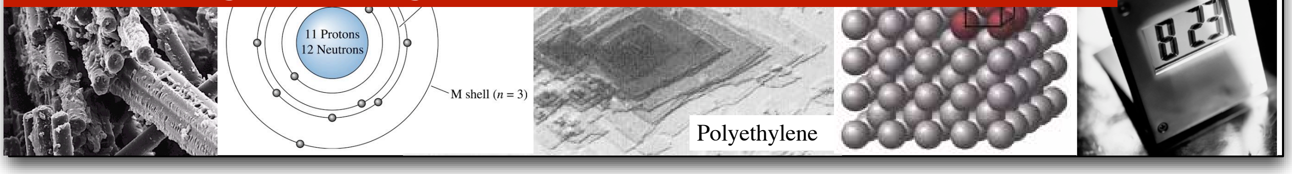
Spring 2007 **Engineering Material**



Exam I

Wednesday, 25 April, 2007

Duration: 50 minutes
Closed Book Exam
Write clearly your derivations and answers on the question sheet

Name:

ID#:

I Diffusion [35 points]

You are designing a turbine engine part made of an FCC single crystal. By using the Schmid law, determine the τ_c necessary for the part to have a uniaxial yield strength of 200 MPa in the [331] crystallographic direction?

Let us determine the Schmid factor of a FCC crystal pulled in the [331] direction.

Slip Systems		(111)			$(\bar{1}11)$			$(1\bar{1}1)$			$(\bar{1}\bar{1}1)$		
		$[\bar{1}10]$	$[0\bar{1}1]$	$[10\bar{1}]$	$[110]$	$[01\bar{1}]$	$[101]$	$[110]$	$[011]$	$[10\bar{1}]$	$[1\bar{1}0]$	$[011]$	$[101]$
Tensile	$\cos\phi$	$\frac{7}{\sqrt{57}}$	$\frac{7}{\sqrt{57}}$	$\frac{7}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{1}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$	$\frac{-5}{\sqrt{57}}$
Axis	$\cos\lambda$	0	$\frac{-2}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	$\frac{6}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$	$\frac{6}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$	$\frac{2}{\sqrt{38}}$	0	$\frac{4}{\sqrt{38}}$	$\frac{4}{\sqrt{38}}$
[331]	M	0	$\frac{-14}{19\sqrt{6}}$	$\frac{14}{19\sqrt{6}}$	$\frac{6}{19\sqrt{6}}$	$\frac{2}{19\sqrt{6}}$	$\frac{4}{19\sqrt{6}}$	$\frac{6}{19\sqrt{6}}$	$\frac{4}{19\sqrt{6}}$	$\frac{2}{19\sqrt{6}}$	0	$\frac{-20}{19\sqrt{6}}$	$\frac{-20}{19\sqrt{6}}$

The Schmid factor is thus $\frac{20}{19\sqrt{6}}$ (tensile test in [331] direction).

So $\boxed{\tau_c = MY = \frac{20}{19\sqrt{6}} \times 200 = 86 \text{ MPa}}$

II Mechanical Properties [30 points]

A tensile specimen is machined to a gage diameter of 0.357-in and is marked with a starting gage length of 2-in. When subjected to a test, the following results were found:

- yield load = 2,000 lbf
- fracture diameter = 0.27-in
- diameter at ultimate load = 0.31-in
- elastic modulus = 25×10^6 psi

After completing this test, you are informed that the tensile specimen had been cold-worked some amount before it was machined and tested, and that in the annealed state $\sigma = K\epsilon^n$ with n=0.5.

a. What is the yield strength Y for this specimen?

b. How much strain was induced by the unknown amount of cold work?

c. What maximum load (i.e. Fu) was reached during the test?

This is a very important exercise: we are given results of a test after the specimen has already been cold-worked. In Day:1 some cold work was done, taking the material into its plastic domain. The workpiece is then left to rest, where it contracted a little bit due to elasticity. And finally the material is being tested at Day:2. Since it is always the same material, it has only one representative curve for its plastic domain. The history of actions is reported on the graph.

Yield Load: We are looking for the "new apparent" yield strength of the specimen pre-strained. So it comes directly from the data of Day:2 experiment.

We assume that the elastic line is almost vertical, i. e. the diameter at yielding is equal to the starting diameter for Day:2 experiment.

$$Y = \frac{2,000}{\frac{\pi D'^2}{4}} = 19,980 \text{ psi} \quad (10)$$

Remark: If we try to account for the elasticity, we get a diameter of 0.3569″ at yielding for Day:2 experiment.

