stress is $\sigma_a = 500$ MPa. The component is made of hot rolled 4340 steel. (36 *pts.*)

$\sigma_a = 500$ MPa

4340 HR   $S_{ut} = 827$ MPa   $S_y' = 634$ MPa   $K' = 1337$ MPa

$n' = 0.168$   $\varepsilon_f' = 0.522$   $\sigma_f' = 1198$ MPa

$b = -0.095$   $c = -0.563$

$$\varepsilon_a = \frac{\sigma_a}{E} + \left(\frac{\sigma_a}{K'}\right)^{\frac{1}{n'}} = \frac{500}{193 \cdot 10^3} + \left(\frac{500}{1337}\right)^{\frac{1}{0.168}} = 0.005457$$

Compute the alternating strain required for an infinite life ($N_f = 10^6$ cycles):

$$\varepsilon_{a_f} = \frac{\sigma_f'}{E}(2N_f)^b + \varepsilon_f'(2N_f)^c = \frac{1198}{193 \cdot 10^3}(2 \cdot 10^6)^{-0.095} +$$

$$+ 0.522 \cdot (2 \cdot 10^6)^{-0.563} = 0.001712$$

The factor of safety is:

$$n = \frac{\varepsilon_{af}}{\varepsilon_a} = \frac{0.001712}{0.005457} = 0.215 < 1$$

the shaft will fail before reaching $10^6$ cycles.

10. A rod has a diameter of 3/4 in is machined from a stock of 1045 annealed steel and is loaded by an axial force that fluctuates between $F_{min}$ = -10 kip and $F_{max}$ = 30 kip. Knowing that the steel rod presents a geometrical stress concentration factor of $K_t$ = 2.1 (notch radius is 0.16 in), determine the number of cycles to failure for this component. (*40 pts.*)

$$A = \frac{\pi d^2}{4} = \frac{\pi \cdot (0.75)^2}{4} = 0.442 \text{ in}^2$$

$$\sigma_{max} = \frac{F_{max}}{A} = \frac{30}{0.442} = 67.87 \text{ ksi}$$

$$\sigma_{min} = \frac{F_{min}}{A} = \frac{-10}{0.442} = -22.62 \text{ ksi}$$

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2} = 22.62 \text{ ksi} \qquad \sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2} = 45.25 \text{ ksi}$$

1045 steel $S_{ut} = 752$ MPa $= 109$ ksi

$r = 0.16$ in
$S_{ut} = 752$ MPa $= 109$ ksi $\} \Rightarrow q = 0.85$

$$K_f = 1 + q(K_t - 1) = 1 + 0.85(2.1 - 1) = 1.935$$

$$k_a = a S_{ut}^b = 2.7 \cdot (109)^{-0.265} = 0.779$$

$$k_b = 1$$

$$k_c = 0.923$$

$$k_d = 1$$

$$k_e = \frac{1}{K_f} = \frac{1}{1.935} = 0.517$$

$$S_e = k_a k_b k_c k_d k_e S_e' = 0.779 \cdot 0.923 \cdot 0.517 \cdot (0.504 \cdot 109) =$$

$$= 20.421 \text{ ksi}$$

Calculate the fatigue strength:

$$\frac{\sigma_a}{S_{N_f}} + \frac{\sigma_m}{S_{ut}} = 1 \Rightarrow S_{N_f} = \sigma_a \frac{1}{1 - \frac{\sigma_m}{S_{ut}}}$$

$$S_{N_f} = 45.25 \cdot \frac{1}{1 - \frac{22.62}{109}} = 57.099$$

$S_{N_f} > S_e \rightarrow$ the component will fail after a finite number of cycles (it does not have an infinite life)

$$a = \frac{(0.9 S_{ut})^2}{S_e} = \frac{(0.9 \cdot 109)^2}{20.421} = 471.26 \text{ Ksi}$$

$$b = -\frac{1}{3} \log \frac{0.9 S_{ut}}{S_e} = -\frac{1}{3} \log \frac{0.9 \cdot 109}{20.421} = -0.227$$

$$S_{N_f} = a N^b \Rightarrow N = \left(\frac{S_{N_f}}{a}\right)^{\frac{1}{b}} = \left(\frac{57.099}{471.26}\right)^{-\frac{1}{0.227}} =$$

$$= 10{,}920 \text{ cycles}$$