Homogenize annealing effect on mechanical properties of stir cast silicon carbide powder reinforced aluminium alloy metal matrix composite

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Abstract. Metal matrix composites (MMC’s) consist of a metallic matrix combined with dispersed particulate phases as reinforcement. Aluminium 6061 based metal matrix composite are used in the field of transportation, aviation and manufacturing of electrical equipments. Silicon carbide is used as reinforcement in aluminium matrix to get better functional properties. The stir casting method is employed for composite preparation. SiC of different weight percentage (5%, 7.5%, and 10%) is added as reinforcement to get MMC of variable compositions. The Stir cast products has got dendritic segregation in the base metal matrix with nonuniformity in chemical composition, known as CORING. To overcome this problem generally homogenize annealing (homogenizing) treatment is given on the cast MMC. The hardness, strength, tensile strength and impact resistance characteristics are analyzed and compared with as-cast specimens. Homogenizing provides uniform chemical composition of the matrix in the microscopic level and improves mechanical properties, especially ductility. In all the characteristic tests 5 trials are performed and the average of three consistent values is considered as result output.

Keywords: AlSiC metal matrix composite, Casting, Homogenizing, Mechanical properties

1. Introduction

Over the years, aluminum alloys have been the materials of choice for both military and commercial aircraft structures. 7xxx series Al alloys are used for structural applications in the aerospace and automotive industry [1]. Al–SiC alloys present a wide range of potential applications due to their high strength and thermal properties. Heat treatment of aluminium alloy is often employed to vary the properties like mechanical, thermal and electrical properties [2]. Two step stir casting process is used to fabricate the MMC. Cast products show nonuniformity in chemical composition with more percentage lower melting point metals segregated along or near the grainboundary. This may produce fluctuations in mechanical properties and badly affect product applications and durability. Homogenizing provides homogeneity in the matrix grain size. This uniform distribution provides better mechanical properties [3]. Homogenizing reduces internal stresses and increases machinability. This heat treatment also provides ductility and toughness.

The homogenize annealing requires reheating the as-cast specimen very closer and below the solidus temperature isothermally for longer duration. The diffusion rate is directly proportional to the increase in temperature [4]. Homogeneous composition requires physical movement of the atoms from one region to another. The driving force for diffusion is the decrease in free energy of the system. The crystal defects present in the casting plays important role in decreasing the time required for the treatment. Higher the temperature more is the kinetic energy for the atoms, hence process is accelerated. Vacancy and interstitial defects are the major source to eliminate dendritic segregation during the treatment [5].

Homogenize annealing also increases the grain size. Increase in grain size depends on the homogenizing temperature and time of treatment. On the other hand the treatment depends on the recrystallization temperature. It also depends on the degree of prior cold or warm deformation given on the specimen. Higher the degree of cold or warm deformation finer is the homogenized grain size and lesser is the processing time [6].

Homogenizing also removes gases absorbed during casting. Because of higher temperature and long processing time involved in the treatment oxidation and grain enlargement are the problems involved. Generally a compromise is required in the increased temperature, treatment time employed and degree of cold or warm deformation used in the process for
optimum mechanical properties [7]. In this paper comparison in mechanical properties of both homogenized and as-cast MMC is performed.

2. Experimental details

2.1 Metal Matrix Composite (MMC) Preparation

Metal matrix composite preparation is done by stir casting method. This method is easy and economical. Silicon carbide particle of size 23 microns is reinforced by Al6061 alloy. Three different percentage of SiC is used for the metal matrix preparation like 5%, 7.5%, 10%. Preheated SiC particles are added to the molten aluminum at temperature of 750°C. Addition of SiC is done while molten aluminium is stirring at a constant speed 250 rpm. Molten material is poured into the preheated dies. After solidification and cooling the solid MMC is taken.

2.2 Homogenizing

Stir cast specimens were heat treated using a muffle furnace heating to 550°C and keeping the specimens for 8 hours. Furnace cooling to ambient temperature makes the specimens homogenized. Oxide layer formed during the homogenizing is removed using emery paper and cleaning with acetone.

2.3 Tensile Test

Tensile specimens are prepared according to the standard ASTM E08 (Fig.1) using CNC turning center. Tensile test is conducted on tensometer of load measurement 20KN maximum with interchangeable load cells and least count +.05% of load cell accuracy 1%.

![Homogenized tensile specimens of ASTM E08 standard.](image)

Fig.1: Homogenized tensile specimens of ASTM E08 standard.

2.4 Hardness Test

Hardness test is conducted on specimens with good surface finish which are faced, emery paper applied and cleaned with acetone. Brinnel hardness no. of the specimens is recorded using laboratory RASL Brinnel Hardness tester. Intender used is of diameter 5mm and loading of 250kgf.

