FRICITION STIR WELDING OF AA7475 HYBRID COMPOSITES

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ABSTRACT

The increasing demand for newer lighter materials with good load bearing capacity in the field of automotive, aerospace and marine leads to the fabrication of aluminium metal matrix composites. Fabrication of high strength aluminium matrix composites in 2000 and 7000 alloy series have been focused for this application. In this work, a hybrid aluminium matrix composite with AA7475 aluminium alloy as matrix material was fabricated using stir casting technique, by adding 5 wt.% volume fraction of reinforcement particles such as Boron carbide (B₄C) and Cerium oxide (CeO₂). To study the effect of B₄C and CeO₂ particles, composites were created with individual reinforcements also, for 5 wt.% volume fraction. Friction Stir Welding (FSW) was conducted on the composite plate specimens to study the mechanical behavior of the welded joint. Mechanical tests were performed before and after friction stir welding of the above aluminium composites and compared. The results revealed a remarkable improvement of mechanical properties after addition of B₄C particles and increased ductility on all the samples.

Keywords: Aluminium matrix composites, hybrid composites, friction stir welding, boron carbide (B₄C), cerium oxide (CeO₂).


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1. INTRODUCTION

Aluminium alloys are the most commonly used materials in transport industries including automobile, aerospace and marine sectors. They find their applications because of their high strength weight ratio and stiffness, which leads to the increase of payload and decrease of the overall structural weight of the vehicle. 2000 and 7000 series aluminium alloys exhibits
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higher strength than the other aluminium alloy series, which makes them to be employed in advance aircraft vehicles [1]. Endless research in tailoring new aluminium metal matrix composites (AMC) with higher specific stiffness and strength is going on, to amend many precise components in aerospace, with the aim of weight reduction without compensating the strength [2]. Varieties of hard ceramic particles are available for producing AMCs with tailor made properties to suit the applications. Shirvanimoghaddam et al fabricated AMCs with B₄C, TiB₂ and ZrSiO₄ as reinforcements with varying volume fractions and compared their mechanical properties [3]. Kaushik and Rao successfully fabricated and investigated the wear behavior of Al6082/SiC/Gr hybrid composites [4]. Fabrication of AMCs with high strength aluminium alloys as matrix material followed by investigating their mechanical properties and examining their weldability are the emerging research areas in the recent years [5–7].

Friction stir welding is a remarkable solid state joining technique which was devised in 1991 particularly for welding the non-weldable aluminium alloy series. The method took advantages on low temperature heating which provides low distortion, shielding gas free thus eco-friendly and minimal surface cleaning over the conventional fusion welding methods [8]. FSW has proved its consistency with many successful results in joining not only aluminium alloys but also aluminium composites. Many researchers proposed eminence results and proved the FSW is an efficient joining method for high strength aluminium alloys, as follows. Malarvizhi & Balasubramanian investigated and suggested that the joint efficiency of AA2219 of FSW joint is higher than GTAW and EBW joints [9]. Buffa et al investigated the FSW of AA7075-T6 tailored blanks with varying thickness and concluded that sound joints can be made by FSW technique [10]. Karthikeyan et al have found that friction stir processing an emerging processing technique of FSW has enhanced the tensile properties of cast aluminium alloy, because of the grain refinement done by the FSW tool [11]. Also researchers have investigated and ensured the constancy of FSW technique in joining high strength AMCs. Uzun performed FSW on AA2124/SiC composites and concluded that the microstructure formed in the weld nugget shows better distribution of SiC particles due to the action of FSW tool [12]. Varunkumar and Balachandar have also studied the microstructure and micro hardness of FSW AA6063-O plates with and without SiC powders [13].

In this present work, a hybrid AMC with B₄C and CeO₂ ceramic particles as reinforcements in AA7475 aluminium alloy as matrix was fabricated by stir casting technique. Characterization of friction welded specimen was conducted following standard metallographic methods and their mechanical properties were studied. In order to acquire the individual effect of the particles, AMCs with individual ceramic particles as reinforcements were also fabricated and welded.

