Influence of High Temperature Solution Treatment on Aging Characteristics of Al-4Cu-6Si Casting Alloy

Suresh Chand  
Lecturer, Dept. of Metallurgical and Materials Engineering  
RGUKT IIIT Nuzvid, A. P, India

Madhusudhan D  
Lecturer, Dept. of Metallurgical and Materials Engineering  
RGUKT IIIT Nuzvid, A. P, India

ABSTRACT

Aluminum alloys are mostly used in aerospace and automotive applications. It has high strength to weight ratio. These alloys also show high corrosion resistance. This work emphasizes to improve the strength by heat treatment which involves forming precipitates of \( \text{Al}_2\text{Cu} \). The strength will depend on the precipitate particles of \( \text{Al}_2\text{Cu} \). The samples were heated to 550 °C for 2 hours and 30 minutes for solution treatment to dissolve \( \text{Al}_2\text{Cu} \) and to get the single phase transformation followed by quenching into water to suppress further transformations. The aging was performed at 180 °C for 3, 4.5, 6, 7, 8 and 9.5 hours. Solution treatment and aging were carried out in a muffle furnace and the hardness values were measured using Rockwell hardness tester. The peak hardness is measured \( R_B 84 \) after the aging time of 7 hours.

KEYWORDS Solution treatment, aging, temperature, furnace, time.

INTRODUCTION

The work of Mercia, Waltenberg and Scott was the beginning of an explanation of age hardening. In their study of an Al-Cu alloy, they observed that the hardness increased after quenching. They stated that the solid solubility of copper in aluminum decreases with decrease in temperature and this led them to propose that the hardening with age after quenching was due to copper atoms precipitating out as particles from supersaturated solid solution [1-2]. Aluminum–silicon copper alloys are generally utilized to manufacture components of automobiles because of good castability, excellent wear resistance and good mechanical properties [3, 4]. In Al–Si–Cu–Mg alloys, the temperature for Artificial aging treatment is typically constrained to around 500 °C. The higher temperatures lead to beginning of incipient melting of the Cu-rich phases, which deteriorate mechanical properties of casting alloys [5-7]. In Al-Cu alloy, upon appropriate heat treatment, the Cu atoms progressively cluster together to form very small particles which separate out within the matrix grains of the alloy; this process is called precipitation. The alloy is initially in a state far from equilibrium and, given sufficient time at applied temperature, diffusion of atoms occurs progressively to transform the metallurgical structure towards the equilibrium state. The precipitation process that creates precipitate particles that usually provides an appreciable hindrance to plastic deformation by slip. Hence, as precipitation progresses and the size and amount of precipitates increases, the alloy hardens and strengthens with time [8]. The full precipitation occurs only when the alloy is artificially aged at temperatures below Guinier PristonI zone’s solvus. The many steps in this process may be covered up by aging at temperatures above the Guinier Priston zones, \( \theta^0 \) and \( \theta^0 \), simultaneously with the solvus line of stable phase \( \theta \) [9, 10]. The primary hardening at 180 °C is added to GP1 zones. After attaining a critical radius of 5 nm, an incubation time starts, during incubation period the size of the zone and the value of hardness remains unchanged [11-12].

EXPERIMENTAL DETAILS

As received sample was 50 mm long, 20 mm diameter cylindrical rod of Al-4Cu-6Si alloy. Six samples of 3 mm length were cut from as received sample. For microscopic examination, the specimens were polished with
Emery papers of grit numbers 600, 800, 1000 and 1200. First emery paper is placed on a bench plate or on any clean, hard, and flat surface such as a glass plate. The paper is held with the hand and the position of the specimen should be such that the scratches introduce during this stage of polishing are perpendicular to the scratches from the belt grinder. This helps to ensure whether the polishing operation has completed or not. During this stage of polishing, scratches are completely removed and the specimen surface becomes scratch free. After paper polishing, the disc polishing was performed on disc covered with an appropriate grade of polishing cloth. These wheels are rotated with motors and provided with speed controls. Low speeds should be used for soft materials. This reduces the amount of distributed metal on the surface. High speed should be used for polishing of hard materials. This reduces the polishing time. After this the specimens were washed in water. And then etching was carried out for 20 seconds using reagent prepared from hydrofluoric (HF) and water (distilled). For solution treatment, the samples were heated at 550 °C for 2 hours and 30 minutes to dissolve Al$_2$Cu and to get the single phase transformations followed by quenching into water to suppress further transformations. Solution treatment and aging were carried out in muffle furnace and the hardness values were measured on C-scale using Rockwell hardness tester. The aging was performed at 180 °C for 3, 4.5, 6, 7, 8 and 9.5 hours. The hardness values are found increasing due to the formation of the (Al$_2$Cu) precipitates.

