

## Effect of alumina on grain refinement of Al-Si hypereutectic alloys

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**Abstract.** The size, volume fraction and distribution of primary as well as eutectic silicon affect the mechanical properties of the Al-Si hypereutectic alloys. It is very difficult for the simultaneous refinement and modification of primary and secondary Si particles in hypereutectic Al-Si alloys through traditional processes. This paper explores the role of  $\gamma$ - $\text{Al}_2\text{O}_3$  nanoparticles on Si particles in the course of solidification in hypereutectic Al-Si alloys at particular pouring temperature. The present study involves incorporation of varying contents dispersed  $\gamma$ - $\text{Al}_2\text{O}_3$  nanoparticles into a molten base metal during stir casting and followed by solidification. It has been reported that the synthesized composites having good interfacial bonding (wetting) between the dispersed phase and the liquid matrix was achieved in order to provide improved mechanical properties of the composite. The cast product of hypereutectic Al-16Si alloy with the reinforcement of nanoparticles, illustrated a significant improvement in both wear behaviour and hardness. The dry sliding wear test has been performed on a group of specimens with varying parameters (different loads and sliding velocities) in a pin on disc wear testing machine. Moreover, the wear rate and specific wear rate also affected in different load and different sliding velocities. However in XRD analysis of the samples, the enhancement of wear resistance as well as hardness was due to the formation of brittle phases like  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and Al-rich intermetallic compounds. The hardness value of the materials increases nearly 6% in addition to increase in the density of only 0.8%. As per literature, the large plate eutectic Si particles were modified in to the fine core particles and it acquires enough potential for various applications.

**Key words:** -  $\gamma$ - $\text{Al}_2\text{O}_3$ , Al-rich intermetallic compound.

### 1. Introduction

Al-Si alloys are familiar as the potential candidate in automobile engines in place of the conventional use of cast iron so as to enhance savings in fuel consumption & reduce vehicle emission. The mechanical behaviour and wear resistance are two factors which determine the correlation between synthesis and performance of engineering materials. In current scenario the modelling of materials has provided a renewed stimulus to develop a good understanding of mechanism and factors involved. Aluminium based materials are one example of which to optimise the microstructure as well as the mechanical properties through different processing or by addition of the grain refiner. The demand for the development of light weight metal matrix composites has been increasing in automobile and aerospace industries to enhance the fuel economy and diminish green house gas emissions [1]. The most quickly rising field of composites is that of aluminium alloy based metal matrix composites because of their enhanced physical, mechanical and tribological properties. In MMCs as engineering materials, Al-Si alloys are extensively used as matrix phase as a result of their unusual combination of properties like good castability, high specific strength, and improved wear resistance with reasonable cost [2-4]. Conventional casting of hypereutectic Al-Si binary alloys gives rise to various morphology of eutectic and primary silicon and the shape, size along with distribution of the constituents play vital role in deciding the mechanical and tribological properties.



Instead of conventional star, polygonal, feathery or plate like primary Si with coarse needle or flake like eutectic Si, achievement of fine spherical & uniformly distributed phases is able to improve mechanical as well as wear properties of hyper-eutectic Al-Si alloys [5-7]. Incorporation of reinforcement particles like  $\text{TiB}_2$ , WC, SiC or  $\text{Al}_2\text{O}_3$  to the matrix of aluminium alloys causes remarkable enhancement in hardness, strength along with wear properties at the cost of slight increase in density [8]. AMCs ensure achieving good interfacial bonding and wettability with matrix and there by resulting in excellent properties and extensive application of the composite [9].

In this paper to explore the synthesis and characterization of Al-Si hyper-eutectic alloys with different wt. %  $\text{Al}_2\text{O}_3$  through stir casting method.

## 2. Materials and experimental methods

The materials used for Al-16Si-x $\text{Al}_2\text{O}_3$  ( $x = 0, 1$  and 2wt. %) composite samples are 99.97% purity aluminium ingot, 99.9% purity alumina (gamma- $\text{Al}_2\text{O}_3$ ) and Al-50%Si master alloy. Al-16Si-x $\text{Al}_2\text{O}_3$  have been manufactured by stir casting methods and the specimens have been inspected for their physical and mechanical properties.

### 2.1 Synthesis of Al- 16Si- x $\text{Al}_2\text{O}_3$ composite

Cp aluminium and Al-50 wt% Si master alloy was melted in a clay-graphite crucible in a pit type melting f/c at 720°C and added the different wt% $\text{Al}_2\text{O}_3$  particles to prepare Al-16Si-x $\text{Al}_2\text{O}_3$  ( $x = 0, 1$  and 2wt%) alloy. The Al-16Si-x $\text{Al}_2\text{O}_3$  composites were manufactured by conventional stir casting method. Dross was removed and melt was degassed with the help of  $\text{C}_2\text{Cl}_6$  before casting, shown in figure 2.1.



