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

Quiz III

Friday, December 5, 2008

The Rules:

1) No calculators allowed

2) One hand written 3x5 index card may be prepared as a crutch, and you may also have the cards you made for the last two quizzes.

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:

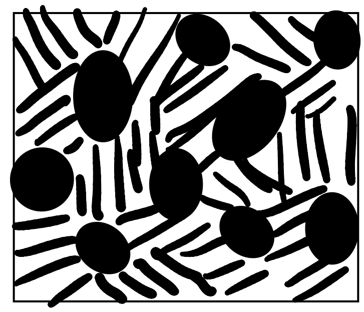
Problem #1: Hypoeutectic Proeutectic Meets Hypereutectoid Proeutectoid

In class we discussed the processing of steel by heat treatment, i.e., by austenitizing and subsequent thermal processing. What if, instead, we consider structure evolution during casting?

Part A:
A high carbon steel with 1.2% C is cast in the liquid state and allowed to cool (you may assume slowly) to room temperature. Describe the microstructure that would evolve during this process, by drawing a few successive pictures of the structure at key points in time. Some boxes are provided- use as many as you need, and add more if you like. Please label everything carefully, including phases, structures, and temperatures.

Part B:
Repeat this problem for an even higher carbon content, in the range typical of cast iron: 3% C.

Problem #2: Load Transfer Transfer



Here's a structure formed by slow cooling in a eutectic A-B system, in which

- the two components have zero solubility in one another,
- there are no intermetallics, and
- the eutectic is at 25% of component B.

Part A:

Draw a phase diagram for this system, consistent with all the information I've given you. Locate and label a composition that would be consistent with the microstructure above. Offer a little explanation of how you picked the composition.

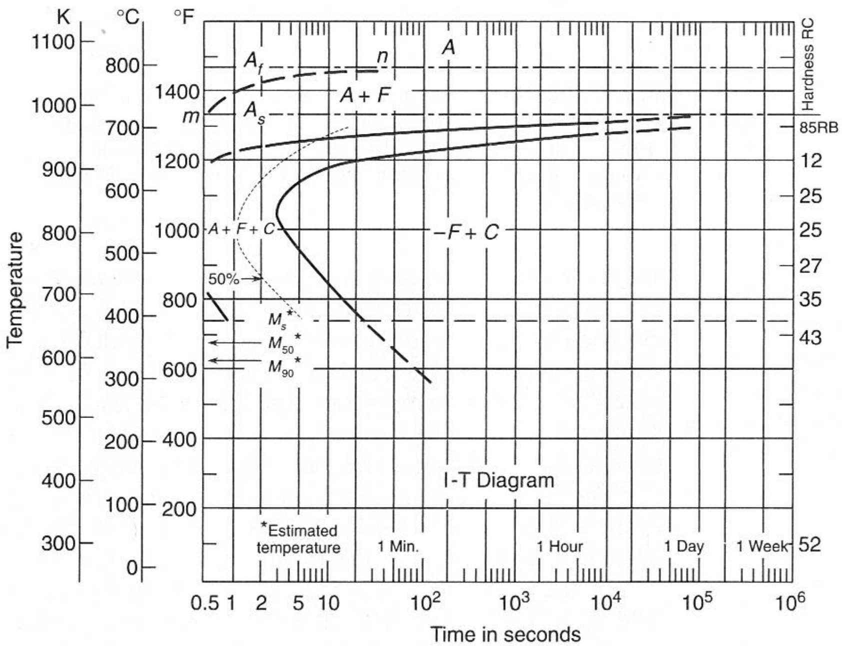
Part B:

Tell me the volume fraction of the three structural features in this structure: (1) the larger blobs of proeutectic phase, and (2,3) the two phases of the eutectic structure. Make sure these add to 1.

Part C:

Make a prediction of the modulus of this material, in terms of the two phase moduli. For this problem, I am not interested in knowing the upper and lower bounds. Instead, I want one model that will give a more accurate prediction than simply using the upper and lower bounds. This model should account for all the structural features of the material. (Note- you have three volume fractions from Part B—what I am asking here is what to do with three volume fractions instead of two, for this microstructure…)

Problem #3: Time-Temperature-Transformation-Trouble



The TTT diagram at the left is for a hypereutectoid steel.

It is austenitized, and then subjected to the following interesting thermal schedule.

Note: You may need the supplementary information at the end of the test to answer these questions.

Part A:

First, the sample is quickly cooled to 750° C and held for one hour. What does the microstructure look like at this point? Draw a picture, and give the volume fraction of the phases present. Explain how you arrived at your answer.

Part B:

After the treatment from Part A, the sample is suddenly quenched. Again, indicate what the microstructure looks like, and give the volume fraction of phases you expect in this sample.

Problem #4: A Precipitation Strengthening Question in which the Solubility Limit is Breached

In the Al-Cu system,
consider an alloy
containing 10 at% Mg.

