The preparation and mechanical properties of Al metal matrix composites by in-situ method

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Abstract: The aluminium-based composites are widely being used in the transport, aerospace, marine, automobile and mineral processing industries. Preparation of Al/TiB₂ composites by in-situ processing offers significant advantages over the conventional processing from both technical and economic standpoints. The technique of salt-metal reactions is an attractive in-situ approach for preparing Al-TiB₂ metal matrix composites. It involves in mixing of Ti and B bearing salts (i.e., K₂TiF₆ and KBF₄) to molten aluminium, giving rise to the formation of dispersion of TiB₂ particles in the aluminium matrix. The obtained as-cast metal matrix composite is carefully machined to prepare the test specimens for hardness, tensile as well as microstructure studies as per ASTM standards. The hardness, tensile strength and microstructure properties of Al6061-TiB₂ composites are explored experimentally. Finally, the material characterisation of heat treated sample and as-cast samples are compared.

Keywords: Al6061-TiB₂ metal matrix composites; hardness; tensile; microstructure.


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1 Introduction

Aluminium alloys are highly preferred to marine, automobile, aerospace and mineral processing industries for various high performing components. The particles reinforced aluminium metal matrix composite have attracted much due to their excellent performance, such as lower density, high specific stiffness, high specific strength and good thermal stability compared with pure aluminium and aluminium alloys (Miracle, 2010; Feng and Froyen, 2000). Particle reinforced metal matrix composite (PRMMC) consists of a uniform distribution of strengthening ceramic particles embedded into a metal matrix. In in-situ method, dispersoids are developed during fabrication and form strong bond with good surface finish and low surface oxides (Guo and Kato, 2015). However, the nano sized particles are uniformly distributed and can stabilise the deformed structure (Chen et al., 2015). The mechanical stirring process also plays a major role for attaining uniform particle distribution. The cast composites are sometimes further extruded to reduce porosity, to refine the microstructure, and to homogenise the distribution of the reinforcement. The major concern associated with the stir casting process is the segregation of reinforcing particles which are caused by the surfacing or settling of the reinforcement particles during the melting and casting processes. The final distribution of the particles in solid depends on material properties and process parameters such as wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification.
The distribution of particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and characteristics of the particles added. In the in-situ process, the matrix material is heated above its molten temperature so that the metal is totally melted. The reinforcements are formed in the in-situ by exothermic reaction between the matrix and precursor element or compound. The interfaces in this in-situ particle/matrix are clean and free of impurities.

Moreover, the size of the in-situ formed reinforcement is finer and the distribution is more uniform compared to the ex-situ composite resulting in better mechanical properties of the in-situ composites. Preparation of Al/TiB₂ composites by in-situ processing offers significant advantages over the conventional processing from both technical and economic standpoints (Tang and Choy, 2015). The technique of salt-metal reactions is an attractive approach developed typically for preparing Al-TiB₂ MMCs. It involves in adding mixed Ti and B bearing salts (i.e., K₂TiF₆ and KBF₄) to molten aluminium in giving rise to the formation of dispersion of TiB₂ particles in the aluminium matrix. Liquid phase route is used to produce in situ particle reinforced MMCs where the reinforcements are formed in-situ by exothermic reaction between the metal matrix and precursor elements or compounds (Lakshmi et al., 1998; Rajasekaran and Sampath, 2011; Niranjan and Lakshminarayanan, 2013). In-situ methods (Kumara et al., 2008) avoiding interfacial defects at the reinforcement, and very fine TiB₂ can be produced. Moreover, it shows stronger bond between matrix and reinforcement which is resulted in higher mechanical property.

In the present work, Al6061-TiB₂ (3% wt) composite was fabricated by using in-situ casting method. The microstructure was examined to study the surface morphology of the metal matrix composite. The mechanical properties such as hardness and tensile strength on heat treated and as-cast condition were investigated.

