# Changes in Structural Features of Al-12Si-3Cu Alloy Due to Age Hardening

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**Abstract -** *In the current work, the effect of artificial ageing on microstructural features of Al-12Si-3Cu alloy is studied. T6 heat treatment is carried out for this purpose. The experimental alloy is solutionized at 500°C for 8 hours and quenched in water at room temperature. Artificial ageing is carried out at 200°C. Hardness of the test specimen is measured and graph of hardness values Vs ageing time is drawn. The micro structural changes are observed under optical microscope and structural changes are correlated with the age hardening behavior of the test alloy.*

***Key Words***: Al-Si-Cu alloy ; Age hardening ; Microstructure.

## 1.INTRODUCTION

Aluminium – Silicon casting alloys are used for automotive applications due to less weight and ability to cast into any complex shapes. The Al-Si alloy group is popular in many applications where copper additions harden the alloy [1]. Copper acts as a strengthening agent in aluminium. Heat treatment improves the microstructure and mechanical properties of these alloys. The most commonly used heat treatment processes are solution treatment and age hardening [2]. Copper additions up to 5 wt.% lead to alloys with very high strength and good toughness when subject to natural or artificial ageing[3]. Typically, T6 heat treatment is applied which involves three steps namely solution treatment, quenching and age hardening and commonly used to improve the mechanical properties of the alloy. [4]. During solution treatment, the alloy is heated to high temperature for relatively long periods of time to dissolve Cu rich particles and to modify the acicular morphology of the eutectic Si to a less detrimental rounded one. [5]. In T6 heat treatment cycle the selection of solution treatment temperature and solution treatment time is critical because if the melting temperature exceeded, the incipient melting takes place at the grain boundaries. This results in reduction in mechanical properties [6]. Wang et al. found 500° C as the suitable solution treatment temperature for alloys with more than 2 wt.% Cu. [7]. After solution treatment the alloys are normally quenched in water at room temperature to obtain a super saturated solid solution and artificial ageing is done at an elevated temperature to obtain a uniform distribution of small precipitates because which gives the high strength [8].

The present study is part of a larger research study, which was conducted to get the better understanding of the effect of T6 heat treatment on the microstructure and hardness of Al-12Si-3Cu alloy.

## 2. Experimental Procedure

Al-12Si alloy was melted in an electrical furnace under a cover flux (45%NaCl+45%KCl+10%NaF), and the melt was held at 720⁰ C. Degassing was done with solid hexachloroethane and 12 wt% of pure copper wire pieces were added to the melt packed in an aluminium foil. The melt was stirred for 30 – 45 seconds with zirconia-coated iron rod. Al-12Si-3Cu alloy specimens were swaged to required dimensions (diameter 22 mm and 250 mm length). Chemical analysis of the test alloy was done using optical emission spectroscopy and found to have following composition:

**Table -1:** Elemental composition of the cast alloys

| Alloy | Composition (wt %) | | | | | |
|---|---|---|---|---|---|---|
| | Si | Cu | Fe | Mn | Mg | Al |
| **Al-12Si-3Cu** | 12.04 | 3.08 | 0.13 | 0.05 | 0.08 | Bal |

The small samples with dimensions of 22 mm diameter and length 12 mm were cut from solidified castings. All the castings were cut in the same dimensions, to avoid the effect of casting size on cooling rate and microstructure, For optical microscopic studies, metallographic samples were prepared and etched with Keller reagent (1.5ml $HNO_3$, 2.5ml HCl, 1.0 ml HF, and 95ml $H_2O$). Experimental test specimens were solution heat treated in muffle furnace at 500°C with holding time of 8 hours and water quenched at room temperature. Artificial ageing was carried at 200°C with different holding time 1, 2, 4, 6, 8, 12, 16, 20, 24, 28, 32 and 36 hours. The surfaces of the test specimens were initially polished on a belt grinder and then on a series of SiC water proof emery papers with increasing grit size. Final stages of polishing were performed on a disc polisher using 75 μm $Al_2O_3$ powder with water until a scratch free surface is obtained. The samples were then cleaned with soap solution and ethyl alcohol followed with drying. The polished samples were etched using Keller's reagent (2.5% $HNO_3$ + 1.5% HCl + 1% HF + 95% $H_2O$ by volume) for about 75-90s in order to develop microstructure with grain boundaries. Test specimens were subjected to metallographic observations in as cast condition, solution treated condition and after age hardening at different time intervals. Hardness of test specimen were measured by Brinell hardness tester with a load of 187.5 Kgf and 2.5 mm diameter ball and a dwell time of 30 s. The hardness value of each test specimen was obtained by an average of at least six measurements.

