EXAM #2 Review Questions

Part A: True/False

1. Increased grain size tends to make a ductile metal stronger. **FALSE.**

   Explanation: Dislocations cannot cross grain boundaries easily, so the size of grains determines how easily the dislocations can move. Therefore, metals with small grains are stronger since there are a larger number of grain boundaries.

2. Creep is a failure mechanism that results from cyclic stress at elevated temperatures for prolonged periods of time. **FALSE**

   Explanation: Creep results from a material being placed under elevated temperatures and <u>constant</u> stress.

3. In general, the stress at the failure point on an engineering tensile stress/strain curve is typically higher than on a true tensile stress/strain curve. **FALSE**

   Explanation: The stress at failure on an engineering tensile stress/strain is typically lower than the failure point on a tensile stress/strain curve since engineering stress/strain curve does not take into account the reduction in cross-sectional area, which would therefore increase the stress at a given strain.

4. Resilience is a measure of the total capacity of the material to absorb energy up to the failure point. **FALSE**

   Explanation: Resilience is the capacity of a material to absorb energy when it is deformed elastically and then upon unloading to have this energy recovered.

5. Cold rolling a metal (i.e. deforming by compressing and squeezing between two rollers) decreases its dislocation density. **FALSE**

   Explanation: Cold rolling a metal increases the dislocation density which results in the dislocations hindering each other's movement and thus acting as barriers, which results in an increase in strength.

6. Critical resolved shear stress represents the minimum shear stress required to initiate slip, and it is a function of loading direction relative to the slip direction. **FALSE**

   Explanation: Critical resolved shear stress it represents the minimum shear stress required to initiate slip and <u>is a property of the material that determines when yielding occurs.</u>

7. Recrystallization is the formation of a new set of strain-fee and equiaxed grains that have low dislocation densities. **TRUE**

8. S-N curves illustrate the evolution of creep strain in metals as a function of time. **FALSE**

   Explanation: S-N curves illustrates how many cycles a material can endure under an alternating stress.

9. As percent of cold work (%CW) of a material increases, the yield and tensile strengths increase while ductility and elastic modulus decrease. **FALSE**

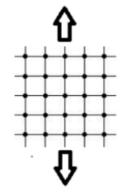
   Explanation: The elastic modulus of a cold worked material does not change.

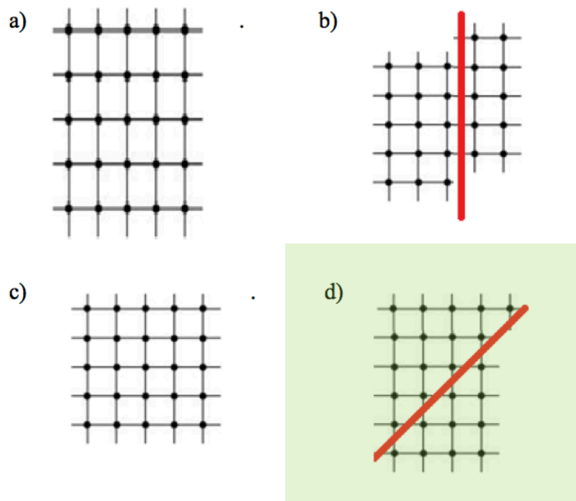
10. Interstitial diffusion involves the interchange of an atom from normal lattice position to adjacent vacant lattice site or vacancy. **FALSE**

    Explanation: Interstitial diffusion is a mechanism by which atomic motion is from an interstitial site to interstitial site.

Part B: Multiple Choice Questions

1. A single crystal initially has the atomic arrangement shown to the right. A small load is applied in tension, and the sample elongates in the vertical direction; after removing the load, the crystal remains elongated. Which of the following best represents the crystal structure in the material after deformation?





Red line indicates the slip direction

2. Which set of planes and directions represent the slip system in FCC materials?

a. {111}<110>
b. {110}<111>
c. {123}<111>
d. {112}<111>

3. Which one of the following represents the Burger's vector for unit dislocation in BCC materials?

a. **b** = a[100]
b. **b** = a/2[100]
c. **b** = a/2[111]
d. **b** = a/2[110]

4. The concentration of defects and imperfections in a crystal lattice:

a. Is fixed based on how the material is made.
b. Depends only on the temperature of the sample.
c. Depends only on the external stress applied to the sample.
d. Depends on the temperature and the deformation history of the sample.

