C. Rajaravi* and P.R. Lakshminarayanan

Effect of pouring temperature on A356-TiB_2 MMCs cast in sand and permanent moulds by *in-situ* method

DOI 10.1515/jmbm-2017-0004

Abstract: The paper describes a different condition of pouring temperature by sand and permanent mould to produce A356-6 wt% TiB_2 metal matrix composites by *in-situ* method salt metal reaction route. The observation of SEM micrographs shows particle distribution of the TiB_2 and it appears in hexagonal shape in Al matrix. The results of X-ray diffraction (XRD) analysis confirmed the formation of those TiB_2 particulates and the results showed TiB_2 particles are homogeneously dispersed throughout the matrix metal. Subsequent structure-property evaluation studies indicated sub-micron size reinforcement of *in-situ* formed TiB_2 particles with improved physical and mechanical properties as compared to sand and permanent mould of Al-TiB_2 composites. From, the permanent mould Al-TiB_2 composite has an advantage of increase the properties over sand mould Al-TiB_2 composite.

Keywords: Al-TiB_2; *in-situ*; metal matrix composite; permanent mould; sand mould.

1 Introduction

Particulate reinforced metal matrix composites (PRMMCs) have been fabricated normally by conventional *ex-situ* research work due to their ease of fabrication, lower cost and isotropic properties. The *ex-situ* composites are fabricated by directly adding reinforcements in to its matrix [1, 2]. Al-TiB_2 composite is particularly adaptable to *in situ* synthesising. Reaction between Ti and B is highly exothermic in behaviour and the heat generated helps to accelerate the formation of TiB_2 readily [3, 4]. In addition TiB_2 is particularly suitable to serve as a reinforcing phase for Al-based composites because of its thermodynamic stability in aluminium [5]. The salt route is used and to synthesise the *in situ* Al-TiB_2 composite [6]. This technique exhibit the presence of a uniform distribution of reinforcement that tends to be fine and associated with a clean interface with the metallic matrix, which assists in the formation of a stronger bond between the reinforcement and the matrix [7]. TiB_2 is particularly attractive because it exhibits high elastic modulus, hardness, high thermal conductivity and mainly TiB_2 particle do not react with molten aluminium [8]. The cast aluminium alloys always contains certain amount of defects such as porosity, oxide films and other inclusions strongly affect mechanical behaviour [9]. This paper investigates the synthesising of Al-TiB_2 composite by the stir casting approach and compare and analyse the microstcure and mechanical properties in sand mould and permanent mould conditions and minimise the above defects.

2 Experimental preparation

2.1 Fabrication of composite

Commercial A-356 was used for the production of Al based MMCs by *in-situ* technique. The stoichiometric mixture of prebaked potassium hexa flouro titanate (K_2TiF_6) and potassium tetra flouro borate (KBF_4) was added to molten metal for 6 wt% TiB_2. Fluxes melted immediately to form a molten layer on the molten metal surface. The stirring of molten metal was continuously up to 30 min. K_2TiF_6 and KBF_4 salts were added into molten Al resulting in exothermic reaction to form *in-situ* TiB_2 particulates in Al. The *in-situ* formed A356-TiB_2 MMCs were cast in both sand and permanent moulds at different pouring temperatures of 780°C, 790°C, 800°C, 810°C and 820°C [10].

2.2 Evaluation of cast composite

Specimens from cast components of A356-6 wt% TiB_2 composite were examined using optical microscope, SEM and XRD techniques. The fracture toughness specimens

***Corresponding author: C. Rajaravi,** Research Scholar, Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar 608002, Tamil Nadu, India, e-mail: rajaravi.mech@gmail.com
P.R. Lakshminarayanan: Department of Manufacturing Engineering, Annamalai University, Annamalai Nagar 608002, Tamil Nadu, India

were pre cracked in accordance with ASTM E399 to provide a sharpened crack of adequate size and straightness. Fracture toughness test was carried out in the Instron 8801 testing machine. Tensile properties of the composite are evaluated using ASTM standards E8-03 on standard 12 mm diameter specimen. Tensile tests were also carried out at UTM servo hydraulic testing machine. The hardness tests were carried out by Brinell hardness testing machine.