2.5 Impact strength

Impact strength of homogenized and as-cast specimen is found out by conducting Charpy test. Test is conducted on Izod testing machine. Specimens are prepared as per ASTM standards (Fig.2).
2.6 Microstructure Analysis
Microstructure was recorded after giving good surface finish on the specimen surface by polishing with emery papers up to the size 1000 microns starting from coarser one to finer and buffing (Fig.3). Before the analysis the required surface should be etched with Keller’s reagent (2ml HF, 3mlHCl, 5ml HNO₃ and 190ml water). After washing and drying the surface is analyzed using inverted metallurgical microscope at 500x magnification. The clear image was observed and recorded on Scanning electron microscope (SEM).

Fig.2: Charpy test specimen with dimensions

Fig.3: Specimen after surface preparation for microstructural analysis
3. Results and Discussion

3.1 Tensile test

Table 1: UTS (Ultimate Tensile Strength) of homogenized and as-cast specimens

<table>
<thead>
<tr>
<th>Composites</th>
<th>Homogenized</th>
<th>As-cast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trail 1</td>
<td>Trail 2</td>
</tr>
<tr>
<td>Al+5% Sic</td>
<td>110.2</td>
<td>123.4</td>
</tr>
<tr>
<td>Al+7.5% Sic</td>
<td>131.1</td>
<td>141.6</td>
</tr>
<tr>
<td>Al+10% Sic</td>
<td>150.5</td>
<td>160.7</td>
</tr>
</tbody>
</table>
Fig. 4: UTS for homogenized specimens
Fig. 5: UTS for In-homogenized specimens

Table 1, figures 4 and 5 show the difference in tensile properties of homogenized and as-cast specimens. Increase in SiC reinforcement increases the tensile properties of MMC. Homogenizing process makes the tensile properties lower than the cast specimens. During homogenizing, the dendritic segregation is removed and chemical composition in the base alloy Al6061 is homogenized. This homogenized chemical composition is responsible for the increase in strength. Brittle nature of solute rich phases makes the ultimate tensile strength lower for as-cast specimens. Graphs shown above reveal analysis. Trials

### 3.2 Hardness test

Table 2. Brinnel Hardness values for homogenized and as-cast specimens

<table>
<thead>
<tr>
<th>Brinnel hardness number (BHN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite</td>
</tr>
<tr>
<td>Trail 1</td>
</tr>
<tr>
<td>Al + 5% SiC</td>
</tr>
<tr>
<td>Al + 7.5% SiC</td>
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<tr>
<td>Al + 10% SiC</td>
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</tbody>
</table>
It is evident from the results shown in table 2, figure 6 and 7 that homogenizing drastically reduces the hardness of the MMC. Because of homogenizing, grains become coarse and uniformly distributed it makes the hardness value to decreases.

### 3.3 Impact Strength

Table 3. Impact Strength for homogenized and as-cast specimens

<table>
<thead>
<tr>
<th>Composite</th>
<th>Homogenized</th>
<th>As-cast</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Trail 1</td>
<td>Trail 2</td>
</tr>
<tr>
<td>Al+ 5% Sic</td>
<td>25</td>
<td>23</td>
</tr>
<tr>
<td>Al+ 7.5% Sic</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>Al+ 10% Sic</td>
<td>25</td>
<td>26</td>
</tr>
</tbody>
</table>
Table 3, figures 8 and 9 show the energy absorbed by the specimen before failure as impact strength of the composite. Homogenizing process on cast specimens shows the improvement in the impact strength of MMC. This increase is due to the removal of cluster solute rich phases from the matrix. It is clear from the graph and table.

3.4 Microstructure Analysis

Microstructural analysis of homogenized specimens show coarse grains compared to as-cast. Metallurgical microscope recorded images of microstructure (Figures 10 and 11) provide more information about microstructure of specimens. SEM image (Fig.12) shows the good reinforcement between SiC particles and aluminium matrix.

Fig.8: Impact Strength for homogenized specimens

Fig.9: Impact Strength for as-cast specimens

Fig.10: Microstructural Image of casted as-cast MMC (7.5% SiC)

Fig.11: Microstructural Image of homogenized MMC (7.5% SiC)
4. Conclusions

Inspite of difference in the density of matrix material and reinforcement, the stir casting method was successfully employed for the manufacturing of composites. The microstructure recorded from metallurgical microscope shows equiaxial grains. The SEM study shows the good distribution of reinforcement in the matrix. There is increase in impact resistance of MMC after the homogenizing. But in the case of hardness and tensile strength, a drop is seen after the homogenizing.

References