Department of Materials Science and Engineering
Massachusetts Institute of Technology
3.14 Physical Metallurgy – Fall 2008

Quiz II

Friday, November 7, 2008

The Rules:

1) No calculators allowed

2) Two hand written 3x5 index cards may be prepared as a crutch—one is the same one you used on the first quiz, the second is new.

3) Complete 4 out of the 5 problems. If you do more than 4 problems, I will grade the first 4 that are not crossed out.

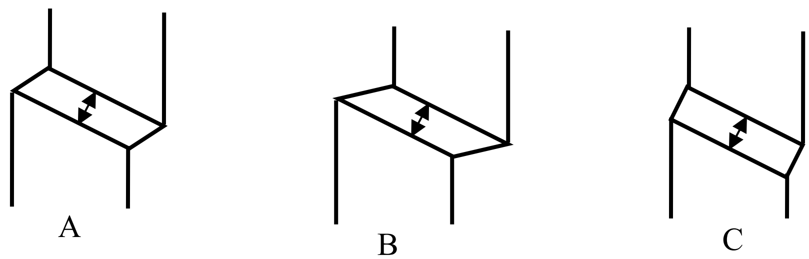
4) Make sure that you READ THE QUESTIONS CAREFULLY

5) Supplementary materials are attached to the end of the test (eqns., etc.)

6) WRITE YOUR NAME HERE:

Problem #1: Fraternal Twins

You have samples of three hexagonal metals, in single crystal form. You load these in COMPRESSION, and they all twin on [1012], exactly as discussed in class. What is more, they each form a twin *of the same width*. In other words, the three twins look like this:



Part A:
Notice that the three twins, although they are the same width, are not identical. Explain what is different. How would this difference appear in the stress-strain curves of the three metals?

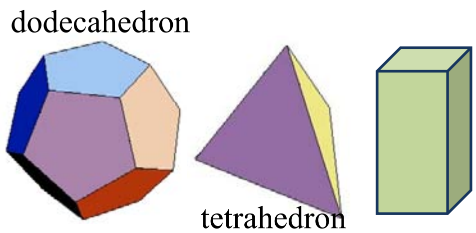
Part B:
The three metals in question are beryllium, zirconium, and magnesium. Using the data attached at the end of the test, decide which of the three samples, A-C, is which metal. Explain.

Problem #2: Science Fiction Solutes

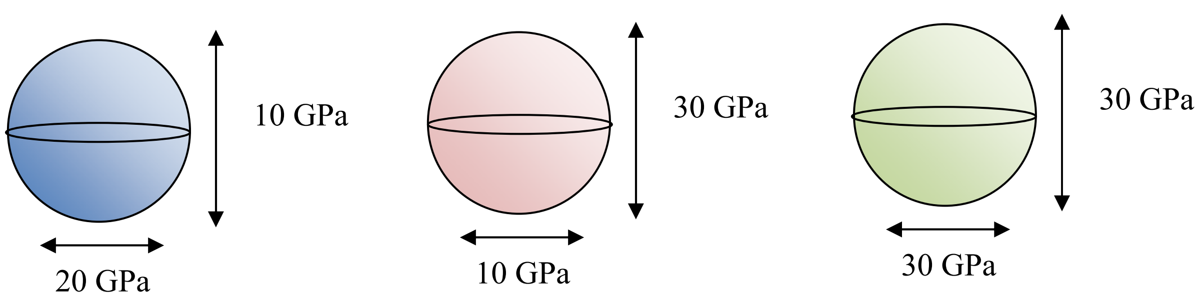
On a far and distant planet, a very advanced species has figured out how to take a metal atom and change its characteristic shape (!).

After being abducted by these aliens and transported to their homeworld, you are asked to consider making new solid-solution strengthened alloys using these fancy solute atoms.