5. Decreasing the average grain size of a ductile alloy tends to:

a. Increase the strength and hardness of an alloy, make the alloy less ductile, and increase the elastic modulus of the alloy.
b. Decrease the strength and hardness of an alloy, make the alloy more ductile, and increase affect the elastic modulus of the alloy.
c. Increase the strength and hardness of an alloy, make the alloy less ductile, and not affect the elastic modulus of the alloy.
d. Increase the strength and hardness of an alloy, make the alloy more ductile, and not affect the elastic modulus of the alloy.

Part C: Short Answer Questions

1. Of those metals listed in below,

Material	*Yield Strength (MPa)*	*Tensile Strength (MPa)*	*Strain at Fracture*	*Fracture Strength (MPa)*	*Elastic Modulus (GPa)*
A	310	340	0.23	265	210
B	100	120	0.40	105	150
C	415	550	0.15	500	310
D	700	850	0.14	720	210
E	Fractures before yielding			650	350

a. Which will experience the greatest percentage reduction in area? Why? Assuming constancy of the volume of material during plastic deformation, the material with the highest "strain at fracture" or "ductility" will experience the greatest percentage reduction in area.

b. Which is the strongest? Why? Material D is the strongest, with the highest "Tensile Strength"

c. Which is the stiffest Why? Stiffness is dictated by "Elastic Modulus". Material E is the stiffest.

2. A single crystal of a metal is oriented for a tensile test such that its slip plane normal makes an angle 63.6° with the tensile axis. Three possible slip directions make angles of 30°, 48° and 78° with the same tensile axis. Which of these three slip directions is most favored?

The slip system with the largest Schmid Factor will be favored

Schmid Factor (SF) = $\cos(\lambda)\cos(\phi)$

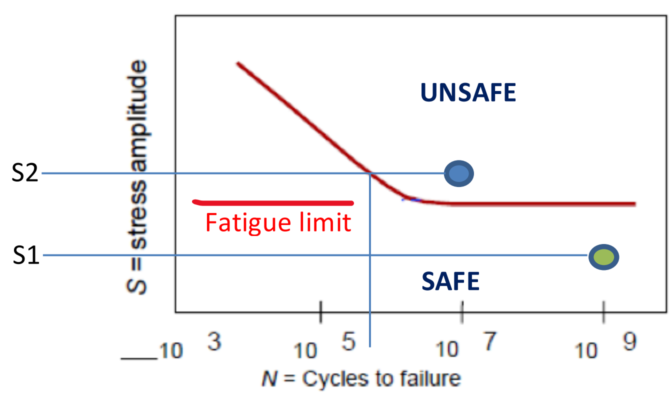
SF1 = $\cos(30°)\cos(63.6°) = 0.385$

SF2 = $\cos(48°)\cos(63.6°) = 0.314$

SF3 = $\cos(78°)\cos(63.6°) = 0.092$

Slip will take place along the direction 30°

3. Label fatigue limit on the S-N curve below. Also explain which region is safe, and which region is not

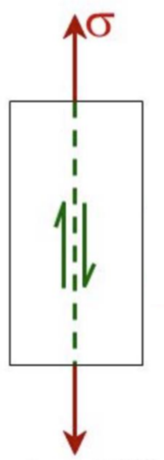


Fatigue limit (sometimes called endurance limit) is defined as the stress amplitude under which a specimen will endure infinite number of cycles. While some materials (e.g. steel) have S-N curves that flatten beyond a certain number of cycles (like the one shown above), some non-ferrous materials (e.g.

aluminum) do not exhibit this behavior and they have decreasing S with increasing N. For these materials, fatigue limit is typically taken as the S value at 10^7 or 10^8 cycles.

