Development and Characterization of Abrasive Wear Behavior of AA-6351-ZrB₂ in-situ Composites

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Abstract

A low-cost system of AA 6351 - xZrB₂ (x = 0, 3, 6 and 9 wt.%) in-situ metal matrix composites (MMCs) has been prepared by the reaction mixture of K₂ZrF₆ and KBF₄ with molten Al alloy at a reaction temperature of 850°C. These in situ prepared composites were characterized by microhardness, x-ray diffractometer and scanning electron microscope (SEM) analysis. The abrasive wear properties of the prepared composite as various parameters were estimated by the abrasive wear testing equipment using the composite material. From those composite materials, the specimens were machined according to the standard sizes, and the tests were conducted as per the standards recommended by the ASTM G99-95a. The wear characteristics of the composite in the as-cast, the solutionized and the solutionized-aged conditions were studied by conducting wear of different parameters. The results indicated that the wear rate decreased with an increase in the weight percentage of ZrB₂ and the wear resistance increased with an increase in the fraction of ZrB₂ particulates in composite and after heat treatment. The heat treatment showed an improvement in wear.

Keywords: AA 6351/ZrB₂ in situ composite, metal matrix composition.

1. abrasive wear

INTRODUCTION:

The difficulties in the development of ex situ particulate metal matrix composites such as poor wettability, inhomogeneous distribution of reinforcement particles, formation of unwanted reaction products at the interface between the matrix and reinforcement, etc., have led to the attempts to synthesize new generation in situ composites [1]. Among the in situ composites, Al composites have become popular in recent years [2–3]. Different sources of Zr and B such as K₂ZrF₆ and KBF₄ salts, Zr and B powders [4-6], ZrO₂ and H₃BO₃, ZrO₂ and B₂O₃ were used for the synthesis of ZrB₂ reinforced Al matrix in situ composites so far.

Metal matrix composites (MMCs) offer designers many added benefits, as they are particularly suited for applications requiring good strength at high temperatures, good structural rigidity, dimensional stability, and lightweight. They are well known for their superior mechanical and tribological properties [7]. While many researchers have worked on the wear behavior of Al composites at normal conditions, only a few studies have focused on the abrasive wear [8-21]. In many practical situations, even when it is not always apparent whether a corrosive action is involved, corrosion might play an important role in developing the wear of metal components through the continuous removal of corrosion products.

Apart from the Zr–B₂ exothermic nature with Al, its clean interface resulting from absence of oxidation during the creation of reinforcement offers its potential as a wear resistant composite. Its strong bonding with the Al matrix has been verified to be the control factor that affects the wear improvement of the composite. In situ composites are multiphase materials where the reinforcing phase is synthesized within the matrix during composite fabrication [3]. Earlier works suggest that albite particle (chemical composition presented in Table 1) reinforced aluminium MMCs offer light weight, low coefficient of thermal expansion, excellent mechanical properties, and good
Table 1: The nominal chemical composition of AA 6351.

<table>
<thead>
<tr>
<th>Element</th>
<th>Si</th>
<th>Mg</th>
<th>Fe</th>
<th>Cu</th>
<th>Zr</th>
<th>T</th>
<th>Aluminnum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wt. %</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Balance</td>
</tr>
</tbody>
</table>

From literature, the addition of reinforcement increases the abrasive wear resistance of matrix material [6]. Reinforcement interfaces play an important role on the mechanical properties of the MMCs and the improvement mainly depends on the strength of the interface between matrix and reinforcement. Most of the Al-based ex situ composites have low reinforcement/matrix bonding strength. To overcome this problem, in situ synthesis techniques were employed in the present study. Among all Al-alloys, Al 6351 is a work horse in automobile, aerospace industries and structural applications. Thus, in the present work Al 6351–xZrB₂ (x=0, 3, 6 and 9 weight percentage (wt. %)) in situ composites have been obtained by the reaction of mixture of K₂ZrF₆ and KBF₄ with molten alloy at a reaction temperature of 850°C. Presence of impurities, metallic debris, and hard dust particles may cause abrasive wear and adversely affect the life of tribological components [11,12].

