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## Original Article

# Mechanical and tribological properties of AA7075–TiC metal matrix composites under heat treated ( $T_6$ ) and cast conditions



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## ABSTRACT

The sliding friction and wear behavior of aluminum matrix composites (AA7075–TiC) have been investigated under dry sliding wear conditions. The aluminum metal matrix composites (AMMCs) are produced as AA7075 matrix metal and TiC particulates of an average size of 2  $\mu\text{m}$  as reinforced particles through stir casting. AMMCs studied are contained 2–10 wt.% of TiC particles in both as cast and heat treated ( $T_6$ ) conditions. All the composites exhibited better mechanical properties (hardness, tensile strength and percentage of elongation) than the matrix metal in both the conditions. The wear tests were carried out at a sliding velocity of 2 m/s, sliding distance 2 km and at normal load of 20 N. The wear resistance of the composites increased with increasing weight percentage of TiC particles, and also the wear rate was notably less for the composite material compared to the matrix material. A detailed analysis in as-cast condition and  $T_6$  condition of the AMMCs was carried out using SEM in order to find out the influence of TiC particles in the AMMCs formed. It has been observed that under  $T_6$  heat treatment condition, matrix as well as composite shown significant improvement in mechanical and tribological properties when compared in as cast condition.

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## 1. Introduction

The evaluation of metal matrix composites (MMCs) has been one of the major revolutions in materials from the last

3 decades. Metal matrix composites are obtaining wide importance in several areas due to its improved mechanical and tribological properties when compared with basic alloys, especially in applications where strength to weight and stiffness to weight ratios are of most importance in automobile, aerospace

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and defense [1]. These MMCs are metals that incorporate particles, whiskers and fibers made of a different composition material. These materials can be tailored to be lightweight and with various other properties including: high strength, high elastic modulus, high toughness and impact resistance, low sensitivity to changes in temperature or thermal shock, high surface durability, low sensitivity to surface flaws, high electrical and thermal conductivity, minimum exposure to the potential problem of moisture absorption resulting in environmental degradation, and improved fabricability with conventional metal working equipment [2–5]. In general, aluminum alloy components are lack in wear resistance, particularly under poor, partial or boundary lubricated conditions. With particles reinforced in the matrix of aluminum alloy, this material exhibits good potential for resistance to wear and consequently becomes more suitable for tribological applications. Aluminum based metal matrix composites (AMMCs) have become a very valuable addition to the field of newer materials for high performance tribological applications. Aluminum based composites are being increasingly used in automobiles, aerospace, marine and mineral processing industries [6].

AA7075 is a matrix metal alloy, with zinc as the major alloying element. It is strong, with strength comparable to many steels and has good fatigue strength and average machinability, but has less resistance to corrosion than many other aluminum alloys. Its relatively high cost limits its use to applications where cheaper alloys are not suitable. The superior stress corrosion resistance of the T173 and T7351 tempers makes AA7075 a logical replacement for 2024, 2014 and 2017 in many of the most critical applications. The T<sub>6</sub> and T<sub>651</sub> tempers have fair machinability [7]. The properties of this ductile AA7075 alloy can be improved by reinforcing with micro sized ceramic particles [8].

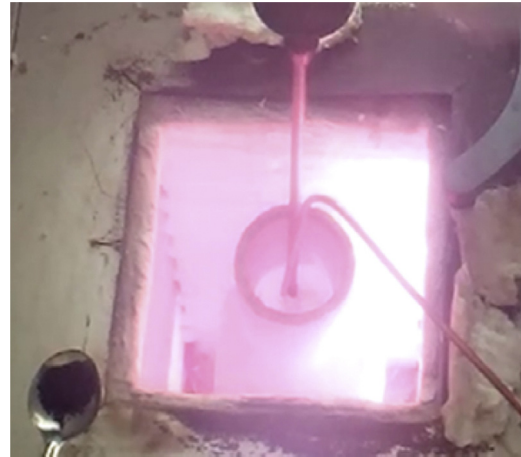
Mainly two common methods are there to fabricate AMMCs in large scales, powder metallurgy method (solid state) and casting (liquid state). There are different methods of liquid state processing to produce metal matrix composites [9]. These methods include stir casting [10], pressure infiltration [11], pressure less infiltration [12] and squeeze casting [13]. Unlu et al. [14] proved that the mechanical properties of aluminum matrix composites reinforced by Al<sub>2</sub>O<sub>3</sub> and SiC through casting method was shown better than powder metallurgy method.

