EVALUATION OF MECHANICAL PROPERTIES OF ALUMINIUM ALUMINA COMPOSITES

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ABSTRACT
The 6061 Aluminium (Al6061) alloy reinforced with Aluminium oxide (Al2O3) particle using various size (25, 50& 80 microns) with constant volume fraction of about 10% is fabricated by stir casting method. Morphology of the composite and the particle distribution were investigated by Scanning Electron Microscope (SEM). The microstructure examined by SEM reveals that Al2O3 particle is well spread evenly in the all the three specimens. The variation in mechanical properties such as hardness, tensile strength and density with respect to increase in particle size of Al2O3 was investigated. The results illustrate that the hardness and yield strength decreases with increase in particle size. The density of the composites increases with increase in particle size and the amount of porosity in the composites increases with decrease in size of particles. The mechanical properties of the composites are improved in relation to the Al6061 alloy.

Keywords: Stir casting, Particles size, Hardness, SEM, Yield strength.

1. INTRODUCTION
Composites are recent innovative material in the field of engineering, which finds its application especially in automotive and aerospace industries. The reduction in weight of these materials allows them to design engineering components with improved mechanical properties. Aluminium reinforced with either Al2O3 or SiC found to be important from other types of ceramics particles. Developments in reinforcing Al2O3 with aluminum alloy enhances the machinability, thus lowering the production cost and widens industrial applications were studied by Al-Qutub et al. (2002). Although various fabrication methods available such as extrusion, powder metallurgy etc. but still stir casting is preferred because it is most economical process. Vencel et al. (2008) studied that the microhardness and density increases with the addition of particle. Das et al. (2003) studied that the particulate shape affects the mechanical properties of composites. Further they concluded that ultimate tensile stress and proof stress increases whereas ductility decreases with the addition of both angular and spherical reinforcements. Wahab et al. (2009) studied the characterization of aluminium metal matrix composites reinforced with aluminium nitride and found that hardness was 44 HV for Al-Si matrix and increased to 89 HV for an Al-Si composite reinforced with 5% by weight of AlN powder. Naik et al. (2011) studied the mechanical properties of carbon-carbon composites performed by yarn method and concluded that the carbon fiber % increases, the material properties also increases. Cannbrnero et al. (2003) and Lewandowski (2000) studied the mechanical properties of particulate-reinforced composites and concluded that Metal Matrix Composites (MMC) is preferred in automotive sector than fiber composites because of their anisotropic properties and low cost. Basavarajappa et al. (2004) studied the mechanical properties of Al2024/SiC and Al2024/graphite MMCS. From the results obtained they concluded that the increases in volume fraction of reinforcement results in increase in mechanical properties. Barekar et al. (2009) reported an improved tensile strength in aluminium graphite composites produced by distributive mixing and dispersive mixing under intensive shearing compared to conventional process. During fabrication of Aluminium boron MMC, the shrinkage porosity was eliminated by applying high pressures during squeeze casting was studied by Olaya-Luengas et al. (2010). Blushan and Kumar (2009) observed that the porosity in Al7075 SiC composite is affected by the stirring speed, holding time and holding temperature.

The objective of present work is to investigate the response of particle size on microstructure & mechanical properties of Al6061/Al2O3 MMC. The microstructure was examined by Scanning Electron Microscope. It is known that MMCS are popular for its high strength and high hardness, which paves the way for its use in aerospace and structural industries, the present investigation aims at studying these properties in the Al6061-Al2O3 composites in detail. The tensile strength and hardness was measured by Universal Testing Machine (UTM) and Rockwell Hardness Tester respectively.

2. EXPERIMENTAL METHODS
2.1 Materials and methods
Three specimens of various micron sizes of Al2O3 particle (25μm, 50μm, 80μm) is reinforced with Al6061 at constant volume fraction of 10% are considered. The composites used in the present work was prepared by stir casting route and moulded in the form of a cylinder of 50 mm outer diameter and height of 200 mm. Various
researchers used stir casting method to fabricate composites (Anilkumar et al., 2011; Premnath et al., 2012; Alaneme, 2012). The apparatus for stir casting is shown in the Figure 1. The chemical composition of the Al6061 alloy is shown in the Table 1. The Al6061 matrix in the form of chips is introduced in the crucible and heated to a temperature of about 800 °C, at which aluminium gets into molten state and then the preheated Al2O3 particles was introduced to it. At this stage a mechanical stirrer which rotates at a speed of 400rpm is used for uniform distribution of Al2O3 particles in the aluminium alloy. The time of mixing as well as mixing rates were adjusted according to the amount of the reinforcement particles. After the complete addition of the particles the stirring was stopped and the metal was poured into the permanent graphite moulds. Thus three grades of specimen were fabricated.