Many researchers investigated the abrasive wear behavior of Al-based composites prepared by different routes [13,14,21,22]. It has been stated that abrasive wear resistance of the composites increases with the amount of reinforcement. In the present work, AA6351 metal matrix composite has been synthesized with ZrB₂ as reinforcement through in situ casting route. The synthesis of ZrB₂ has been done through a spontaneous reaction between K₂ZrF₆ and K₂BF₄ powders in aluminium alloy melt. The wear of the as-cast and heat-treated composites has been studied at elevated temperature using the pin on disc sliding wear experimentation.

2. EXPERIMENTAL DETAILS

2.1 Preparation of specimens

AA 6351 – x ZrB₂ (x = 0, 3, 6 and 9 wt. %), were prepared by the addition of salts, namely, K₂ZrF₆ and KBF₄. The salts were stirred in the above aluminium alloy melt at a temperature of 850 °C in the furnace for a period of 30 minutes. The chemical reaction between the two required salts as shown in Table 2 and the molten aluminium alloy resulted in the formation of the ZrB₂ particulates in Al–Mg–Si matrix. One set of the samples were retained without heat treatment to test in as-cast condition. The second set was solutionized at 505°C for one hour followed by quenching in water. The third set of composites was solutionized as above followed by aging at 170°C for 6 hours.

Table 2: The amounts of chemicals added for various composites.

<table>
<thead>
<tr>
<th></th>
<th>AA 6351-0wt.% ZrB₂</th>
<th>AA 6351-3wt.% ZrB₂</th>
<th>AA 6351-6wt.% ZrB₂</th>
<th>AA 6351-9wt.% ZrB₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>K₂ZrF₆ in gms</td>
<td>0</td>
<td>36</td>
<td>71</td>
<td>106</td>
</tr>
<tr>
<td>KBF₄ in gms</td>
<td>0</td>
<td>38</td>
<td>76</td>
<td>114</td>
</tr>
</tbody>
</table>

2.2 X-Ray diffraction analysis:

X-ray diffraction test was carried out to confirm the formation of ZrB₂ phase. XRD phase evaluation was performed on the D/MAX ULTIMA III XRD machine supplied by Rigaku Corporation, Japan using Cu-Kα radiation (1.54056 A°).

2.3 Hardness test

The microhardness of the composite was found using Zwick Vicker’s hardness tester at a load of 0.5 kg. The specimens were polished using standard metallographic procedure. Polished samples were etched with Keller’s reagent. The composite materials were examined under a scanning electron microscope to find out the formed ZrB₂ particles and their surface morphology. On the worn samples, the surface morphology was studied under the scanning electron microscope (SEM) to analyze the wear behavior analysis.

2.4 Abrasive wear test

Wear tests were carried out using silica sand (white) to understand the wear behavior of AA 6351 with and without dispersoids. Dry wheel
abrasive wear tests (as per ASTM G65 standard) were performed using the chlorobutyl rubber-rimmed rotary wheel machine as shown in figure 1. Abrasive-silica sand test details were: (white, with a mesh size of 50/70 µm, sand flow rate 380–400 g/min, speed of wheel 200 rpm, diameter of rubber wheel 170.1mm, testing time (60 seconds), and loads (40, 50 and 60 N). The wear rate was estimated as the volume lost in mm³. The surface morphologies of the worn out surface of the composites were studied by the scanning electron microscope (SEM).

