New Paradigm on the Mechanical Properties of *In Situ* Formed by Al/TiB_2 and $Al/TiB_2/Cu$ MMCs

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Research Article

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ABSTRACT

In the current study, *in situ* formed Al/TiB_2.6 wt.% and Al/6 wt% TiB_2/4 wt% Cu metal matrix were investigated. Composites were made using the stir casting method, and both composites were compared. The composite is synthesized by combining two precursor salts, Potassium hexa fluro titanate (KBF_4) and Potassium tetrafluoroborate (K_2TiF_6), with stoichiometric compositions corresponding to 6% by weight of TiB_2 particles, with A356 aluminium melt at 820°C, speed 300 rpm, and holding time 30 minutes. Following that, 4 wt.% Cu powder was added to the composite melt, which was then poured into the permanent mould. Mechanical properties tests such as tensile strength, hardness, and fracture toughness were carried out in accordance with ASTM guidelines. The mechanical properties of the *in situ* formed Al/6 wt% TiB_2/4 wt% Cu composite outperform those of the Al/6 wt% TiB_2 composite and base metal. Optical micrograph and XRD analysis both confirm the presence of TiB_2 and Cu particles.

Keywords: TiB_2; A356 aluminium; Fracture toughness; Mechanical properties; Optical micrograph; XRD

INTRODUCTION

Particulate reinforced metal matrix composites, in general, have appealing mechanical and tribological properties. In particular, aluminium matrix composite has a low melting point, low density, high thermal stability, and high specific strength. AMCs have been reinforced with reinforcement particulates such as TiB_2, B_4C, TiC, SiC, and Al_2O_3. Typically, aluminium alloys are reinforced with ceramic particles, which provide good wear resistance, increased strength, and elevated temperature properties [1]. There are two methods for fabricating aluminum-based composite materials. *Ex-situ* formed MMCs are one type; while *In situ* formed MMCs is another. *Ex-situ* formed MMCs have some limitations, including non-uniformity, clustering, poor bonding strength, a higher potential for porosity, and, most importantly, low thermal stability. These limitations are overcome by *In situ* techniques because the exothermic reaction that occurs between precursor salts and molten aluminium causes severe agitation within the melt, resulting in uniformly distributed reinforcement particles in the aluminium matrix, good interfacial bonding, and elimination of the inherent defects associated with the *Ex-situ* process.

Currently, researchers are focusing on *in situ* formed MMCs. According to Xie, et al. adding 5% TiB_2 particles to MMC improves mechanical properties. According to Rajaravi, et al. the mechanical properties of an *in situ* formed Al/6 wt.% TiB_2 composite have higher tensile strength and hardness than the base metal. There is a scarcity of literature on Al/TIB_2/Cu MMC and its mechanical properties [2-12]. As a result, stir casting methods were used to create a novel *in situ* formed Al/TiB_2/Cu composite. Mechanical properties such as tensile strength, hardness, and fracture toughness were evaluated according to ASTM standards and compared to Al/TIB_2 MMC and base metal. Metallographic analyses were performed using optical microscopy and X-Ray Diffraction (XRD) [5].

MATERIALS AND METHODS

Table 1 shows the chemical composition of the base metal in this work, which is 99.9% pure Aluminium A356. As initiative materials, 98.5% pure Potassium hexaflurotitanate (KBF_4), Potassium tetrafluroborate (K_2TiF_6), and 98.5% pure copper are used. Using a shaper machine, an aluminium ingot was chipped into small pieces of chip. All materials are carefully weighted according to the rule of mixtures; specifically the precursor salts KBF_4 and K_2TiF_6 are weighted according to stoichiometric composition corresponding to 6 wt.% TiB_2 particles and 4 wt.% Cu is weighted. The aluminium was melted using a graphite crucible. An electrical resistance furnace operating at room temperature was used. The precursor salts were preheated at 250°C for 30 minutes and mixed together before being manually blended into the liquid aluminium that had been kept at 820°C for 30 minutes.

