HEAT TREATMENT OF ALUMINUM ALLOYS

Introduction

Pure aluminum is too soft for most structural applications and therefore is usually alloyed with several elements to improve its corrosion resistance, inhibit grain growth and of course to increase the strength. The optimum strengthening of aluminum is achieved by alloying and heat treatments that promote the formation of small, hard precipitates which interfere with the motion of dislocations. Aluminum alloys that can be heat treated to form these precipitates are considered heat treatable alloys. Pure aluminum is not heat treatable because no such particles can form while many heat treatable aluminum alloys are not weldable because welding would destroy the microstructure produced by careful heat treatment.

Virtually all heat treatable aluminum alloys are strengthened by precipitation hardening. Precipitation hardening involves raising the temperature of the alloy into the single phase region so that all of the precipitates dissolve. The alloy is then rapidly quenched to form a supersaturated solid solution and to trap excess vacancies and dislocation loops which can later act as nucleation sites for precipitation. The precipitates can form slowly at room temperature (natural aging) and more quickly at slightly elevated temperatures, typically 100°C to 200°C (artificial aging). The degree of hardening obtained depends on the size, number and relative strength of the precipitates. These factors are determined by the composition of the alloy and by the tempering temperature and tempering time.

Hardness measurements can provide a good indication of the strength of a material and since strength is related to the number, type and spacing of precipitates then hardness measurements can be used to monitor the precipitation process. In this experiment the aging process of three heat treatable aluminum alloys: 2024, 6061, and 7075, is investigated. Each alloy will be solution treated then naturally and artificially aged for up to six days. The effect of the aging treatments is evaluated by hardness testing and metallography. It should be possible to observe the various stages of GP zone and 2-phase formation. The maximum hardness obtained can also provide insights into the kinetics of precipitation hardening and the practical trade-offs involved in specifying the times and temperatures of the aging treatments.

Preparation

Before attempting this experiment one should be familiar with the certain technological and theoretical aspects of the physical metallurgy of the aluminum alloys used in this experiment. One should also start thinking about possible outcomes of the experiment. The following questions should help get you started:

1. There is a four digit classification system for wrought aluminum alloys. This classification system consists of nine groups, 1XXX to 9XXX, each for a different major alloying element. What is the major alloying element for each group? What is the general reputation for each group? What do the three remaining numbers in the four number code represent?

2. ANSI has adopted a system for designating the heat treatments of all wrought and cast product forms of aluminum alloys. Each designation refers to a specific sequence of thermal

and mechanical processing and the goal of producing specific properties and microstructure. The major divisions are in this classification system are represented by the letters: O, T and W. What general treatment do these letters designate? What is the processing history of the three alloys used in this experiment? What are the temper designations, if any, of the heat treatments used in this experiment?

3. Pure aluminum is considered to be non-heat-treatable. Alloys at the aluminum rich end of the binary Al-Si and Al-Mn systems are also considered to be non-heat-treatable. Explain. Also, in what situation would you need to heat treat a non-heat-treatable alloy?

4. The aluminum rich end of the Al-Cu binary system is often used as a classic example of heat treatable aluminum alloys. Precipitation from the supersaturated solid solution to the equilibrium 2 phase (Al_2Cu) occurs in stages. Describe these stages, the precipitates formed in each stage and their effect on the hardness of the alloy.

5. What phases might we find in the microstructure of the three alloys being studied in this experiment? What are their compositions? Describe their kinetics of formation. How might each phase effect the hardness of the alloys?

6. What is the typical hardness values for the alloys being investigated? Do any of the heat treatments we plan to do fit any of the ANSI designations?

Safety Considerations

This experiment involved heating treating aluminum alloys and hardness testing the specimens. The primary hazards are those associated with the moderately high temperatures involved in the heat treating.

Chemical Hazards

None. No chemicals are used and the specimens themselves are common aluminum alloys.

Physical Hazards

Although aging temperatures will not exceed 200°C the solution treating temperatures will be over 500°C. Burn hazards definitely exist. Care should be taken when using the furnaces and handling hot specimens so that people don't get burned and the laboratory benches and floor don't get damaged.

