Property Analysis of Aluminium (LM-25) Metal Matrix Composite

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Abstract— Particulate reinforced graded material composites are one of the potential and advanced classes of engineering materials, which contain reinforcement particles whose volume fraction varies continuously thereby bearing a non-uniform microstructure and the composition in a specific direction leading to variation in functional performance of a component with continuously changing properties. The present investigation is on processing of SiC particles reinforced functionally graded aluminium matrix composite cylinders and non-reinforced aluminium cylinders by centrifugal casting to obtain the microstructure and mechanical properties for evaluation. Aluminium alloy (Al 356/LM 25) is used as matrix and SiC as reinforcement. Composite is primarily synthesized by liquid metal stir casting method. Cylinders of pure alloy and composite were fabricated using vertical centrifugal casting technique. The segregation of SiC particles towards the outer periphery of the cast cylinder has resulted in higher hardness towards this region. Precipitation hardening heat treatment enhanced the hardness of both pure alloy and composite cylinders.

Keywords— Aluminium matrix, Centrifugal casting, Composites, Microstructure, Particulate, Stir casting.

I. INTRODUCTION

In this research, the Functionally Graded Material and the pure alloy is processed by using the Centrifugal Casting method. Aluminium-SiC composite is made by the liquid metal stir casting method and functionally Graded Composites are fabricated by using the vertical centrifugal casting. Aluminium 356/LM25 is used as the matrix and 5% SiC is used as the reinforcement. Characterization is done to evaluate the microstructure and mechanical properties. The gradations of the particles from outer to inner periphery are noted from the optical microstructure. The mechanical properties like Hardness testing is done using the Zwick micro Vickers Hardness Tester. Tensile Tests are carried out using the Instron universal testing machine for both pure alloy and composite.

II. ALUMINIUM-MAGNESIUM-SILICON ALLOY

Aluminium casting is dominated by the automotive industry. Roughly two thirds of all aluminium castings are used in automotive industries where the use of aluminium castings continues to grow at the expense of iron castings. Although aluminium castings are significantly more expensive than ferrous castings, there is a continuing market requirement to reduce vehicle weight and to increase fuel efficiency. It is this requirement which drives the replacement of ferrous parts by aluminium. Melting point of Al is 660°C and is Light weight, density is about 1/3 that of steel or copper alloys. Certain aluminium have a better strength to weight ratio than that of high strength steel. Have good malleability and formability, high corrosion resistance and high electrical and thermal conductivity.

LM25 is mainly used where good mechanical properties are required in castings of shape or dimensions requiring an alloy of excellent castability in order to achieve the desired standard of soundness. The alloy is also used where resistance to corrosion is an important consideration, particularly where high strength is also required. It has good wettability. Consequently LM25 finds applications in the food, chemical, marine, electrical and many other industries, and above all - in the automotive industry where it is used for wheels, cylinder blocks and heads. Its potential uses are increased by its 3 available levels of heat treatment in both sand and chill castings. It is, in practice, the general purpose high strength gravity die-casting alloy.

III. EXPERIMENTAL PROCEDURE

A. Materials

The aluminium silicon-magnesium (356/LM25) alloy is chosen as the matrix alloy. The composition of the alloy is given in Table 1.
The 356-aluminium alloy is one of the commonly used age-hardenable cast alloy for various applications. The alloy can be cast in permanent or sand mould and possesses excellent castability, good corrosion resistance, good wear resistance and pressure tightness and better machining and welding characteristics. It has also proven as a potential matrix alloy in the fabrication of cast aluminium matrix composites. The properties of matrix alloy are given in Table 1.

### TABLE I
**Chemical Composition of the Matrix Alloy**

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Mg</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>356</td>
<td>7.0</td>
<td>0.35</td>
<td>0.2</td>
<td>0.2</td>
<td>0.1</td>
<td>Balance</td>
</tr>
</tbody>
</table>

All Aluminium and its alloys is by far the dominant matrix system for metal matrix composites. It is in general a low cost material, which presents a low melting point, facilitating fabrication. With its low density (2.7 g/cm³) and the fact that it can be worked into any form by plastic deformation, and cast by all foundry processes, its dominant position for use in Metal Matrix Composites (MMCs) is readily explained. Interestingly, a closer look at the literature indicates that there has not been a large effort to develop alloys specifically designed for use as composite matrices; rather MMCs have largely made use of commercial alloys that were not originally designed for this purpose [17], even though there exist important exceptions e.g., [18]. As a consequence virtually all classes of aluminium alloys have been studied in MMCs; namely cast and wrought alloys with most of the main alloying element systems.

