MAE 212: Spring 2001

FINAL EXAM

Thursday, May 17

9:00 - 11:30 a.m.

Closed books and notes. Answer all questions. Make sure your answers are legible.

1. (20 points) **True or False: Read VERY CAREFULLY. State your answers to each of the following questions sequentially. Do not show your calculations as credit will only be given to your final T or F selection.**

   (a) (1 point) In extrusion processes, we can calculate the maximum reduction conditions by setting the extrusion pressure equal to the yield stress of the material.

   (b) (1 point) The shear modulus G can be expressed in terms of the Young's modulus E and Poissons ratio ν as $G = \frac{E}{2(1+\nu)}$.

   (c) (1 point) Consider a thin sheet on the xy plane under plane stress elastic conditions with known material properties (z=normal to the sheet axis). Someone will only need to properly place two linear strain gages on the surface of the sheet if she (he) wants to use these measurements to compute all three normal strain components (i.e. ϵ_x, ϵ_y and ϵ_z (out of plane normal strain component)).

   (d) (1 point) For the same applied load in tension, the true stress is always less in magnitude than the engineering stress.

   (e) (1 point) The Taylor factor was introduced in class to relate the average velocity of a dislocation to the dislocation density.

   (f) (1 point) For a screw dislocation the Burgers vector is parallel to the dislocation line.

   (g) (1 point) According to the von Mises yield criterion, a state of pure hydrostatic stress will not induce yielding.

   (h) (1 point) TTT diagrams define equilibrium phase transformations.

   (i) (1 point) Since there are no close-packed planes in a FCC crystal, any plane containing a [110] direction can act as a slip plane.

   (j) (1 point) The recrystallization temperature decreases with the amount of previous cold working.

   (k) (1 point) Superplastic materials are usually refer to materials with very high strain-hardening exponent.

(l) (1 point) The Schmid factor is used to define the relation between the yield stress of a polycrystal and the critical resolved shear stress on a slip plane of a single crystal.

(m) (1 point) Some of the effects of applying front tension in flat rolling include a reduction in the average pressure and moving the neutral point towards the entrance.

(n) (1 point) At the neutral point in flat rolling the frictional forces are maximum assuming sliding frictional conditions.

(o) (1 point) In the sticking friction assumption used in the analysis of forging processes, the coefficient of friction is defined as $\mu = \kappa/p$, where κ is the yield stress in shear and p the pressure at the die/workpiece interface.

(p) (1 point) A strain-rate sensitive material can result in much higher ductility than a strain-hardening material.

(q) (1 point) The angle between [111] and $[11\bar{1}]$ is $\arccos(\frac{1}{\sqrt{3}})$

(r) (1 point) The Arhenious law governs the temperature dependence of the rate of physical phenomena that can be thermally activated such as the motion of dislocations.

(s) (1 point) Aluminum foils are commonly produced by flat rolling of thin sheets of Aluminum and with subsequent laser heat-treatment in one of their sides to give it the shining feel that everyone is familiar with.

(t) (1 point) Fick's laws are fundamental laws governing diffusion processes.

2. (10 points) **Multiple choice questions: Read VERY CAREFULLY. State your answers to each of the following questions sequentially. Do not show your calculations as credit will only be given to your final letter (A,B,C) selection.**

(a) (1 point) Isotropic elastic materials can be described with the following independent material properties:

- (A) Elastic modulus & Poissons ratio
- (B) Elastic modulus, Poissons ratio and shear modulus
- (C) Elastic modulus, Poissons ratio, shear modulus and bulk modulus.

