Research Article

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Effect of pouring temperature on cast Al/SiCp and Al/TiB$_2$ metal matrix composites

Abstract: The effect of pouring temperatures of an ex situ (Al/SiCp) and in situ (Al/TiB$_2$) metal matrix composites (MMCs) synthesized using stir casting method were studied. The Al/SiCp composite were fabricated by mixing of 6wt.% of SiCp into cast A356 aluminium alloy melt and poured at diverse pouring temperatures (730°C, 750°C and 770°C). The Al/TiB$_2$ MMCs were obtained by melting A356 aluminium alloy and mixing of KBF$_4$ and K$_2$TiF$_6$ precursor salts whose stoichiometric ratio composition corresponds to 6wt.% of TiB$_2$ reinforcement and other parameters were constant (stirring speed 300 RPM and holding time 30 minutes). The composite melt was poured into the permanent mould with varied pouring temperatures (800°C, 820°C and 840°C). Coarser and homogenous SiC particles were presented in the Al/SiCp MMCs, whereas, finer and uniformly distributed TiB$_2$ particles were appeared at the MMCs of Al/TiB$_2$. The mechanical properties viz. tensile strength, fracture toughness and hardness of Al/SiCp and Al/TiB$_2$ MMCs were experimentally determined as per the ASTM standards and compared. Higher tensile and fracture strength were occurred at the MMCs of Al/TiB$_2$ as compared to Al/SiCp MMCs and base alloy of aluminium as well. Maximum hardness was attained at the pouring temperatures of 820°C and 750°C in the MMCs of Al/TiB$_2$ and Al/SiCp, respectively.

Keywords: Al/SiC, Al/TiB$_2$, stir casting, pouring temperatures, microstructure, mechanical

1 Introduction

Aluminium based MMCs reinforced with ceramic particulates have attracted many researchers. Mainly due to the exhibited low density, low melting point, high specific strength and thermal conductivity of aluminum. A wide variety of ceramic particulates such as SiC, B$_4$C, Al$_2$O$_3$, TiC and graphite have been reinforced into aluminium matrix materials. Nowadays, the need of engineering materials with higher strength, better wear resistance and superior temperature performance variety of ceramic reinforcements compatible with aluminum matrix is a reason for their investigation. In the fabrication of MMCs, poor wettability of reinforcement (which can affect the bonding at the reinforcement-matrix interface) with aluminum matrix and increasing weight percentage of reinforcement addition into the matrix material leads to increase in porosity [1–3]. In ex situ processing of Al/SiC MMCs, reinforcements are directly added into the molten metal. Whereas, in the in situ technique, the reinforcements are formed inside the molten metal by exothermic reaction, which takes place between the molten aluminium and halide salts. In the last two decades, numerous research work has been dealt with the fabrication of aluminium based MMCs reinforced with silicon-carbide (SiC) or alumina (Al$_2$O$_3$) as reinforcement materials [4, 5]. Al/TiB$_2$ MMCs possess outstanding characteristics such as high melting point, hardness, good thermal stability high elastic modulus. TiB$_2$ particle does not react with molten aluminum and hence, prevents the occurrence of brittle reaction products at the reinforcements-matrix interface. Especially, Al/TiB$_2$ MMCs has brought a special attention, due to its high wear resistance, higher hardness and tensile strength than the monolithic alloy [6].

From the industrial point of view, the most important advantage of Al-TiB$_2$ composite is its recycle ability, when compared with conventional Al-SiC composites. Therefore, the present paper is aimed to describe the Al-6wt.% of SiCp ex situ formed MMC and Al-6wt.% of TiB$_2$ in situ formed metal matrix composites fabricated by stir casting technique and the effect of pouring temperatures on mechanical properties such as tensile strength, fracture tough-
ness and hardness were studied [7]. The size and distribution of reinforcement particles were examined by optical and scanning electron microscopy (SEM). Whereas the presence of reinforcing materials was confirmed by X-ray diffraction analysis (XRD).