Biohazards

None.

Radiation Hazards

None.

Protective Equipment

Recommended: apron, heat resistant gloves and safety glasses. The use of protective coverings for the floor and counter tops is also recommended.

Required: none

Waste

All specimens can be recycled.

Materials

The three alloys studied in this experiment are among the most widely used heat treatable aluminum alloys. They represent three different alloy groups, Al-Cu, Al-Mg and Al-Zn. The following are a few comments on the alloys studied in this experiment. For more information, refer to references [4] and [7].

2024-T351: (Al-4.5Cu-1.5Mg-0.6Mn) This is one of the most widely used high strength aluminum alloys. It has good formability in the "O" condition but, like many heat treatable alloys, has poor weldability. This alloy is normally naturally or artificially aged. Natural aging results in the formation of GP zones which consist of Cu and Mg atoms on certain crystallographic planes. Artificial aging produces finely dispersed precipitates of Al_2CuMg while over-aging produces incoherent precipitates. Long term dimensional stability suffers due to continued aging.

6061-T651: (Al-1Mg-0.6Si-0.25Cu-0.2Cr) This is the most popular 6000 series alloy. It has moderate strength but excellent weldability compared to other heat treatable alloys, excellent corrosion resistance and a high plane strain fracture toughness. 6061 will age naturally to an essentially stable T4 condition. The softer conditions can be preserved by refrigeration. The formability of the "O" condition can be preserved for 2 hours at room temperature, 2 days at 0°C, and 7+ days or more at -7°C.

7075-T651: (Al-5.6Zn-2.5Mg-1.6Cu-0.3Cr) This alloy has very high strength and hardness. General corrosion resistance is similar to 2024 but loses its strength advantage over 2024 at elevated temperatures. It has excellent plane stress and plane strain fracture toughness. High static strength is not reflected by fatigue resistance. Loss of fatigue strength is thought to occur by progressive breakdown of the hardening particles which lie on slip planes. These particles become progressively smaller until they become unstable and redissolve into the matrix. When heat treating avoid overheating. Eutectic melting or high temperature oxidation may occur. Such material cannot be salvaged by reheating. After annealing, quench as rapidly as possible.

Procedure

1. Preliminary

The specimens used in this experiment were cut from standard rod stock material and painted to identify the alloy. Note the color codes used. Next, device a heat treatment code that clearly identifies the specimen by composition and heat treatment and engrave it on each specimen. Finally, measure the hardness of the several as received specimens.

2. Solution Treatment

Solution treat all three alloys for at least one hour then quench, with minimum delay, in iced brine. Proper solution treating and quenching is essential for the success of this experiment. Measure the hardness of each specimen immediately after quenching.

3. Aging Treatments

Perform the natural and artificial aging treatments on each alloy using the aging temperatures and times given in the table 2. Measure the hardness after each treatment.

Analysis

The following questions should help you analyze the results and to begin to develop the ideas you will put into your report.

1. Are the hardness readings which were made in general agreement with those considered typical for these alloys and these heat treatments?
2. Plot the hardness data. Note the times required to obtain under-aging, peak hardness and over-aging.

3. Do you see any evidence of the different stages of 2 precipitation? Does there appear to be a relationship between aging temperature and peak hardness? Alloy composition and peak hardness? How about time to achieve peak hardness at different aging temperatures?

