Studies on Mechanical Properties of 2024 Al – B₄C Composites

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ABSTRACT

The present study was aimed at evaluating the mechanical properties of Aluminium 2024 alloy reinforced with B₄C. An effort is made to enhance the mechanical properties like tensile strength and hardness of AMCs by reinforcing 2024 Al matrix with B₄C particles. By stir casting method, aluminium matrix was reinforced with boron carbide particulates of 325 mesh size. Composite combinations of different weight % - 0%, 1%, 2%, 3%, 4% & 5% were fabricated. The microstructure and mechanical properties of the fabricated AMCs were analyzed. Based on the results obtained from tensile strength test and hardness test of the metal matrix composites of different weight %, comparison study was made. The optical microstructure images reveal the homogeneous dispersion of B₄C particles in the matrix. The reinforcement dispersion has also been identified with X-ray diffraction (XRD). The tensile strength and hardness were found to increase with the increase in wt. % of the reinforcement.

1. Introduction

Composites are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties that remain separate and distinct within the finished structure. The bulk material forms the continuous phase that is the matrix (e.g., metals, polymers) and the other acts as the discontinuous phase that is the reinforcements (e.g., ceramics, fibers, whiskers, particulates). While the reinforcing material usually carries the major amount of load, the matrix enables the load transfer by holding them together [1]. Composite materials are gaining wide spread acceptance due to their characteristics of behaviour with their high strength to weight ratio [2]. The interest in metal matrix composites (MMCs) is due to the relation of structure to properties such as specific stiffness or specific strength. Metal Matrix Composites are being increasingly used in aerospace and automobile industries owing to their enhanced properties such as elastic modulus, hardness, tensile strength at room and elevated temperatures, wear resistance combined with significant weight savings over unreinforced alloys [3, 4]. The metal matrix composite can be reinforced with particles, dispersoids or fibers. However, the biggest interest in composite materials is observed for those reinforced with hard ceramic particles due to the possibility of controlling their tribological-, heat- or mechanical properties by selection of the volume fractions, size, and distribution of the reinforcing particles in the matrix [5]. They are used more often, compared with the composite materials of other metals, due to the broad range of their properties, and also due to the possibility of replacing the costly and heavy elements made from the traditionally used materials [6, 7]. MMCs reinforced with particles tend to offer enhancement of properties processed by conventional routes [8].

Aluminum matrix composites (AMCs) are the competent material in the industrial world. Due to its excellent mechanical properties, it is widely used in aerospace, automobiles, marine etc. [9]. The aluminum matrix is getting strengthened when it is reinforced with the hard ceramic particles like SiC, Al₂O₃, and B₄C etc. Aluminium alloys are still the subjects of intense studies, as their low density gives additional advantages in several applications. These alloys have started to replace cast iron and bronze to manufacture wear resistance parts. The alloys
primarily utilized today in transport aircraft are 2024-T4 and the alloys having still higher strength (2014-T6, 7075-T6, 7079-T6 and 7178-T6).

Aluminium alloy 2024 has good machining characteristics, higher strength and fatigue resistance than both 2014 and 2017. It is widely used in aircraft structures, especially wing and fuselage structures under tension. It is also used in high temperature applications such as in automobile engines and in other rotating and reciprocating parts such as piston, drive shafts, brake rotors and in other structural parts which require light weight and high strength materials [10]. Aluminium is also a ubiquitous element and one of the trace elements with moderate toxic effect on living organism [11]. One of the main drawbacks of this material system is that they exhibit poor tribological properties. Hence the desire in the engineering community to develop a new material with greater wear resistance and better tribological properties, without much compromising on the strength to weight ratio led to the development of metal matrix composites [12, 13].

A limited research work has been reported on AMCs reinforced with B4C due to higher raw material cost and poor wetting. B4C is a robust material having excellent chemical and thermal stability, high hardness (HV=30 GPa), and low density (2.52 g/cm3) and it is used for manufacturing bullet proof vests, armor tank etc. Hence, B4C reinforced aluminum matrix composite has gained more attraction with low cost casting route [14].

2. MATERIALS AND METHODS:

2.1. Materials:
Aluminium alloy used for the matrix is purchased from perfect metal works, Bangalore, Karnataka, India, particles of B4C were purchased from Sigma Aldrich, Bangalore, Karnataka, India and Magnesium powder was commercially available. The chemical composition of the matrix alloy is given in the table 1.

Table 1: Composition of matrix metal

<table>
<thead>
<tr>
<th>C</th>
<th>C</th>
<th>M</th>
<th>Si</th>
<th>Fe</th>
<th>Mn</th>
<th>Zn</th>
<th>Ti</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.29</td>
<td>1.29</td>
<td>0.07</td>
<td>0.20</td>
<td>0.54</td>
<td>0.03</td>
<td>0.06</td>
<td>0.01</td>
<td>R em</td>
<td></td>
</tr>
</tbody>
</table>

2.2. Experimental Work:
The simplest and the most cost effective method of liquid state fabrication is stir casting [15]. In this work stir casting technique is employed to fabricate, which is a liquid state method of composite materials fabrication, in which a dispersed phase (reinforcement particulates) is mixed with a molten metal by means of stirring. The base metal 2024 Al was melted at 700°C in an electric furnace at Linson Alloys Pvt. Ltd. Hyderabad. At this high temperature magnesium ribbons are added into the molten aluminum metal. The magnesium ribbons are added to increase the wettability of aluminum metal so that the reinforcement added to the metal is evenly dispersed. An appropriate amount (1% of the wt. of base metal) of boron carbide powder was then added slowly to the molten metal. The boron carbide added to the molten metal was pre-heated for 500°C to remove the moisture (if any) in it. Simultaneously, the molten metal was stirred thoroughly at a constant speed of 300 rpm with a stirrer. The high temperature molten metal was poured into the pre-heated (300°C) cast iron moulds to get the required specimens. The same procedure was followed to get the AMCs of different wt. % - 2%, 3%, 4% & 5%. The experimental setup is shown in fig.1.