2 Experimental preparation

The chemical composition of Aluminium matrix material is given in the Table 1. The SiC particles size of 74 microns were preheated at 750°C for 2 hours to improve the wettability by removing the moisture and volatile matter sticking into the SiC particles. The furnace temperature was raised to 800°C to melt the matrix completely. 15 grams of magnesium was added into the aluminium melt in order to enhance the wettability. At this stage the preheated SiC particles were mixed into the melt. Mechanical stirring arrangement was employed about 30 minutes with the constant speed of 300 RPM.

Table 1: Chemical composition of cast 356.0

| Elements | Si | Mg | Mn | Fe | Cu | Ni | Ti | Al |
|----------|----|----|----|----|----|----|----|----|
| A356.0   | 7  | 0.33 | 0.3 | 0.5 | 0.1 | 0.1 | 0.2 | bal |

The total melt at 730°C was poured in to the permanent mould (70mm × 55mm × 180mm) and allowed to be solidified and then removed. Similarly, the above procedure was followed for the other pouring temperatures of 750°C and 770°C. The fabrication of Al/TiB₂ MMC involved weighted halide salts (K₂TiF₆ and KBF₄) as per the stoichiometric ratio corresponding to 6wt.% and preheated at 250°C for about 30 min and mixed into the molten aluminium. Mechanical stirring was continued up to 30 min and composite melt was poured in to the permanent mould at different pouring temperatures like 800°C, 820°C and 840°C and allowed to be solidified.

Morphology of synthesized composites was studied by optical and scanning electron microscopy. The presence of reinforcing materials and intermetallic is confirmed through XRD study. The hardness test was carried out by Brinell hardness testing machine. The hardness was taken at three different points and average value was listed in Table 3. The hardness tests were carried out with three replications. The hardness test specimens are shown in Figure 1(a). Tensile test was conducted as per ASTM E08-M16 guidelines. Tensile test was carried out in 100 KN, (UNITEK-94100) Electro-Mechanical Controlled Universal Testing Machine. The specimen was loaded at the rate of 1.5 KN/min as per the ASTM specifications. Three replications were made for each condition and their values were recorded in Table 2. Tensile samples are shown in

![Figure 1](image)

(a) Hardness specimens after testing conditions; (b) tensile specimens after testing conditions; (c) 3-point bends specimens after testing conditions
Figure 1(b). The fracture toughness specimens were pre-cracked in accordance with ASTM E399 to provide a sharpened crack of adequate size and straightness. Fracture toughness test was conducted in the Instron 8801 dynamic testing machine. The 3 point bend specimens are shown in Figure 1(c).

3 Results and discussion

3.1 Effect of pouring temperature on microstructural of an Al/SiCp and Al/TiB₂ MMCs

The pouring temperature has synergetic impact on microstructure of the composites. The microstructures of the Al/SiCp and Al/TiB₂ MMCs with varied pouring temperatures are shown in Figures 2-3. It is evident that the reinforcing particles were uniformly distributed in the aluminium matrix, but some regional agglomeration was found in the composites. From the optical micrograph in Figures 2(a)-(c) corresponding to Al/ SiC MMCs cast with pouring temperature 730°C, 750°C and 770°C not much of a variation would be found. The aluminium grains were not affected by the diverse of pouring temperature. However, in the SEM micrograph in Figures 3(a)-(c) for the same pouring conditions, increased agglomeration was observed in Figure 3(a) corresponding to 730°C pouring temperature. It may lower the pouring temperature of particles, which are settled in some areas. Whereas, in the Al/TiB₂ MMCs, the distribution of TiB₂ particles were confirmed by optical micrograph in Figures 2(d)-(f), more number of TiB₂ particles were observed in the composite synthesized at 820°C pouring temperature and formation of Al₃Ti intermetallic phase was lesser as compared to composite made with 840°C pouring temperature. The similar trend has been observed in the SEM micrograph in Figures 3(d)-(f). Al₃Ti is naturally a brittle phase and it was formed as a by-product, while composite was synthesized through in situ reaction. The pouring temperature beyond 820°C, the formation of Al₃Ti intermetallic was accelerated. Moreover, when the pouring temperature increases, it leads to the forming of bigger and needle-like TiB₂ particles. It is due to the fact that during in situ reaction, the fluorine gas, formed as a byproduct, would escape from
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Figure 2: (a) Optical micrographs of Al/SiCp prepared 730$^\circ$C; (b) Optical micrographs of Al/SiCp prepared 750$^\circ$C; (c) Optical micrographs of Al/SiCp prepared 770$^\circ$C; (d) Optical micrographs of Al/TiB$_2$ prepared 780$^\circ$C; (e) Optical micrographs of Al/TiB$_2$ prepared 820$^\circ$C; (f) Optical micrographs of Al/TiB$_2$ prepared 840$^\circ$C