4. Discuss the kinetics of the hardening processes observed in this experiment.

5. What properties other than hardness would you expect precipitation hardening to influence?

References and Further Reading

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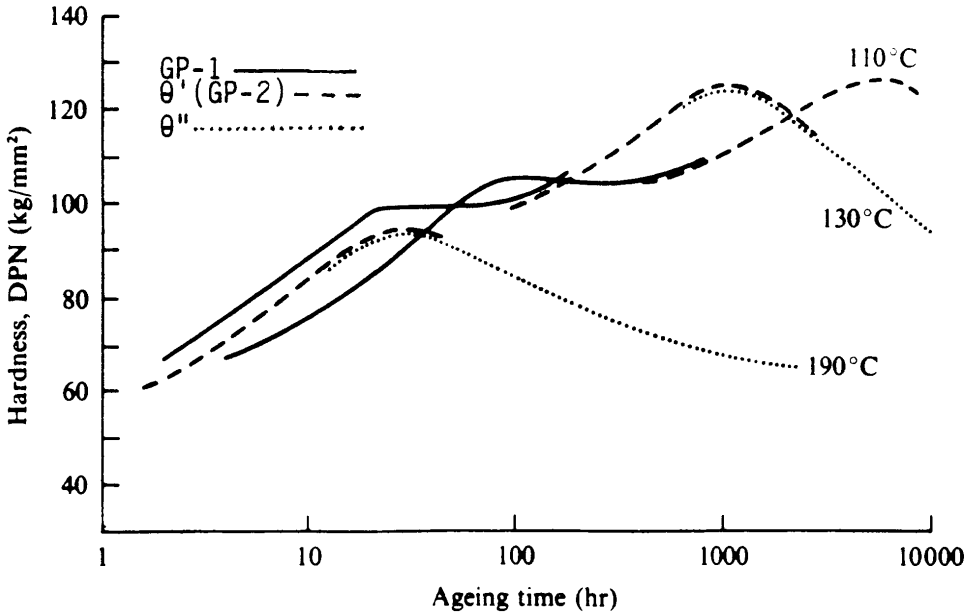

Figure 1. Precipitation hardening of Al-4Cu: hardness and precipitate structure versus time at various temperatures [11]. (Solution treated: 540°C for 2 days.)

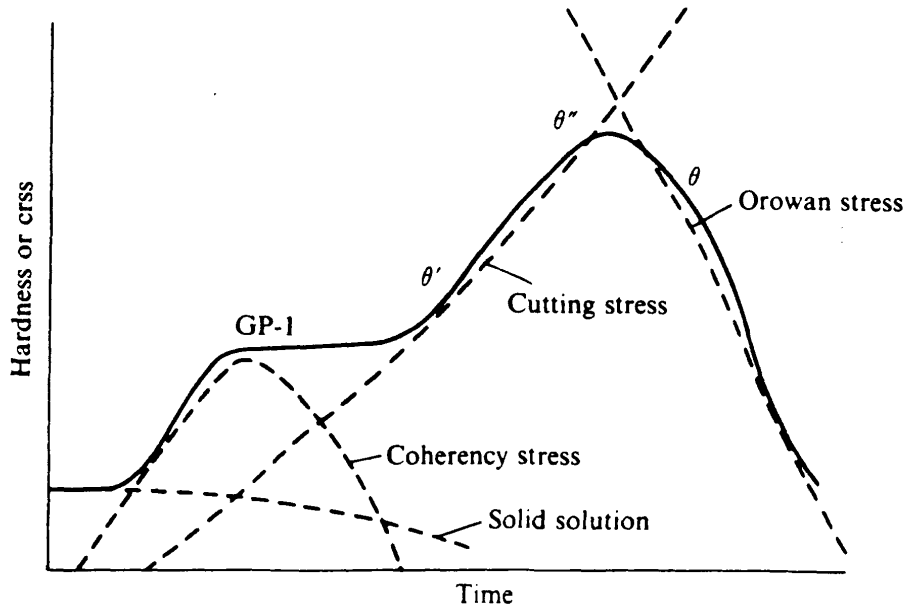

Figure 2. Interplay of various precipitation hardening mechanisms to successive stages in the hardness-time curve [12].

Table 1. Hardness of three solution treated aluminum alloys before and after solution treatments.

Alloy	Original Temper	Solution Treatment Temperature	Rockwell Hardness	
			As Received	Solution Treated
2024	T351	495°C		
6061	T651	525°C		
7075	T651	490°C		

Table 2. Hardness of three aluminum alloys after both natural and artificial aging treatments.

Aging Time (hours)	Rockwell Hardness						
	2024		6061		7075		
	RT	190°C	RT	175°C	RT	120°C	175°C
0.00							
0.33							
0.66							
1.0							
1.5							
2.0							
3.0							
4.0							
5.0							
6.0							
12							
24							
48							
72							
144							