Following that, for about 10 minutes, the preheated Cu powder was added to the composite melt. This temperature was held for about 15 minutes to keep the TiB_2 particles *in situ*. To avoid atmospheric contamination, Argon gas was supplied through fine copper pipe. The dross was skimmed from the melt and poured into a permanent mould for solidification (Figures 1a-1d).

Figure 1a. Copper metal powder stored in the bottle to prevent oxidation.

Figure 1b. Titanium and boron salt in powdered form.

Figure 1c. Milling chips collected from aluminium bars.

Figure 1d. Stir casting setup to perform the operation.

Table 1. Chemical composition of the A356 elements.

Elements	Si	Mg	Mn	Fe	Cu	Ni	Ti	Al
Cast Al alloy	7	0.33	0.3	0.5	0.1	0.1	0.2	1.47

Optical microscopy was used to examine the morphology of the synthesized composites, and XRD analysis was used to confirm the presence of reinforcement and intermetallic. Tensile testing was performed on a (UNITEK-94100) 100 KN

Electro-Mechanical Controlled Universal Testing Machine. According to the ASTM E08-M16 specifications [6] the specimen was loaded at a rate of 1.5 KN/min.

The Instron 8801 dynamic testing machine was used to perform the fracture toughness test. Figure depicts 3-point bend specimens. The fracture toughness specimens were pre-cracked according to ASTM E399 to provide a sharpened crack of sufficient size and straightness. The Brinell hardness testing machine was used to perform the hardness test, and the specimens were prepared in accordance with the ASTM standard [7]. Tensile strength, fracture toughness, and hardness by averaging the results of two repetitions to calculate the characteristics of the properties, as shown in Table 2 and Figures 2a-2c.

Figure 2a. Tensile specimens to perform tension test.

Figure 2b. Fracture toughness specimens to perform mechanical failure.

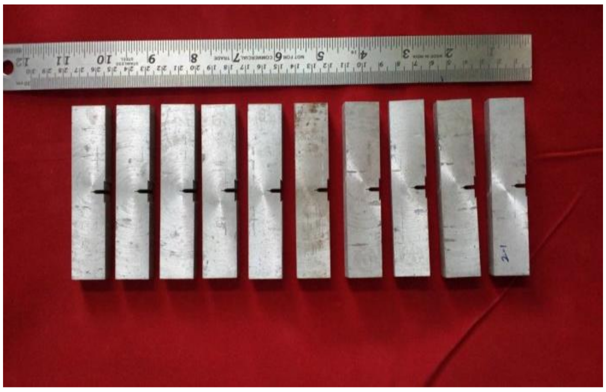


Figure 2c. Hardness specimens to perform the hardness test.

Table 2. Mechanical properties of synthesized composites and its base metal.

S.No	Materials	Mechanical properties		
		UTS	Hardness	Fracture toughness
		(MPa)	(BHN)	(Mpa $\sqrt{m}$)
		Avg	Avg	Avg
1	Base metal	95	70	9.6
2	Al/TiB_2 MMC	124	93	19.33
3	Al/TiB_2/Cu MMC	158	114	23.19

RESULTS AND DISCUSSION

Microstructural of an Al/TiB_2 and Al/TiB_2/Cu MMCs

Figures 3a-3c depicts the optical microstructures of Al/6 wt.% TiB_2 MMC. The TiB_2 reinforcing particles were clearly distributed uniformly in the aluminium matrix. Furthermore, some regional agglomeration of TiB_2 particles was observed at the grain boundaries, as shown in Figure 3a. Because the fine TiB_2 particles are pushed away from the interdendritic region by the solidification front during the solidification process.

