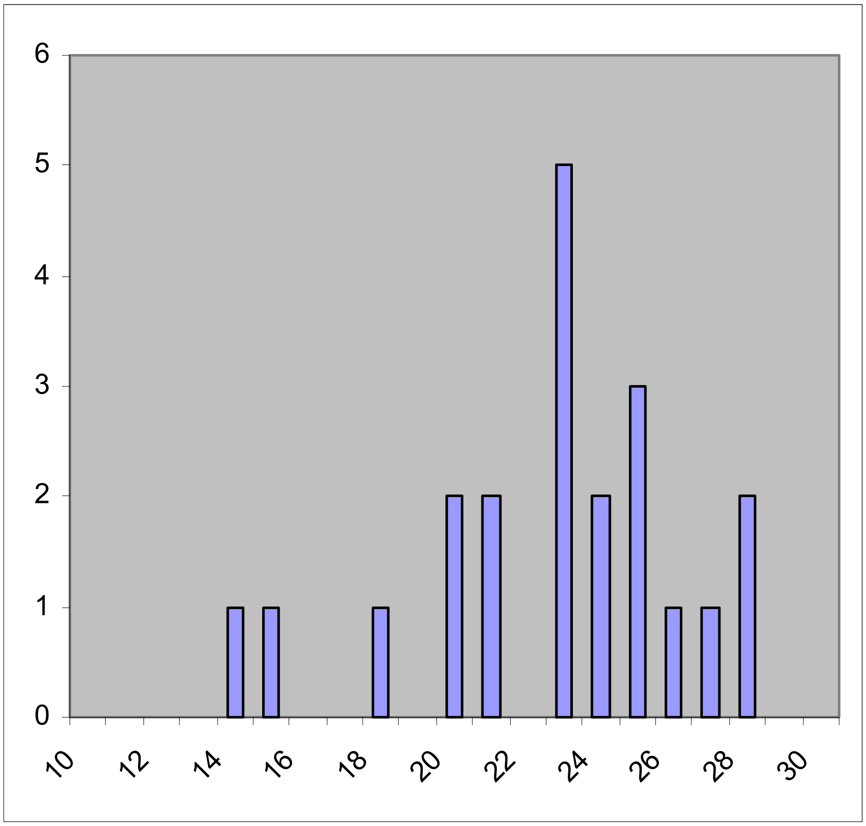
Department of Materials Science and Engineering
Massachusetts Institute of Technology
3.14 Physical Metallurgy – Fall 2003

Exam II



Class average: 22.4 out of 30

Problem #1: Steel Microstructures

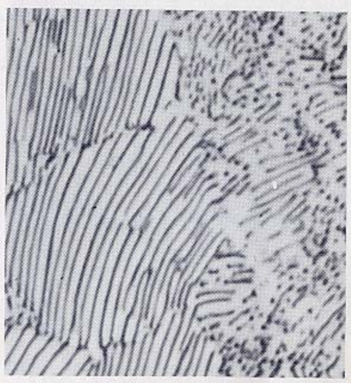
Oh no! You dropped your steel specimens and can't remember which is which. You remember that the three steel grades are 1030, 1045, and 1080, but that's all.

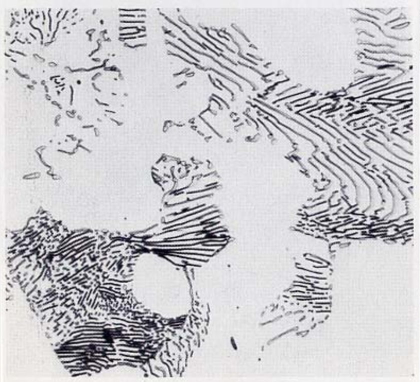
With nothing at your disposal but optical metallography facilities and furnaces (and the Fe-C phase diagram attached to the test), you quickly devise a scheme to save your job. Vowing to carefully label the specimens next time, you put all three in the oven to austenitize them for an hour.

Part A:

What temperatures and times are acceptable for the austenitization and why?

After austenitizing you turn off the furnace and allow the specimens to cool very slowly. You obtain the following microstructures:


(a)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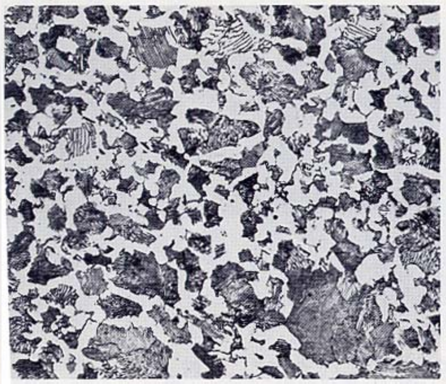

(c)

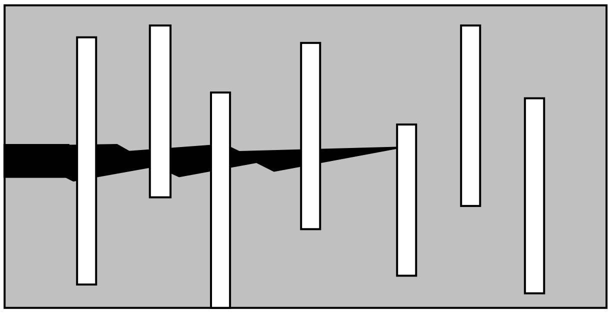
Part B:

Identify which steel is which on the basis of the microstructures, and write the logic of your thought process that led to your conclusions.

