Fabrication and Characterization of Aluminum based composites reinforced with silicon carbide particles

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Abstract
In present investigation, problems such as lower resistance, ductile, low tensile/compressive strength and fracture toughness of Aluminum metal matrix has been overcome by adding silicon carbide (SiC) as a reinforcement particle. The experiment was performed on different composition of SiC (5, 10, 15, 20, 25 and 30 of wt.% of Al). The Ultimate tensile strength (UTS) of the composites increases, on increase in wt.% of SiC. At 25 wt.% of SiC particle UTS is increased by 176.4 % as percentage elongation decreases to as compared to Aluminum metal matrix whereas SiC particle results in brittleness fabricated composites. Compressive strength of the AMCs increases whereas fracture toughness decreases with increase in the reinforcing phase. Further, enhancement in wettability of metal and ceramic particle has been done by adding Magnesium (Mg) which results in decreasing matrix alloy surface tension and solid/liquid interfacial energy. Al is a good conductor of electricity and reinforcing it with SiC, which is a semiconductor has high influence on the conductivity of composite. On increasing wt % of SiC, reduce in conductivity can be observed. But after applying threshold voltage the same will have the reverse effect on conductivity.

Keyword: Metal matrix composites; Wettability; Fracture toughness; electrical conductivity

INTRODUCTION
Composite material comes under engineering materials which have elevated mechanical properties as compared to conventional material. In Composites, materials are combined by mechanically or metallurgically binding them together[1,2,3]. Metal matrix composites (MMCs) one of the classification of composites material in which reinforcing
material dispersed into the metal matrix. These composites can be used at higher service temperature than their base metal counterparts. These reinforcements in these materials may improve specific stiffness, specific strength, abrasion resistance, creep resistance and dimensional stability. The MMCs is light in weight and resist wear and thermal distortion, so it mainly used in automobile industry.

**Material and Methods**

**Methods**

A schematic view of the set up has been shown in Figure 1 representing all the components of the set up. Coal fired furnace is used to melt the matrix material (aluminum) in graphite crucible covered with insulation lid. Once the material is completely melted and raised to desirable temperature, measured using thermocouple, reinforced material is added and stirs using mild steel stirrer aided with motor to provide necessary RPM. Convention casting method is employed to fabricate the composites material. To fabricate the composite raw Aluminium first melted in a crucible by heating in a coal fired furnace at 800º C. The stirrer is placed at the depth of 2/3 from the bottom surface of crucible and also preheated before immersing into the melt. First Aluminum is completely melted by heating the furnace above the liquidus temperature which is about 760 ºC. Then slurry is cooled down just below the liquidus temperature to maintain it in a semi-solid state. Silicon carbide particles are introduced into the molten metal in a semi solid state and manual
mixed for 10 minutes. Silicon carbide particles have been varied form 5-30 wt.% with respect to Aluminium to obtained AMCs. Surface of Silicon carbide particles is oxidized by preheated at temperature of 1100 ºC before adding to Aluminium matrix. After mixing the composite, slurry is again reheated to the liquid state and again automatic mechanical mixing is done for 10 minutes. To get desire shape slurry is poured into mould after stirring process. Further magnesium about 1 wt. % with respect to Aluminum is added to increase the wattablity and to reduce floating of silicon carbide particles on the molten surface between the contact surfaces. Air cooling has been opted for solidification of the casted composites. Similar procedure, as explained above has been adopted to make the composites having particles of silicon carbide and magnesium. Size of the casted composites is 150 × 120 × 12 mm³.

**Tensile and Compression test**

Tensile and compression test of Al-SiC and Al-SiC-Mg Composites are performed on 100 KN servo hydraulic UTM machine (model 2008, ADMET make) at the displacement rates of 1 mm/min. For tensile test specimens are prepared as per ISO-6892 standard and for compression tests Specimens having aspect ratio (length/diameter) of 1.5 are taken as per the ISO-1708 standard.