3 Results and discussion

3.1 Microstructure analysis

The optical micrograph of sand and permanent mould Al/TiB_2 MMCs is prepared using optical microscopy. Figure 1 shows a typical microstructure of the TiB_2 particles were found to be distributed along the grain boundary during solidification still existed, despite the formation of TiB_2 in the melt and very minimal agglomeration of the particles was observed [11]. In the case of Al/TiB_2 MMCs cast in permanent moulds due to sudden cooling fine grained structure are seen as found in optical micrograph (Figure 1A and B). In the case of Al/TiB_2 MMCs cast in sand moulds due to slow cooling coarse grains are obtained as seen optical micrograph (Figure 1C and D).

Figure 2A shows the SEM micrograph of permanent mould which shows the presence of TiB_2 particles and its distribution in the aluminium metal matrix. The morphology of the TiB_2 particles is typically hexagonal or nearly spherical and there are clear interfaces between particles and matrix. It can be seen in the micrograph of TiB_2 content some TiB_2 particles distributed evenly also some small particle agglomerate to form some particle clusters [12]. The TiB_2 particles are visible and the average size of particles is 1.5–2.0 µm, sudden cooling fine grained structures are seen as found. The permanent mould is high temperature and fluidity of molten metal are also high then the TiB_2 particles will disintegrate into smaller sizes