Figure 1 Abrasive wear equipment

3. RESULTS AND DISCUSSION

3.1 Scanning electron microscopy

Figures 2(a) and 2(b) show the SEM micrographs of the composites, namely, AA 6351 alloy with ZrB₂ (9 wt. %) particles. It is observed that the ZrB₂ particles are more spherical in shape and looks like cluster of embryo throughout the matrix. The smaller and bigger size particles seem to be intact at some places which gives rise to more hardness. The agglomeration of ZrB₂ particles was observed in the composites. Figure 2(c) shows the EDAX analysis of the above spherical particles with the evidence of the formation of ZrB₂ as fine dispersion. The above particles were observed to be uniformly distributed throughout the matrix. The average size of ZrB₂ particles is in the order of 5-13 µm in diameter.

3.2 X-ray diffraction analysis

X-ray diffraction patterns of the matrix specimen and of the specimens reinforced with different amounts of ZrB₂ are shown in figure 3.

Figure 2 (a), (b) SEM images of AA 6351-9% ZrB₂ and its (c) Sum spectrum produced by EDAX analysis

The increase in relative intensity of the ZrB₂ peaks with an increased amount of ZrB₂ in composite is also evident. The gradual and the marginal shift in the Al peaks to higher angles with an increased in the weight fraction of the reinforcement is evident. This indicates a decrease in the lattice parameter of Al. The volume fractions of ZrB₂ particles in the corresponding composites were determined as 2.88%, 5.52% and 8.17% against the targeted values. These reduced fractions against the targeted values are due to losses happened during the melt operation.
3.3 Abrasive wear behaviour

Primarily the abrasion took place via ploughing, in which the material is displaced on either side of the abrasion groove without being removed, or through wedge forming, where tiny wedge shaped fragments are worn only during the initial contact with the abrasive particle [15, 16]. It was found that three-body abrasive wear is ten times slower than two-body wear since it has to contend with other mechanisms such as adhesive wear [17, 18]. The present observations reveal that the abrasive wear rate decreases with increase in wt.% of ZrB$_2$ particles. Abrasive wear is a process where the abrasive particle when slides over the soft material will plough the surface of soft material and removes the material on the sides of the groove and subsequent sliding of abrasive will lead to material loss [19, 20]. As the number of ZrB$_2$ particles increase, the ploughing tendency of the abrasive particle reduces, which is due to higher hardness of the composite.

SivaPrasad et al. [6] found that in situ formed ZrB$_2$ composites are effectively covering the matrix alloy and restrict the metal removal by abrasive particles in case of composite. The ploughing action of AA 6351 is reduced due to increase in wt.% of ZrB$_2$ particles. When compared to the 9 wt.% with 3 and 6 wt.% ZrB$_2$, 9 wt.% ZrB$_2$ wear scar shows thinner grooves than 3 and 6 wt.% ZrB$_2$. Thus, 9 wt.% ZrB$_2$ offers more resistance than 3 and 6 wt.% ZrB$_2$. Grooves are not continuous here, since ZrB$_2$ particles resist the movement of abrasive through the wear interface. Thus, the wear mechanism appears to be grain pull-out, mix-up of micro-cutting and ploughing.

**Conclusion:**

The XRD analysis confirms the formation of ZrB$_2$ particles in the Al alloy matrix and hence the feasibility of the composite for industrial applications. Abrasive wear resistance of Al 6351 alloy increases with progressive addition of ZrB$_2$ reinforced particles. SEM examination for abrasive studies indicate a mix-up of micro-cutting, ploughing and grain pull-out mechanisms. The effect of the reinforcement volume fraction on the wear resistance of the composite is the highest for 9 wt% of ZrB$_2$ reinforcement for solutionized and aged condition. The wear mechanism of AA 6351-ZrB$_2$ composites for the as-cast, the solutionized and the solutionized-aged condition has been established. The lower wear rate of composites for heat treated conditions under these circumstances are due to...
their higher value of the hardness and precipitate formation in aged condition.

References:


5. K. B. Shah, S. Kumar, and D. K. Dwivedi, Aging temperature and abrasive wear behaviour of cast Al–(4%, 12%, 20%)Si–0.3% Mg alloys, Mater. Design, 2007 No. 28, p. 1968.