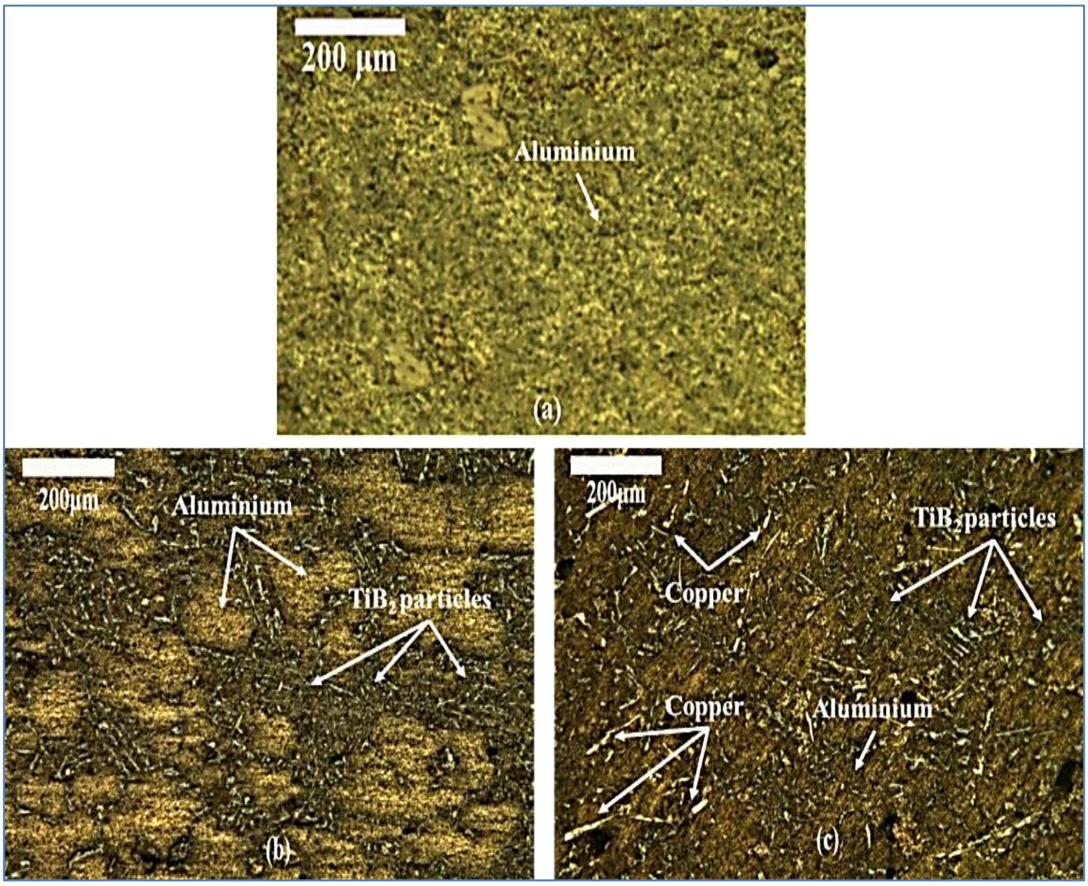
Furthermore, a large number of elongated dendritic grains appear in compounds. As shown in Figure 3b, Microstructure of Al/6 wt.% TiB_2/4 wt.% Cu MMC, TiB_2 particles are uniformly distributed in the matrix, and copper particles have a high brightness. The brightness of Cu particles is caused by their higher atomic number when compared to base aluminium [8].

Because of the ductile nature of copper, copper adds toughness to the composite [9]. James, et al. investigated microstructure and mechanical characterization of AlTiB_2 *in situ* metal matrix compounds produced *via* master alloy path and discovered the presence of hexagonal TiB_2 particles with fairly uniform distribution in the a-Al matrix, as well as traces of Al_3Ti particles. James, et al. investigated the microstructural and mechanical properties of *in situ* Al 6061/TiB_2 composites [9]. The optical microphotographs of Al 6061 alloy and developed composites show uniformly distributed TiB_2 particles as well as traces of flake such as Al_3Ti.

The XRD results of the base metal and its compounds are shown in Figures 4a-4c. Shown depicts the base metal results, which show the presence of aluminium and its alloying elements such as Si and Mg. As shown in Figure 4b, XRD results of Al/TiB_2 composite results, the presence of TiB_2 particles coupled with Al_3Ti brittle phase [10-15] is confirmed. The presence of TiB_2 particles, Al_3Ti brittle phase, and copper is confirmed by the XRD results of an Al/6 wt% TiB_2/4 wt% Cu composite, as shown in Figure 4c.

