Interfacial Study Of Aluminium Alloy (Lm4) - Boron Carbide (B\textsubscript{4}C) Metal Matrix Composites

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ABSTRACT
Aluminium alloy Al LM4 reinforced with Boron Carbide (B\textsubscript{4}C) composites are widely used in engineering applications due to their low density, reasonable good strength and wear resistance as compared to the monolithic metal alloy. Despite these advantages, it has been observed that there is a declining trend in their application due to high cost. Additions of high modulus particles to Aluminium alloy offers potential to develop a high stiffness, lightweight composite. Boron carbide is one of the hardest materials known, ranking third behind diamond and cubic Boron Nitride. Boron Carbide is alloyed with low or medium cross-section materials, such as Iron or Aluminium, due to its lower cost. In the present work, the attention is on the use of early available Aluminium alloy material reinforced with boron carbide (B\textsubscript{4}C) composite without degrading the mechanical properties of composites. It describes processes and characterization of Aluminium alloy reinforced boron carbide particulates and reports the possible effects of interfacial reactions on its mechanical properties. AlLM4 reinforced composites filled with different proportions of 5%, 10%, 15% of Boron Carbide particulate were fabricated by stir casting technique. The mechanical properties like hardness, tensile strength, and impact strength of composites were evaluated. All of these results were critically investigated for the effect of interfacial effect on their mechanical properties and examined by using Scanning Electron Microscope (SEM). Characterization of the fabricated material showed the presence of agglomerates of B\textsubscript{4}C particles and some residual porosity. Evaluation of the mechanical properties showed little improvement to the elastic modulus, low tensile strength and no significant amount of ductility.

KEYWORDS: Aluminium LM4; Boron carbide; Mechanical Properties, Aluminium matrix composites; stir casting; SEM

INTRODUCTION

Aluminium metal matrix composites (AMMCs) are an important engineering material in aerospace, automotive and marine applications. They provide better properties and performance like low density, high strength, high stiffness, good wear resistance and improved thermal and electrical properties [1]. Ceramic particles such as Al\textsubscript{2}O\textsubscript{3}, SiC is the most widely used materials for reinforcement of aluminium. Boron carbide (B\textsubscript{4}C) could be an alternative to SiC and Al\textsubscript{2}O\textsubscript{3} due to its high hardness. Boron carbide has attractive properties like high strength, low density (2.52 g/cm\textsuperscript{3}), extremely high hardness, good wear resistance and good chemical stability [2]. These popular composites are currently manufactured by liquid metallurgy, powder metallurgy, diffusion bonding and spray forming method. However, the most simplified approach to develop aluminium based metal matrix composites is by the liquid metallurgy technique as it is most economical and used in mass
production [3]. The primary function of the reinforcement in AMMCs, is to carry the applied load, where the matrix binds the reinforcements together and transmits and distributes the load to the individual reinforcement [4]. Good wetting is an essential condition for the generation of a satisfactory bond between particulate reinforcement and liquid. Aluminium metal matrix composite, during casting to allow transfer and distribution of load from the matrix to reinforcement without failure. Strong bonds at the interface are required for good wetting. The reaction phenomena are very detrimental to the composite as they bring about a decrease of the mechanical properties [5]. The enhancement in strength and modulus of the composite depends on the total load transfer behavior at the matrix and reinforcement interfaces. Since the interface between the matrix and reinforcement play a vital role in the properties of aluminium metal matrix composites. It is necessary to characterize the interfacial micro structures of a composite. Interfacial studies usually include identification of the interfacial microstructures and reaction products and the determination of crystallographic relations [6, 7]. Substantial information is available in the literatures on wetting and interface of aluminium alloy metal matrix composites reinforced with Al₂O₃ and, SiC [8-14]. Some studies on reactivity B₄C in aluminium processed by infiltration and powder metallurgy methods reported the formation of different compounds at different processing temperatures [15,16]. A very few literature related to the micro structures and interface of Al-B₄C composites processed by stir cast method. The main purpose of this work to see the feasibility study to produce Al (LM4)-B₄C composites by using conventional stir casting process and attempts are made to study the micro structural interfacial aspects of resulting composites and also deals with possible interfacial reactions.