The area under the curve in the S-N plot is considered as “safe” while the area above is “unsafe”. For instance, if we load our material in a cyclic manner at an S value corresponding to the green circle in the figure above (S1), we will safely get 10^9 cycles from our material. In fact, since S1 is below the fatigue limit, our material will endure an infinite number of cycles at this stress level. However, if we need to increase the stress level to S2 and need to achieve 10^7 cycles, our material will fail at around $5x10^5$ cycles.

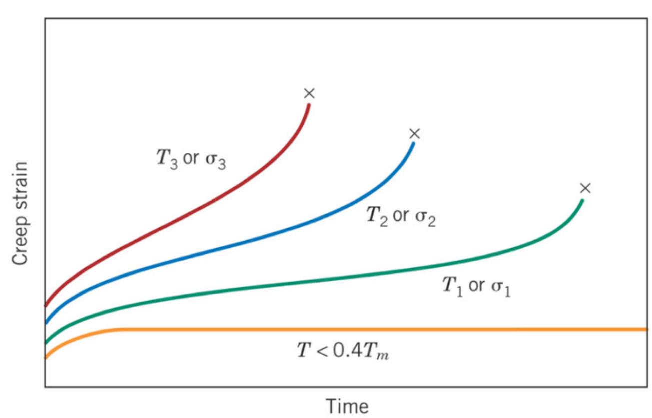
4. If a crystalline material has only one slip plane and it is loaded in the direction normal to that slip plane, will this material yield? Why or Why not? Since Schmid factor is 0 in this case, the material will not yield under this load. There will be no shear stress on this particular slip system.



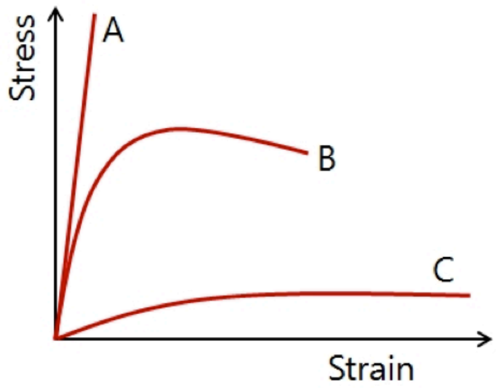
5. Write three strategies for strengthening pure copper (Cu). Briefly explain how each strategy works.

1. **Grain refinement.** Grain boundaries act as pinning points impeding the propagation of dislocations. Since the lattice structure of adjacent grains differs in orientation, it requires more energy for a dislocation to change directions and move into the adjacent grain. The grain boundary is also much more disordered than inside the grain, which also prevents the dislocations from moving in a continuous slip plane. Impeding this dislocation movement will hinder the onset of plasticity and hence increase the strength of the material.
2. **Solid solution strengthening**. When solute atoms are introduced to a pure material, local stress fields are formed that interact with those of the dislocations, impeding their motion and causing an increase in the strength of the material. E.g. Pure Cu can be made stronger by alloying with another element that is soluble in Cu, like Ni (substitutional solid solution). E.g, adding C to Fe (interstitial solid solution).
3. **Work hardening (cold work).** As a material is work hardened it becomes increasingly saturated with new dislocations, and more dislocations are prevented from nucleating (a resistance to dislocation-formation develops). This resistance to dislocation-formation manifests itself as a resistance to plastic deformation; hence, the observed strengthening.

6. In the creep strain vs time curve shown below, list the temperatures from highest to lowest.
T3 > T2 >T1



7. You are developing a new alloy for a car bumper. You have developed two different materials (A, B and C). Which one would you use for a car bumper, and why?



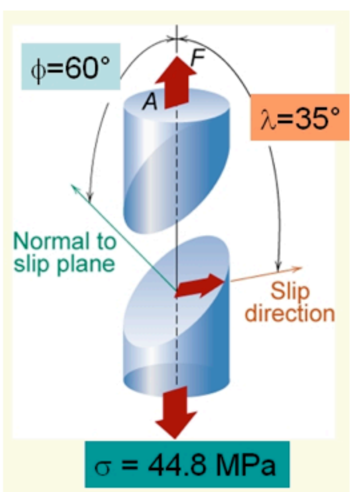
You would ideally want the bumper to have a combination of good strength and ductility, leading to the highest toughness value (for energy absorption). Therefore, the best choice would be Material B.

