An Exploratory Comparative Study of Fabricated Silica – Aluminium Metal Matrix Composites with Casted Aluminium-Silicon Alloys

Sourav Debnath¹*, Soumyajit Roy², Akshay Kumar Pramanick³
¹,²,³ Metallurgical and Material Engineering Department, Jadavpur University, Kolkata- 700032, India

*souravdebnath262@gmail.com

Abstract. Different commercial grades of aluminium have been used in which LM6 grade is most available. An attempt has taken towards developing Aluminium-Silicon Alloys (Al-Si alloys) via conventional casting and investment casting separately. Parallel effort has made to develop silica – aluminium metal matrix composites using both crystalline and non-crystalline form of silica separately as reinforcement. Comparative study has carried out based on different physical and mechanical properties of developed products.

Keywords- Al-Si Alloy, Silica-Aluminium Metal Matrix Composite, Casting, Powder Metallurgy, Surface Morphology, Density, Porosity, Hardness.

1. Introduction

Aluminium is attractive metal [1-3] due to its low density, lightweight, easy machinability, corrosion resistive [4-5], moreover easily available on Earth crust. LM6 grade [6] is most common, easily available and being used from many hundreds of thousands of years ago in both academics and industries, especially in electrical, electronics, automobile and aerospace [7] for its various attractive properties [8].

Conventionally “Sand Casting” is generally preferred for low production cost but observed high shrinkage during solidification. Thin section production in sand casting is very difficult [9-10] and that’s why Indian traditional casting technique can be used, namely “Lost wax investment casting process in Hot Clay mold” [11].

Unlike other metals, mechanical properties of LM6 are highly influenced by its solidification rate. Solidification rate for conventional sand casting technique was fast but in Hot Clay mold it was very slow.

On the other hand, pure aluminium suffers from lack of strength and low melting point concentrate limited field of applications [12]. Hence, potential has adopted for shorting out these problems of pure aluminium with incorporating ceramic reinforcement into it for enhancing the strength and stiffness [13-15].

Present study, authors have casted LM6 via conventional and investment casting methods. In addition, fabrication of silica- aluminium metal matrix composites with various compositions also carried out followed by “Powder Metallurgy” techniques. Finally, comparative study has made among different developed metals based on various characterizations and different physical as well as mechanical properties.
2. Experimental Procedure

The experimental procedure has been elaborated.

2.1 Fabrication of Silica-Aluminium Metal Matrix Composites

Conventional Powder Metallurgy technique has adopted towards fabrication of various compositions of silica-aluminium metal matrix composites with maintaining the steps of grinding and mixing into mortar parcel, pressing and finally sintering. Crystalline silica and silica gel have considered separately for reinforcement of pure sintered aluminium, considering 600°C as sintering temperature for an hour into hot pressing unit (Nascor Technogies Pvt. Ltd., Howrah, West Bengal, India) as described elsewhere [4–5]. Stated that development through ‘Powder Metallurgy technique’ maintaining such fabrication conditions, any reaction has not been addressed between matrix and reinforcement for silica-aluminium metal matrix composites, described in the previous studies carried out by these authors [4–5].

2.2 Casting of Al-Si Alloy

Traditional sand casting method was adopted for making sand mold to pour liquid aluminum into it. A traditional rural Investment casting technique was also adopted [16-17], in conjunction with sand casting. The process is known as Lost-Wax Casting process, where wax pattern was used and the mold was made up with natural clay. Liquid metal was poured into the red hot mold. Top gating system was used for both the casting techniques. Liquid metal temperature was 685°C, measured with K type Thermocouple.

3. Results and Discussion

The following results have been discovered and discussed below.

3.1 Chemical Analysis

Chemical analysis for casted LM6 has carried out as per IS: 4027 and reported in table 1.

Table 1: Chemical Analysis of casted LM6.

| Composition | Aluminium | Silicon | Iron | Manganese | Lead | Copper | Other |
|-------------|-----------|---------|------|-----------|------|--------|-------|
| wt %        | 87.6      | 10.2    | 0.5  | 0.5       | 0.1  | 0.1    | 1.0   |

3.2 Microstructure [Optical and SEM (Scanning Electron Microscope)]

Surface morphology of various compositions of crystalline silica-aluminium composites have shown from figure 1 to 2. Crystalline silica has oriented systematically throughout entire metal matrix.

Surface morphology based on SEM image of pure sintered aluminium and 20 Wt. % crystalline silica-aluminium composite have shown in figure 5 and figure 6 respectively. Grain size belongs in the range of ~ 30 µm noted in figure 5 and figure 6.