### TABLE II
**Standard Properties of the 356 Al Matrix Alloy**

<table>
<thead>
<tr>
<th>Property</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2670 kg/m³</td>
</tr>
<tr>
<td>Melting Point (Liquidus)</td>
<td>615°C</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>71 GPa</td>
</tr>
<tr>
<td>Tensile Strength (T6)</td>
<td>250-280 MPa</td>
</tr>
<tr>
<td>Percent Elongation</td>
<td>5%</td>
</tr>
<tr>
<td>Hardness (T6)</td>
<td>90 BHN</td>
</tr>
</tbody>
</table>

B. **Stir Casting**

The composites are fabricated mainly by liquid metal stir casting techniques. The aluminium alloy is melted in a clay graphite crucible using resistance-heated furnaces. The composite synthesis is carried out in 10 Kg capacity furnace. The alloy melt is mechanically stirred using an impeller driven by an electrical motor. The rotational speed of the stirrer is controlled to around 350 rpm. The stirring speed is controlled by a dynamometer. The SiC particles are preheated to about 600°C prior to the addition. The preheated particles are added to the melt with a known feed rate of around 1 gm/sec, stirring speed of 350 rpm and melt temperature of 740°C. Before powder addition 1% Mg is added at 730°C to compensate the loss of Mg in the melt due to the oxidation. The particles are added to the molten metal in the crucible via manual powder addition mechanism. After the powder addition baffle is introduced in the crucible for uniform mixing of the composite. With the baffle allow stirring for 15 minutes, after that degassing should be done. Degassing is done to avoid the hydrogen entrapment. Degassing is done by passing N₂ gas to the molten metal through the sulphuric acid. Sulphuric acid will act as purifier and the N₂ gas will remove the H₂ from the molten metal. Degassing is done for about 20 minutes till the temperature reaches 760°C and after manual stirring the composite is poured to the rotating centrifugal mould.

C. **Microstructural Analysis**

Microstructural analysis was done on the A356/LM25 and A356/LM25-5%SiC components fabricated using centrifugal casting. Samples for characterization were prepared using standard metallographic techniques. The gradations of the particles from outer to the inner periphery were analyzed using optical microscope. A convenient specimen is prepared from the sectioned cylinder components. Cross sectional surfaces have been polished for microscopical examination. Scale are removed from the area for microscopical examination by polishing on successively finer emery papers, of grid size 100, 220, 400 and 600 and the specimens are washed thoroughly using liquid soap and water while going to next paper size and the orientation of polishing surfaces was changed by 90°. The disk polishing has been carried out in a rotating wheel fixed with silvet cloth (around 500 rpm) with a gentle applied pressure and using diamond paste of varying size ranging from 6, 3, 1 and 0.25 µm to get final finish.
D. Heat Treatment

Al-7Si-0.3Mg (356)/LM25 is a precipitation hardening alloy. The common heat treatment procedure applied is T6 condition, i.e. solution treatment followed by precipitation or age hardening. The prescribed solution treatment is 10 hrs. at 525°C and age hardening at 165°C for 8 hrs.

![Diagram of Heat Treatment](image)

**Figure 1 Diagram Representing The Heat Treatment.**

The mechanical properties of Functionally Graded Materials (FGM) are evaluated by various tests. In this work tensile and hardness measurements are done to evaluate the FGM properties. There will be variation in the properties from outer to inner periphery. The standard specimens are cut from the fabricated components and testing are to be done.

IV. RESULTS AND DISCUSSION

Functionally Graded components of SiC reinforced Aluminum composite cylinder was fabricated using the vertical centrifugal casting technique. In addition, base alloy cylinder was also fabricated for comparison. The length of the alloy and composite hollow cylinders are 150 mm and a wall thickness of 30 mm. The samples were cut from the cylinder fabricated and they are polished using disk polishing technique with polishing pastes of different micron to reveal the microstructure.

A. Microstructural Evaluation of the Cast Alloy Cylinder

Figure II shows the optical micrographs of the Precipitation Treated alloy cylinder taken at different locations from outer to the inner periphery of the casting. The microstructural features of the alloy ring are similar both towards the outer and inner periphery, however the porosities are observed towards the inner periphery due to the segregation of low density gas porosities. The size of the primary aluminium and eutectic silicon phases are finer towards the outer periphery due to the higher solidification rate.

The eutectic silicon segregation is there in the sample and higher concentration of eutectic silicon is in inner region. The eutectic silicon particles in the matrix have spherodised during heat treatment.

