MSE170 U. Washington

Fundamentals of Materials Science

LAB V
Heat Treatment of Steel 4340 and Aluminum 2024 Alloys
Effects on Microstructure and Properties

I. Purpose

This lab is designed to give you the opportunity to witness first hand the effects of heat processing on two different metal alloys. For this purpose, we have picked two commonly used alloys: Steel 4340 and Aluminum 2024.
This lab is relevant to the material covered in class in chapters **10** and **11 in Callister**. In particular, you will predict metal microstructure by using phase diagrams and TTT diagrams, and investigate the effects of cooling rates and annealing on microstructure characteristics, and thus material properties. Finally, you will compare the similarities and differences that heat treatments have on the microstructure and properties of the two different materials.

II. Heat Treatment

Each lab group will receive two alloys to test: Steel 4340 and Aluminum 2024. The steel samples will be austenitized at 900ºC for 30 minutes. The aluminum samples will be heated to 550ºC for 30 minutes. The samples will then be cooled in two different ways. The first cooling treatment will be a slow air-cool, which should result in a sample experiencing approximately equilibrium cooling. The second cooling treatment will be water quenching, a non-equilibrium cooling method. A subset of these samples will then be reheated (annealed) to a temperature that will allow limited diffusion for 30 minutes.

III. Experimental Procedure

1. Heat the steel samples up to 900ºC in furnace A. Heat the aluminum samples to 550ºC in furnace B. Allow samples to equilibrate for approximately 30 minutes.
2. 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 the cooling rate).
3. Take 1 sample of each alloy and cooling rate, and place in Furnace C for steel and Furnace D for aluminum samples. Steel will be reheated to 300ºC and aluminum to 200ºC for 30 minutes.

4. Once the samples are cool, they may have to be ground to remove the oxide layer (particularly in the steels). Do this using sand paper.
5. Measure the hardness of the samples using Rockwell C and/or Rockwell B scales. Take at least 3 measurements on each sample and average the values. Be careful not to place hardness indentations too close together as this may affect the results.
6. Compare the properties (hardness) of ALL alloys after all heat treatments and explain in term of the phase transformations, resulting microstructure and ease of dislocation motion. Look at the microstructures provided on the course website to help you explain these phenomena

	Aluminum 2024	**Steel 4340**
Quench	Heat 550ºC 30 min Quench in water	Heat to 900ºC 30 min Quench in water
Quench + Anneal	Heat 550ºC 30 min Quench in water Reheat 200ºC 30 min	Heat to 900ºC 30 min Quench in water Reheat 300ºC 30 min
Slow Cool	Heat 550ºC 30 min Cool in Vermiculite	Heat to 900ºC 30 min Cool in Vermiculite
Slow Cool + Anneal	Heat 550ºC 30 min Cool in Vermiculite Reheat 200ºC 30 min	Heat to 900ºC 30 min Cool in Vermiculite Reheat 300ºC 30 min

IV. Analysis (answer these questions in a typed document that you will hand in as your lab report)

Use your data, phase diagrams, TTT diagrams, and the microstructure pictures on the course website to help you answer the following questions:

Before you start, you should find the following material using the ASM metal handbooks or other resources. Included at the end of this lab are several references that may be helpful.

a. The chemical composition for Steel 4340, and Aluminum 2024
b. Microstructures of Steel 4340 in the normalized, quenched, and tempered conditions.
c. Microstructure of Aluminum 2024 in the slow cooled & solutionized and the solutionized & aged conditions
d. Phase diagrams for the alloys systems of interest.
e. Time-Temperature-Transformation (TTT) diagrams for each alloy, if possible. If not, try to find heat treatment information for each alloy, e.g. hardness vs. time, etc.

You will need to refer to these to analyze/interpret your data and answer the following questions:

1. Consider the Iron-Carbon Phase Diagram shown in your textbook. For Steel 4340 that has been slow 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. (10 points)

2. What is the minimum temperature to heat Steel 4340, and Aluminum 2024 in order to form a single phase material? (5 points)

3. Please answer the following questions using the TTT diagrams and phase diagrams of alloys: Steel 4340, and Al 2024 (25 points)

   a. Predict what phases will form from the following heat treatments. Assume linear cooling rates:
      i. Steel 4340 cooled from 900°C to below 500°C in 1 second and room temp in less than 5 seconds
      ii. Steel 4340 cooled from 900°C to below 500°C in 20 seconds and room temp in 200 seconds
      iii. Aluminum 2024 cooled from 550°C to room temp in less than 1 second
      iv. Aluminum 2024 cooled from 550°C to room temp in 200 seconds

   b. Why does martensite not appear on the Fe-C phase diagram?

4. What does the “T#” signify after Al2024-TO, Al2024-T3, Al2024-T6? (5 points)

5. How did the different cooling rates affect the properties of the steel? Do these properties agree with the microstructure predicted from the TTT, and Phase diagrams? (10 points)

6. What did reheating (annealing) do to the steel's microstructures and properties? Why? (10 points)

7. What did reheating (annealing) do to the aluminum's microstructure and properties? Why? (5 points)

8. What is the difference between the way Steel 4340 and Aluminum 2024 responded to the heat treatments? Which heat treatment resulted in the hardest sample? Which treatment resulted in the softest sample? Are the trends for the two materials the same? In terms of chemical composition and microstructure explain why. (15 points)

9. For aluminum alloys, how do T0, T3 and T6 refer to? Did you treat Al 2024 to any of those conditions? (5 points)

10. 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 the deviations could be corrected. (10 points)

V. References:

1. William D. Callister, Jr., **Materials Science and Engineering an Introduction, 6th Edition.** *John Wiley and Sons*, New York. (2000), Chap. 10-11.
2. E.C. Subbarao, et al., **Experiments in Materials Science.** *McGraw-Hill*, New York, (1972).
3. George L. Kehl, **The Principles of Metallographic Laboratory Practice, 3rd Ed.** *McGraw-Hill*, New York (1949), pp. 232-240.
4. L. Van Vlack, **Elements of Material Science and Engineering, 6th Ed.** *Addison Wesley*, Reading, MA (1986), pp. 257-262, 292-304.
5. R.E. Smallman, **Modern Physical Metallurgy, 4th Ed.** *Butterworths*, London, (1985), pp. 335-379.
6. ASM Metals Handbooks

APPENDIX

Possibly useful diagrams and microstructures can be found in:

George F. Vander Voort ed. **Metals Handbook 8th Edition, Vol. 7: Atlas of Time-Temperature Diagrams for Nonferrous** *ASM International*, 1991

George F. Vander Voort ed. **Atlas of Time-Temperature Diagrams for Irons and Steels edited** *ASM International*, 1991.