MATERIAL AND METHOD

A. Materials:
Material has been selected based on the properties, cost and application where it is needed. Aluminium LM4 is remarkable for the metals, low density and for its ability to resist wear which contains silicon as major constituent and it was used as matrix material and its composition is given in Table I.

Table I: Composition of Aluminium Alloy LM4

<table>
<thead>
<tr>
<th>Composition</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>91.70</td>
</tr>
<tr>
<td>Silicon</td>
<td>4.792</td>
</tr>
<tr>
<td>Iron</td>
<td>0.323</td>
</tr>
<tr>
<td>Copper</td>
<td>2.572</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.215</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.202</td>
</tr>
<tr>
<td>Chromium</td>
<td>0.030</td>
</tr>
<tr>
<td>Tin</td>
<td>0.043</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.015</td>
</tr>
<tr>
<td>Lead</td>
<td>0.070</td>
</tr>
<tr>
<td>Bismuth</td>
<td>0.016</td>
</tr>
</tbody>
</table>

The reinforcement materials selected as boron carbide of particle size 30µm were used in this study. The properties of boron carbide are shown in Table II.

Table II: Properties of Boron Carbide (B₄C)

<table>
<thead>
<tr>
<th>Reinforcement</th>
<th>Melting point (°C)</th>
<th>Density (g/cm³)</th>
<th>Thermal conductivity W/(m.K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boron carbide (B₄C)</td>
<td>2785-2830</td>
<td>2.3-2.55</td>
<td>110</td>
</tr>
</tbody>
</table>

Boron carbide is extremely hard ranking about nine on Mohr’s scale and with a Vickers number of around 2600.

B. Methodology:
The metal matrix composite is processed by using stir casting method. Stir casting is initiated in 1968 and introduced by S. Ray.

C. Experimentation:
The experimental arrangement consists of the main furnace and components along with four mild steel stirrer blades. The first process in the experiment is preheating. Here, the empty crucible and the reinforcement powders, namely boron carbide and alumina powders are heated separately to a temperature close to that of the main process temperature. The melting of the aluminium alloy (95%) ingot is carried out in the graphite crucible inside the furnace. Initially, the ingot was preheated to 3-4 h at 550 °C. At the same time boron carbide and alumina powders are also preheated to 400° C in the respective containers. Then, the crucible with aluminium alloy is heated to 830 °C while the preheated powders are mechanically mixed with each other below their melting points.
This metal matrix is then kept in the furnace at the same temperature. The furnace completely melts the pieces of aluminium alloy and the powders if alumina and boron carbide. The stirring mechanism is lowered into the crucible inside the furnace and set at the required depth. The vigorous automatic stirring of the material takes place for 10 min with 550 rpm of stirring rate, thereby uniformly dispersing the additive powders in the aluminium alloy matrix. The temperature rate of the furnace should be controlled at 830 ± 10 °C in the final mixing process. The degasser removes all the trapped gases from the mixture in the crucible and ensures that the temperature of the mixture in the crucible does not get transferred easily to the atmosphere. This experiment is repeatedly done by varying the compositions of the composite powder. For each composition, a total of 1.5 kg (1500 g) material mix is used for preparing the samples. Apart from the above compositions, the aluminium alloy [LM4] alone is melted and solidified in dies.