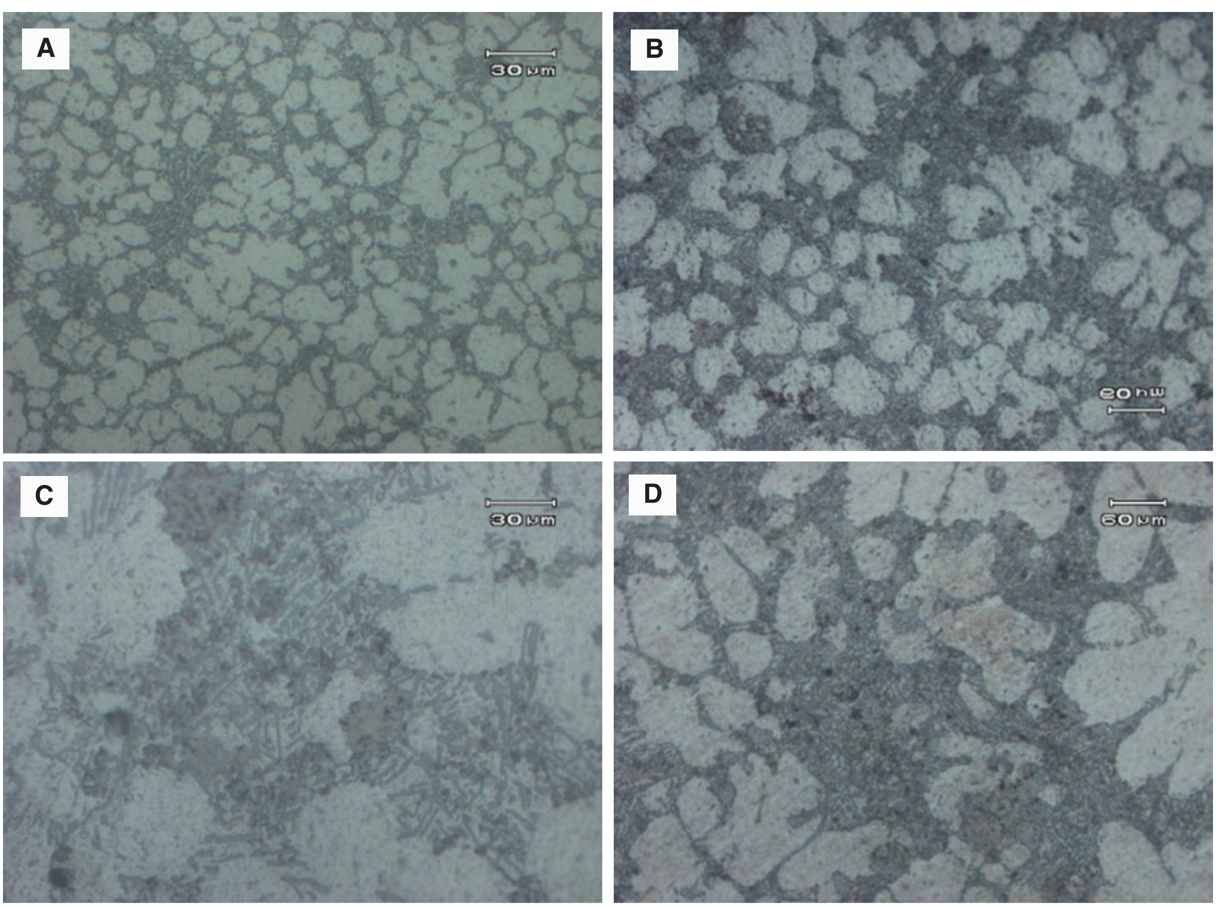

Figure 1: (A and B) Optical micrographs of A356/TiB_2 permanent mould, A356/TiB_2 sand mould composite and closed grain structure refinement (C) and (D).

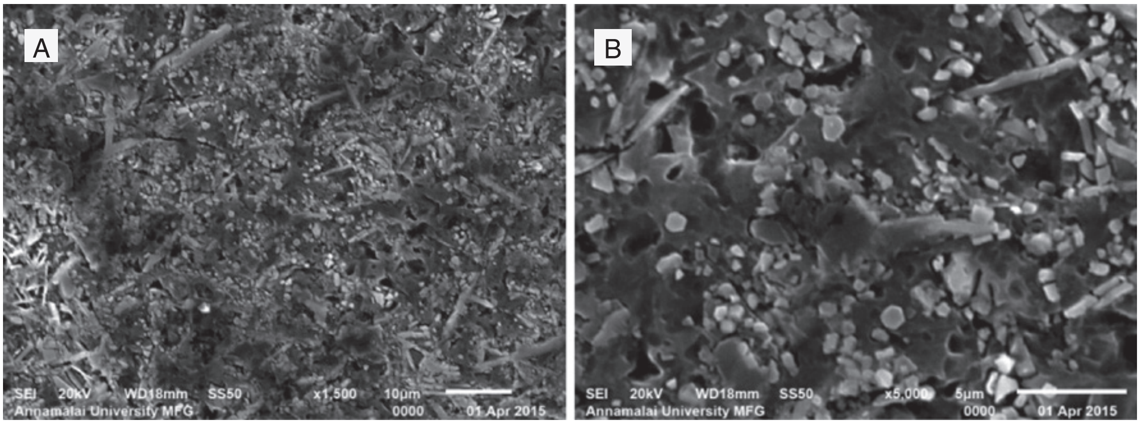

Figure 2: SEM micrograph shows Al/TiB_2 prepared 820°C at permanent mould (A) TiB_2 evenly distributed in matrix, and (B) interface of the reinforcing TiB_2 particle hexagonal shape l in matrix.

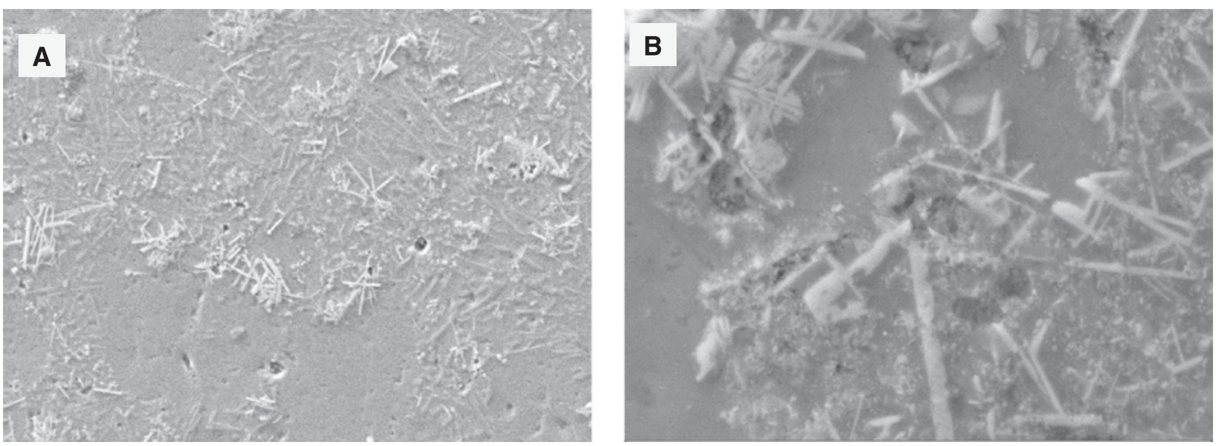

Figure 3: SEM micrograph shows Al/TiB_2 prepared 800°C at sand mould (A) TiB_2 evenly distributed in matrix, and (B) interface of the reinforcing TiB_2 particle with the soft metal matrix.