Part D: Problems

1. Figure below shows the deformation of a single crystal. For the given loading and slip conditions and τ_{CRSS} (critical resolved shear stress) value of 8.9 MPa:

a. Will the single crystal yield?

b. What is the yield stress?



a. Resolved shear stress (τ_r) for the given slip system can be found using the formula:

$$\tau_r = \sigma \cos\lambda \cos\phi = 44.8 \cos 35 \cos 60 = 18.3\ MPa$$

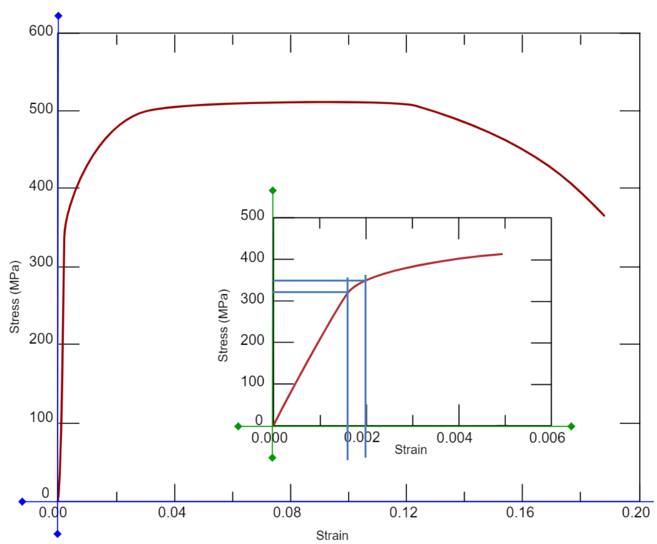
Since τ_r is larger than τ_{CRSS}, the single crystal will yield.

b. Yield strength of the material can be found using the formula:

$$\sigma_y = \frac{\tau_{CRSS}}{\cos\lambda \cos\phi},\ \sigma_y = \frac{8.9}{\cos 35 \cos 60} = 21.7 \text{ MPa}$$

2. Figure below shows the tensile stress-strain curve of a cylindrical rod made from an unknown alloy. The rod has a cross-section are of 0.5×10^{-3} m^2.

a. What is the maximum load that this rod can support, yet still recover its initial shape when the load is removed?
b. What is the value of modulus of elasticity?
c. The rod has an initial length of 0.5 m. What is the new length of the rod once it is placed under a static tensile stress of 350 MPa?
d. What is the value of the tensile strength?
e. What is the value of toughness in joule per cubic meter ($J \cdot m^{-3}$)? (A rough estimate is acceptable as long as you show your calculation)
f. Can you estimate the type of this alloy? (e.g. steel, aluminum, magnesium alloy, etc.)



a. Since we want the rod to recover its initial shape when the load is removed, stresses should be in the elastic range. Looking at the inset, it is seen that elastic limit is around 320 MPa. To convert this stress to load, we need to multiply by the cross-section area:
$F= 320 \times 10^6$ Pa * 0.5×10^{-3} m^2 = 160×10^3 N = 160 kN
b. E can be found again from the elastic region, as the slope of the stress-strain curve:
E= 320/0.0015 = 213 GPa (note that strain was approximately taken as 0.0015)
c. At 350 MPa, strain is around 0.002. From the definition of strain:
$0.002 = \Delta l/l_0 \rightarrow \Delta l = 0.002 \times 0.5 = 0.001$ m
The new length $l_f = l_0 + \Delta l = 0.501$ m
d. From the stress-strain plot, tensile strength is slightly above 500 MPa.
e. To approximate the area under the stress-strain curve, I will fit a rectangle bounded by Stress (σ): 0 to 450 MPa, and Strain (ε): 0 to 0.18
The area of the rectangle is 450×10^6 $N/m^2 \times 0.18$ m/m = 81 J/m^3
f. The most reliable to estimate the type of the material is to look at its E value, since E does not depend on the processing history of the material (affecting its shape, dislocation density, grain

size). Values like ductility and strength are strongly affected by the processing history. This material is probably a type of steel, since E of steel is around 210 GPa.