2 Experimental analysis

Figure 1 shows the experimental setup for fabrication of Al-3 wt% TiB₂ composites. Table 1 presents the chemical composition of matrix materials. For developing composite, the Al 6061 raw ingot was chipped using shaper machine. The K₂TiF₆ (Potassium hexa fluoro titanate), KBF₄ (Potassium tetra fluoro borate) salts were blended in the ratio of 1:2, then it was preheated in an oven at 250°C for 1hr to remove the moisture. An electric stir casting furnace operating under normal atmospheric condition was used for melting and processing. The Ti and B bearing salts were preheated at 250°C for half an hour in order to remove the moisture and added into aluminium molten metal with continuous stirring (Wang et al., 2010; Mallikarjuna and Shashidhara, 2007). Chipped aluminium was melted above 850°C and then salts were added separately, which underwent exothermic reaction with aluminium matrix alloy as given in equation (1).

\[ Ti + 2B + Al \rightarrow Al + TiB₂ \] (1)

Finally, the melt was poured into a permanent mould which has preheated to 200°C. The as-cast bar was cut into two samples. Then one half of the cut sample solution was treated at 530°C for 4 hr followed by water quenching for 2 hr. Further, this sample was ageing
at 175°C for 8 hr. Then, the aged sample was air cooled at room temperature. Microstructure samples were prepared carefully by polished in various grade emery papers 800–1,500 grade and then to mirror finish using 1.5 µm diamond paste. FESEM was used to study the surface morphology of as-cast and heat-treated composites.

**Figure 1** The experimental setup for the fabrication of Al/TiB₂ MMC (see online version for colours)

![Experimental setup](image)

**Table 1** Chemical composition of Al6061 by weight percentage

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al 6061</td>
<td>0.62</td>
<td>0.23</td>
<td>0.22</td>
<td>0.03</td>
<td>0.84</td>
<td>0.22</td>
<td>0.10</td>
<td>0.10</td>
<td>Bal</td>
</tr>
</tbody>
</table>

The vickers hardness was measured using digital micro hardness testing machine with square pyramid shape diamond indenter in 500 gram load. Tensile testing was carried out using INSTRON 1195-5500R machine. The strain rate used for tensile testing was $1.1 \times 10^{-3}$ s⁻¹. A knife edge extensometer was used to measure the strain.

The tensile specimen for as-cast and heat treated samples were prepared as per ASTM standard E8M (Miracle and Donaldson, 2001) as shown in Figure 2.

**Figure 2** Test samples used for tensile testing (see online version for colours)

![Test samples](image)
3 Results and discussion

The hardness and tensile specimens were tested for as-cast and heat treated samples. The average value of both the test sample values of the hardness and tensile strength of composite samples were observed. The results of the as-cast composite were compared with the heat treated (T6) composite samples.

3.1 Microstructure

Figures 3 and 4 show the FESEM microstructure of as-cast and heat treated of Al-3 wt% TiB\textsubscript{2} composites. From Figures 3 and 4, it can be observed that the distributions of reinforcements in the respective matrix are fairly uniform. It is noticed in Figures 3 and 4 that TiB\textsubscript{2} dispersoids in the matrix. Figure 4 reveals that after heat treatment, the average size of TiB\textsubscript{2} dispersoids were reduced. Moreover, the heat-treatment minimised the porosity and improve properties.

Figure 3 SEM microscopic images of as-cast Al/TiB\textsubscript{2} composites (see online version for colours)

Figure 4 SEM microscopic images of heat treated Al/TiB\textsubscript{2} composites (see online version for colours)
3.2 Micro-hardness

The vickers micro hardness of as-cast and heat treated composite were evaluated using diamond pyramid indenter. Figure 5 represents the micro hardness of as-cast and heat treated composite. From Figure 5, it can be observed that the hardness of the heat treated composite was greater than that of as-cast composite. The improvement in the hardness of heat treated composite may be due to the refinement of TiB₂ dispersoids.

**Figure 5** Hardness for as-cast and heat treated samples (see online version for colours)

3.3 Tensile strength

The tensile strength of as-cast and heat treated composites were evaluated by using tensile testing machine with the extensometer. The tensile strength result of as-cast and heat treated composites are shown in Figure 6. From Figure 6, it can be observed that the tensile strength of heat treated composite was higher than that of the as-cast composite. The increased tensile strength of heat treated composite was due to the refinement of TiB₂ particles and good bonding between matrix and TiB₂ dispersoids.

**Figure 6** Tensile strength for as-cast and heat treated samples (see online version for colours)
4 Conclusions

The significant outcomes of the studies of as-cast and heat-treated Al/TiB$_2$ MMC are given as follows:

- in-situ casting method is successfully adopted for the preparation of Al/TiB$_2$ composites
- the uniform dispersion of TiB$_2$ particles in the aluminium matrix have been made
- micro hardness of the composite is found increased in heat treated composite sample than that of the as-cast aluminium MMC
- the tensile strength of the composite is found that heat treated sample is higher than that of the as-cast aluminium MMC
- in these studies, it can be concluded that heat treated Al/TiB$_2$ MMC has superior tensile and hardness properties.

References