(1.0–1.5 μm) observed. The more number of TiB_2 particles will get trapped in the freezing metal because more amount of cooling MMC is circulated in that condition.

Figure 3A and B shows the micrographs of sand mould which shows the presence of TiB_2 particles and its distribution in the aluminium metal matrix. It can be seen in the micrograph of TiB_2 content the particles are evenly distributed. The TiB_2 particles are visible and the average size of particles is 2.0–2.5 μm. These strong interfaces between the particle and matrix but slow cooling coarse grains are obtained. Hence in sand mould which is lowest corner of the ingot more molten metal will get circulated molten metal will get trapped [13]. Dispersion of reinforcing particles and assume a needle shape and flaky form. It is seen that the presence of Al_3Ti hinders the uniform distribution of the reinforcement. The size of TiB_2 particles will be more for higher pouring temperatures at the same time the cooling rate is also low the TiB_2 will disintegrate into larger sizes. Hence the size of the TiB_2 particles, 2–2.5 μm as observed.

The XRD patterns of the *in-situ* composites TiB_2 particles have formed as evidenced by XRD both permanent and sand mould with different conditions as shown in (Figure 4A and B). The peak intensity is increasing with increasing amount of TiB_2 particles. Apart from the Al and TiB_2 peaks, the XRD patterns also show peaks corresponding to Al_3Ti (θ), as expected from the phase diagram. After pouring as the cooling rate is low the TiB_2 particles grow in size affecting the mechanical properties. The effect of pouring temperature exclusively can be understood by analyzing the percentage of particles. At lower pouring temperature of 750°C at 50% TiB_2 content is found the fluidity will be less [14]. The pouring temperature of 810°C the TiB_2 content is maximum at 70–80% where the fluidity are maximum and first to be filled in the mould.

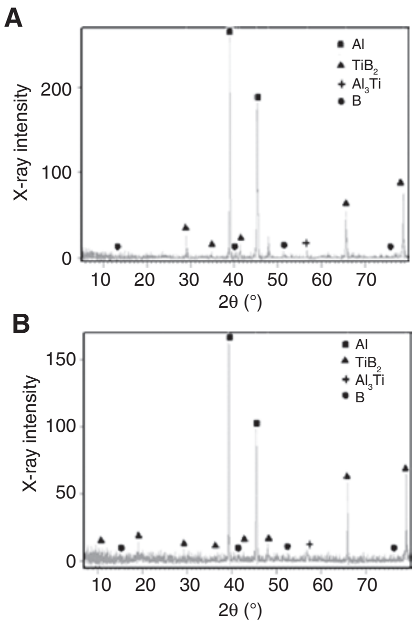

Figure 4: (A) XRD of extracted second phase particles boundaries of A356/TiB_2 permanent mould, (B) A356/TiB_2 sand mould.

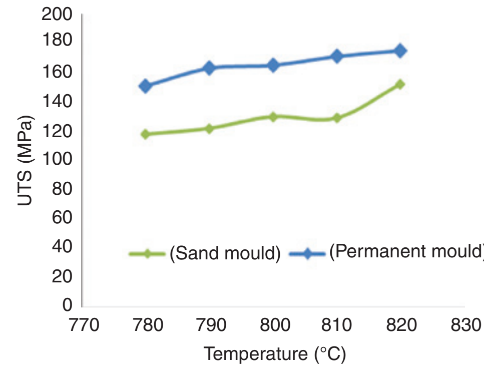

Figure 5: Effect of processing temperature on UTS of Al/TiB_2 MMC on sand and permanent mould.