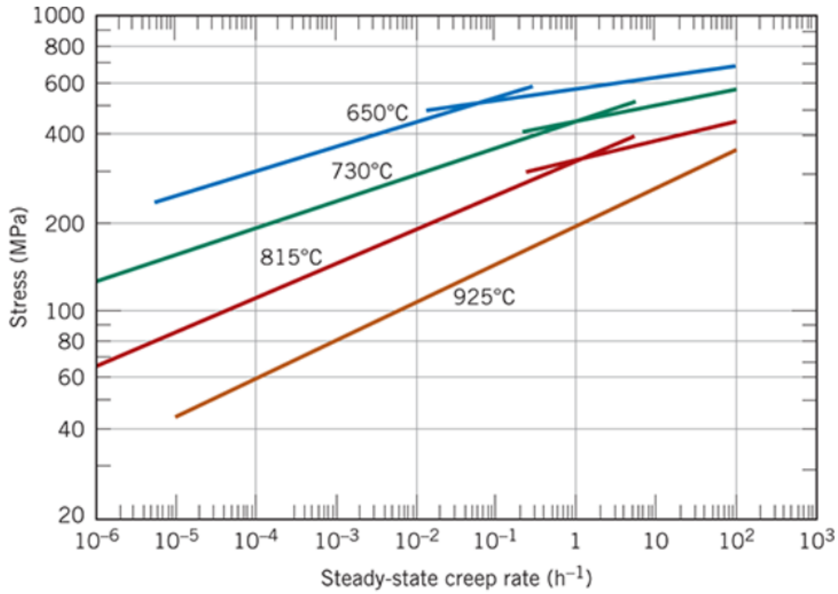
3. A specimen of a 4340 steel alloy having a plane strain fracture toughness of $45 MPa\sqrt{m}$ is exposed to a stress of 1000 MPa. Will this specimen experience fracture if it is known that the largest surface crack is 0.75 mm long? Why or why not? Assume that the parameter Y has a value of 1.0.

This problem asks us to determine whether the 4340 steel alloy specimen will fracture when exposed to a stress of 1000 MPa, given the values of K_{Ic}, Y, and the largest value of a in the material. This requires that we solve for c:

$$\sigma_c = \frac{K_{Ic}}{Y\sqrt{\pi a}} = \frac{45 \text{ MPa}\sqrt{\text{m}}}{(1.0)\sqrt{(\pi)(0.75 \times 10^{-3} \text{ m})}} = 927 \text{ MPa}$$

Therefore, fracture will most likely occur because this specimen will tolerate a stress of 927 MPa before fracture, which is less than the applied stress of 1000 MPa.

4. A specimen 750 mm long of an S-590 alloy is to be exposed to a tensile stress of 80 MPa at 815°C. Determine its elongation after 5000 h. Assume that the total of both instantaneous and primary creep elongations is 1.5 mm.



From the 815°C line in the given figure, the steady state creep rate $\dot{\varepsilon}_s$ is about $5.5 \cdot 10^{-6}$ h^{-1} (*your value might be different depending on how you calculate from the plot*) at 80 MPa. The steady state creep strain, ε_s, therefore, is just the product of $\dot{\varepsilon}_s$ and time as

$$\varepsilon_s = \dot{\varepsilon}_s \times \text{(time)}$$

$$= \left(5.5 \times 10^{-6}\ \text{h}^{-1}\right)(5000\ \text{h}) = 0.0275$$

Elongation (Δl_s) can be found as the product of the creep strain and the initial length l_0:

$$\Delta l_s = l_0\, \varepsilon_s = (750\ \text{mm})\left(0.0275\right) = 20.6\ \text{mm} \quad (0.81\ \text{in.})$$

Finally, the total elongation is just the sum of this Δl_s and the total of both instantaneous and primary creep elongations (i.e., 1.5 mm). Therefore, the total elongation is 20.6 mm + 1.5 mm = 22.1 mm