Synthesis and characterization of Al6061-Fly Ash\textsubscript{p}-SiC\textsubscript{p} composites by stir casting and compocasting methods


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Abstract

Stir casting is one of the simplest ways of producing aluminum matrix composites (AMCs). This work focuses on the fabrication of AMCs reinforced with various weight percentages of SiC particulates and a constant weight percentage of Fly Ash by modified stir casting route. The wettability of SiC and Fly ash particles in the matrix was improved by adding magnesium into the melt. The microstructure and mechanical properties of the fabricated AMCs were analyzed. The optical and scanning electron micrographs revealed a homogeneous dispersion of both SiC and Fly ash particles in the aluminum matrix. The SEM micrographs revealed that the addition of Fly Ash helped to prevent SiCp dissolution and the formation of Al\textsubscript{4}C\textsubscript{3}. The mechanical properties like hardness and tensile strength were improved with the increase in weight percentage of SiC particulates with constant weight percentage of Fly Ash in the aluminum matrix.

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Keywords: Al/SiC\textsubscript{p} composites; SiC dissolution; Aluminum carbide

1. Introduction

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, AMCs is widely used in aerospace, automobiles, marine etc. [1–3] Researchers, especially in the defense application, are continuously striving hard to find the materials that suit their specific requirements. Improvement in production methods and finding the alternate materials are a few options to meet the above requirement. While their current usage is relatively limited apparently

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due to their high production cost. Among the various discontinuous reinforcements used, fly ash (FA) is one of the cheapest available reinforcement. The advantages of using FA as the reinforcement due to its low density paves way for the development of effective and low-cost AMCs. Most of the effort to develop Aluminum based composites from waste materials are centered on the use of FA. In addition to lowering the cost of production, incorporation of FA into aluminum has been proved to decrease the composite density, increase the hardness, abrasion resistance and stiffness.

AMCs are fabricated using conventional liquid phase processing methods such as high energy laser melt injection, plasma spraying, cast sinter and electron beam irradiation [7–10]. The high processing temperature causes decomposition of ceramic particles and the formation of brittle compounds. SiC_p reinforced aluminium matrix composite is fabricated through pressure infiltration of liquid aluminium [12,13], powder metallurgy [14], powder injection molding process [15] and squeeze casting technique. Among the various manufacturing processes, the conventional stir casting is an attractive processing method for producing AMCs [7] as it is relatively inexpensive and offers a wide selection of materials and processing conditions and suitable for mass production and production of complex profiled composite components without damaging the reinforcement particles. Due to these salient features of stir casting method, recently many attempts have been made to produce different composites using this method [19–20].

In the present work, an attempt has been made to fabricate AA6061/(SiC + Fly Ash) hybrid composite and study the microstructure and sliding wear behavior. In particular, when the same composites are fabricated by the melt infiltration route, degradation of SiC takes place. SiC is potentially attacked by liquid aluminum, according to the following reaction

$$3\text{SiC} + 4\text{Al} \rightarrow \text{Al}_4\text{C}_3 + 3\text{Si} \quad (1)$$

Among the most recent procedures proposed to prevent the attack of SiC, the intentional oxidation of SiC particles and the incorporation of SiO2 particles into the SiCp preforms have been proved to be effective [11–14]. It was reported by some researchers that the addition of a certain amount of silicon into the aluminum matrix prevents SiC dissolution and consequently avoids the formation of the unwanted aluminum carbide (Al_4C_3). Interestingly, FA contains SiO_2 as the main constituent and both represent potential sources of Si. Depending on the content of Mg in the aluminum alloy and processing temperature, reactions for the formation of MgO or MgAl2O4 in the composites may be favored [7,8].

$$2\text{Al} + 2\text{SiO}_2 + \text{Mg} \rightarrow \text{MgAl}_2\text{O}_4 + 2\text{Si} \quad (2)$$

<table>
<thead>
<tr>
<th>Nomenclature</th>
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<tbody>
<tr>
<td>SiC</td>
</tr>
<tr>
<td>Al_4C_3</td>
</tr>
<tr>
<td>Si</td>
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2. Experimental Procedure