2.2 Experimental procedure

Microstructure and mechanical characterization of both matrix material and composites includes metallographic examinations with SEM, hardness and yield tensile strength measurements. The sample preparation for microstructure study was done first by polishing the sliced samples with emery paper up to 1200 grit size, followed by polishing with diamond suspension on a buffing wheel using velvet cloth. The polished surface was examined by using scanning electron microscope.

Table 1 Chemical composition of 6061 Aluminum alloy.

<table>
<thead>
<tr>
<th>Element</th>
<th>Si</th>
<th>Cu</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Zn</th>
<th>Sn</th>
<th>Ti</th>
<th>Pb</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt %</td>
<td>0.80</td>
<td>0.35</td>
<td>0.8</td>
<td>0.02</td>
<td>0.008</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
<td>97.9</td>
<td></td>
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</tbody>
</table>

The cast composite specimens were machined using a CNC lathe to get the standard dimensions to perform the tensile test. The tensile test was conducted using electronic tensile testing machine at room temperature using ASTM E8-95 standard (1989) at a strain rate of 10⁻³ s⁻¹. Hardness tests were performed on composites to know the effect of Al2O3 particles in the matrix materials. The hardness of a material determines the strength of materials. The polished composite specimens were tested for their hardness, using Rockwell hardness testing machine with diamond indenter for 100 KgF load. The load was applied for 30 secs. The Rockwell hardness tests were conducted in accordance with the ASTM E10. The most common method used to measure hardness for MMC and Al alloys is Rockwell hardness B scale. (Shen et al., 2001; Ceschinetti et al., 2006). Five sets of reading were taken on the specimen on various places to assess the reproducibility and an average value was calculated. The density of the composites can be calculated theoretically by rule of mixture and experimentally by Archimedian principle. The density calculated by rule of mixture uses the formula

\[ P_h = P_m V_m + P_i V_i \] (1)

where \( V_m \) and \( V_i \) represents the volume fraction of matrix and reinforcements respectively. The density is measured in Archimedian method by weighing small workpieces cut from the composite cylinder first in air and then in water. The porosity of the composite materials was determined by using the theoretical and experimental densities, according to the equation

\[ \text{Porosity}\% = \frac{\rho_h - \rho_{exp}}{\rho_{exp}} \] (2)

where \( \rho_h \) and \( \rho_{exp} \) represents the theoretical and experimental densities respectively.

![Figure 1 Stir casting set up.](image1)

![Figure 2 Microstructure of the specimen a) Al6061 alloy, b) Al6061 with Al2O3 (25 µm), c) Al6061 with Al2O3 (50 µm) & d) Al 6061 with Al2O3 (80 µm).](image2)
3. RESULTS AND DISCUSSION

3.1 Microstructure

As the microstructure plays a major role in the overall performance of a composite and the physical properties depend on the microstructure, reinforcement particle size and distribution in the alloy, prepared samples were investigated using a SEM. Figure 2 shows the micrograph of Al6061 alloy and Al–Al2O3 composites. The distribution of the alumina particles in the aluminium matrix is noticeably uniform with random orientation throughout the matrix. Further from the Figure 2b & 2d the homogeneity of the cast composites is revealed. Homogeneous distribution of the reinforcement in the matrix is essential to form a composite with uniform mechanical properties. From the Figure 2c, the produced cast composite shows clustering of Al2O3 particles at some specific places. Porosity may be due to improper casting or particles pull out during grinding and polishing. The EDAX (Energy Dispersive X-ray analysis) analysis shown in the Figure 3 reveals the composition of the three cast specimens. The specimen consist only major peaks of aluminium in all the three cast specimen as expected and no reaction products were found.

