Studies on microstructure and mechanical behaviour of A7075- Flyash/SiC hybrid metal matrix composites

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Abstract. Experiments have been performed under laboratory condition to review the mechanical behaviour of the hybrid composites with aluminium matrix A7075 alloy, reinforced with silicon carbide (SiC) and Flyash. This has been possible by fabricating the samples through usual stir casting technique. Scanning electron microscopy was used for microstructure analysis. Chemical characterization of both matrix and composites was performed by using EDAX. Density, hardness, tensile and deformation studies were conceded out on both the base alloy and composites. Enhanced hardness and deformed properties were observed for all the composites. Interestingly improved tensile results were obtained for the composites than alloy. Dispersion of (SiC) and Flyash particles in aluminium matrix enhances the hardness of the composites.

Keywords: A7075 alloy, (SiC) and Flyash, (EDAX) Energy Dispersive X-ray Spectroscopy.

Nomenclature:

\[ \rho_{\text{MMC}} = \text{density of composite} \]
\[ m = \text{mass of the composite} \]
\[ m_1 = \text{mass of the composite in distilled water} \]
\[ \rho_{\text{H}_2\text{O}} = \text{density of distilled water} \]
\[ V_r = \text{weight ratio of reinforcement} \]
\[ \rho_i = \text{density of reinforcement} \]
\[ \rho_c = \text{density of composite} \]
\[ \rho_{\text{al}} \text{ is the density of the unreinforced alloy} \]

1 Introduction

Aluminium metal matrix composites (AMMCs), a metal/alloy reinforced with ceramic particles, are known for their high specific strength, tailor made materials and having superior modulus and hardness properties [1–3]. They share a good fraction in automobile and aerospace applications [4-6]. In order to attain high strength to low weight ratios in materials the usage of Aluminium metal matrix composites (AMMCs) are used very extensively which can be used for sophisticated aerospace and automobile structures because of their properties which can be customized in the course of the accumulation of preferred reinforcements . Among these particles reinforced metal matrix composites have found unique interest due to their elevated specific stiffness and specific strength at normal or elevated temperature. Normally micron sized ceramic particles are used as reinforcement to improve the properties of the MMCs. Due to their high heat resistant properties, ceramic particles are mainly used as reinforcements. Out of various ceramics used flyash is one of the economical as well as low density reinforcement which is available in plenty as waste derivative during incineration of charcoal at thermal power plants.
Ibrahim et al. [7] in his review observed that the properties of material obtained by means of metal matrix A composites with varying reinforcement percentage up to 20% in increment of five, by considering dissimilar alloys A6061, A2014, and A356. It is concluded that by rising reinforcement percentage the tensile properties like yield, and ultimate strengths has been increased whereas the elongation of alloy found to be decreased. Lloyd et al. [8] W.H et al. [9] and D Silva et al. [10] particle induced damage in MMCs has been studied, with Metal matrix composites with a size superior to 10 µm. The cracking of particles has been observed which indicate the dominant damage mechanism. Accordingly properties of metal matrix composites will depend on the particulate size.

In the present study an attempt has been made to obtain good strength and ductility by using hybrid reinforcements.

2. Experimental

2.1 Fabrication of composites

Aluminium based hybrid MMCs having 5 and 10 weight percentage SiC and Flyash particles of 53µm were fabricated by eddy process. AA 7075 was used as base material and chemical composition is depicted in table 1.

Table 1: Elemental analysis of AA 7075 alloy by wt. %.

| Zn | Cu | Mg | Si | Cr | Mn | Fe | Pb | Sn | Ti | Al |
|----|----|----|----|----|----|----|----|----|----|----|
| 5.1 | 1.2 | 2.1 | 0.4 | 0.18 | 0.3 | 0.5 | 0.029 | 0.012 | 0.2 | balance |

