Midterm 2

November 13, 2012

Name: Solutions

Prob. #1  25
Prob. #2  25
Prob. #3a  10

Prob. #3b  10
Prob. #3c  10
Prob. #4  15
Prob. #5  15

Total  105

Instructions: Answer all questions on the examination sheets. (use backs if needed). If there is a fact you cannot recall, ask and I will write it on the board for everyone.

As always, this exam includes 10 T/F and 10 fill-in-the-blank. You have 75 minutes, the full class time + 5 minutes. Exam over at 10:55+5 = 11:00 AM

Calculators Allowed but No Books & No Reference Sheet. Time: 80 minutes.
1. (25 pts) Your boss is all excited about saving money on your company’s high performance 6061-T6 aluminum wind turbine mounts by replacing the bolted structures with a welding method at the base of the structure and “asks” you to check into it by email. Please compose the email message you send back. A complete answer will describe how Alloy 6061-T6 gets its strength, in detail, in terms of the metallurgical processing and the particles that produce resistance to deformation, then go on to tell what happens when this microstructure is welded.

The problem with welding precipitation hardened aluminum is that welding (local melting + freezing) residue heat in the alloy but does not have a quench, so in effect it erases the precipitation strengthening — now to complete the email.

To: bosse.mycompany.com

While welding might be possible on some alloys, it is not recommended for 6061 unless we are willing now able to be heat treat the entire part, a situation not practical for our wind turbine base structures.

This is because 6061-T6 gets its strength from precipitation hardening. The aluminum company heats the metal to a high temperature to dissolve all the alloying elements in a single phase solid solution. Then it uses a water spray quench to cool the material, solidifying in a low temperature so fast that phase separation have time to occur. This produces a large undercooling and a large AG (free energy at transformation) that promotes nucleation of very fine precipitates. At first, just alloy rich region known as GP zone (diff alloy types like 5083-T6024 have diff type but basically all similar). Then initially coherent precipitation ( ) with their strain fields result in micro shrink, increasing as they grow and with extreme times, the particles lose coherency and are no longer able to provide strengthening.

Over
Prob. #1

At this point, the particles have lost coherency and may begin to coarsen with time by surface energy. A typical aging plot looks like this packaged

![Aging Plot Diagram]

Hardness (a surrogate for Tensile Strength) vs. Log (Aging Time)

Often, the aging is accelerated by using an artificial age, not in age at elevated temperature noted than a natural age at Room Temperature.

It takes years 10-20 for an aluminum alloy to overage at Room, so we need not worry.

Now, when we weld it, many parts near the weld get so hot they severely overage and the metal adjacent to the weld is resolidified but not quenched. Thus, they are changed to extremely soft annealed condition, too weak for our product.

If we want to use welding, we will have to switch to a non-precipitation hardened alloy.

I recommend against substituting welding for bolting in this application.
2. (25 pts) It has been discovered that heating a martensitic steel just below its eutectoid temperature for 24 hours causes the excess carbon in to agglomerate, forming spherical particles of Fe₃C. These relatively coarse particles leave the surrounding ferrite matrix soft and therefore easy to deform and machine. This microstructure is called spheroidite and the process is called spheroidization.

You have a eutectoid steel with a fine pearlitic microstructure that is too hard to machine into parts. Write an essay to describe how to spheroidize the starting material, then, once you have machined the softened raw material into parts, continue the essay to describe how to change the microstructure back to fine pearlite. Assume you have all the equipment you need such as lead baths, quench tanks, etc. and that you will use isothermal processing on this first run just to make sure you get what you expect.

A complete answer to this question must include sketches of the isothermal TTT curves showing the heat treatment paths. Be sure to label all the regions of the IT curve and put numerical values on the axis labels of your schematic. The nose is at 2 seconds, Ms is 200°C and M90 is 100°C.

First, we need to make martensite. We heat to a 50°C above the eutectoid temp of 727°C, hold for 1 hour to make sure we are fully austenitized. Then quench in cold water, first though T, M7 etc. Note the nose in the TTT curve, we may have to nudge that we have cooled guide enough or use milder quench such as Bride. Then we put it back in the furnace and heat to 720°C (a little below 727°C wait 24 hrs and cool at any rate (we need to quench) this produces the spheroidite.

Now we machine the parts—easy to cut them, shape etc.