D. Stir Casting Process:

The stir casting method is more economical for fabrication of metal matrix composite. Figure 1 shows stir casting set up. In this method electrical furnace is used to melt the metal. Aluminium LM4 with varying weight % of Boron carbide 5, 10 and 15 has been fabricated by using this method. Aluminium LM4 billets are loaded in the crucible and placed in an electrical furnace. This allows the aluminium LM4 billets to melt to above 900°C. Boron carbide particles are preheated above 600°C. Remove the slag from crucible liquid state metal using hexa-chloro ethane. After preheated Boron carbide powder manually mixed with aluminium alloy LM4. Then electric motor attached stirrer used to stirring for 20 minutes. Finally the molten metal poured in to die. After the solidification cast rod is used to prepare the test samples as per ASTM standard.

Fig. 1: Stir Casting Setup

RESULT AND DISCUSSION

A. Hardness Measurement:

Hardness of the composites was evaluated using Vickers hardness testing machine. Before to testing, the surface of composite test specimens were subjected to grinding and polishing operation to obtain a flat and smooth surface finish. A direct load of 1 kgf was applied to the specimens for 10 seconds and hardness readings are taken the standard procedure. The numbers of hardness tests were performed on each sample and the average value taken as a measure of the hardness of the specimen. The Table III and Figure 2 show the hardness of different samples of composite material.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample Name</th>
<th>Hardness value in HV</th>
<th>Mean Value in (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trial 1</td>
<td>Trial 2</td>
</tr>
<tr>
<td>1</td>
<td>Al LM4</td>
<td>82</td>
<td>81.8</td>
</tr>
<tr>
<td>2</td>
<td>Al LM4+ 5% B,C</td>
<td>88.1</td>
<td>83.9</td>
</tr>
<tr>
<td>3</td>
<td>Al LM4+ 10% B,C</td>
<td>93</td>
<td>91.5</td>
</tr>
<tr>
<td>4</td>
<td>Al LM4+ 15% B,C</td>
<td>86.8</td>
<td>83.4</td>
</tr>
</tbody>
</table>
Fig. 2: Hardness of different samples

From the above table and figure shows the variation of hardness with weight % B₄C. It is observed that the hardness of Al LM4-15% B₄C is lower than the hardness value of the other two samples of aluminium LM4-5% B₄C and LM4 10% B₄C. But, higher than that of unreinforced Al-LM4 sample.

B. Tensile Strength:

The tensile strength of different sample composites was tested using an Instron universal testing machine. The tensile specimens prepared as per ASTM E8 standard. The three difficult repeat test was performed on each sample on the average value taken as a measure of tensile strength of the specimen.

Table IV and Figure 3 shows the effect of amount of boron carbide particulates with aluminium LM4.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Sample Name</th>
<th>Tensile strength in MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al LM4</td>
<td>124.39</td>
</tr>
<tr>
<td>2</td>
<td>Al LM4 5% B₄C</td>
<td>81.93</td>
</tr>
<tr>
<td>3</td>
<td>Al LM4 10% B₄C</td>
<td>133.43</td>
</tr>
<tr>
<td>4</td>
<td>Al LM4 15% B₄C</td>
<td>134.16</td>
</tr>
</tbody>
</table>

Fig. 3: Tensile Strength

It has been inferred that the tensile strength of sample Al LM4-15% B₄C is marginally higher than other two reinforce sample of Al LM4-5% B₄C, Al LM4-10% B₄C and unreinforced Al LM4.

C. Impact Energy:

Impact testing is used to determine the amount of energy observed by the specimen when sudden and dynamic application of the load applied by Izod impact testing machine. According to ASTM E23 standard test specimen was prepared and the load is applied. The multiple tests were performed on each sample and average value taken as the impact strength of the specimen. Figure 4 shows the impact test specimens. Table V and Figure 5 shows the impact strength of different samples of composites.
Table V: Impact Strength

<table>
<thead>
<tr>
<th>Material</th>
<th>Al LM4</th>
<th>Al LM4+ 5% B₄C</th>
<th>Al LM4+ 10% B₄C</th>
<th>Al LM4+ 15% B₄C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact strength in Joules</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 4: Impact Strength

Fig. 5: Impact Strength

It is clear that the result of impact test, the impact value of the Al LM4 and Al LM4-15% B₄C is lower than the other two samples of Al LM4-5% B₄C and Al LM4-10% B₄C.

