LAB IV

Effects of Heat Treatment on Steel, Aluminum and Brass Alloys - Microstructure and Properties

PRE LAB PREPARATION (required!)

1. Using the ASM metal handbooks or other resources find and print/copy the following or as close as you can get. For example 4140 for 4340, if 4340 not available. Included in this lab are several pages from ASM handbooks that may be helpful.
   a. The chemical composition ranges for Steel 4340, 1018 (A36), Aluminum alloy 2024 and 70-30 (260) brass
   b. Microstructures of 4340 and 1018 (A36) steel in the normalized, quenched and tempered conditions
   c. Microstructure of aluminum alloy 2024 in the slow cooled, solutionized & and solutionized and aged conditions
   d. Phase diagrams for the alloys systems of interest.
   e. Time-Temperature-Transformation diagrams for each alloy, if possible. If not try to find heat treatment information for each alloy, e.g. hardness vs. time, etc.

2. In terms of heat treatment and the development of microstructure, what are two major limitations of the iron-iron carbide phase diagram?

3. Consider the Iron-Carbon Phase Diagram shown in your textbook. For steel alloys 1018 and 4340 which have been slowly cooled from the austenite region (1100°C) to room temperature, calculate the relative amounts and compositions of the phases present at room temperature. Draw the microstructure, which would result in each case.

4. What is the minimum temperature (for each alloy) to heat Steel 4340, 1018 (A36), Al 2024 and 70-30 (260) brass in order to form a single phase material?

5. Please answer the following questions using the TTT diagrams and phase diagrams of alloys: Steel 4340, 1018 (A36), Al 2024 and 70-30 (260) brass
   a. Predict what phases will form from the following heat treatments Assume linear cooling rates:
      i. 4340 and 1018 (A36) cooled from 900C to below 500 C in 1 sec and room temp in less than 5 secs
      ii. 4340 and 1018 (A36) cooled from 900C to below 500 C in 20 sec and room temp in 200 secs
      iii. Al 2024 and Brass 70-30 (260) cooled from 550 C to room temp in less than 1 sec
      iv. Al 2024 and brass 70-30 (260) cooled from 550C to room temp in 200 secs.
   b. Why does martensite not appear on the Fe-C phase diagram?

6. What does the “T#” signify after Al2024-TO, Al2024-T3, Al2024-T6?
**Purpose:**

- Understand the effect of cooling rates and reheating on microstructure and properties of steel, aluminum and brass alloys.
- To observe the heat treatment process for a 4340 and a 1018 (A36) steel sample and effect on properties.
- To observe the heat treatment process for a 2024 aluminum sample and effect on properties.
- To observe the effect of heat treatment on 260 Brass sample and effect on properties.
- Relate microstructure to mechanical properties

**Heat treatment**

Each lab group will receive four alloys to test. We will be using 4340 and 1018 steel, 2024 aluminum and 70-30 (260) brass... The steel samples will be austenitized at 900 degrees C for 30 minutes. The aluminum and brass samples will be heated to 550 C for 30 minutes. The samples will then be cooled in two manners. The first will be a slow air- cooling, which should result in a piece approximately in equilibrium. The second piece will be quenched in water resulting in a non-equilibrium sample. A subset of these samples will then be reheated to temperature that will allow limited diffusion for 30 minutes.

**Procedures:**

1. Wrap a piece of wire approximately 6 inches long around all samples. This will be used to place and remove samples from furnaces.
2. Heat the steel samples up to 900 °C in furnace A. Heat the Aluminum and Brass samples to 550 C in furnace B. Allow samples to equilibrate for approximately 30 minutes
3. Cool the samples:
   a. Take the first two samples of EACH alloy and quench them in water. They must be removed from furnace and placed in the water very quickly, approximately 1-2 seconds, so everything has to be ready.
   b. Remove second set of samples of each alloy and place in to bucket of vermiculite (an insulating material to slow cooling rate).
4. Take 1 sample from each alloy and cooling rate and place in Furnace C for steel and Furnace D for Aluminum and Brass samples. Steels will be reheated to 300 C and aluminum and brass to 200 C for 30 minutes.
5. Once the samples are cool they may have to be ground to remove the oxide layer (Steels!!). Do this using the belt sanders with water cooling.

6. Take the hardness measurements using Rockwell C and/or Rockwell B scales. Take at least 3 measurements on each sample and average the value. Be careful not to place indents too close together as it may affect the results.