Figure 2.1 Casting of AMC Al-16Si-2%Alumina by stir casting method.

### 2.2 Characterization

The samples of size 10mm x 10 mm x 2mm was taken for XRD analysis which was carried out with Cu- $\text{K}\alpha$  target to recognize different phases present in the sample by matching of obtained peaks with JCPDS data files.

### 2.3 Hardness and density

The hardness values of the specimens have been obtained using Microvicker's hardness tester with square base diamond pyramid indenter and applied load of 1kgf for fifteen seconds. Care was taken make both the horizontal faces of the test sample parallel by polishing. Vickers Hardness Number of the prepared specimens were determined from the diagonals of the impressions made at five selected spots of single test sample. The density tests were carried out with the use of a Mettler density tester following standard procedure.

### 2.4 Wear test

To investigate the dry sliding wear behaviour of the composite sample with 10mm diameter and 30mm height were tested in a pin on disc wear testing machine. The load was varied from 40 to 60N with rotation speed of 300, 400 and 500rpm (having 40mm radius of track) for 5 minutes at room temperature without use of any lubricating stuff. The apparatus used is a microprocessor controlled machine and

provides simultaneous data for height loss (in micron). After every test the mass loss due to wear of each specimen was determined. The role of applied load and alumina content on wear behaviour of the prepared composites was studied.

### 3. Results and discussions

#### 3.1. XRD analysis of composites

The major peaks obtained from the XRD test describe the presence of mainly of aluminium and silicon where as the minor peaks signify the existence  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ . As the % of  $\text{Al}_2\text{O}_3$  increases the intensity of peaks of the Al-rich intermetallic compound ( $\text{Al}_{3.21}\text{Si}_{0.47}$ ) was increased significantly as shown in figure 3.1(a-c).