Fig.1 Molten metal in the furnace

2.3. Testing:
The fabricated specimens were proposed to test for mechanical properties like Tensile strength and hardness. The SEM analysis and XRD analysis were proposed to be done to know the dispersion of the reinforcement in the metal matrix.

2.3.1. Tensile testing:
The specimens were machined to get dog boned structure as per ASTM E-8 standards. Test was carried out on a computerized UTM (TUE-C-600 Model Machine). The tensile test specimens are shown in fig.2.

Fig.2 tensile Test Specimens
2.3.2. Hardness Test:
Bulk hardness measurements were carried out on the base metal and composite samples by using standard Rockwell hardness test machine. Rockwell hardness measurements were carried out in order to investigate the influence of particulate weight fraction on the matrix hardness. Load applied was 100 kg and indenter used was 1/16’.

3. Results & Discussions:

3.1. Tensile Strength:
The tensile test results are given in the table 2. The tests revealed that, the ultimate tensile strength gradually increased by the increase in wt. % of the reinforcement added to the metal matrix. The maximum Tensile strength was observed at 4% B4C. The trend of increase in ultimate tensile strength is plotted in a graph shown in fig. 3. When the reinforcements are added, the particulate reinforcements form nuclei which results in greater number of grain formation. Thus the movement is restricted further, which results in greater strength [16]. Thus the observation in the overall increase of the tensile strength is aptly justified and explainable.

Table 2: Tensile Test Result

<table>
<thead>
<tr>
<th>S. No</th>
<th>Composition</th>
<th>Tensile Strength N/mm²</th>
<th>Yield Strength N/mm²</th>
<th>% Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Al 2024</td>
<td>222.4</td>
<td>167.37</td>
<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>Al+1% B4C</td>
<td>190.983</td>
<td>150.86</td>
<td>3.23</td>
</tr>
<tr>
<td>3</td>
<td>Al+2% B4C</td>
<td>199.476</td>
<td>160.818</td>
<td>3.3</td>
</tr>
<tr>
<td>4</td>
<td>Al+3% B4C</td>
<td>210.957</td>
<td>172.233</td>
<td>3.03</td>
</tr>
<tr>
<td>5</td>
<td>Al+4% B4C</td>
<td>235.489</td>
<td>182.76</td>
<td>2.37</td>
</tr>
<tr>
<td>6</td>
<td>Al+5% B4C</td>
<td>215.903</td>
<td>179.183</td>
<td>2.83</td>
</tr>
</tbody>
</table>

3.2. Hardness:
The tests revealed that, the hardness of the composite specimen had increased gradually with increase in the wt. % of boron carbide powder incorporated in the metal matrix. The trend of increase in hardness is shown in fig.4.

Table 3: Hardness Test Result

<table>
<thead>
<tr>
<th>S.No</th>
<th>Combination</th>
<th>Hardness No (HRB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0% B4C</td>
<td>77.7</td>
</tr>
<tr>
<td>2</td>
<td>1% B4C</td>
<td>81.3</td>
</tr>
<tr>
<td>3</td>
<td>2% B4C</td>
<td>85.3</td>
</tr>
<tr>
<td>4</td>
<td>3% B4C</td>
<td>88</td>
</tr>
<tr>
<td>5</td>
<td>4% B4C</td>
<td>95.3</td>
</tr>
<tr>
<td>6</td>
<td>5% B4C</td>
<td>97.7</td>
</tr>
</tbody>
</table>

3.3. Optical & SEM Analysis:
The morphology, density, type of reinforcing particles and its distribution have a major influence on the properties of particulate composites [1]. The specimens were prepared for microstructure analysis by thoroughly polishing and etching. Then the specimens were observed under an optical microscope for studying the microstructure. The optical micrograph is shown in fig.5, which shows the even dispersion of the reinforcement in the matrix. The SEM images of the prepared samples were taken & shown in fig. 6. Also the SEM images of fractured surfaces of the tensile test specimens were taken and shown in fig. 7&8. The fracture surfaces clearly show the pull out of the reinforcement particles which is the main cause of fracture. The XRD analysis confirmed the presence of B4C within the matrix. The XRD pattern is shown in the fig.9.
Conclusions:

The 2024 Al-B4C composites of combinations 1%, 2%, 3%, 4% & 5% were produced through stir casting method. The mechanical properties of the samples were evaluated and compared with base metal properties. The following conclusions are made from the study.

1. Al-B4C composites were successfully fabricated by stir casting method.
2. The tensile strength of 2024 Al with 5% B4C showed highest value.
3. The hardness was found to be the maximum for 5% B4C composite.
4. Optical micrographs revealed that the B4C particles were well distributed in the aluminium matrix.
5. XRD analysis revealed the presence of B4C particles in the composite with homogeneous dispersion.

Acknowledgement

The authors are grateful to Laser Company, Sydney, for providing materials for this research.

References