**Hardness test**

Rockwell Hardness test machine is been employed to study the effect of SiC particle on the hardness of Al-SiC and Al-SiC-Mg composites. To perform the experiment indenter having spherical diamond-tipped cone with angle 120° and tip radius of 0.2 mm is used. Effect of surface irregularity has been removed by applied minor load of 10 kg. After that, the dial is set to zero and then major load is applied. After unloading of the major load indentation is measured while the minor load is still on. The value of hardness number directly obtained from the main scale.

**Fracture toughness test**

Fabricated composites may have internal defect due to dislocation, chemical inhomogeneity, residual stress etc. which results in stress concentration. Fracture Toughness is the ability of material to resists crack growth therefore, fracture toughness becomes important parameter. Fracture Toughness (K_Ic) of Metallic Materials is tested according to ASTM E399 standard. Fracture toughness (Klc) of AMCs is
calculated through equation (1).

\[ K_Q = \frac{3PL}{2bw^2} f(\frac{a}{w}) \]  

(1)

\[ f(\frac{a}{w}) = 1.93 - 3.07(\frac{a}{w}) + 14.53(\frac{a}{w})^2 - 25.11(\frac{a}{w})^3 + 25.80(\frac{a}{w})^4 \]  

(2)

Where, \( P, a, b, L \) and \( w \) are the applied load, notch depth, width, span length and depth respectively.

Conditions for \( K_Q \) to be \( K_{lc} \) are

\[ 0.45 < \frac{a}{w} < 0.55 \]  

(3)

\[ 1 \leq \frac{P_u}{P_Q} \leq 1.1 \]  

(4)

\[ a, b, (w - a) > 2.5 \left( \frac{K_Q}{\sigma_{ys}} \right)^2 \]  

(5)

**Electrical conductivity**

Through this test effort has been made to find the effect on electrical conductivity after adding SiC in various percentages. SiC is semiconductor, therefore effect of SiC particles on electrical conductivity become important parameter for the characterization of composites. Test to measure conductivity is performed by using four probes. To calculate the electrical conductivity disc sample of diameter 30 mm and 5 mm thickness is used, before conducting the experiment both sides is polished and four point probe technique used. Semiconductor has voltage-dependent resistance. When certain voltage known as threshold \( V_T \) is applied to the cross-section resistance of material is decrease. Therefore, electrical conductivity of AMCs are also evaluated at higher voltage.

**Result and Discussion**
Figure 2: Stress-strain relation for compressive strength (A) varying SiC wt. % and (B) varying SiC wt. % with 1 % Mg

Table 1: Compressive strength and hardness of different aluminum composite

<table>
<thead>
<tr>
<th>% Composition</th>
<th>Compressive strength (MPa)</th>
<th>Hardness (HBR)</th>
<th>Fracture Toughness (MPa√m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>213 ± 11</td>
<td>31 ± 1</td>
<td>9.68 ± 0.73</td>
</tr>
<tr>
<td>Al + 5% SiC</td>
<td>247 ± 13</td>
<td>43.33 ± 2.08</td>
<td>9.16 ± 0.71</td>
</tr>
<tr>
<td>Al + 10% SiC</td>
<td>260 ± 12</td>
<td>47.00 ± 2</td>
<td>8.80 ± 0.53</td>
</tr>
<tr>
<td>Al + 15% SiC</td>
<td>295 ± 21</td>
<td>51.66 ± 4.16</td>
<td>7.92 ± 0.43</td>
</tr>
<tr>
<td>Al + 20% SiC</td>
<td>335 ± 22</td>
<td>55.33 ± 3.79</td>
<td>7.25 ± 0.41</td>
</tr>
<tr>
<td>Al + 25% SiC</td>
<td>360 ± 25</td>
<td>59 ± 3.61</td>
<td>6.16 ± 0.31</td>
</tr>
<tr>
<td>Al + 30% SiC</td>
<td>379 ± 29</td>
<td>51.66 ± 3.2</td>
<td>4.40 ± 0.13</td>
</tr>
<tr>
<td>Al + 5% SiC +1% Mg</td>
<td>361 ± 31</td>
<td>58 ± 4.2</td>
<td>7.043 ± 0.33</td>
</tr>
<tr>
<td>Al +10% SiC +1% Mg</td>
<td>383 ± 33</td>
<td>64 ± 4.9</td>
<td>5.28 ± 0.24</td>
</tr>
<tr>
<td>Al+ 15% SiC+ 1% Mg</td>
<td>389 ± 35</td>
<td>63 ± 4.3</td>
<td>3.52 ± 0.17</td>
</tr>
</tbody>
</table>