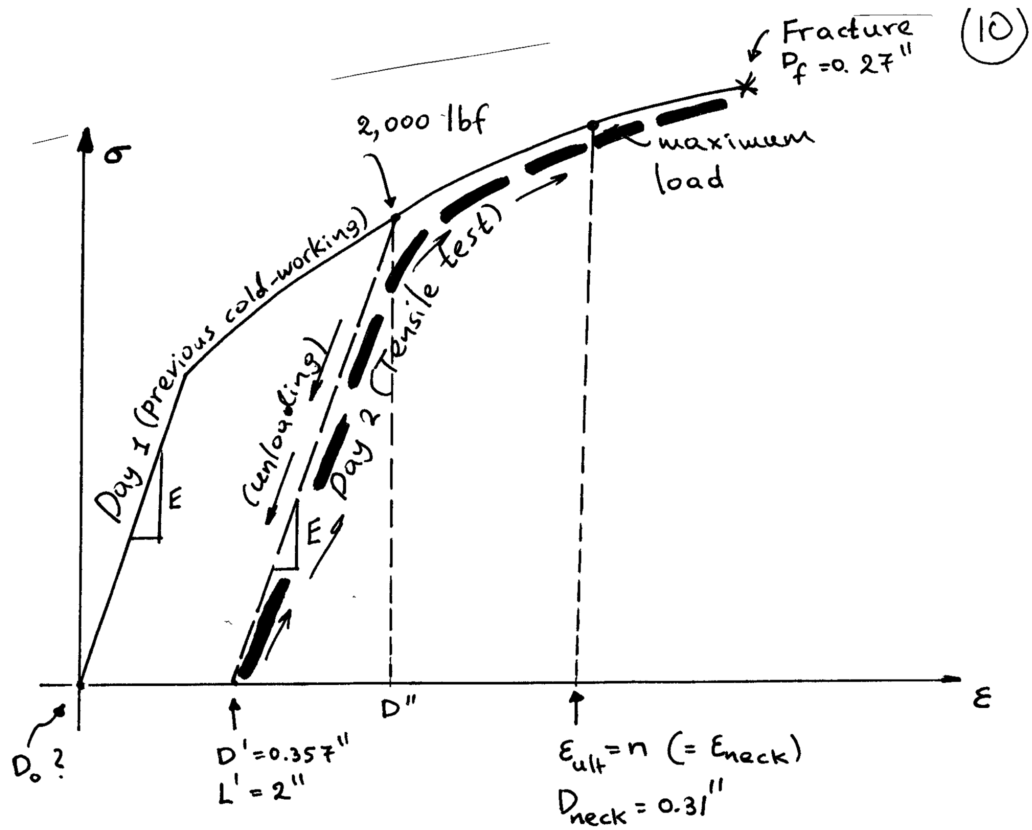


Figure 1: Note that Day:1 is referred to the previous cold-working, while Day:2 is referred to the tensile test. Also note that the elastic deformation has been enlarged to make the presentation clear.

Pre-strain: When considering necking, we must consider the curve representing the material and we can write $\epsilon_{\text{neck}} = n, \epsilon$ starting without pre-strain. So

$$\epsilon_{\text{neck}} = n = 0.5 = 2\ell n \frac{D_o}{D_{\text{neck}}} \tag{11}$$

$$\Rightarrow D_o = D_{\text{neck}} \exp\left(\frac{\epsilon_{\text{neck}}}{2}\right) = 0.398 - in \tag{12}$$

Pre-strain:

$$\epsilon' = 2\ell n \frac{D_o}{D'} = 0.217 \tag{13}$$

Maximum load: Let us first determine K from yielding point of Day:2 experiment:

$$\sigma' = Y = K\epsilon'^n \Rightarrow K = \frac{Y}{\epsilon'^n} = 42,892 \text{ psi} \tag{14}$$

Let us use K and n at necking where the maximum load is applied.

$$\epsilon_{\text{neck}} = n, \sigma_{\text{neck}} = K\epsilon_{\text{neck}}^n = Kn^n = 30,329 \text{ psi} \tag{15}$$

And

$$F_u = \frac{\pi D_{\text{neck}}^2 \sigma_{\text{neck}}}{4} = 2289 \text{ lbf} \tag{16}$$

Summary

- $Y = 19,980$ psi (yielding for Day 2 experiment).
- Cold work induced strain $\epsilon' = 0.217$.
- Maximum load $= F_u = 2,289$ lbf.