Figure 1 Stir casting

Figure 2 Casted fingers
The composites were produced by one of the oldest technique of stir casting as shown in figure 1. Small sized ingots of aluminium zinc alloy are loaded into a crucible made of graphite and placed in an electric furnace in which the melting was performed. A pool is created in the middle of graphite crucible using a stirrer operated mechanically and the temperature should be maintained around 770°C throughout the casting. The preheated particulates of SiC and flyash were dropped uniformly into the melt. To ensure continuous and smooth flow of the particles proper care should be taken to avoid the agglomeration. The inert gas shielding should be maintained throughout to avoid the oxidation as the casting is exposed to the atmosphere during the stirring time approximately 2 to 3 minutes. Still, the melt with reinforcement was in stirring condition the same was casted into cast iron mould which is preheated to 200°C as shown in figure 2. The fabricated ingots were homogenized at 110°C for 24hrs to minimize the chemical inhomogenities and to remove any internal stresses induced in the castings.

2.2 Characterization of composites

2.2.1 Metallography and hardness
To evaluate the morphological changes and elemental analysis of the composites and base alloy, a Scanning electron microscopy (SEM) (Model: Hitachi S-3400N - Japan) was used. Vickers micro hardness tester (Model: VHS 5B-Banbros) is used to find the hardness of the composites and base alloy by taking 10 readings on an average.

2.2.2 Density studies
By using the technique of Archimedes drainage method the densities of composites and base alloy were found by using the relation:

$$\rho_{MMC} = \frac{(m)}{((m-m_1) \times \rho_{H_2O})}$$

by using the concept of rule of mixtures the theoretical density calculations was done using following relation.

$$\rho_{composite} = Vr \rho_r + (1-Vr) \rho_m$$

2.2.3 Tensile tests
Tensile properties of alloy and composites were determined by means of INSTRON testing machine as per American Society for Testing and Materials- E-8 standards. Plotting has done continuously through a data attainment system with an electronic extensometer.

3 Results and discussions

3.1 Microstructures & EDS of composites and base alloy
Figure 3 (a-d) shows the SEM micrographs of flyash, SiC particles, and hybrid composites varying with wt. percentages. We can observe that, addition of particulates of the SiC and flyash in the base alloy, i.e. by increasing the reinforcement content by weight percent which can be seen noticeably, figure c shows the microstructure of the base alloy and whereas the figure (d) shows the addition of the particulates to the base alloy, difference was noticed clearly in the microstructures. From figure (e) it is noticed that the SiC particle embedded in the matrix.
2.3 EDS analysis

The EDS spectrum of the composite depicts the existence of Al, Zn, Mg and other elements which is shown clearly in figure 4 and no contamination has occurred. Since, perfect shielding of argon gas is maintained, traces of oxygen is not seen either with the matrix or the reinforcements.

Figure 3: (a) Microstructure of flyash particles (b) SiC particles
c) base d) 5% FA/SiC composite e)10% FA/SiC composite
Figure 4 spectrum for composite

2.4 XRD analysis
The XRD analysis in figure 5, shows the presence of silica $\text{SiO}_2$, alumina $\text{Al}_2\text{O}_3$, and Mullite $3\text{Al}_2\text{O}_3\cdot2\text{SiO}_2$.

Figure 5 XRD of composite

2.5 Density and hardness studies
The average theoretical and measured values of the density for the base alloy and composites are shown in table 2. It was observed that the SiC and flyash particulate addition to the base alloy drastically decreases the density of the resultant composites when compared to the base.
Table 2 Densities of alloy and composites

| S. No | Specimen                     | Measured density (g/cc) | Theoretical density (g/cc) |
|-------|------------------------------|-------------------------|----------------------------|
| 1     | Alloy                        | 2.81                    | 2.81                       |
| 2     | 5% FA/SiC composite          | 2.54                    | 2.59                       |
| 3     | 10% FA/SiC composite         | 2.45                    | 2.50                       |

By increasing the reinforcement percentage in base alloy the density was found to be decreased due to the low density of flyash particulates and the decrease was more for 10 percent reinforcement when compared to 5 percent and base alloy, also the decrease may be attributed to the increase of porosity with flyash. The obtained densities were checked by measured densities and found lower than theoretical ones as depicted in table 2. Due to the presence of hard alumina and silica present in flyash and SiC, the hardness was found to be increased from 102 VHN to 120 from base alloy to composite with 5% reinforcement and 125 VHN for composite with 10% reinforcement. The result reported by Hassan, S. F et al. and Ma, NG et al. [11,12] is in similar lines.