Compressive strength

SiC is a ceramic which is brittle in nature and has high compressive strength compared to Aluminum. Investigation to find the interaction between Al and SiC is a major parameter to optimize the wt. % of SiC. Compressive strength results of the Al-SiC composites samples are presented in the Table 1. The interaction effect is shown in Figure 2. As observed, compressive strength of the composites increases with increase in wt. % of SiC. When SiC particles
increases from 5 to 10 wt % about 6 % increase in compressive strength is observed, but the difference is not equal to the one observed at 5 wt % of SiC is added to aluminum. There is sudden increase in compressive strength by 16 % over base Al used. In Al based SiC composite Al with 30 wt % of SiC gives maximum compressive strength of 379 MPa which is 78 % higher than Al matrix. Adding 1 wt % of Mg, results in further enhancement in the compressive strength and at 15 wt. % of SiC compressive strength found to be 389 MPa which is 82 % higher than parent metal.

**Hardness**

Table 1 represents the hardness of different Al-SiC and Al-SiC-Mg composites. Hardness of the parental material is about 31 HBR. With increase in SiC content hardness increases upto 25 wt.% and lateral on decreases at 30 wt.%. At 25 wt % of SiC particles composite hardness is about 59 HBR which about 90.32 % higher than parental metal. Further enhancement in the hardness is achieved by adding 1 % Mg at each level of SiC composition. At 15 wt % of SiC particles composite, addition of 1 % Mg results in increase in hardness about 106.64 % than parental metal and 18.52 % with respect to Al-15%SiC.

Beyond this weight fraction the hardness trend started decreasing as SiC particles interact with each other leading to clustering of particles and consequently settling down. Eventually the density of SiC particles started decreasing locally thereby lowering the hardness. Directly below the indentation the density of the particles increased locally, compared to regions away from the depression. The hardness increases with the amount of silicon and the presence of 1 wt % of Mg just aids to the hardness. But clustering of particles affects the hardness to extent of concern.

**Fracture toughness**

Table 1 provides the necessary parameters required to calculate fracture toughness. Equations (3-5) are the three validity equations which are necessary for $K_Q$ to be equal to $K_{IC}$. Here, except first others two are not verified. Hence, $K_Q$ is not equal to $K_{IC}$. Therefore, this test provides local fracture toughness. Result shows that with increase in SiC content fracture toughness of Al-SiC composites decreases, addition of 1 % Mg results in further decrease in fracture toughness. Fracture toughness is the resistance of material to brittle fracture. Al with no particulate has 9.6 MPa√m while 30
wt % of SiC has 4.4 MPa√m, which is reduction of 54.5% in the fracture toughness. Similarly, on adding 15 wt % of SiC with 1 wt % Mg to the Al matrix reduction of 63.6% in the fracture toughness is observed.