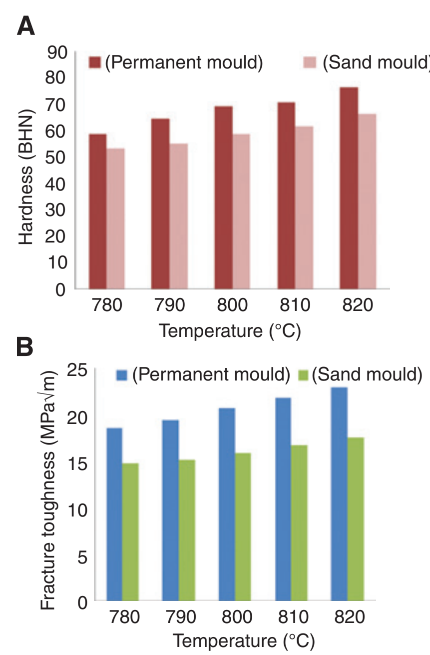

Figure 6: (A) Comparison of hardness in different mould condition with different temperature of Al/TiB_2 MMCs, (B) Comparison of fracture toughness in different mould condition with different temperature of Al/TiB_2 MMCs.

3.2 Mechanical properties of Al/TiB_2 MMCs

Figure 5 shows the comparison of UTS bar graph values with permanent mould and sand mould conditioned samples. In permanent mould casting have more UTS with higher temperature as the cooling rate is high and TiB_2 particles formed is are finer [15]. The Brinell hardness test results are shown in Figure 6A. In permanent mould condition as the temperature increases hardness also increases in range tested. In sand mould condition fissure cracks were formed due to Al_3Ti formation and it affect the hardness of Al/TiB_2 composites at temperature above 800°C. The fracture toughness of sand mould and permanent mould were improved considerably by *in-situ* TiB_2 reinforcement. The fracture toughness improvement was more in permanent mould as compared to sand mould composite as shown in Figure 6B.

4 Conclusion

Aluminium (A356) with salts K_2TiF_6 and KBF_4 were synthesised to get Al/TiB_2 MMCs were fabricated through salt metal route and cast permanent mould/sand mould. The SEM micrograph show and XRD graphs confirm the presence of TiB_2 particles. The optical micrograph show fine grained structure for Al/TiB_2 MMCs cast through permanent moulds and coarse grained structure for Al/TiB_2 MMCs cast through sand moulds. The fracture toughness, tensile and hardness values observed for Al/TiB_2 MMCs cast through permanent mould are more than that cast through sand mould. Show significant improvements of fracture toughness, hardness and tensile strength in permanent mould condition of the Al 6% wt of TiB_2 are 22.89 Mpa√m, 175 MPa and 76.33 BHN. It is concluded finally that the permanent mould casting are more suitable for Al/TiB_2 composite fabrication as compared with sand mould.

Acknowledgment: This work was financially supported by RGNF. The authors also wish to thank Annamalai

Univeristy for providing the facilities for experimentation and, their constant support.

References

[1] McCullough RR, Jordon JB, Brammer AT, Manigandan K, Srivatsan TS, Allison PG, Rushing TW. *J. Mater. Eng. Perform.* 2014, 23 (1), 65–76.
[2] Teo HL, Lu L. *Scripta Mater.* 2001, 45, 1017–1023.
[3] Cui C, Shen Y, Meng F. *Mater. Sci. Technol.* 2000, 16, 619–626.
[4] Ramesh CS, Ahamed A, Chanabasappa BH, Keshavamurthy R. *Mater. Design* 2010, 31, 2230–2236.
[5] Tee KL, Lu L, Lai MO. *Compos. Struct.* 1999, 47, 589–593.
[6] Zhang Y, Naiheng N, Wang H, Le Y, Li S. Scripta *Mater.* 2005, 53, 1171–1174.
[7] Yue NL, Lu L, Lai MO. *Compos. Struct.* 1999, 47, 691–694.
[8] Fan T, Yang G, Zhang D. *Metall. Mater. Trans. A* 2005, 36, 225–233.
[9] Emamy M, Mahta M, Rasizadeh J. *Compos. Sci. Technol.* 2000, 66, 1063–1066.
[10] Fjellstedt J, Jarfors AEW. *Mater. Sci. Eng. A* 2005, 413, 527–532.
[11] Wang C, Wang M. *Mater. Sci. Eng. A* 2007, 459, 238–243.
[12] Feng CF, Froyen L. *Mater. Sci.* 2000, 35, 837–850.
[13] Zhao DG, Liu XF, Pan YC, Bian XF, Liu XJ. *J. Mater. Process. Technol.* 2007, 189, 237–241.
[14] Christy TV, Murugan N, Kumar S. *Miner. Mater. Char. Eng.* 2010, 9 (1), 57–65.
[15] Tjong SC, Ma ZY. *Mater. Sci. Eng. R.* 2000, 29, 49–113.