7. Look at the microstructures of ALL samples at each of the four heat treatments. Polished and etched samples of each type will be provided by the TA's. These samples were polished to a 1 micron finish and then chemically etched to reveal the grain boundaries. View each of the samples, comment on the microstructures in your lab report and include microstructures at all heat treatments in your report. Compare the properties (hardness) of ALL alloys at after all heat treatments and explain in term of the phase transformations, resulting microstructure and easy of dislocation motion.

**Questions:**

1. What is the difference in 4340 steel vs 1018 (A36) steel.
2. Which steel sample was harder, the air-cooled or water quenched? Why was it harder?
3. Which steel alloy was harder? Why was it harder?
4. How did the different cooling rate affect the microstructure of each steel? Do these microstructures agree with what would be predicted from the TTT diagrams?
5. What did reheating do to the steels (4340 and 1018 (A36)) microstructure and properties? Why?

<table>
<thead>
<tr>
<th>Sample 1</th>
<th>Steel 1018 (A36)</th>
<th>Steel 4340</th>
<th>Aluminum 2024</th>
<th>Brass 70-30 (260)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heat to 900 Quench in H₂O</td>
<td>Heat to 900 Quench in H₂O</td>
<td>Heat to 550 C Quench in H₂O</td>
<td>Heat to 550 C Quench in H₂O</td>
</tr>
<tr>
<td>Sample 2</td>
<td>Heat to 900 Quench in H₂O</td>
<td>Heat to 900 Quench in H₂O</td>
<td>Heat to 550 C Quench in H₂O</td>
<td>Heat to 550 C Quench in H₂O</td>
</tr>
<tr>
<td></td>
<td>Reheat at 300 C</td>
<td>Reheat at 300 C</td>
<td>Reheat at 200 C</td>
<td>Reheat at 200 C</td>
</tr>
<tr>
<td>Sample 3</td>
<td>Heat to 900 Cool slowly</td>
<td>Heat to 900 Cool slowly</td>
<td>Heat to 550 Cool slowly</td>
<td>Heat to 550 Cool slowly</td>
</tr>
<tr>
<td>Sample 4</td>
<td>Heat to 900 Cool slowly</td>
<td>Heat to 900 Cool slowly</td>
<td>Heat to 550 Cool slowly</td>
<td>Heat to 550 Cool slowly</td>
</tr>
<tr>
<td></td>
<td>Reheat to 300 C</td>
<td>Reheat to 300 C</td>
<td>Reheat to 200 C</td>
<td>Reheat to 200 C</td>
</tr>
</tbody>
</table>
6. Compare the TTT diagram for 1018 (A36) with that of 4340. What are the major differences? Why does the decomposition of austenite take longer in 4340 than 1018 (A36)?

7. What would be the effect of quenching in oil instead of water?

8. What was the effect of reheating the samples on microstructure and properties?

9. What would happen to the microstructure and hardness if the samples were reheated to 600°C for 30 minutes and then quenched?

10. For aluminum alloys, what do T0, T3 and T6 refer to? Did you treat Al 2024 to any of those conditions?

11. Compare the hardness values you measured for each alloy in each condition with values from the literature. If there are any significant deviations from expected values, provide likely causes for this and how could it be corrected.

**Lab Report**

The lab report should address all the questions above but should not consist only of these questions. Please follow the procedures outlined on the homepage and in the lab. Look under lab handouts and report formats (How to write a lab report) for point distribution and requirements. 

**References:**

6. ASM Metals Handbooks

Type: 1019

Composition: Fe - 0.17% C - 0.92% Mn

Grain size: 0-2

Austenitized at 1316°C (2400°F)
The micrographs on this and the next two pages are of alloy 260 (cartridge brass, 70%) sheet. All specimens received the same preliminary processing: sheet was hot rolled to a thickness of 0.06 in., annealed to a grain size of 0.12 mm, cold rolled 40% to a thickness of 0.039 in., and annealed to a grain size of 0.10 mm. All specimens were etched in a mixture of ammonium hydroxide and hydrogen peroxide of 2.33%.

The micrographs at lower left in each micrograph indicate the orientation of the view with respect to the rolling plane of the sheet.
2031 Heat Treated Aluminum Alloy 2024 Plate and Sheet

2031: "Alloy 2024-T851 plate, 8 in. thick, cold rolled, solution heat treated, stretched and artificially aged. Section was taken in the rolling plane (long transverse) from an area near the surface showing elongated grains."