Figure 3 Fracture toughness of AMCs (A) effect of variation of wt.% of SiC and (B) effect of 1 wt % of Mg

Electrical Conductivity

Al is a metal while SiC is binary compound which is semiconductor. Table 2 provides the information of electrical conductivity of various composite used in the investigation at 35 °C at 1 Volt. Aluminum is a good conductor of electricity. Aluminum used in investigation has conductivity of 4.78289 Siemens per metre(Sm⁻¹). Addition of SiC, which is a ceramic particle, decrease in conductivity, is experienced. At 30 wt % of SiC in Al matrix conductivity become zero at 1 Volt, while increases to 0.02393 Sm⁻¹ at 10 Volts has been observed. Figure 4.12 shows the variation of electrical conductivity of Al composites with various wt % of SiC. Since SiC is a semiconductor hence increases in applied voltage to 10 Volts helps in breakdown, which in turns results in mobility of charge carriers therefore increase in electrical conductivity are experiences. Once the breakdown voltage is achieved increase in conductivity is found with increase in amount of SiC particles. To enhance wettability addition of Mg to Al matrix with various (5, 10, 15) wt % of SiC resulted in decrease in electrical conductivity. Addition of Mg leads to formation of MgO on the interface. MgO is ionic compound and thus does not conduct electricity in its solid state because there are no delocalized electrons in its ionic lattice structure. But if provided with increased applied voltage it can conduct electricity due to transfer of ions (cations and anions) in
lattice. Figure 4 shows variation in electrical conductivity of Al matrix with various wt % of SiC and 1 wt % of Mg. 5 wt % of SiC + 1 wt % of Mg shows 0.2385 Sm\(^{-1}\) conductivity at 1 Volt but, 10 wt % of SiC + 1 wt % of Mg and 15 wt % of SiC + 1 wt % of Mg shows zero conductivity at 1 Volt and 35\(\text{o}\)C due to increase in SiC particles and layer of MgO. Increase in applied voltage upto 100 Volts helps to excite the charge carries since; at 100 Volts breakdown phenomenon occurs as shown in figure 4. Once the breakdown voltage of 100 Volts is achieved increase in conductivity can be seen with increase in amount of SiC particles. Therefore, at 100 Volts conductivity of 15 wt % of SiC + 1 wt % of Mg is 0.18983 Sm\(^{-1}\) which is greater than conductivity of 10 wt % of SiC + 1 wt % of Mg is 0.07231 Sm\(^{-1}\).

Table 2: Electrical conductivity for various composites at 35\(\text{o}\)C at 1 Volt

<table>
<thead>
<tr>
<th>% Composition</th>
<th>Electrical conductivity (Sm(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 V</td>
</tr>
<tr>
<td>Al</td>
<td>4.783</td>
</tr>
<tr>
<td>Al + 5% SiC</td>
<td>0.335</td>
</tr>
<tr>
<td>Al + 10% SiC</td>
<td>0.279</td>
</tr>
<tr>
<td>Al + 15% SiC</td>
<td>0.229</td>
</tr>
<tr>
<td>Al + 20% SiC</td>
<td>0.0316</td>
</tr>
<tr>
<td>Al + 25% SiC</td>
<td>0.0267</td>
</tr>
<tr>
<td>Al + 30% SiC</td>
<td>0.00</td>
</tr>
<tr>
<td>Al + 5% SiC +1% Mg</td>
<td>0.239</td>
</tr>
<tr>
<td>Al +10% SiC +1% Mg</td>
<td>0.00</td>
</tr>
<tr>
<td>Al+ 15% SiC + 1% Mg</td>
<td>0.00</td>
</tr>
</tbody>
</table>
4 Conclusions

The results indicate that the mechanical properties of the composite, including tensile strength and hardness are enhanced by the increment of the weight fraction of reinforcing phase but the elongation of the composite decreased as the reinforcing phase increased. This is mainly due to the brittleness of the SiC particles which act as micro void initiator. The Ultimate tensile strength of the composites increases, on increase in wt% of SiC. Maximum strength of 88 MPa is achieved on 25 wt% of SiC which can be further increased to 104 MPa on addition of 1 wt% of Mg by increasing of wettability of Al composite.

References