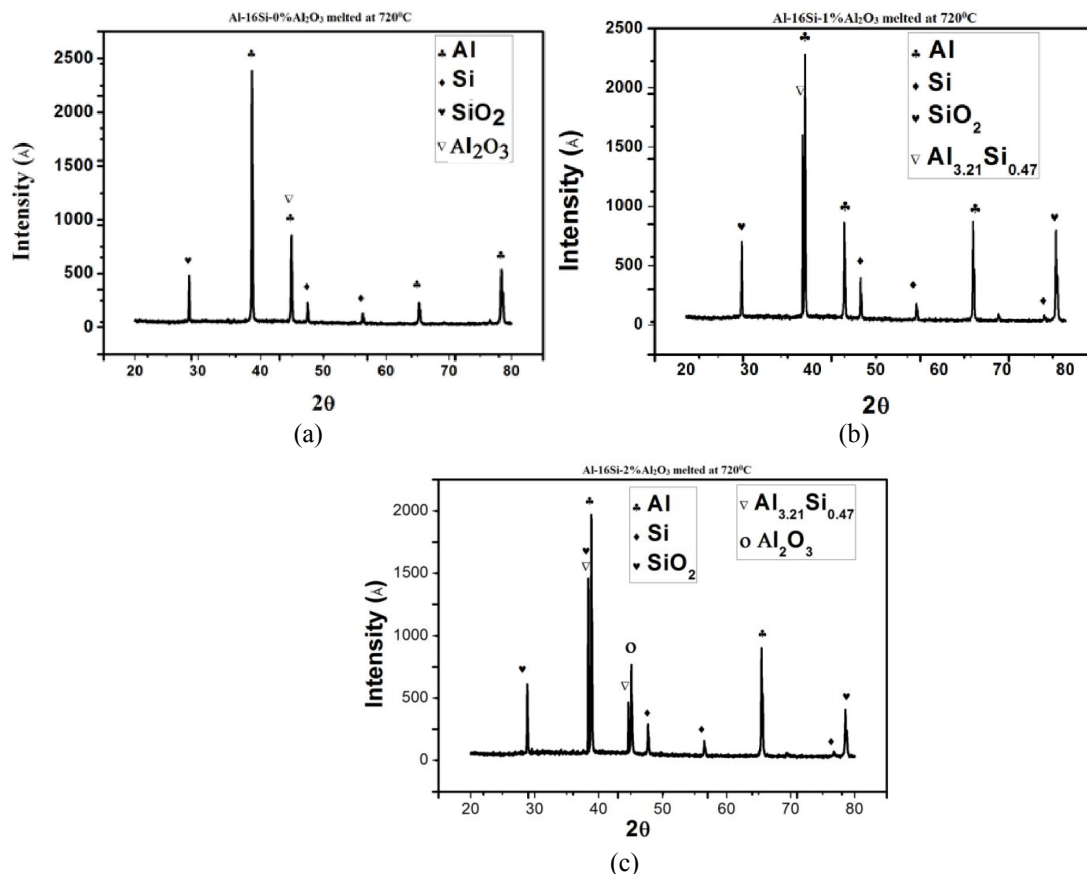


Figure 3.1 X-ray diffraction patterns of (a) Al-16Si-0% $\text{Al}_2\text{O}_3$  (b) Al-16Si-1% $\text{Al}_2\text{O}_3$  and (c) Al-16Si-2% $\text{Al}_2\text{O}_3$  melted at 720°C.

#### 3.2. Hardness and density

Table 1. The Density and Hardness of the different compositional samples.

| Sample                             | Density(g/cc) | Hardness(VHN) |
|------------------------------------|---------------|---------------|
| Al-16Si                            | 2.6213        | 52.565        |
| Al-16Si-1% $\text{Al}_2\text{O}_3$ | 2.6388        | 54.29         |
| Al-16Si-2% $\text{Al}_2\text{O}_3$ | 2.644         | 55.69         |

From the table 1, it is found that the density and hardness increases with increasing of alumina. The density of  $\text{Al}_2\text{O}_3$  is about 3.95g/cc. The increase in formation of Al-rich intermetallic harder phase causes for increasing hardness.

#### 3.3. Wear test

The wear increases with load and sliding speed as shown in figure 3.2 and 3.3 respectively. The figure 3.4 shows that the wear resistance was significantly increased with increase in alumina content. This may be attributed to the role of  $\gamma$ - $\text{Al}_2\text{O}_3$  in grain refinement of the base alloy along with modification of Si phases.

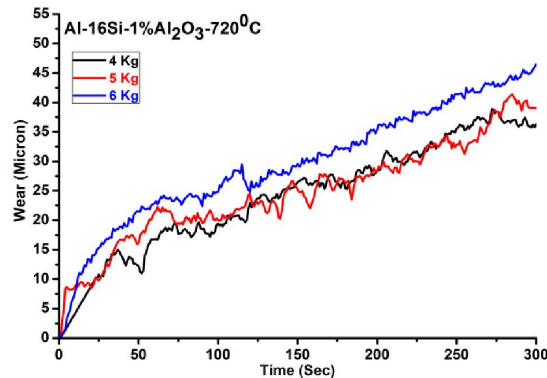


Figure 3.2 Wear vs time graphs of Al-16Si-1% $\text{Al}_2\text{O}_3$  at different load.

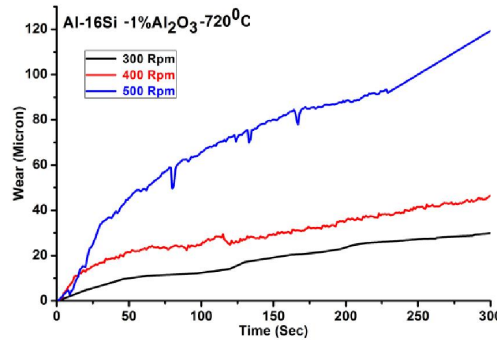


Figure 3.3 Wear vs time graphs of Al-16Si-1% $\text{Al}_2\text{O}_3$  at different speed.

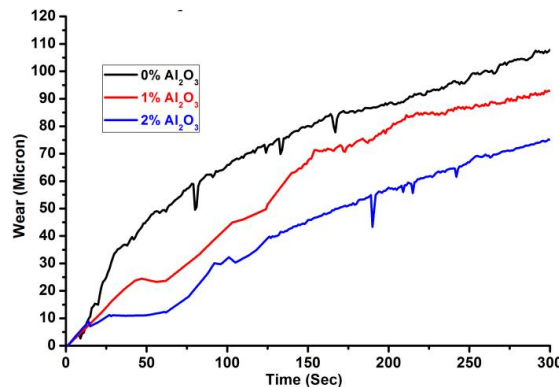


Figure 3.4 Wear vs time graphs of 6kg load having different composition.

#### 4. Conclusions

- The XRD analysis shows the major peaks of aluminium and silicon and minor peaks of  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$ . As the increasing alumina content the peaks of Al-rich intermetallic compound also shown into the picture.

- The Hardness and density of the MMC increases with alumina content because of formation of harder intermetallic compound and higher density of the alumina respectively.
- The wear of the alloys was increased with increasing load and rotation speed where as less wear was detected in Al-16Si-2%Al<sub>2</sub>O<sub>3</sub> sample.

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