(b) (1 point) The Miller indices of a close-packed plane in HCP are

- (A) (0001)
- (B) $(2\bar{1}\bar{1}0)$
- (C) None of the above

(c) (1 point) Let F be the number of the independent state variables, P the number of phases present in equilibrium and C the number of components. One of the forms of Gibb's law used for phase transformations in metallic alloys (not accounting for pressure) is

- (A) $F = C - P + 1$
- (B) $C = F - P + 1$
- (C) None of the above

(d) (1 point) In terms of the principal stresses σ_1, σ_2 and σ_3, a plane stress state is defined as one in which

- (A) one of the principal stresses is the average of the other two, e.g. $\sigma_2 = \frac{1}{2}(\sigma_1 + \sigma_3)$.
- (B) one of the principal stresses is zero
- (C) the size of the specimen/workpiece in one of the principal directions is much longer than the size in the other two directions

(e) (1 point) The number of atoms per unit cell in a BCC crystal is:

- (A) 2
- (B) 3
- (C) None of the above

(f) (1 point) For axisymmmetric deformations with the assumptions introduced in this class, the equivalent strain increment is given as:

- (A) $d\bar{\epsilon} = |d\epsilon_{\text{axial}}|$
- (B) $d\bar{\epsilon} = \frac{\sqrt{3}}{2}|d\epsilon_{\text{axial}}|$
- (C) None of the above

(g) (1 point) Let Y be the yield stress and $1, 2, 3$ the principal stress/strain directions. For plane strain plastic deformations ($\epsilon_2 = 0$), the von-Mises yield condition takes the form:

- (A) $|\sigma_1 + \sigma_3| = \frac{2}{\sqrt{3}}Y$
- (B) $|\sigma_1 - \sigma_3| = Y$
- (C) None of the above

(h) (1 point) Under ideal conditions, the maximum possible reduction in axisymmetric drawing of a non-hardening material is about equal to:

- (A) 83%
- (B) 63%
- (C) 73%

(i) (1 point) For any type of hardening behavior, the following condition is true at the ultimate point (maximum load point) in a tensile uniaxial test:

- (A) $\frac{d\sigma}{d\epsilon} = \epsilon$
- (B) $\frac{d\sigma}{d\epsilon} = \sigma$
- (C) None of the above

(j) (1 point) Consider plane stress conditions ($\sigma_2 = 0$) ($1, 2, 3 =$ principal stress axes). The maximum disagreement between the von-Mises and Tresca criteria appears in the case of

- (A) Equal biaxial tension $\sigma_1 = \sigma_3$
- (B) When $\sigma_1 = 2\sigma_3$
- (C) When $\sigma_1 = -\sigma_3$

Solutions to problems $3 - 8$ **not supported by appropriate development will not be accepted.**

3. (10 points) Short problems

(a) (3 points) What is the value of the die pressure at the exit when an ideal wire drawing process is being carried out at the maximum reduction per pass.

(b) (4 points) The energy E necessary to generate a dislocation is proportional to the square of the magnitude of the Burgers vector $\mathbf{b}$. This means that the most stable dislocations have the minimum magnitude $|\mathbf{b}|$. For the BCC structure, calculate relative to $E_{b=[111]}$ the dislocation energy for $E_{b=[110]}$ (i.e. find the ratio $\frac{E_{b=[110]}}{E_{b=[111]}}$). Based on your result, explain why the dislocation prefers to move on the close-packed direction $b = [111]$.

(c) (3 points) You are designing a turbine blade from an FCC crystal. Determine the critical shear stress τ_c necessary for the part to have a uniaxial yield strength of 200 MPa in the [331] crystallographic direction (assume that the active slip system is $(\bar{1}\bar{1}1)[101]$).

4. (15 points) Consider wire (axially symmetric) drawing of a non-hardening material through a conical converging die. For small semi-die angles α, we can assume that inside the deformation zone the radial (r), circumferential (θ) and axial (z) axes are fixed principal axes. As you already have seen in class, to emphasize that σ_r is a compressive stress we use the notation $\sigma_r = -p$ ($p \geq 0$, p=pressure).

Assume that the yield stress is constant and given as Y. Using the approximation $\sigma_r = \sigma_\theta$, it was shown in class that according to the von Mises criterion, yielding occurs when:

$$\sigma_z + p = Y \tag{1}$$

(a) (8 points) Assume that the die is well lubricated such that friction can be neglected. Analyze a slab of material in the deformation zone and apply equilibrium in the z-axis to show that:

$$\frac{dD}{D} = \frac{dp}{2Y} \tag{2}$$

(b) (7 points) With an appropriate integration of your slab equilibrium equation (Eq. 2) compute the pressure p in the die-workpiece interface as a function of the diameter D in the deformation zone with a given constant yield stress Y and diameter D_o in the entry region.