2.1. Fabrication Process

AA6061 rods were placed in a graphite crucible and the crucible was coated to avoid contamination and heated using an electrical furnace. The chemical composition of AA6061 aluminum alloy is presented in Table 1. The ultimate tensile strength of cast AA6061 was found to be 160 MPa. The micro and
The macrohardness of cast AA6061 were 45 VHN and 30 BHN respectively. The AA6061 rods weighing 1500 g was melted at a temperature of 920°C using an electric furnace shown in Fig. 1. The molten alloy was agitated with the help of a mechanical stirrer to form a fine vortex. The mixtures of preheated SiC and Fly ash particles at a temperature of 900°C for 90 minutes were then added at a constant feed rate into the molten aluminum. 1 wt.% of magnesium particles was used as a wetting agent and the amount of silicon carbide particles used in each MMC was varied from 7.5 and 10 wt.% and a constant weight percentage of 7.5 wt.% fly ash was considered for this fabrication. The various process parameters employed are given in Table 2. Argon gas was supplied into the melt during the operation to provide an inert atmosphere. Two stage stirring was used to disperse the silicon carbide and Fly ash particles in the matrix alloy.

The SEM micrograph of the Fly ash and Silicon Carbide powder are shown in fig 2. The first stage of the stirring was carried out when the slurry was in a semi-solid condition and the second stage when the slurry was remelted to a temperature above liquidus of aluminum. The stirring was continued till the composite was poured into a permanent mold. The fabricated castings of the AMCs are shown in Fig. 3.

Table 1. Chemical composition of alluminum alloy (6061-T6).

<table>
<thead>
<tr>
<th>Elements</th>
<th>Mg</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
</tr>
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<tbody>
<tr>
<td>% by weight</td>
<td>0.95</td>
<td>0.54</td>
<td>0.22</td>
<td>0.17</td>
<td>0.13</td>
<td>0.09</td>
<td>0.08</td>
<td>0.01</td>
<td>Balance</td>
</tr>
</tbody>
</table>

Table 2. Chemical Composition of Fly Ash

|-------------|--------|--------|--------|--------|--------|--------|--------|--------|------------|

Table 3. Process Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle speed</td>
<td>Rpm</td>
<td>350</td>
</tr>
<tr>
<td>Stirring time</td>
<td>Second</td>
<td>600</td>
</tr>
<tr>
<td>Stirring temperature</td>
<td>°C</td>
<td>775</td>
</tr>
<tr>
<td>Preheating temperature of SiC &amp; FA</td>
<td>°C</td>
<td>900</td>
</tr>
<tr>
<td>Preheating time</td>
<td>Minutes</td>
<td>90</td>
</tr>
<tr>
<td>Preheat temperature of mold</td>
<td>°C</td>
<td>300</td>
</tr>
<tr>
<td>Powder feed rate</td>
<td>g/s</td>
<td>1.2 to 1.6</td>
</tr>
</tbody>
</table>
Specimens were prepared from the castings to carry out microstructure and mechanical characterization. The specimens prepared from the cast AMCs were The casted specimen is polished and etched as per the standard metallographic procedure. The microstructures of color etched specimens were observed using a scanning electron microscope (SEM). The microhardness was measured using a microhardness tester at 500 g load applied for 15 s. The tensile specimens were prepared as per ASTM E08 standard and the dimensions are shown in fig 4. The ultimate tensile strength (UTS) was estimated using a computerized universal testing machine. The fracture surfaces of the failed tensile specimens were observed using SEM.
Fig 3. A. Composition of AA6061/SiC7.5p/Fly ash7.5p, B. Composition of Al6061/SiC7.5p/Fly ash7.5p & C. Cast Al6061 alloy

Fig 4. A Tensile Test Specimen, B. After Test & C. Dimension of the Test Specimen
3. Results and discussion

3.1. Evaluation of Microstructure:

Fig. 5 shows the microstructures of fabricated AA6061 alloy matrix as well as AA6061 alloy matrix reinforced with Fly Ash_{p} and SiC_{p} composites. Microstructure of cast AA6061 alloy matrix is presented in Fig. 5a which reveals the formation of a-aluminium dendritic network structure which is formed due to the supercooling of composite during solidification. Precipitation of Mg2Si is also visible in the microstructure.

Fig. 5B–E shows the microstructure of AA6061–Fly Ash_{p}-SiC_{p} composites containing different weight percentages of Fly ash and SiCp reinforcement. Microstructures of the composites presented in Fig. 5B–E clearly reveals the homogeneous distribution of the Fly ash and SiCp in the Al alloy matrix and there is no evidence of porosity and cracks in the castings. This might be related to proper process parameters employed for the production of castings. During solidification of AA6061–Fly ash and SiCp composite, Fly ash and SiCp are rejected in the direction of refined a-Al grains. Refinement of a-Al grains may be due to Fly ash and SiCp themselves, which act as nucleus on which the a-aluminium grains solidify and Fly ash and SiCp offer resistance to the growing a-Al phase during the solidification process. Fig. 5C shows the precipitation of Mg2Si. The sources for the formation of Mg2Si are addition of Mg in molten Al alloy matrix and Mg and Si are already present in the AA6061 alloy as major constituent.