Figure 3: (a) SEM micrograph shows Al/SiCp prepared at 730$^\circ$C; (b) SEM micrograph shows Al/SiCp prepared 750$^\circ$C; (c) SEM micrograph shows Al/SiCp prepared at 770$^\circ$C; (d) SEM micrograph shows Al/TiB$_2$ prepared at 800$^\circ$C; (e) SEM micrograph shows Al/TiB$_2$ prepared at 820$^\circ$C; (f) SEM micrograph shows Al/TiB$_2$ prepared at 840$^\circ$C
the melt surface, causing low pressure between the TiB$_2$ molecules. Meanwhile, the surrounding aluminium melt eventually consolidated the TiB$_2$ molecules together and formed bigger and needle-like TiB$_2$ particles as shown in Figure 3(f). These particles and intermetallic phases slightly affect the mechanical property of the composite. From the XRD analyses, it has been confirmed the presence of reinforcement particles viz. SiC & TiB$_2$ and Al$_3$Ti intermetallic phase as shown in Figures 4(a) and (b).

### 3.2 Effect of pouring temperature on mechanical properties of an Al/SiC and Al/TiB$_2$ MMCs

The effect of pouring temperature on mechanical properties of an ex situ and in situ formed MMCs were studied. When the cast metal was poured at 820°C, a homogeneous distribution of reinforcing particles was observed and by-product formation was much lesser than that of composite synthesized at 840°C, hence better mechanical properties were attained. The increase of pouring temperature results in the increasing number of TiB$_2$ particles, but beyond the 820°C, it is the chance for the formation of Al$_3$Ti intermetallic (by-product). These intermetallic phases synergistically affect the mechanical properties of the composite [8, 12]. The foregoing subtitles quantify the effect of pouring temperature on mechanical properties such as tensile strength, fracture toughness and hardness.

#### 3.2.1 Effect of pouring temperature on tensile strength

The tensile strength of Al/SiCp and Al/TiB$_2$ MMCs demonstrates that there is a significant improvement over the base metal, as shown in Table 2. The tensile strength of Al/SiC MMC was found to be maximum of 157 MPa for the composite poured at 750°C, whereas, in Al/TiB$_2$ MMC poured at 820°C the tensile strength was of 175 MPa. The strength of Al/TiB$_2$ MMCs is higher than that of Al/SiC MMCs, because TiB$_2$ particles have superior property than SiC particle and the average size of the formed TiB$_2$ particles lies between the range of 1-3 µm. Whereas the SiC average particle size was of 74 µm. The finer TiB$_2$ particles arrest the movement of dislocation effectively and hence, highest tensile strength was attained in the Al/TiB$_2$ MMC poured at 820°C [9]. When the composite was poured at lower temperature (730°C for Al/SiC MMC and 800°C for Al/TiB$_2$ MMC) the formation of reinforcing particles along with some regional clusters and fine pin holes were observed. It is because of the low pouring temperature, as it leads to reduction of the fluidity of the cast metal and hence the premature solidification may occur. This premature solidification leads to cluster formation and casting defects, so the properties of the composite reduce significantly. In the case of higher pouring temperature (770°C for Al/SiC MMC and 840°C for Al/TiB$_2$ MMC) the formation of intermetallic phases plays major role for weakening the composite’s properties.