2. EXPERIMENTAL PROCEDURE
AA7475 alloy whose chemical composition is as shown in table 1, was used as matrix material while 5%wt. of boron carbide and cerium oxide were used as reinforcements for preparing the hybrid composite. Moreover, these reinforcements were added individually to the base metal, for studying the effect of each of them. Table 2 shows the chosen composition of the composites along with their volume fraction of the reinforcements.

Table 1 Composition of AA7475

<table>
<thead>
<tr>
<th>Element</th>
<th>Zn</th>
<th>Mg</th>
<th>Cu</th>
<th>Si</th>
<th>Fe</th>
<th>Cr</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>5.86</td>
<td>2.34</td>
<td>1.56</td>
<td>0.08</td>
<td>0.11</td>
<td>0.21</td>
<td>Balance</td>
</tr>
</tbody>
</table>
Stir casting technique was used for preparing the aluminium matrix composites, in which the AA7475 ingots were melted. The reinforcement particles were preheated at 400 °C and were added to the aluminium matrix retained at 800 °C. The molten mixture was stirred continuously for 30s and left free for next 5s. This stirring cycle was continued for four more times and poured into the preheated mould. Thus, specimens of 100 mm X 100 mm X 10 mm thickness plates were cast and air cooled up to room temperature. Further the plate thickness was reduced by machining to 6 mm thickness. Bead-on friction stir welding was done using a super HSS tool (HSS with 10% of Co) with a conical profile as shown in figure 1. A computer numerical controlled FSW machine was utilized for welding the specimens. A hardened conical tool with reducing diameter from 6 mm to 5mm, 18 mm shoulder diameter and 5.7 mm pin length was used for welding all the specimens. The weld parameters were so chosen that rotating speed was at 800 rpm while traverse speed at 25 mm/min. The vertical axial load of 6 kN and a tool tilt of 2° was provided during the weld.

Standard metallurgical practices were followed and the microstructures were evaluated before and after the friction stir welding. The tensile specimens were prepared as per ASTM E08 standards from the base metal and the composites plates before & after FSW. A servo controlled Universal Testing Machine UNITEK-94100 was utilized for conducting the tensile tests.

![Figure 1 FSW tool](image)

### 3. RESULTS AND DISCUSSIONS

#### 3.1. As-Cast Base Materials

The optical microstructure and the tensile tests results of the four different compositions viz (a) AA7475, (b) AA7475/B₄C, (c) AA7475/CeO₂ and (d) AA7475/B₄C/CeO₂ are as shown in figure 2 & table 3 respectively. Optical microstructure of AA7475 aluminium alloy shows a dendritic structure formed by the severe cooling rate when the metal solidifies during casting.

**Table 2 Composites with wt.%**

<table>
<thead>
<tr>
<th>Materials</th>
<th>AA7475 (wt.%)</th>
<th>B₄C (wt.%)</th>
<th>CeO₂ (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA7475</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AA7475/B₄C</td>
<td>95</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>AA7475/CeO₂</td>
<td>95</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>AA7475/B₄C/CeO₂</td>
<td>95</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>
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Figure 2 Optical micrographs before FSW (a) Base metal AA7475, (b) AA7475/B₄C, (c) AA7475/CeO₂ and (d) AA7475/B₄C/CeO₂

Table 3 Tensile test results of as-cast base materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>As cast</th>
<th>UTS (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA7475</td>
<td></td>
<td>114</td>
<td>5.4</td>
</tr>
<tr>
<td>AA7475/B₄C</td>
<td></td>
<td>210</td>
<td>7.8</td>
</tr>
<tr>
<td>AA7475/CeO₂</td>
<td></td>
<td>49</td>
<td>3.0</td>
</tr>
<tr>
<td>AA7475/B₄C/CeO₂</td>
<td></td>
<td>209</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Microstructure of AA7475/B₄C composite reveals that the B₄C particles are distributed uniformly, with very less cluster formation. B₄C with 220 mesh size, the particles are visible in lower magnification micrographs. In higher magnification, AA7475/B₄C composite shows almost the same type of microstructure as like the base metal, revealing no evident change of B₄C. Grain boundary precipitation was found on all the samples, with and without reinforcements.