Problem #2: Fracture Toughness and Fatigue in Ceramics

Part A:

In ceramics, there is basically no plastic deformation around crack tips, so toughness is usually rather low because surface creation is the only means of dissipating strain energy. One approach to fix this problem is to create ceramic-matrix composites with reinforcements that can bridge the cracks:



Describe how this approach could increase the toughness of ceramics.

Part B:

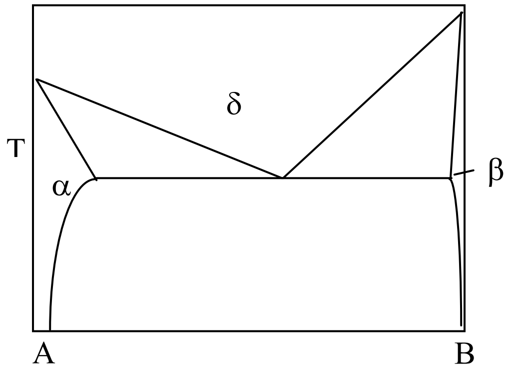
Ceramic materials usually don't exhibit fatigue behavior like metals, where cracks propagate progressively in short bursts across the material. On the basis of what you know about the mechanism of fatigue crack growth in metals, explain why fatigue is unusual in ceramics.

Part C:

By making ceramic composites as in part A, we make ceramics tougher (like metals). By the same token, can we then also expect to see fatigue behavior (like metals) in these composites? Why or why not?

Problem 3: Microstructure Design

Down the road, as a wizened graduate student, you are helping a naïve undergrad to improve the properties of a binary alloy system with the following (partial) phase diagram:



Your undergrad has produced a whole host of fascinating microstructures through compositional control and ***slow cooling*** of the alloy, trying to generate the highest strength possible in this system. He has been focusing on the high-B side of the diagram, because β is the higher strength phase.

Part A:

Your young assistant is very disappointed that despite trying a number of compositions, he has not made an alloy of higher strength than the pure component B (β phase). Explain why not.

Part B:

Lay out a new strategy to make a high strength alloy in this system. Specify the composition and processing you would use; add labels to the diagram above if necessary.

Problem #4: Structure and Strength of Martensite

Through alloying additions, you have created a new Fe-C-based alloy never before seen. The alloy can be quenched to a Martensitic state quite readily, but you are shocked to discover that in this state the alloy is rather weak. Upon further examination, you find that this is no ordinary BCT Martensite, but rather has a nearly ideal FCC structure.

Describe the strengthening mechanisms that normally operate in BCT Fe-C Martensite, and on this basis, explain why the new FCC Martensite is not so strong.

Problem #5: Structural Evolution and Strengthening Mechanisms

You are working with a multi-component alloy that derives strength from three sources:

1. a fine grain size
2. solid solution strengthening from a fine interstitial
3. a precipitated dispersion of ~25 nm intermetallic particles

Your specimen was just deformed past the upper yield point, so that the dislocations have broken away from their solute atmospheres.