Note: You can answer question (b) above using Eq. 2 even if you could not prove this equation in part (a) of the problem.

5. (15 points) The Figure below indicates a forging of a metal slab from an initial size of 1-in by 1-in by 10-in to a final size of 0.5-in by 2-in by 10-in. This is accomplished using a flat faced drop hammer to supply the necessary force. Sliding friction is assumed with $\mu = 0.1$. For the combination of temperature and strain rate involved, the yield stress of the material is approximately constant, $Y = 2,500$ psi.

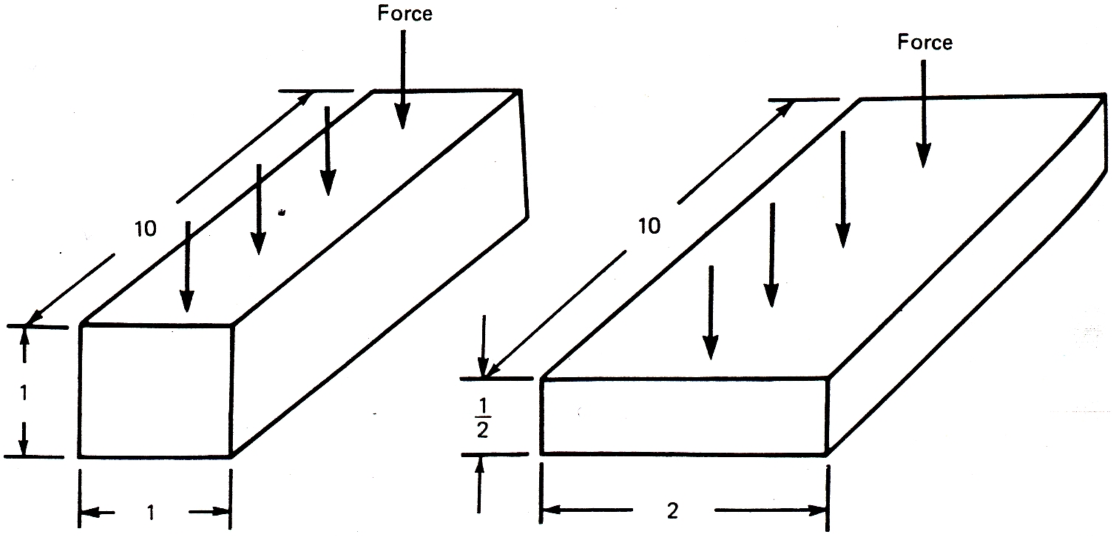

Figure 1: The initial and final geometry in plane strain forging.

(a) (5 points) Find the force required to produce the final thickness.

(b) (10 points) How much work is required to perform the operation?

(Hint: It is given that at a given height h the average pressure in plane strain forging is approximately equal to: $p_{\text{ave}} = \frac{2Y}{\sqrt{3}}[1 + \frac{\mu b}{2h}]$ where the notation used here is standard!)

6. (10 points) A forging process of a rectangular slab was approximated numerous times in class as 'plane strain compression' ($\epsilon_y = 0$, y=width direction). Assume that the axes x, y and z are principal stress/strain axes and that the material obeys a hardening law of the form $\bar{\sigma} = K\,\bar{\epsilon}^n$. The initial dimensions of the workpiece are $h_o \times b_o \times w_o$ and during compression we denote the dimensions with $h \times b \times w$ (w=width, h=height).

(a) (3 points) The workpiece is reduced to a height of $h = \frac{h_o}{2}$. Calculate the effective strain $\bar{\epsilon}$ at this reduction.

(b) (3 points) Calculate the yield strength of the workpiece after the reduction in part (a) above.

(c) (4 points) A cylindrical specimen of diameter d_o is machined from the forged workpiece. At what load (force) would this specimen yield if it is loaded in uniaxial tension?