## 3. Results and Discussion

### 3.1 Microstructural Observations

Figure 1(a) shows Optical micrograph of as cast Al-12Si-3Cu experimental alloy. As seen in the figure, the alloy has α-Al matrix with dispersed needle like eutectic Si. Figure 1 (b) shows dark contrasted intermetallic phase.

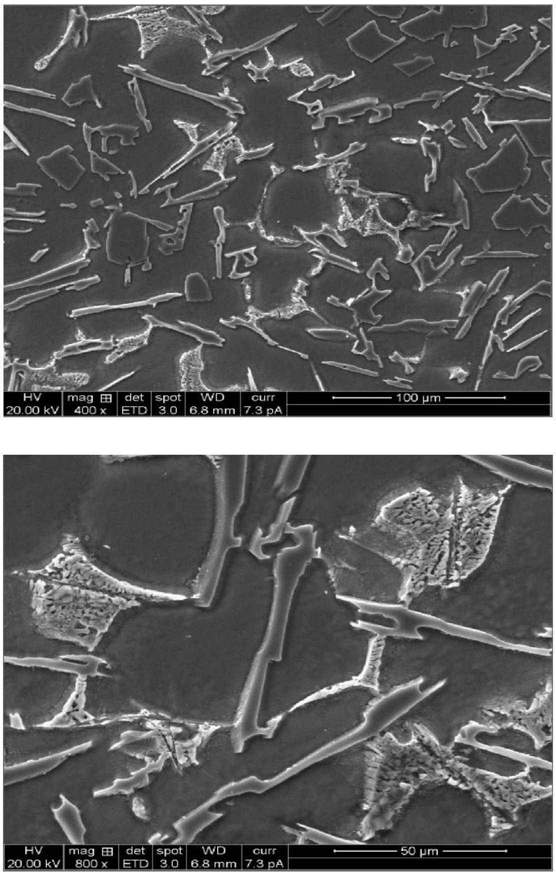



**Fig -1**: SEM image of (a) as-cast Al-12Si-3Cu alloy and (b) intermetallic phase

The EDX analysis of the precipitate proves that the precipitate contains Cu. The chemical composition of the intermetallic is $CuAl_2$. This is generally named as $\theta$ phase for Al-Cu alloys [3].

Figure 2 shows the microstructure of the test alloy observed after its solution treatment at 500°C for 8 hours. The optical microstructure demonstrated the changes in the size and shape of the Si particles. In copper containing Al alloys, quenching of specimen in water after solution treatment results in formation of GP zones. These zones distributed uniformly in α-Al matrix form copper atoms in the aluminium lattice. These GP zones typically have coherent interface with the matrix resulting in higher hardness.

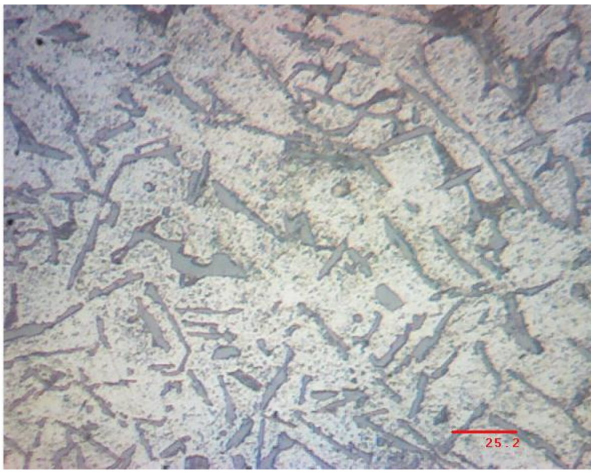
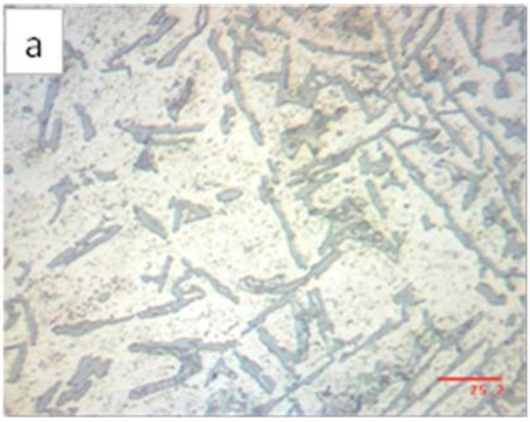