2032: "Same alloy and condition as for 2031, but a longitudinal section showing the edge view of an area near the surface of the plate. Grains are flattened and elongated in the direction of rolling. See micrograph 2033.

2033: "Same alloy and condition as for 2031, but a short transverse section showing the end view of an area near the surface of the plate. Grains are flattened, but are not as elongated as grains in micrograph 2032."

2034: "Same alloy, condition and orientation as for 2031, but specimen was from the center of the plate thickness, which received less cold working than the surface."

2035: "Same alloy, condition and orientation as for 2034, but specimen was from the center of the plate thickness. There is less flattening and elongation of the grains."

2036: "Same alloy, condition and orientation as for 2034, but specimen was from the center of the plate thickness. Less cold work has resulted in less deformation."

2037: "Alloy 2024-T851 plate, 4 in. thick, hot rolled, solution heat treated, stretched and artificially aged. Fragmented grain structure; one small recrystallized grain. High rolling temperature limited strain and recrystallization."

2038: "Alloy 2024-O plate, 1/4 in. thick, hot rolled and annealed. Longitudinal section. Elongated recrystallized grains and unaerystallized structures resulting from polygonization that occurred during the hot working."

2039: "Alloy 2024-O sheet. Structure consists of light gray particles of intermetallic (Cu-Pb-Mn)Al and black particles of unalloyed CuMgAl, and fine particles of CuAl that precipitated during annealing."
Structures in 1025, 1030 and 10B35 Steels

215 1025 steel that was normalized by austenitizing at 2000 F (1093 C) and air cooling. Coarse-grain structure consisting of pearlite (black constituent) in a matrix of ferrite (white constituent). See micrograph 216.

216 Same as 215 except the steel was normalized by austenitizing at 1700 F (927 C) and air cooling. The lower austenitizing temperature is responsible for the finer grain size of the normalized steel.

217 1030 steel austenitized for 1 hr, then 40 min, held at 1300 isothermal transformation. Ferrite and bainite.

218 1030 steel austenitized at 1475 F (802 C) for 45 min, held at 1000 F (704 C) for 15 min, and reheated to 1200 F (649 C) and held 10 hr. Partly spheroidized pearlite in a ferrite matrix.

219 10B35 steel austenitized at 1560 F (849 C) for 1 hr, quenched in still water, tempered at 500 F (260 C) 1 hr. Ferrite (small, white areas) and lower bainite (dark areas) in a matrix of tempered martensite.

220 10B35 steel as 219, but quenched and tempered at 600 F (316 C) for 1 hr. Temperate and bainite. Structure.

221 10B35 steel austenitized at 1560 F (849 C) for 1 hr, water quenched, tempered at 450 F (232 C) 1 hr. Core is tempered martensite, surface of specimen (ferrite) is severely decarburized (white area near top).

222 Same steel and heat treatment as for 221 except austenitizing was done in an atmosphere that had a carbon potential that more nearly matched that of the steel, resulting in less decarburization at surface (top).

223 Same steel as 221 and 222 and quenched and tempered at 350 F (177 C) for 1 hr in an atmosphere of note absence of decar...
152 ASTM A537, grade A, steel plate, 2 in. thick. Normalized by austenitizing at 1670 F (910 C) and cooling in air. Specimen was taken near the plate surface. Light areas are ferrite; dark areas are pearlite.

153 Same steel and heat treatment as for 152, but the specimen was taken from the center of the plate. Note that the grains are larger than those shown in the specimen taken from near the plate surface (see 154).

154 ASTM A537 steel, grade A, steel plate, 2 in. thick, quenched at 1650 F (900 C) and tempered at 1100 F. Carbide particles are larger than those shown in the specimen taken from near the plate surface (see 152).

155 Same steel and heat treatment as for 152, but shown by a replica transmission electron micrograph. The carbide particles now appear as small black dots. The matrix (gray) is tempered martensite.

156 ASTM A537, grade B, steel plate, ½ in. thick, quenched and tempered. Austenitized at 1700 F (927 C), water quenched, tempered at 1100 F (593 C). The structure consists of tempered martensite.

157 ASTM A537 steel, grade B, steel plate, ½ in. thick, quenched at 1700 F and tempered at 1200 F. Carbide particles are larger than those shown in the specimen taken from near the plate surface (see 152).

158 Same steel and heat treatment as for 157, but a replica electron micrograph that resolves a general distribution of fine carbide particles (black and white). See 147 for explanation. Matrix, probably tempered bainite.