3.2 Hardness

The size of Al2O3 particles was found to have influence in determining the hardness of the composites. Hardness values of pure aluminium matrix are 48HRB. Composites reinforced with 25µm Al2O3 have the highest hardness values of 77HRB and with 50µm Al2O3 have an intermediate value of 72HRB. Meanwhile, composites which are reinforced with 80µm Al2O3 have the lowest hardness values of 65 HRB. From the Figure 4 it is observed that smaller the reinforcement particle size, higher will be the hardness value. Addition of particles of various larger micron sizes significantly decreases the hardness of the composites (Rahimiana et al., 2010). This is because Small reinforcement particles permit larger contact area with aluminum particles and hence smaller is the alumina particle greater is the hardness. Study carried out by Ahmad et al. (2003) explained that alumina act as a barrier to dislocation flow in aluminium matrix. Therefore, the increase of alumina will give more barriers and hence dislocation density.
Composites reinforced with smallest Al2O3 particles have higher number of barrier per unit area compared to composites reinforced with larger particle at the same weight percentage and hence composites with smaller particle size will have higher strength. Similar results were also observed by Faraji et al. (2011).

3.3 Tensile Properties
The results of tensile tests of both Al alloy and Al- Al2O3 composites reinforced with different particle size and constant volume fraction of Al2O3 particles are shown in Figure 5. The tensile strength of pure aluminium matrix is 80MPa. Composites reinforced with 25μm Al2O3 particle have the highest tensile strength value of 135 MPa and with 50μm Al2O3 have an intermediate value of 115MPa. At the same time, the tensile strength of 80 μm Al2O3 particle are found to be 97MPa. It is observed from the Figure 5, that the addition of alumina particles enhances the yield tensile strength of composites than Al 6061 alloy, further the decrease in strength of composites as the particle size increases is of two reason , first is because of good bonding strength at smaller particle size of the alumina particles and the second is because larger flaws and more defects mostly occur in larger particles when compared to smaller particles which ultimately reduces the strength of composites was studied by Dong et al. (2007). For smaller particle size, the spacing between particles is reduced therefore for same volume fraction the smaller particles will provide more interface area which gives more resistance to plastic deformation which ultimately leads to the increase in strength. Thus to conclude as the particle size decreases the yield tensile strength of composites increases (Cho et al., 2006).

The density of the composites materials increases with increases in Al2O3 particle size. Figure 6 represents the porosity of composites with increasing particle size. The results show that amount of porosity in the composites decrease with increasing the size of particles. The obtained results are in line with Sahin (2003).

<table>
<thead>
<tr>
<th>Materials</th>
<th>Density in g/cm³</th>
<th>Particle size in microns</th>
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<tbody>
<tr>
<td>Al 6061</td>
<td>Theoretical</td>
<td>2.80  2.80  2.80</td>
</tr>
<tr>
<td>Al2O3</td>
<td>Experimental</td>
<td>2.73  2.75  2.77</td>
</tr>
</tbody>
</table>

Figure 6 Variation of porosity of Al6061 – Al2O3 composites with increasing particle size.

3.4 Density and porosity
Table 2 shows the comparison of theoretical density obtained by rule of mixture and experimental density values obtained by Archimedian method for the composites. The results shows that compared with the base metal the density of composites are higher, further increases in Al2O3 particle size. Figure 6 represents the porosity of composites with increasing particle size. The results show that amount of porosity in the composites decrease with increasing the size of particles. The obtained results are in line with Sahin (2003).

4. CONCLUSION
On the base of the investigation carried out in the present research work, it is concluded that the fabrication of composites by stir casting method is used to prepare the composites with uniform distribution of reinforced Al2O3 particles. The microstructure of the composites reveals that the Al2O3 particles are fairly distributed in the matrix and also shows some amount of porosity and clustering of Al2O3 particles. The uniform distribution of Al2O3 particulates and good Al2O3 -matrix interface indicates the efficiency of the process. The hardness of obtained composites materials significantly decreases in regards to the increase in particle size of the reinforcement material. It is therefore concluded from the experiment, hardness of Al- Al2O3 composite of 25 μm size is found to have higher hardness compared with other specimens (50 μm, 80 μm) and also with the base alloy. With respect to tensile strength, compared to base matrix the composites fabricated have higher tensile strength. Further the tensile strength increases with decrease in Al2O3 particles size. The density of the composites increases with increase in size of Al2O3 particles and porosity decreases with increase in particle size.

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