**Fig -2**: Optical microstructure after Solution treatment.

Figure 3a and 3b shows the optical micrograph of test alloys artificially aged for 2 hours and 12 hours at 200°C, respectively. It can be seen from the figure, the intermetallic phases have dissolved and eutectic silicon particles have spheroidized in comparison to plate shaped as-cast specimen before heat treatment. At this stage of ageing, the intermetallic compounds and eutectic Si is more homogeneously distributed.



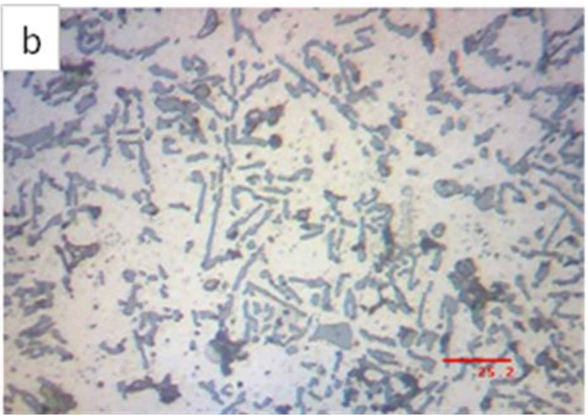



**Fig –3**: Optical microstructure after (a) 2 hours and (b) 12 hours of ageing.

### 3.2 Effect of age hardening on hardness

The test specimens were subjected for hardness measurement in as cast condition (prior to solution treatment), after solution treatment and at different ageing times. The hardness of the test specimen was 78 BHN prior to solution treatment. Hardness of the specimen increased to 98 BHN after solution treatment for 8 hours at 200° C. At the early stage of ageing, the hardness of the specimen increased with ageing time until it reached the first peak of 115 BHN after 2 Hrs. The second hardness peak of 145 BHN was reached after 12 Hrs of solution treatment. Later hardness of the test specimen decreased with increase in ageing time.

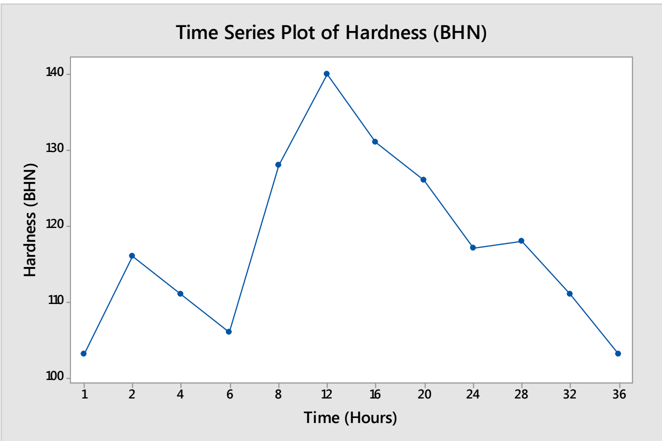



**Fig –4**: Influence of ageing time on hardness

Figure 4 shows variation in hardness with ageing time. The age hardening peaks are highly correlated to their precipitation sequence. The first peak of hardness is attained depending on the high density GP zones, while the second hardness peak is attained in terms of metastable particles. The ageing plateau is corresponding to the continuous transition from GP zones to metastable phases [9]. At the final stage of ageing, the hardness decreases as a result of over-ageing.

### Conclusions

The main focus of the study was to investigate the effect of T6 heat treatment on the microstructure and hardness of A l-12Si-3Cu alloys. The solution treatment was done at 500°C for 8 hours. The ageing time ranged between 0 to 36 hours. From the findings of the experimentation, the following conclusions can be drawn:

1. Hardness of Al-12Si-3Cu alloys is highly influenced by heat treatment. Peak hardness of 145 BHN was achieved after 12 hours of ageing at 200°C. This is about 86 % higher as compared to a hardness of 78 BHN of as cast alloy prior to heat treatment.
2. The improvement in hardness of heat treated Al-12Si-3Cu alloy can be attributed to the changes in the morphology and size of the eutectic Si phase particles. After the heat treatment most of the intermetallic phases dissolve and the eutectic Si particles tend to spheroidize.

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