159 ASTM A537, class 2, steel plate, 4.5 in. thick, austenitized 8 hr at 1700 F (927 C), quenched in agitated brine, tempered 4 hr at 1050 F (566 C). Specimen from mid-thickness. Structure is tempered bainite.

160 ASTM A537 steel, class 2, steel plate, 4.5 in. thick, austenitized at 1700 F, quenched, tempered 4 hr at 1050 F and cooled in air.
Plate Steels ASTM A36, A201 and A285

116 ASTM A36 steel plate, ½ in. thick, as rolled. Structure consists of equiaxed ferrite (white areas) and pearlite (black areas).

117 ASTM A36 steel plate, 1 in. thick, as rolled. Pearlite (black), and ferrite (white) with small nonmetallic inclusions.

2024 Alloy

Time-temperature-corrosion diagram

Effect of temperature and time in interrupted-quenching experiments on type of corrosion attack developed in 2024-T4 sheet by an accelerated corrosion test.
287 4130 hot rolled steel bar, 1-in. diam. 
annulated at 1120 F (605 C) for 1 hr 
cooled to 1250 F (677 C) and held for 2 hr, 
and air cooled. Partly spheroidized pearlite (dark) in a matrix of ferrite (white).

288 Same as 287 except that the time at 
1250 F (677 C) was increased to 4 hr. 
Structure is essentially the same as that of the 
 specimen shown in micrograph 287, but the de- 
gree of spheroidization of the pearlite is greater.

289 Same as 287 and 288 except that the time at 
1250 F (677 C) was increased to 8 hr. 
Structure is similar to those shown in 287 and 
288, but the degree of spheroidization of the 
pearlite has further increased.

290 Same as 287, 288 and 289 except that the 
time at 1250 F (677 C) was increased to 
16 hr. Note that the degree of spheroidization 
of pearlite is greater than that in 289.

291 Same as 287, 288, 289 and 290 except that 
the time at 1250 F (677 C) was increased 
to 15 hr. Spheroidization of the pearlite is now 
neatly complete.

292 Same as 291, Electron micrograph of a 
platinum-carbon-shadowed two-stage 
carbon replica. Spheroidized pearlite (middle) and 
ferrite upper right and lower left.

293 4130 hot rolled steel bar, 1-in. diam. 
annulated at 1120 F (605 C) for 1 hr 
and water quenched. Untempered martensite.

294 Same as 293, but an electron micrograph 
of a platinum-carbon-shadowed two-stage 
carbon replica. Untempered martensite.

295 4130 steel in the annealed condition. 
Replica electron fractograph. Note fatigue 
striations, removed only at high magnification.
296. Resulturized 4140 steel forging normalized by austenitizing at 1650°F (900°C) 1 hr, air cooling; annealed by heating at 1900°F (1038°C) 1 hr, furnace cooling to 1890°F (1028°C), air cooling. Blocky ferrite and fine-to-coarse lamellar pearlite. Black dots are sulfide.

297. 4140 steel bar, 1-in. diam, austenitized at 1550°F (843°C) 1 hr, cooled to 1260°F (680°C) and held 1 hr for isothermal transformation, then air cooled to room temperature. White areas, ferrite; gray and black areas, pearlite with fine and coarse lamellar spacing.

298. 4140 hot rolled steel round bar, 1 in. in diameter, austenitized at 1500°F (815°C) for 1 hr and water quenched. Structure consists entirely of fine, homogeneous, untempered martensite. Tempering at 300°F (148°C) would result in a darker-etching structure.

299. Same as 298 except the steel was quenched in oil instead of water, resulting in the presence of bainite (black constituent) along with the martensite (light).

300. 4140 steel bar austenitized at 1550°F (843°C), oil quenched to 130°F (65°C), and tempered 2 hr at 1120°F (610°C). Tempered martensite; some ferrite (small, white areas).

301. As-polished (not etched) 4140 steel bar, 1 In. in diameter. The stringers are parallel to the direction of rolling on the as-polished surface of the bar.

302. 4140 steel. Replica electron fractograph showing the dimpled structure that is typical of the overstress mode of failure.

303. 4340 steel quenched in oil from 1550°F (843°C) and tempered at 800°F (427°C). Structure is tempered martensite.

304. Electron beam weld in 4340 steel that had been quenched, and double tempered at 500°F (260°C), before electron beam welding.