### Table 1: Chemical composition of Al-Cu-Si aluminum alloy.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Al</th>
<th>Cu</th>
<th>Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight %</td>
<td>90</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

### Table 2: Process variables for artificial aging of aluminum alloy.

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Aging time (hours)</th>
<th>Aging temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>180</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>180</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>180</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>180</td>
</tr>
<tr>
<td>6</td>
<td>9.5</td>
<td>180</td>
</tr>
</tbody>
</table>

### RESULTS AND DISCUSSION

#### Hardness measurement

### Table 3: Rockwell hardness values on B-scale of aluminum alloy.

<table>
<thead>
<tr>
<th>Specimens</th>
<th>Aging time (hours)</th>
<th>Rockwell Hardness (Rc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>4.5</td>
<td>73</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>84</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>9.5</td>
<td>70</td>
</tr>
</tbody>
</table>
Aging curve of Al-4Cu-6Si aluminum alloy:

![Aging curve of Al-4Cu-6Si aluminum alloy](image)

**Figure 1:** Hardness vs aging time plot of Al-4Cu-6Si aluminum alloy.

Microstructural analysis

![Microstructural analysis](image)

**Figure 2:** Optical microstructures of artificially aged specimens at 180 °C of aluminum alloy, (a) aged, 3 hrs, 200X, (b) aged, 7 hrs, 200X, (c) Overaged, 9 hrs, 200X.
DISCUSSION

The solution treatment was carried out at 550 °C for 2 hours and 30 minutes. The fine precipitate particles can easily be dissolved in the solid solution but it is very difficult to dissolve blocky Al₂Cu precipitate in the small time of interval. The hardness value of solution treated specimen is measured Rₐ 44, this shows that the higher solutionizing temperature enabled to dissolve big particles of Al₂Cu precipitate in solid solution. Optical microstructure shown in figure 2 (a) reveals very small amount of Al₂Cu precipitate (dark phase) in α-aluminum matrix (bright phase). Figure 2 (b) is the optical microstructure of maximum hardened specimen which reveals large amount of fine Al₂Cu precipitate particles. These Al₂Cu precipitates are responsible for the hardening of the alloy. It is clearly visible in figure 2 (c) that the precipitate particles have grown up sufficiently large which results lattice mismatch. Some needle like phase is visible in figure 2 that phase is identified as Al₅FeSi. Figure 1 shows the variation of hardness with aging time. This plot is called aging curve of the as cast Al-4Cu-6Si aluminum alloy. The aging curve is found more steeply rising upward and attaining peak hardness in seven hours only. This rapidly rising nature of aging curve is imparted by solution treatment. The hardness values are found increasing due to the formation of the (Al₂Cu) precipitates. As the number of precipitate particles increase the value of hardness also increases. After aging time of 3 hours the hardness is found Rₐ 65. The maximum hardness is measured Rₐ 84 after the aging time of 7 hours. For the aging times more than the 7 hours, the hardness values are found decreasing. For the longer aging periods the Al₂Cu precipitates coarsening take place because of that precipitate particles becomes coarser at the expense of some smaller precipitate particles. The coarsening of the precipitate particles lead to loss in coherency between the precipitate particles and the aluminum matrix, which results decrease in hardness of the alloy.

CONCLUSION

1. The higher solutionizing temperature enables dissolution of big Al₂Cu precipitate in smaller time of interval.
2. The single peak hardness is measured Rₐ 84 after the aging time of 7 hours.
3. For the aging time more than the 7 hours, the hardness values are found decreasing.
4. The aging curve is observed rising more steeply up to maximum hardness.
5. The time and temperature play a very important role in the strengthening process of the alloy.
6. The coarsening of the Al₂Cu precipitate particles lead to loss in coherency between the precipitate particles and the aluminum matrix, which results decrease in hardness of the as cast aluminum alloy.

REFERENCES