Microstructure of AA7475/CeO₂ composite shows a completely different microstructure when compared with the base metal. The CeO₂ particles being 5 µm in size are visible in high magnification micrographs and the particles were found uniformly distributed. The dendritic structure of the base metal was found changed and the presence of second phase particles was found uniformly in the micrographs, while very few CeO₂ particles clusters were also observed. AA7475/B₄C/CeO₂ hybrid composite has microstructure similar to AA7475/B₄C
composite with well identified grain boundaries. Presence of precipitates along the grain boundaries and few inside the grains were also observed. Hybrid composite has the effect of both $B_4C$ and $\text{CeO}_2$ particles, but highly influenced by the $B_4C$ particle.

3.2. Friction stir welded samples

The optical microstructure and the tensile tests results of the four different welded plates with the following compositions, (a) AA7475, (b) AA7475/$B_4C$, (c) AA7475/$\text{CeO}_2$ and (d) AA7475/$B_4C$/CeO$_2$ are as shown in figure 3 & table 4 respectively.

![Figure 3](image)

**Figure 3** Optical micrographs of stir zone after FSW (a) AA7475, (b) AA7475/$B_4C$, (c) AA7475/$\text{CeO}_2$ and (d) AA7475/$B_4C$/CeO$_2$

<table>
<thead>
<tr>
<th>Materials</th>
<th>After FSW</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>UTS (MPa)</td>
<td>Elongation (%)</td>
<td></td>
</tr>
<tr>
<td>AA7475</td>
<td>115</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>AA7475/$B_4C$</td>
<td>192</td>
<td>13.75</td>
<td></td>
</tr>
<tr>
<td>AA7475/$\text{CeO}_2$</td>
<td>85</td>
<td>7.5</td>
<td></td>
</tr>
<tr>
<td>AA7475/$B_4C$/CeO$_2$</td>
<td>164</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

* From three samples

Microstructure of the friction stir welded specimens shows the dendritic structure of AA7475 was found distorted and realignment of grains has happened. Additionally particle redistribution was observed due to the material flow caused by the FSW tool on the weldment. Further uniform distribution of the particles in the weld zone and disintegrated clusters of $\text{CeO}_2$ were observed. This disintegration could be contributed to the stirring action.
of the FSW tool in the stir zone resulting in the material flow from the advancing side to the retreating side, also evident in previous research works [14, 15].

![Figure 4 Tensile test specimens after FSW](image)

Tensile tests were conducted on the welded composite plates and the specimens are shown in figure 4. Tensile test results revealed the significance of FSW in ductility improvement for all the aluminium composites. This improvement of ductility was noticed in the welded AA7475 alloy and the AA7475/B₄C composite specimens and the tensile samples failed either in the TMAZ or in the TMAZ-BM interface indicating stronger weld zone. The result could be corroborated to the fine grain structure in the nugget and elongated, non-recrystallized grains in the TMAZ, which shows similar to the results obtained by Gopalakrishnan and Murugan [16].

Even though the base material did not result in better tensile strength, the welded AA7475/CeO₂ composite specimens resulted in comparatively fair values. But the tensile failure was spread along the other zones indicating comparatively stronger weld nugget. Redistribution of CeO₂ particles uniformly in the nugget zone due to the action of FSW tool could be the phenomenon involved, which goes in par with the research work done in FSP by Hosseini et al [17].

4. CONCLUSIONS

The conclusions of this work are

1. Stir casting technique was used successfully to fabricate AA7475/B₄C/CeO₂ composites with almost no clusters of reinforcement particles.
2. Improved mechanical properties of the AA7475 metal matrix composite was observed upon addition of B₄C particles as reinforcement and had adverse effect with CeO₂. Hybrid composite with (B₄C + CeO₂) particles as reinforcement resulted in optimum tensile strength and ductility.
3. FSW resulted in improved ductility than that of as-cast AA7475 and the reason for that could be corroborated to the grain refinement and redistribution of particles.
4. Addition of B₄C particles in AA7475 resulted in improved weld properties viz. tensile strength and ductility, than addition of CeO₂ particles.
5. Friction stir welding upon B₄C + CeO₂ reinforced AA7475 metal matrix composite resulted in lower tensile and ductility than B₄C reinforced AA7475 but higher tensile and ductility than CeO₂ reinforced AA7475 composites.

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