Fig. 5B–E shows the scanning electron micrographs of the fabricated AMCs. The SEM micrographs reveal that the dispersion of SiC and Fly ash particles in the matrix is homogeneous. It is evident from the figure that the formation of the aluminium carbide (Al_{4}C_{3}) needle phase is successfully avoided by the presence of FA in the SiCp preforms. The distribution of the FA and SiC particles appears to be uniform throughout the aluminum matrix. This can be attributed to the effective stirring action and the use of appropriate process parameters. Homogeneous distribution of particles is a prerequisite to enhance the mechanical properties of the matrix alloy. Further, the FA and SiC particles are well bonded to the aluminum matrix.

3.2. Evaluation of mechanical properties:

The mechanical properties of matrix alloy AA6061 is improved upon the incorporation of SiC and FA particles. Fig. 6 shows the relation between weight percentage of SiC and FA reinforcement particulates and hardness of fabricated AMCs. It is observed that the micro and macrohardness of AMCs linearly increase when the reinforcement particulates increases. Addition of reinforcement particles in the matrix increases the surface area of the reinforcement and the matrix grain sizes are reduced. The presence of such hard surface area of particles offers more resistance to plastic deformation which leads to increase in the hardness of composites. It is reported [3] that the presence of hard ceramic phase in the soft ductile matrix reduces the ductility of composites due to reduction of ductile metal content which significantly increases the hardness value evaluated against the weight percentage of SiC and Fly ash particulates. SiC and FA particles are very effective in improving the tensile strength of the composite from 173 Mpa to 213Mpa. It may be due to the strengthening mechanism by load transfer of the reinforcement [19]. The addition of SiC and Fly ash particles in the matrix induces much strength to matrix alloy by offering more resistance to tensile stresses. It is well known that the thermal expansion coefficient of SiC and Fly ash particle is 3.25 x 106/ °C and for aluminum alloy is 23 x 106 / °C. The thermal mismatch between
Fig 5. SEM micrographs of AA6061/fly ash compo cast composites containing fly ash: (a) AA6061 (b) 7.5wt.% SiC 7.5wt.% Fly ash, (c) 7.5wt.% SiC-7.5wt.% Fly ash (d) 10wt.% SiC-7.5wt.% Fly ash (e) 7.5wt.% SiC-7.5wt.% Fly ash

matrix and the reinforcement causes higher dislocation density in the matrix and load bearing capacity of the hard particles which subsequently increases the composite strength [14]. Fig. 8a reveals
the fracture surface of AA6061 matrix alloy. It shows a net work of large size dimples which indicate large amount of plastic flow prior to failure. Fig. 9b reveals the fracture surface of AA6061–10wt. %SiC - 7.5wt. % Fly ash composite. It shows a net work of dimples whose size is smaller compared to matrix alloy. The Fly ash and Silicon carbide refined the grain size of matrix alloy and reduced the ductility which resulted in smaller size dimples.

![Graph 1](image1.png)

**Fig 6.** The effect of amount of Fly ash and SiC particulates on the hardness of stir cast AMCs

![Graph 2](image2.png)

**Fig 7.** Effect of Weight % of SiC & Fly Ash content on tensile strength

![Graph 3](image3.png)

**Fig 8.** Effect of Weight % of SiC & Fly Ash content on Elongation
4. **Conclusion**

The Al–SiC-Fly ash composites were produced by modified stir cast route with different weight percentage (viz 7.5 wt. % of FA and varying weight percentage 7.5 and 10wt.% of SiC) of reinforcement and the microstructure, mechanical properties were evaluated. From this study, the following conclusions are derived.

1. The SEM micrographs revealed the presence of SiC and FA particles in the composite with homogeneous dispersion.
2. The formation of the Al₄C₃ phase was successfully avoided by the presence of FA in the SiCp preforms.
3. The micro and macrohardness of the composites were increased from 69.53 HV to 78.8 HV and 49.4 BHN to 57.21 BHN with respect to addition of weight percentage of SiC and constant weight percentage of FA particles.
4. The reinforcement of particles has enhanced the tensile strength of aluminum matrix and composites from 173 MPa to 213 MPa.

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