Here are three atoms that the aliens have proposed to you. All other things being equal (i.e., solute concentration, solute atom size), rank these shapes as potential SUBSTITUTIONAL solid solution strengtheners in an FCC metal. Please write some explanatory sentences so I understand your thoughts.



They can also make individual spherical atoms with elastic anisotropy—they are stiffer in one direction than the others (!). Rank the following atoms again for their potential for substitutional solid solution strengthening. The two stiffnesses are shown in each case.

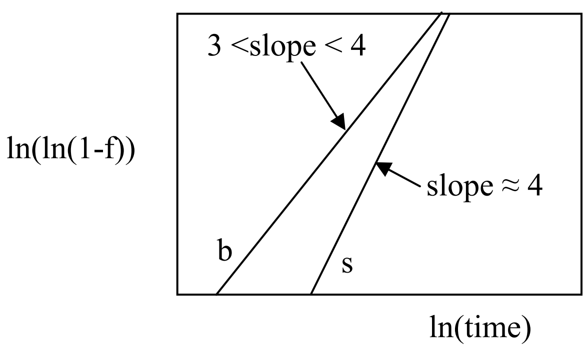


Problem #3: Mono-ReX and Bi-ReX

You have two samples of a pure metal. One is a single crystal, and one is a bicrystal (two grains, one grain boundary, as shown):

Single crystal Bicrystal

Now, you take these two samples and give them exactly the same treatment. First you deform them to the same strain level, and then you heat them to the same temperature. They both recrystallize, and as they do, you measure the fraction recrystallized, f. You plot the data in a very smart way:



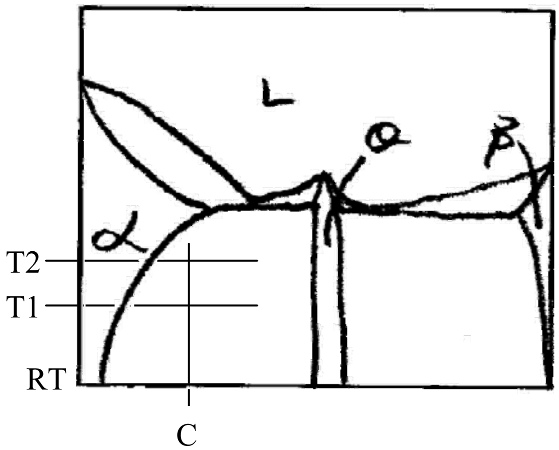
The two lines here are the results for the two samples, “s”ingle crystal and “b”icrystal.

Part A:
Explain why the bicrystal has faster ReX kinetics.

Part B:
Explain why the slopes of the two data sets are different.

Part C:
In light of these data and your answers to Parts A and B, draw a picture of what you think the recrystallized structure might look like.

Problem 4: A Rather Messy Annealing Problem in Which Precipitates are Embroiled



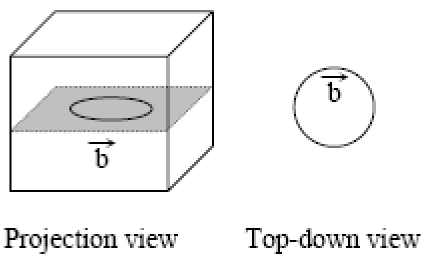
Here is the phase diagram of a hypothetical alloy. It is precipitation strengthened in the normal way, at the composition "C": first, it was solutionized, and then precipitation aging was carried out at T_1.

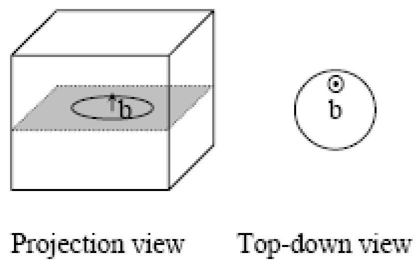
Consider what would happen if this alloy were worked and annealed. At room temperature (RT), the alloy is strained. Then annealing is carried out at T_2.