B. Microstructural Evaluation of the as-cast Composite Cylinder

Figure III shows the optical micrographs of the as-cast composite cylinder and figure IV shows the optical micrograph of the heat treated composite cylinder, taken at different locations from outer to the inner periphery of the casting. The region near the outer periphery shows higher concentration of particle and the region near the inner periphery shows particle depletion. The region very close to the outer periphery (0–2 mm) shows lower particle concentration compared to the adjacent region (3–9 mm) due to the chill zone formation, immediately after the metal is poured into the mould. The region beyond chill zone will get higher concentration of particle due to the centrifugal force. A particle graded region (6–10 mm) is formed between the particle rich and particle depleted region. The region near the inner periphery, i.e. beyond 12 mm from outer periphery shows the presence of porosities and agglomerated particles.

C. Mechanical Properties

Hardness tests are done using the Vickers hardness testing machine. From the graphs the hardness is more in the outer periphery of the as-cast and precipitation treated samples. The variation in the hardness from the outer to inner periphery can be seen clearly from the graph. The hardness values of the Precipitation Treated samples are more than that of the as-cast samples. The extreme end shows less hardness because of the chill zone near the mould wall. After the chill zone there exists higher hardness and gradual reduction in hardness towards the inner periphery of the cylinder. Figure V shows the plot for the Vickers hardness values of the as-cast and Precipitation Treated samples from the alloy cylinder. The hardness values in the chill zone are 74 HV in as-cast and 88 HV in heat treated conditions, whereas in the particle rich region hardness ranges 85–91 HV in as-cast and 98–107 HV in heat treated conditions. The hardness in the particle graded region is between 77–84HV in as-cast and 90–99 HV in heat treated conditions, and in the particle depleted region in the range of 77–75 HV in as-cast and 88–92 HV in heat treated conditions.
Figure II Optical Micrograph Of Precipitation Treated Alloy Cylinder Taken At Different Locations 2mm Interval From Outer To Inner Periphery Of Casting.

Figure III Optical Micrograph Of As-Cast Composite Cylinder Taken At Different Locations 2mm Interval From Outer To Inner Periphery Of Casting

Figure IV Optical Micrograph Of Precipitation Treated Composite Cylinder Taken At Different Locations 2mm Interval From Outer To Inner Periphery Of Casting
The region near the inner periphery shows hardness, 71 HV in as-cast and 82 HV in heat treated conditions due to the presence of porosities.

The tensile test for the alloy and composite samples are done using Instron universal testing machine. Tests are performed for the five sets of samples, each set having four samples and the samples are cut from alloy ring, alloy cylinder, outer region of composite ring, inner region of composite ring and composite cylinder.

**TABLE III**

<table>
<thead>
<tr>
<th>Tensile Samples</th>
<th>UTS (Mpa)</th>
<th>Load at maximum tensile stress(N)</th>
<th>% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite cylinder</td>
<td>216</td>
<td>6050</td>
<td>3.2</td>
</tr>
<tr>
<td>Alloy cylinder</td>
<td>229</td>
<td>6456</td>
<td>3.6</td>
</tr>
</tbody>
</table>

**V. CONCLUSION**

Functionally Graded Al-SiC Composite and pure alloy cylinders have been successfully fabricated using vertical centrifugal casting technique. Centrifugally cast base composite and alloy cylinders have also been fabricated for structure and properties comparison. The microstructural features of the base alloy are similar both towards the outer and inner periphery, however the porosities are observed towards the inner periphery due to the segregation of low density gas porosities. The size of the primary aluminium and eutectic silicon phases are finer towards the outer periphery due to the higher solidification rate.

Microstructures of Functionally Graded Al-SiC Composite cylinder shows the presence of higher volume fraction of SiC particles towards outer periphery, gradually decreases towards the inner periphery and the particle depleted zone is observed. Similar to the base alloy few gas porosities are observed towards the inner periphery, however here the gas porosities are associated with agglomerated particles. The agglomerated particles are segregated towards the inner periphery due to the lower density of the particle agglomerates. These particle agglomerates are formed due to partially wetted particles associated with voids and gas porosities. The higher volume fraction of particles is observed at the outer periphery of the composite cylinder. The surface closer to the outer periphery (0-10mm) shows lower volume fraction due to the chill zone formation.

The functionally graded composite cylinder shows higher hardness towards the outer periphery, due to the presence of high volume fraction of silicon carbide particles.
The maximum hardness of 140 HV is observed towards the outer periphery and minimum hardness of 90 HV is observed towards the inner periphery of the heat treated cylinder. The base alloy also shows higher hardness (107 HV) towards the outer periphery than the inner periphery (85 HV) due to the refinement of primary aluminium grains and eutectic silicon phases. Similar to the hardness observations, higher tensile strength is observed towards the outer periphery.

Future studies can be carried out on processing and evaluation of FGMs with different aluminium alloy combinations with SiC and other reinforcements like Al₂O₃, B₄C, AlN, BN, MgAl₂O₄ and Graphite. Tribological studies and other mechanical properties evaluation of the above system can also be investigated.

REFERENCES