7. (10 points) Consider plane strain ($\epsilon_y = 0$) bending of a thin sheet (Let z=thickness axis, y=width axis and x=main stretch axis – All three axes are principal stress axes).

   - (5 points) In terms of the uniaxial yield stress Y, compute the critical value σ_o of σ_x for which yielding occurs for the above stress/strain conditions (use the von-Mises yield criterion). Recall that in class we called σ_o the 'effective plane strain yield stress'.
   - (5 points) Find the tool radius necessary to produce a final bend radius of 10-in in a part made from a steel of thickness 0.03-in. Assume a yield stress Y=$38,971$ psi, Young's modulus of $E = 30 \times 10^6$ psi and Poissons ratio of $\nu = 0.33$.

     Hint: You can use without proof the formula $\frac{1}{r} - \frac{1}{r'} = \frac{3\sigma_o}{tE'}$, where E' is the 'effective plane strain elastic modulus' and the other parameters are as discussed in class.

8. (10 points) A 0.097% wt-percent hypoeutectoid plain carbon steel is slow-cooled from the austenitic region to room temperature (see Fig. 2 for the Fe-C phase diagram). Assuming no change in structure on cooling from just below the eutectoid temperature to room temperature, compute the weight percentage of the obtained eutectoid ferrite.

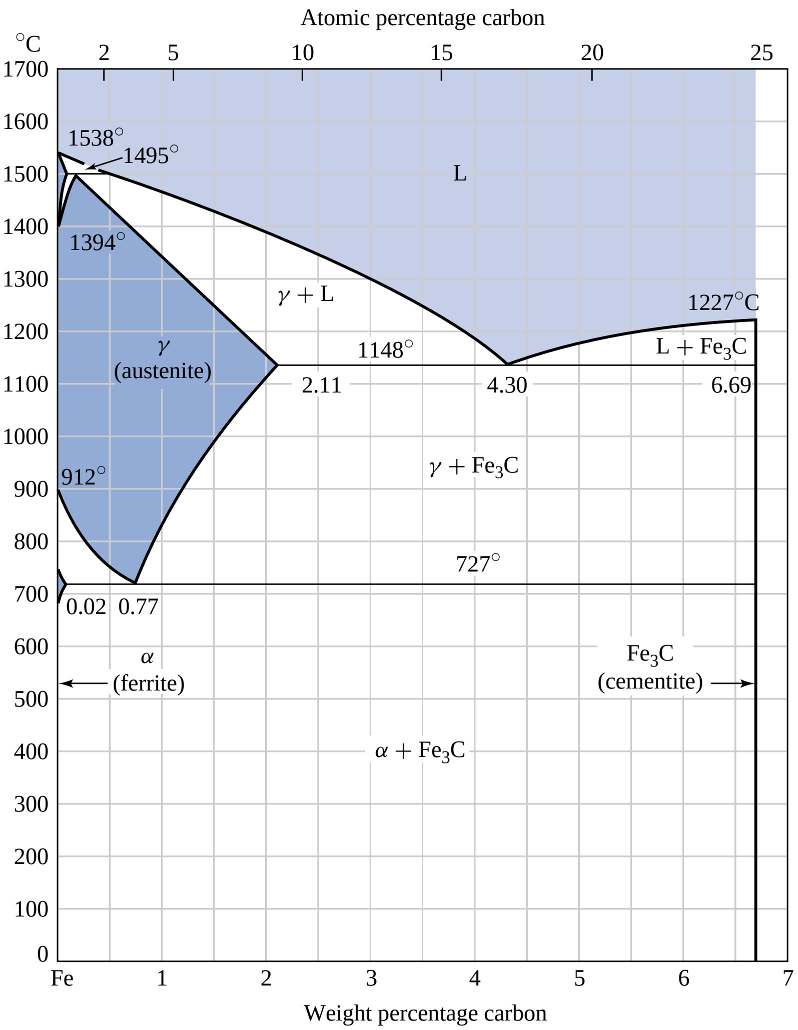

FIGURE 5-26

Figure 2: The Fe-C equilibrium phase diagram.

HAVE A GOOD SUMMER!