III Phase Diagrams [35 points]

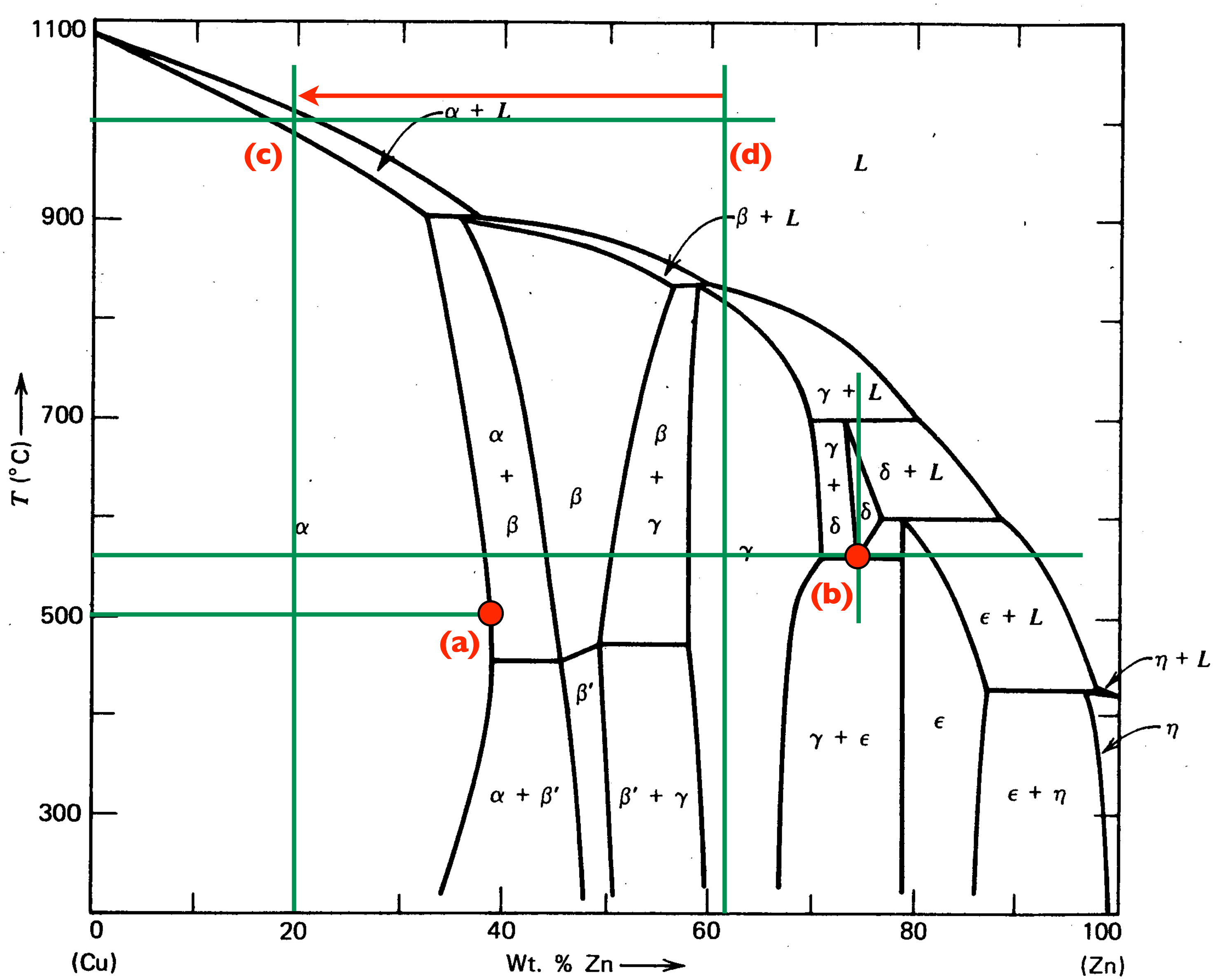
a. What is the solubility (in wt% Zn) of An in α at 500˚C

b. Describe a eutectoid transformation in the Cu-Zn system by giving the eutectoid temperature, the eutectoid composition and the phase(s) just below and just above the eutectoid temperature for an alloy at the eutectoid composition

c. For a Cu-Zn alloy containing 20 wt% Zn, sketch the cooling curve from 1100˚C to 500˚C and give the liquidus and solidus temperatures

d. A Cu-Zn alloy containing 63 wt% Zn weighs 100 g. The temperature is 1000˚C. How many grams of Cu can be added in order to saturate the liquid solution with copper?

e. A Cu-Zn alloy containing 20 wt% Zn is stronger than pure copper. Why?



Data and Formula

Avogadro's number: 6.023×10^{23} /mol

Gas Constant: 8.31 J/mol•K, 1.987 cal/mol•K

Boltzmann's constant: 1.38×10^{-23} J/atom•K, 8.62×10^{-5} eV/atom•K