Surface morphology based on optical microscope has shown from figure 3 to 4 for casted LM6. Very dense ‘dendritic structure’ of silicon has seen on the aluminium metal matrix for the sample prepared through conventional sand casting. On the other, small size of ‘dendritic structure’ of silicon has observed for the same aluminium metal matrix developed through investment casting. Granular silicon is found out for investment casted LM6.
Grain size is relatively smaller than ‘Investment Casting’ samples. Also density of dendritic silicon is more. In conventional casting, Dendrites are Thicker and Longer than the sample of investment casting as shown in figure 9.

3.3 EDX and Mapping

EDX data for investment casted LM6 has shown in figure 9 where aluminium is present 98.7 % by weight. However, EDX analysis has carried out on the marked portion on SEM image, denoted in figure 9 (a) and (b).

Mapping on SEM have carried out on silica gel- aluminium metal matrix composites and corresponding image for 10 % and 30 % (based on Wt. %) silica gel- aluminium metal matrix composites have shown in figure 7 and figure 8 respectively. In mapping, distribution of aluminium is denoted with red, green represents the distribution of silicon and yellow color has been used for representing distribution of oxygen in the surface of fabricated composites. EDX analysis along with the mapping on SEM image for the developed crystalline silica- aluminium metal matrix composites are described in the previous study carried out by these authors [4].

3.4 Density Measurement

It has seen that pure sintered aluminium shows the density 2.705 gm/cm$^3$ [4] whereas density value for casted LM6 is 2.64 gm/cm$^3$, 20 % (based on Wt. %) crystalline silica- aluminium composite 2.615 gm/cm$^3$ [4] and 20 % (based on Wt. %) silica gel- aluminium composite is 2.2 gm/cm$^3$. Density, hence weight, of fabricated silica- aluminium composites have lower than pure sintered aluminium and even, casted LM6 products.

3.5 Apparent Porosity

Unlike other metal and alloys, porosity measurement cannot be performed on casted Al-Si alloy as LM6 has melted during casting. In the case of silica- aluminium composites, sintering has carried out at lower temperature than the theoretical melting point of constituent members and hence, porosity measurement has conducted for each fabricated composite. Pure sintered aluminium has porosity value of 0.21 % and apparent porosity was observed in the range of 0.218 % to 0.2857 % for 2.5 % to 30% (based on Wt. %) crystalline silica- aluminium composites, described somewhere [4]. Furthermore, apparent porosity value was recorded nearly 0.9 % to 2% corresponding to 2.5 Wt. % and 30 Wt. % silica gel – aluminium metal matrix composites respectively.

3.6 Hardness

Casted LM6 shows the bulk hardness (HV 5/10) number 50.6, having measured MPa value of 496.2, for the sample prepared through investment casting. Hardness value has improved significantly with incorporating silica into aluminium matrix and it has reported that hardness was increased nearly two times with addition of 30 % (based on Wt. %) crystalline silica into aluminium matrix [4].

![Figure 1: Microstructure of 5 Wt. % Crystalline silica- Aluminium Metal Matrix Composite](image-url)
Figure 2: Microstructure of 30 Wt. % Crystalline silica- Aluminium Metal Matrix Composite

Figure 3: Optical Microstructure of Al-Si alloy prepared in Sand mold (100X and 200X)

Figure 4: Optical Microstructure of Al-Si alloy prepared through Investment Casting (100X and 200X)

Figure 5: Microstructure (SEM) of Pure sintered aluminium

Figure 6: Microstructure (SEM) of 20 Wt. % Crystalline silica- Aluminium Composite
4. Conclusions

Striking observations based on this study are as follows.

- Crystalline silica-aluminium and silica gel-aluminium metal matrix composites are fabricated through Powder Metallurgy technique with improved physical and mechanical properties, concluded with consulting previous studies carried out by these authors [4].

- Both the cases, exact dimensions of products can be achieved with proper designing the mold or die in case of casting or fabricating composites through Powder Metallurgy technique. Investment casting can be described as an art or technique by which thin products, having thickness of ~ 1 mm, can be prepared with exact dimensions.

- Silica-Aluminium composites have fabricated with reduced cost compared to casted Al-Si alloy as firstly, less electricity consumption and secondly, used crystalline silica has prepared from natural sand.
Satisfactory improvement of hardness has observed in case of silica-aluminium composites and noted that only 5 % (based on Wt. %) addition of crystalline silica is able to significant improvement of hardness compared to casted Al-Si alloy.

Fabricated silica gel- aluminium composites are more porous compared to crystalline silica-aluminium composites of same compositions.

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