The mechanical alloying followed by hot pressing temperature and pressure shown an effect on hardness and distribution of Ti particles in Al7075–TiC nanocomposite [15]. Venkataraman observed that there exists a strong correlation between the friction, wear and transition (from mild to severe wear) behavior of the Al7075 alloy and Al-MMCs [16]. Kumar examinations have shown that the tremendous improvement in the wear resistance for Al7075 alloy can be obtained by increasing addition of SiC, which restricts the deformation of the aluminum matrix material with respect to load [17]. Kumar also investigated Al–7Si alloy reinforced with in situ TiB<sub>2</sub> particles was synthesized by using salt reaction route and the wear resistance of the alloy also significantly improved with the addition of TiB<sub>2</sub> particles [18].

In present work effect of TiC particle on mechanical and wear behavior of AMMCs are studied in as cast and heat

**Table 1 – Chemical composition of AA7075 alloy (wt.%).**

Element	Composition % in AA7075
Zinc	5.8
Copper	1.5
Manganese	0.06
Magnesium	2.4
Ferrite	0.24
Chromium	0.20
Silicon	0.08
Titanium	0.07
Aluminum	Remaining



**Fig. 1 – Molten metal in furnace.**

treated condition. AMMCs were produced with 2–10 wt.% of TiC through stir casting technique as mention in previous work [19].

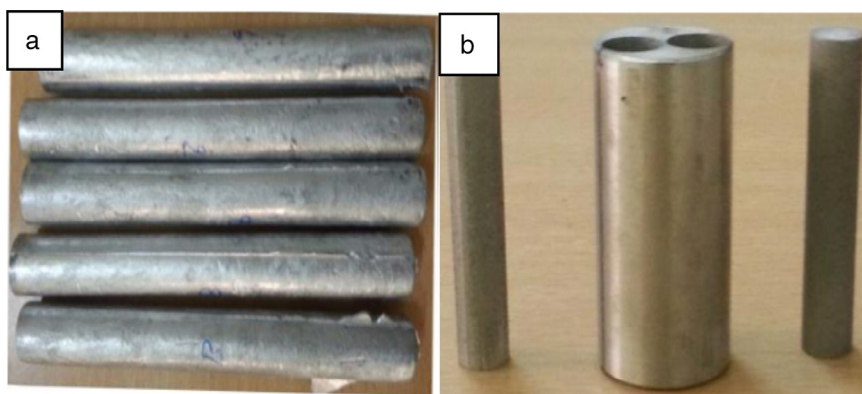
## 2. Experimental

### 2.1. Materials

In the present investigation AA7075 as matrix material and TiC particulates of an average particle size of 2 μm is used as a reinforcement material and the chemical composition of AA7075 alloy is shown in Table 1.

### 2.2. Fabrication of composites

The composite, matrix material as AA7075 and reinforced material as titanium carbide (TiC) with 2, 4, 6, 8 and 10 wt.% TiC about an average particulate size of 2 μm, was prepared by a stir casting process. About 0.750 kg of AA7075 matrix material was fed into the electric furnace and was melted at 800 °C. The experimental setup is shown in Fig. 1. The magnesium ribbons are added at high temperatures to increase the wettability of aluminum so that the reinforcement added to the metal is evenly dispersed. An appropriate amount (2% of the wt. of base metal) of TiC particulates was then added slowly to the molten metal. The TiC particulates added to the molten metal was pre-heated up to 300 °C to remove the moisture (if any) in it. Simultaneously, the molten metal was stirred



**Fig. 2 – Specimens of composite (a) cast and (b) wear.**

thoroughly at a constant speed of 300 rpm with a mechanical stirrer. After casting the composite specimens were obtained in the dimension of  $\varnothing 15 \text{ mm} \times 150 \text{ mm}$  as shown in Fig. 2a. The same procedure was followed to get the AMMC's of different weight percentages – 4%, 6%, 8% and 10% [19].

### 2.3. Heat treatment ( $T_6$ )

Matrix material and its composites were heat treated and aged at  $T_6$  condition. The  $T_6$  temper is done by homogenizing the material at  $450^\circ \text{C}$  for 2 h, and then aging at  $121^\circ \text{C}$  for 24 h.

### 2.4. Hardness test

The hardness tests were carried out according to test procedure IS 1501:2002 ASTM standards using Vickers hardness testing machine with a 10 mm diamond indenter and 5 kg load for 25 s. The test was conducted at room temperature ( $28^\circ \text{C}$ ) and the measurement of hardness was taken at three different places on each sample to obtain an average value of hardness.