The presence of copper reduces the formation of clusters and Al_3Ti brittle phases compared to the Al/6 wt% TiB_2 XRD result. This phenomenon is crucial in achieving the superior properties of Al/6 wt% TiB_2/4 wt% Cu composite over Al/6 wt% TiB_2 composite. Because Al_3Ti is a naturally brittle phase, the toughness of the composite increases as the amount of Al_3Ti intermetallic phases and clusters decreases.

Figure 3. Optical microstructures of a) base metal b) Al/TiB_2 MMC and c) Al/TiB2/Cu MMC.

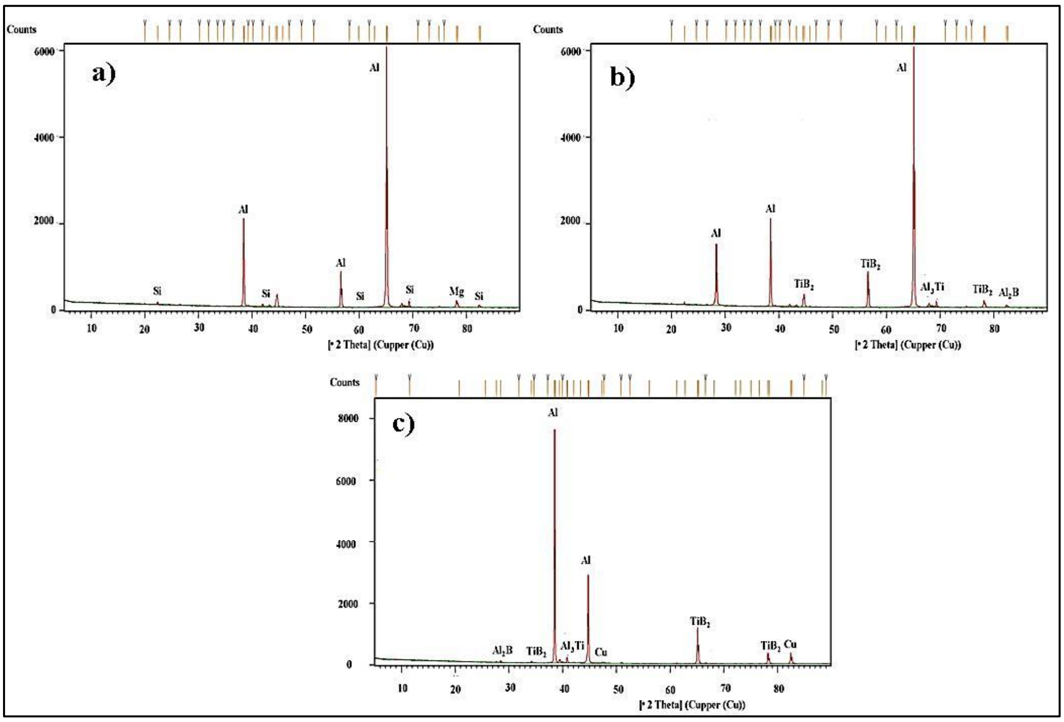


Mechanical property of Al/TiB_2 and Al/TiB_2/Cu MMCs

The mechanical properties of Al/6 wt% TiB_2, Al/6 wt% TiB_2/4 wt% Cu MMC, and its base metal are shown in Table 2 and Figure 5. TiB_2 particle has smaller grain formed both MMCs in permanent mould condition. Base metal properties such as UTS, hardness, and fracture toughness are 95 MPa, 70 BHN, and 9.6 Mpa√m, respectively, whereas the corresponding properties for Al/6 wt% TiB_2 composite are 124 MPa, 93 BHN, and 19.33 Mpa. UTS, hardness, and fracture toughness of Al/6 wt% TiB_2 composite over base metal are improved by 30.52%, 32.85%, and 101.35%, respectively. Mechanical properties are generally determined by the nature and properties of matrix and reinforcement materials.