Microstructure Analysis:

Fig. 6: Scanning Electron Microscope

To study the microstructure of the specimens were cut and prepared as per the standard metallographic procedure. The specimen surfaces were prepared by grinding through 600 to 1000 mesh size grit papers. Velvet cloth polishing is done for the specimen to get fine surface finish. After that the specimens were etched using Keller’s reagent (HCl+HF+HNO₃). The microstructures of etched specimens were observed using scanning electron microscope.
Fig. 7: SEM Image of Al LM4+5% B₄C

The Figure 7 and 8 shows the microstructure of the sample. It consists of aluminium alloy LM4 and the inner surface of the sample 5% B₄C and 10% B₄C which consists of aluminium and other components like silicon, copper, magnesium, etc., it consists of tighter packing than the other composites which having better hardness, tensile and impact strength compares to sample 15% B₄C. The uniform distribution of B₄C particles in the Al LM4 matrix could be attributed to the closer density value between Al LM4 matrix and 5% B₄C and 10% B₄C particles.

Fig. 8: SEM Image of Al LM4+10% B₄C

Fig. 9: SEM Image of Al LM4+15% B₄C

The Figure 9 shows the sample of 15% B₄C can be clearly distinguished from those of sample 5% B₄C and 10% B₄C. As this image, lack the elliptical molecules of the reinforcement which are visible in the sample of 5% B₄C and 10% B₄C and the intermetallic phases were observed in the composite and randomly dispersed in the Al LM4 – 15% B₄C, AlB₂ (brown, block-like phase) and Al₁B₃C (grey phase). When fabricating the Al-15% B₄C composites. The secondary phase are produced in the Al LM4 15% B₄C system, decrease the properties of composites. The three composites with the highest reinforcement of particles Al LM4 15% B₄C particles where the fracture to investigate the nature of bonding between B₄C and Al LM4 matrix. The bonding
seems to be weaker than that of Al LM4 5% and 10% B,C due to the relatively low occurrence of the matrix alloy to the particulates. The void and micro void where present at the particle and matrix interface of Al LM4 15% B,C indicating a weak bonding.

**Conclusions:**

The Al LM4-B,C composites were produced by stir casting technique with different weight percentage (0, 5, 10 & 15) of reinforcement and the mechanical and microstructure analysis are evaluated. From the research work, the following conclusions are derived.

- Fabrication of aluminium LM4-B,C composites produced successfully.
- The various mechanical test was conducted as per ASTM standard.
- The Vickers hardness, tensile strength and impact strength was found to be the minimum value of the 15 % weight of B,C which is lower than 10 % B,C and higher than 5 % B,C.
- Scanning electron microscopy (SEM) were done in the Al LM4 B,C metal matrix composites. A clean interface of B,C between aluminum was obtained in this experiment was obtained.
- The SEM analysis study revealed that the presence of B,C particles in the composites and it shows that strong interface bonding in the 5 % and 10 % B,C in aluminium LM4.
- The tensile strength and impact strength decrease with the 15% B,C due to the formation of voids poor load transfer between reinforcement and matrix. The B,C particles aggregated to form a coarse cluster in the matrix and which form the intermetallic compounds it leads to brittle nature and reduce the effective amount of particulates for strengthening.
- A clear interfacial reaction product was found in Al LM4-15% B,C interface for composite processed for long periods while no reaction product was absorbed at Al LM4, 5%B,C and 10 % B,C. Two secondary phases in the Al LM4- 15% boron carbide. Al LM4 5% and 10% boron carbide composites seem to exhibit a better interfacial bonding has compared to other Al LM4, 15% B,C composites.
- It is expected that the present work will be beneficial to understand the effect of Al LM4 – B,C on the mechanical behavior and interfacial study will be effectively utilized for the development of high strength, low weight and low cost composites.

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**REFERENCES**