Now for the heat treatment back to fine pearlite. We austenitize again at ~ 777°C (50°C below the T, M7) then use lead bath to instantly cool to fine pearlite (middle of the nose of TTT curve as shown next page.
Prob. #2

\[
\begin{align*}
\text{Equim. Temp.} & \quad 172^\circ C \\
\text{Surf. Temp.} & \quad 580^\circ C \\
20^\circ C & \sec \\
100^\circ C & \text{Ms} \\
\text{Log Time:} & \quad 1/2 \text{hr.}
\end{align*}
\]

SO we hold at \( \approx 500^\circ C \pm 50^\circ C \) to get a
diffusion controlled grain growth forming
fine pearlite. Etch here due to large \( 227^\circ C \) unduly
we can identify the microstructure in a sample part
by nondestructively cross-sectioning, polishing, etching.
The hold in \( \approx 2 \) hrs, details depending on obtaining
the exact transformation finish time (95%) from notation.

Now the part is fine pearlite. The size scales the
pearlite can be controlled by the specific temp we use.

IT would be advisable to coat a protective atmosphere
of carbon rich/mo oxygen gas to keep carbon
from changing concentrations due to chemical
on the surface.
3a. (10 pts) Sketch a typical eutectic phase diagram with 100%A at the left, 100%B at the right, labeling the axes. The eutectic tie line starts at 10w%B and ends at 20w%A at a temperature of 300°C. The melting point of A is 400°C and the melting point of B is 500°C. The eutectic invariant is at 60w%B.

3b. (10 pts) An AB alloy with 30w%B is heated to 500°C and slowly cooled until it has fully solidified, then it is quenched to room temperature. How much proeutectic α phase and how much proeutectic β phase will be formed.

3c. (10 pts) How much β phase is in the alloy when it is at room temperature.
4. (10 pts (1 point each)) Answer the following short answer questions with T or F.

a. **T** Binary intermetallics typically have integer ratios between atomic fractions of the two constituent elements.

b. **F** Solution hardening refers to the strength increase caused by precipitate particles formed from a solid solution.

c. **F** Fick’s first law says that the flux is inversely proportional to the concentration gradient.

d. **F** People weld aluminum all the time so its safe to assume that this does not compromise the mechanical properties.

e. **T** In quantitative metallography, one can use a circle to measure the linear intercept instead of a straight line.

f. **F** When determining the case depth for case hardening, \( x = \sqrt{2D_t} \) is a handy rule of thumb.

g. **T** Excessive undercooling leads to a large energy driving a phase transformation so that the formation of very fine size scales of the microstructure is an expected outcome.

h. **T** Diffusive motion of atoms occurs in a solid even if there is only one type of atom in the system.

i. **F** Grain Growth is a classic example of a nucleation and growth phase transformation.

j. **F** Hypereutectoid steel transforms to Fe3C and proeutectoid ferrite.
5. (15 pts (1.5 points each lettered question)) Fill in the blank or complete the phrase with one or more words to make a true statement.

a. A vacancy or missing atom, is an example of a \( \text{point} \) defect.

b. Dislocations are examples of \( \text{line} \) defects while grain boundaries, stacking faults, and free surfaces are examples of \( \text{plane or surface} \) defects.

c. The Hirth-Pound model of a free surfaces helps us understand catalysis because it shows the surfaces are comprised of \( \text{edge} \) and \( \text{step} \) (or \( \text{slip} \)) which serve as preferred sites for atoms loosely adhering to the surface to find one another and react.

d. The concentration of vacancies in a metal near its melting point is always about \( \frac{1}{4} \) \( \text{vac} \) \( \text{site} \). Make sure to give units with the numerical answer.

e. The hardenability of steel is characterized by the \( \text{Jominy END QUADRANT test} \).

f. Martensite and Bainite are similar because \( \text{transformation} \). On the other hand, Pearlite and Bainite are similar because \( \text{diffusion controlled} \).

g. Using a gas with a high carbon concentration and no oxygen allows us to change the chemistry of a steel. The name for this process is \( \text{case carburizing} \) when only a thin surface layer is affected.

h. The Gibbs phase rule is often simplified to exclude pressure as a variable. When this is done the Gibbs phase rule is \( F = \text{ Freedom} - \# \text{ phases} + \# \text{ components} \). (give equation)

i. The distinction between globular, rod-like, and plate-like eutectic transformation products is a result of differences in the \( \text{structure} \) energy.

j. To obtain coarse pearlite during isothermal transformation one needs to \( \text{transform just below eutectoid temp and wait} \). (Keep temp high for transformation)