2.6 Tensile studies

Tensile test specimens with 6 mm gauge diameter were machined from extruded materials. Fig 6a and b depicts the experimental setup respectively.

Tensile properties of both alloy and composites were determined by means of INSTRON testing machine as per American Society for Testing and Materials- E-8 standards. Plotting has done continuously through a data attainment system with an electronic extensometer.

![Figure 6a](image1.png)  ![Figure 6b](image2.png)

(a) Tensile specimen measurements as per ASTM E-8 (b) Tensile testing machine

From table 3 it is evident that the composites exhibited superior properties when compared to the base alloy. Figure 7 shows the fractured specimens for composites.
Table 3 Mechanical behaviour of alloy and composite

| Composite       | Yield strength (MPa) | Ultimate tensile strength (UTS), Mpa | Young’s modulus (Gpa) |
|-----------------|----------------------|-------------------------------------|-----------------------|
| Alloy           | 140.1                | 186.8                               | 19.4                  |
| 5% composite    | 145.1                | 202.1                               | 21.3                  |
| 10% composite   | 151.2                | 223.1                               | 24.2                  |

Mohan Vanarotti [13] reported a subsidiary increase in ultimate tensile strength with the increment in reinforcement (SiC) in the matrix. Increased strength was not in apt with consequent increment in hardness due to improper rousing during the fabrication of the composite leading to inhomogeneities. A decrease in elongation is observed with the increase in reinforcement content and appears to be quite noticeable from the enhanced hardness allied with increased Silicon carbide content.

Khalid A et al. [14], reported that, with the increase in reinforcement content of Al₂O₃ in 6061 matrix the mechanical properties like yield strength, modulus of elasticity, ultimate tensile strengths seems to be improved, whereas the ductility found to be decreased. The improvement in properties may be attributed because of hard and brittle particles incorporated in 6061alloy matrix where higher functional stress are required to commence plastic deformation in the matrix.

Gonzalez et al [15] reported, at the preliminary stages of deformation the increment in load conceded by the particles is mostly due to the strain hardening behavior of the adjoining matrix, which is relatively ductile. Several authors [16-19] reported, the final fracture of the composites occurs by a ductile mechanism concerning the nucleation and expansion of voids in the base matrix, contributing to the final coalescence of the voids which are large and originating about fractured particle and also the strain hardening capacity is swamped from fractured particles result in the transfer of stress to nearby particles causing greater fracture of the particle.

Figure 7 Fractured specimens of composites

Figure 8 (a) and 5 (b) shows the microstructures of fractured specimens of base alloy and composites, particle cracking is identified in figure 5(b). It is also evident from the microstructures that the incorporation of SiC and flyash particles in base alloy leads to enhance the tensile strength. The improvement in properties is attributed due to the large particles which have slightly sharp corner profile used for fabrication because of the notch effect due to sharp ends. The other reasons might be the large particles have less exterior area in the matrix, and also the flaws present in large particles enable easy fracture under loading. The fractures in the composites during the tensile loading mainly depends on some important factors like cracking of particle, debonding of particle...
from the matrix, particle agglomerations and also due to interface inhomogenities, structural alternations in the matrix close to the interfaces or notch effects around and brittle reinforcement particles.

![Composite images](image.png)

(a) (b)

**Figure 8** (a) 7075 base alloy (b) flyash particle cracking of composite

4. **Conclusions**

1. Hybrid composites were fabricated by stir casting path successfully.
2. Uniform distribution of particles in the matrix phase is identified.
3. From the SEM figures, it clearly shows that there was a good interfacial bonding between the particles and matrix phase and also there were no voids and discontinuities.
4. With the increase in reinforcement content, the density of the composites found to be decreased when compared to the base alloy.
5. From the EDX analysis of composites, oxygen peaks were not observed in the matrix area, confirming the non contamination of the composites from the atmosphere.
6. The composite hardness was increased by increase in the reinforcement content.
7. The tensile properties like yield, ultimate and elastic modulus are enhanced to the composites when compared to the base alloy.

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