#### 3.2.2 Effect of pouring temperature on fracture toughness

Fracture toughness test was carried out to examine the fracture resistance behavior of cast composites. The average values are presented in Table 3. The maximum enhancement was observed in Al/SiC MMC and Al/TiB$_2$ MMC, which are 16.89 Mpa$\sqrt{\text{m}}$ and 22.89 Mpa$\sqrt{\text{m}}$, respectively [10]. When the composites were poured at moderate temperature (750°C for Al/SiC MMC and 820°C for Al/TiB$_2$ MMC) the formation of intermetallic phases plays major role for weakening the composite’s properties.
Table 4: Hardness of Al/SiCp and Al/TiB$_2$ MMCs

| Materials  | Pouring temperature in°C | Hardness (BHN) Replication | Avg |
|------------|--------------------------|-----------------------------|-----|
|            |                          | 1  | 2  | 3  |     |
| Cast 356.0 | 740                      | 55 | 58 | 61 | 58  |
| Al/SiCp    | 730                      | 54 | 56 | 58 | 56  |
|            | 750                      | 65 | 69 | 72 | 69  |
|            | 770                      | 61 | 63 | 65 | 63  |
| Al/TiB$_2$ | 800                      | 57.70 | 58.78 | 59.86 | 58.78 |
|            | 820                      | 76.12 | 76.33 | 77  | 76.33 |
|            | 840                      | 69  | 69.44 | 69.89 | 69.44 |

MMC) the distribution of reinforcing particles were more homogeneous and lesser formation of intermetallic phases was found to correlate with other pouring temperatures. It is due to the fact that, enough fluidity was achieved by this temperature, leading to the good quality of casting, and hence considerable resistance to propagation of crack enhancement. This phenomenon gives the higher fracture toughness compared to other pouring conditions.

3.2.3 Effect of pouring temperature on hardness

The maximum enhancement of hardness 76.33 BHN was achieved in the Al/TiB$_2$ MMC poured at 820°C, whereas, Al/SiC MMC was 66 BHN poured at 750°C as shown in Table 4. It is due to the existence of fine and uniform distribution of TiB$_2$ particles in the aluminium matrix. Moreover, exothermic reaction offers good interfacial boning between the matrix and TiB$_2$ particles and hence matrix efficiently transfers the penetration load to TiB$_2$ particles, so as resistance to penetration increased vastly, when compared to ex situ (Al/SiC) formed composites [11, 13].

4 Conclusions

- The Al/SiC MMCs and Al/TiB$_2$ MMCs were successfully synthesized by stir casting route. Microstructural analysis shows the presence of SiC and TiB$_2$ and its distribution in the aluminium matrix. The XRD graphs confirm the presence of SiC, TiB$_2$ particles and Al$_3$Ti intermetallic phases. At the pouring temperature of 820°C, Al/TiB$_2$ MMCs, a higher number of fine TiB$_2$ particles appeared along with lesser Al$_3$Ti phases and good interfacial bonding led to the achievement of the best mechanical properties.

- In Al/SiC MMC, poured at 750°C, the distribution of reinforcements is better, when compared with other pouring temperatures and the size and distribution of SiC particles play a vital role for deciding the final property of the composite; the SiC size is 74µm and coarser in structure and hence the properties of Al/SiC MMC were worse than Al/TiB$_2$ MMCs.

- Moreover, at the lowest pouring temperature (730°C for Al/SiC MMC and 800°C for Al/TiB$_2$ MMC) agglomeration of reinforcement particles and porosity has been found, because the lower pouring temperature causes the less fluidity and premature solidification, therefore so the mechanical properties were worse. At the highest pouring temperature (770°C for Al/SiC MMC and 840°C for Al/TiB$_2$ MMC), the formation of intermetallic phases and clustering of reinforcing particles were the causes for the diminution of the mechanical properties.

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