The alloy is slowly cooled
after casting.

Al-Cu phase diagram removed due to copyright restrictions.

Part A:

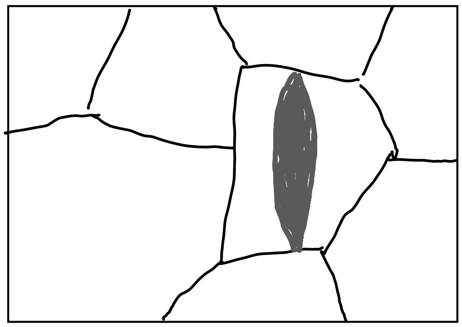
In normal precipitation strengthening, we begin by solutionizing. What happens if we conduct a "normal" solution treatment on this abnormal alloy? If we heat to 545° C and wait for an hour, then quench, what is the result?

Part B:

Again, in "normal" precipitation strengthening, we would re-heat the solutionized and quenched metal to age it. What happens in this alloy if, after the treatment in Part A above, we now reheat to 350° C and age the alloy? Will there be any strengthening? Explain why or why not, and indicate what the microstructure will look like.

Problem #5: Mystery Lenticular-Looking-Thing

You are looking at a microstructure of a metal under an optical microscope, and you see this:



In the center of one grain, you see this weird lenticular-looking-thing. Hmm. What is that lenticular-looking-thing? From your 3.14 training, you can think of three possibilities: (1) a twin, (2) a lath of Martensite, or (3) a lath of Bainite.

Briefly describe a simple series of tests that you could do to unambiguously discern whether it is option (1), (2), or (3). (You need not know specific analysis methods—you can simply say "measure the _____" where the blank is a material property, etc.).

Helpful (?) Bonus Information

Stress field around an edge dislocation:

$$\sigma_{xx} \propto \frac{y(3x^2 + y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{yy} \propto \frac{y(x^2 - y^2)}{(x^2 + y^2)^2}$$

$$\sigma_{xy} \propto \frac{x(x^2 - y^2)}{(x^2 + y^2)^2}$$

all other σ components are = 0.

Stress field around a screw dislocation:

$$\sigma_{rz} \propto \frac{1}{r}$$

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:

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

JMAK Equation:

$f = 1-\exp(-k\nu^d t^{d+1})$

Orowan bowing strength:

$\Delta\tau = \mu b v_f / r$

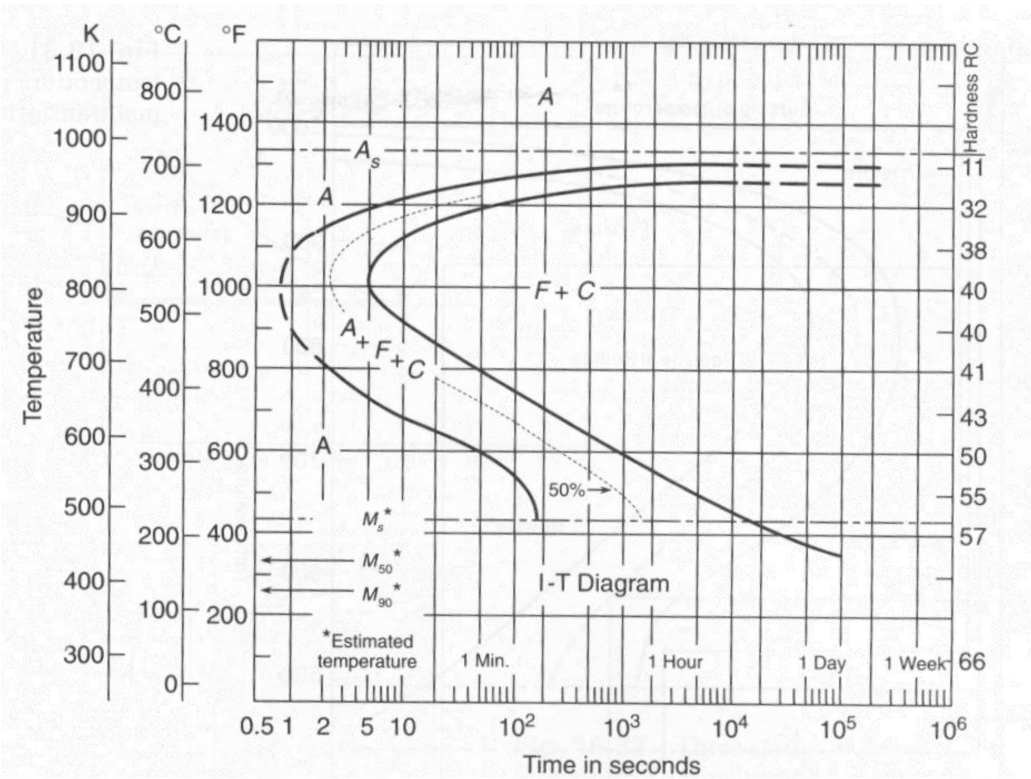
Strength gain from APB creation in a precipitate:

$\Delta\tau = (\pi\gamma_{APB} v_f)/(2b)$

Strength gain from surface area creation; precipitation strengthening:

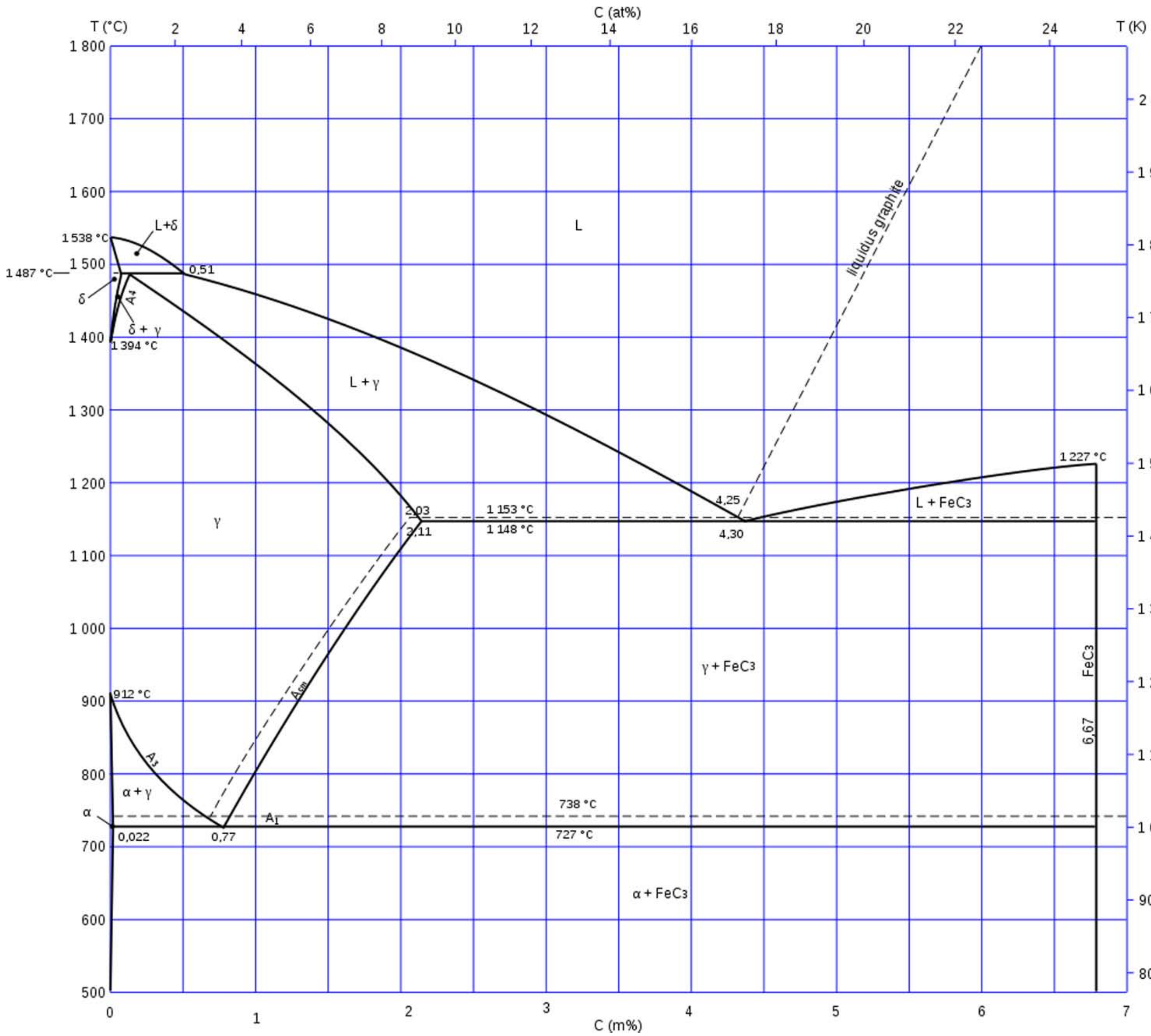
$\Delta\tau = (\pi\gamma_s v_f)/(b)$

Isostrain analysis: $E_c = E_1 v_1 + E_2 v_2$



TTT diagram for eutectoid steel.

Please see Fig. 19.17 in Reed-Hill, Robert E., and Reza Abbaschian. *Physical Metallurgy Principles*. Boston, MA: PWS Publishing, 1994.



Fe-C diagram with Fe_3C at 6.7% C. Image from Wikimedia Commons, http://commons.wikimedia.org

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