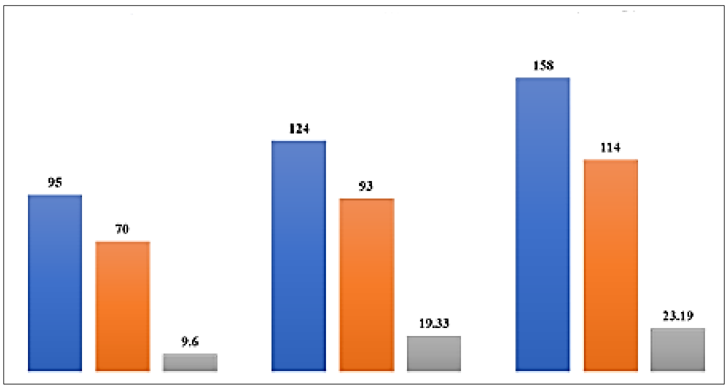
The compatibility of matrix and reinforcement also plays an important role in improving the UTS of composites. The reinforcement particles act as a barrier against dislocation movements under load. As a result, more loads are required for void nucleation and propagation, resulting in higher tensile strength in composites. The presence of TiB_2 particles in the composites improved the mechanical properties of the composites. UTS, hardness, and fracture toughness of Al/6 wt% TiB_2/4 wt% Cu composites are 158 MPa, 114 BHN, and 23.19 Mpa√m, respectively. The UTS, hardness, and fracture toughness improvements of Al/6 wt% TiB_2 composite over base metal are 66.31%, 62.85%, and 141.56%, respectively.

Figure 4. XRD results of a) Base metal b) Al/TiB_2 MMC and c) Al/TiB_2/Cu MMC.



This is due to the presence of TiB_2 particles in the aluminium matrix, which results in an increase in mechanical properties. The presence of Cu has a significant impact on the final properties of the Al/6 wt% TiB_2/4 wt% Cu composite. Because of the ductility and toughness of Cu, it has higher fracture toughness [11,12]. the grain refinement and fineness of the reinforcement are also important factors in determining the hardness of composite materials. The addition of copper reduces the formation of clusters and Al_3Ti brittle phases, so copper acts as a grain refiner for the Al/6 wt% TiB_2/4 wt% Cu composite. Furthermore, during *in situ* composite fabrication, an exothermic reaction occurs, resulting in fine and clear interfacial bond. Due to the manufacturing technology and the strength of the casting, the hardness of the composite material is significantly improved and the load transfer capacity of the matrix to the reinforcement is enhanced by the reaction free interface.

Figure 5. Comparison of mechanical properties of Al/TiB_2MMC, Al/TiB_2/Cu and its base metal. **Note:** ■ UTS (MPa), ■ Hardness (BHN), ■ Fracture toughness (Mpa $\sqrt{m}$).



CONCLUSIONS

The mechanical properties of *in situ* formed Al/TiB_2 and Al/TiB_2/Cu MMCs were compared, and the following significant findings were discovered.

- *In situ* Al/TiB_2 and Al/TiB_2/Cu metal matrix composites were successfully synthesized in the molten aluminium matrix *via* an exothermic reaction between (K_2TiF_6) and (KBF_4) precursor salts. XRD analysis confirmed the formation of TiB_2 particles, and optical micrograph confirmed the distribution of reinforcement particles.

- The mechanical properties of an Al/6 wt% TiB_2 composite, such as UTS, hardness, and fracture toughness, are 124 MPa, 93 BHN, and 19.33 Mpa√m. UTS, hardness, and fracture toughness of Al/6 wt% TiB_2 composite over base metal are improved by 30.52%, 32.85%, and 101.35%, respectively.

- The mechanical properties of the Al/6 wt% TiB_2/4 wt% Cu composite, such as UTS, hardness, and fracture toughness, are 158 MPa, 114 BHN, and 23.19 Mpa√m, respectively. The corresponding improvements of Al/6 wt% TiB_2 composite over base metal are 66.31%, 62.85%, and 141.56%, respectively.

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