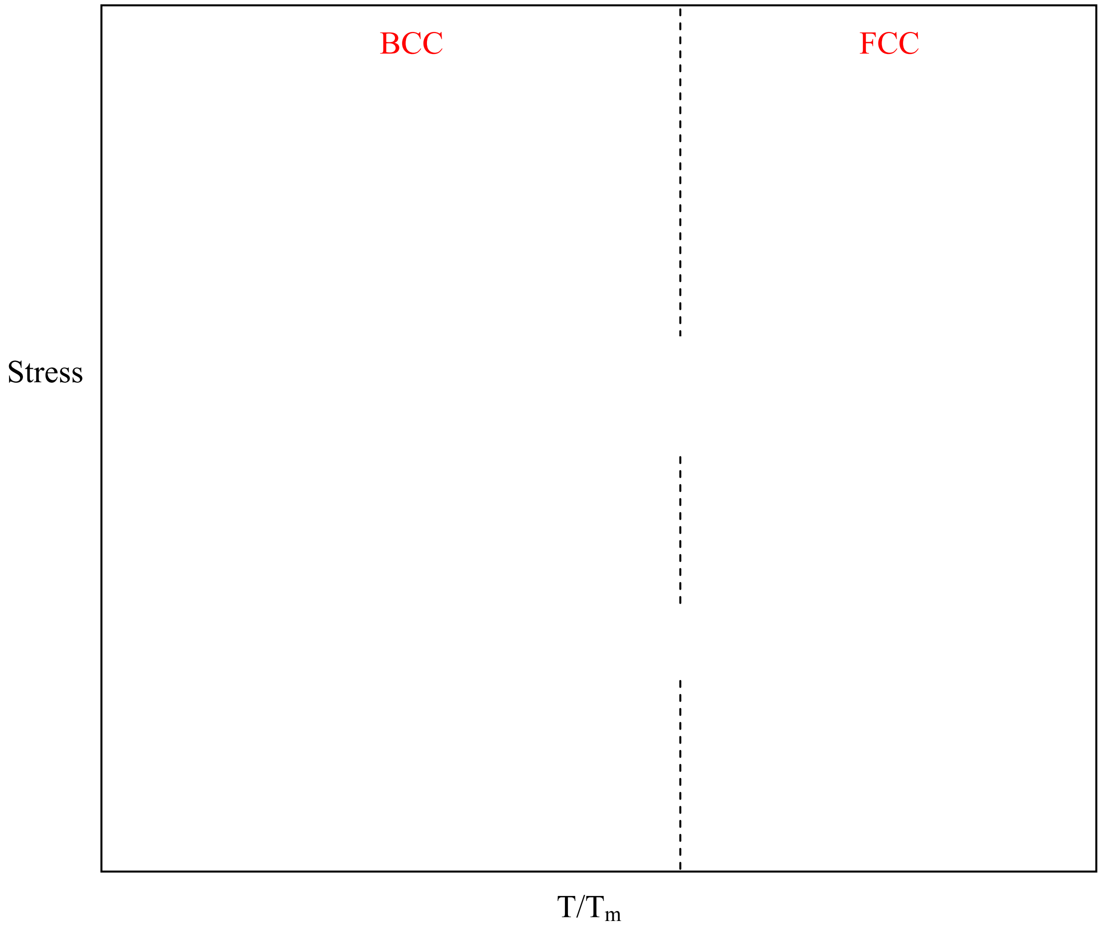
Describe the three major processes of structural evolution that take place in the alloy *when you anneal it*, and explain how these changes affect the strengthening gained from (1), (2), and (3) above. Include in your description the time laws of each process.

(Continued on next page.)

Problem #6: Fracture Mechanisms

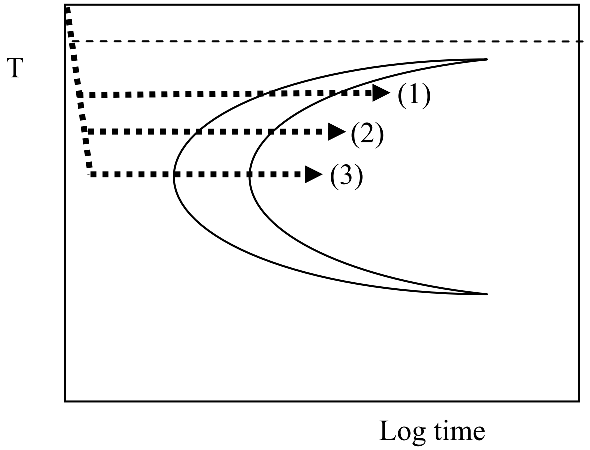
Pure iron undergoes a phase transformation from BCC to FCC at ~910° C, which is about 65% of the melting temperature (1183/1811 in Kelvin). The phase transformation introduces discontinuities in the properties of iron, for example, in the deformation and fracture mechanisms.

Using your knowledge of fracture mechanisms in polycrystalline FCC and BCC metals, draw a schematic fracture mechanism map for pure iron, keeping in mind the phase transformation (which occurs at the dashed line)…

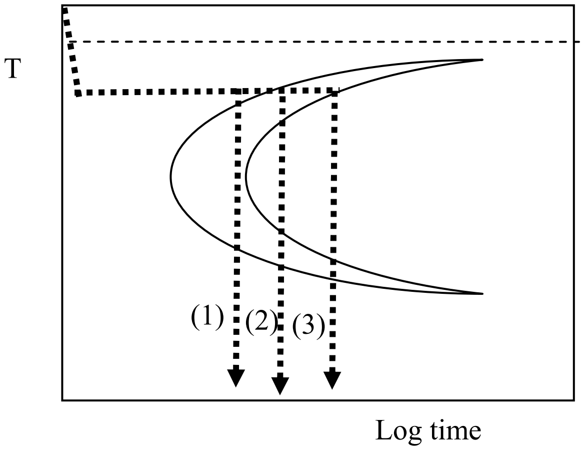


Problem #7: TTT Diagrams and Strengthening

For a eutectoid composition steel, the TTT diagram is shown schematically below (reproduced twice for clarity).



(A)



(B)

Part A:

Refer to diagram A above, and consider the three temperature histories shown. If you are trying to design a steel that best takes advantage of dislocation interactions with a second phase (i.e., strength controlled by bowing), which path is best and why?

Part B:

Refer to diagram B above, and consider the three temperature histories shown. If you are trying to produce a microstructure that derives strength through load transfer *without being brittle*, which path is best and why?