List at least three important microstructure changes that happen during annealing, and explain whether each of these would promote strengthening or weakening of the alloy.

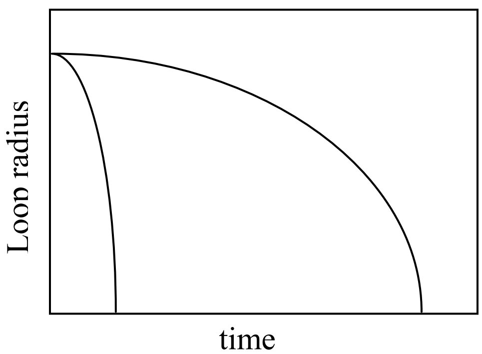
Problem 5: Feelin' Loopy

Here are two dislocation loops, in the same material, but far separated from each other.





At room temperature, these loops are present and do not evolve over an appreciable time scale. However, upon heating, both loops shrink. At a temperature T, the radius declines as shown:



Part A:
Explain why these curves are concave-down. That is, explain why the shrinkage accelerates as the loops get smaller.

Part B:
Match each of the two loops above with one kinetic curve, and explain why the one loop shrinks faster than the other.

Helpful (?) Bonus Information

Stress field around an edge dislocation:

$$\sigma_{xx} = -\frac{\mu b}{2\pi(1-\nu)} \frac{y(3x^2 + y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{yy} = \frac{\mu b}{2\pi(1-\nu)} \frac{y(x^2 - y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{xy} = \frac{\mu b}{2\pi(1-\nu)} \frac{x(x^2 - y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{zz} = \nu(\sigma_{xx} + \sigma_{yy})$$

all other σ components are = 0.

Stress field around a screw dislocation:

$$\sigma_{rz} = \frac{\mu b}{2\pi r}$$

all other σ components are = 0, and note that $r^2 = x^2+y^2$

Forces between dislocations:
Parallel edge:

$$F_y = \frac{\mu b^2}{2\pi(1-\nu)} \frac{y(3x^2 + y^2)}{(x^2 + y^2)^2}$$

$$F_x = \frac{\mu b^2}{2\pi(1-\nu)} \frac{x(x^2 - y^2)}{(x^2 + y^2)^2}$$

Parallel screw:

$$F_r = \frac{\mu b^2}{2\pi r}$$

Please see Appendix B in Reed-Hill, Robert E., and Reza Abbaschian. *Physical Metallurgy Principles.* Boston, MA: PWS Publishing, 1994.

JMAK Equation:

$f = 1\text{-}\exp(-kv^d t^{d+1})$

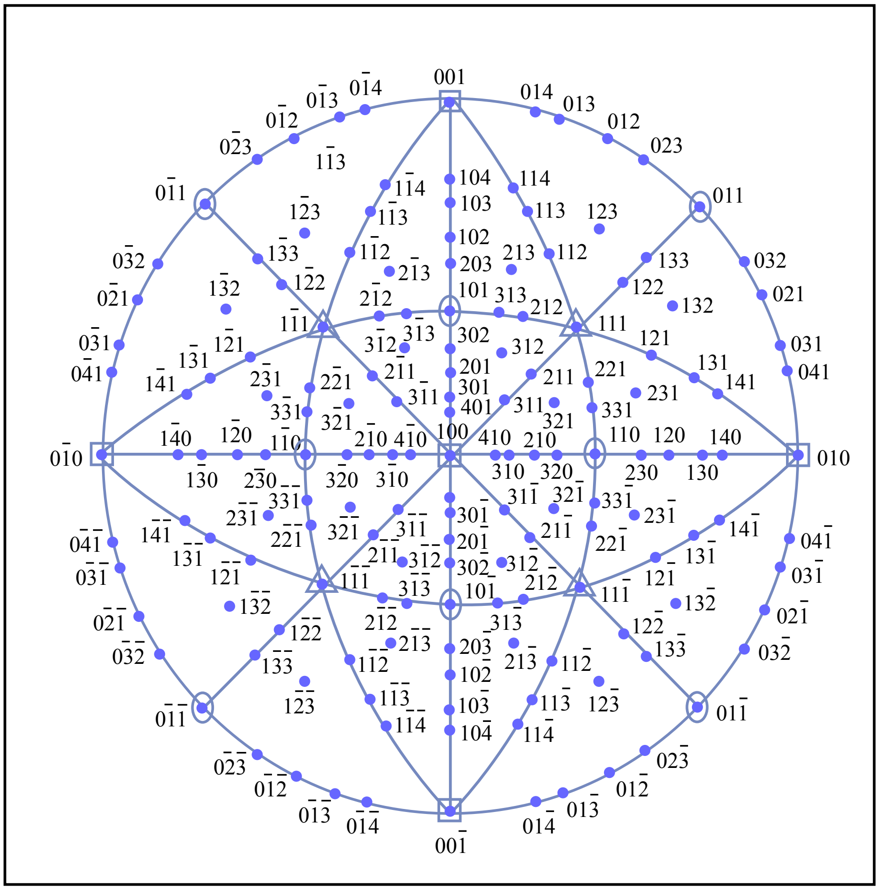


Figure by MIT OpenCourseWare.

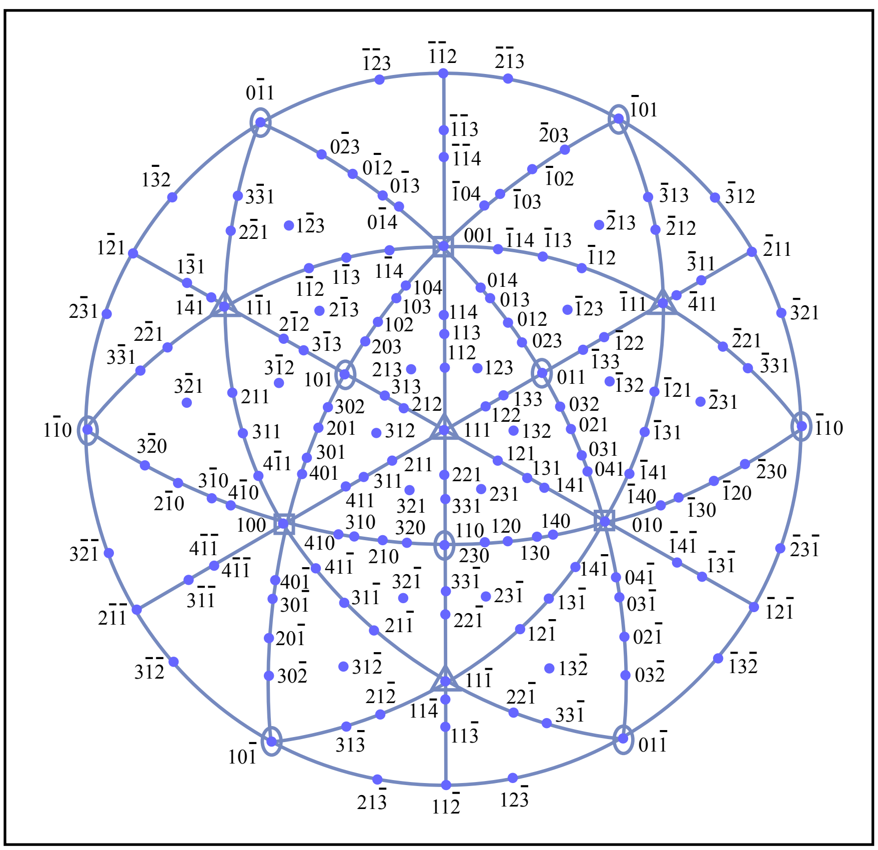


Figure by MIT OpenCourseWare.