### 2.5. Tensile test

As per the ASTM B 557:2006 standard, the tensile strength was evaluated on the cylindrical rod of as-cast and heat treated condition ( $T_6$ ) composites. The tensile specimens were shown in Fig. 4 with gage dimensions of 50 mm in length and 10 mm in diameter, respectively. The emery papers were used to polish the test specimens in order to decrease the machining scratches and the effects of surface defects on the sample. The universal testing machine (FIE/UTN-40) was used to conduct the tensile test. The tensile strength was evaluated at cross head speed of 2 mm/min.

### 2.6. Wear test

A wear and friction monitor shown in Fig. 3 was used to investigate the dry sliding wear behavior of AMMCs. Standard wear pin specimens of 8 mm diameter and 30 mm height for wear test were prepared from the above composites and were retrieved through wire cut EDM process as shown in Fig. 2b and polished metallographically. The wear tests have been conducted under heat treated and cast condition at a fixed sliding



**Fig. 3 – Wear and friction monitor.**

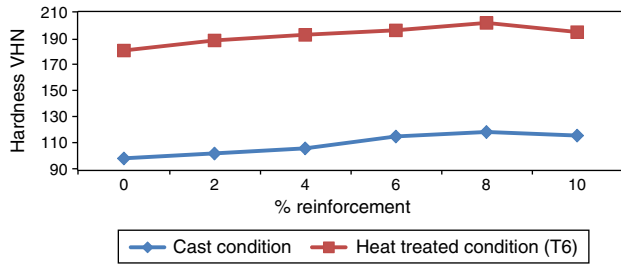


**Fig. 4 – Tensile specimens.**

velocity of 2.00 m/s. Each wear test has been carried out for a total sliding distance of about 2 km.

### 2.7. Scanning electron microscopy (SEM)

The wear mechanisms of the composites were established by scanning electron microscopic (SEM) analysis of the surface morphology of the test samples. The scanning electron microscopy (model: SEM – Quanta 400, FEI, Netherlands) with EDAX energy dispersive X-ray spectroscopy (EDS) was used in



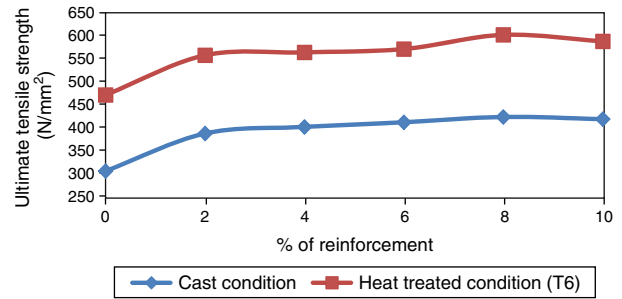
**Fig. 5 – Vicker hardness behavior of AA7075/TiC composites at cast and heat treated condition.**

order to evaluate the morphological changes and the elemental analysis of composites.

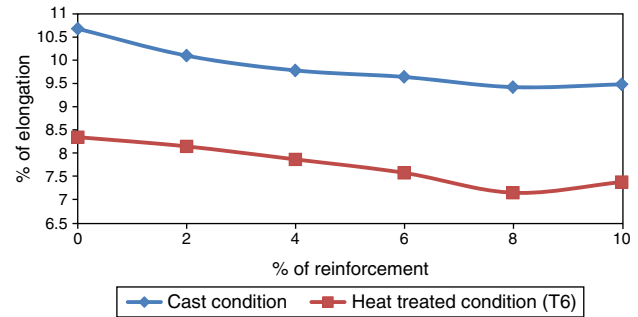
### 3. Result and discussion

#### 3.1. Hardness

The Vickers hardness test results of AA7075 matrix material and their composites containing TiC particles (0–10 wt.%) were presented in the form of graph and showing the relationship between the hardness values and % of reinforcement of TiC at cast condition and heat treated (T<sub>6</sub>) condition in Fig. 5. It can be observed that hardness of all the composites was significantly higher than that of the matrix material characterized to the hard nature of TiC particles. However, the hardness drops after 8% TiC addition. This increase trend was observed in as cast and heat treated conditions from 98.4 VHN to 118.6 VHN and 181 VHN to 202.1 VHN for AA7075 matrix material to 8 wt.% of TiC reinforced composite, respectively. Some variations in the trend could be due to the agglomeration and non-uniform distribution of the particles in the metal matrix. The hardness values of 2,4,6,8 and 10 wt.% TiC are markedly higher than that of the AA7075. Due to the increased strain energy the hardness of the composites is increased at the peripheral of the particles dispersed in the matrix [20]. The scanning electron micrograph of 8 wt.% and 10 wt.% of TiC reinforced composite at heat treated condition was shown in Fig. 6. It should be noted that at 8 wt.% of TiC reinforced composite (Fig. 6a) the TiC particles are dispersed uniformly in the AA7075 matrix material and at 10 wt.% of TiC reinforced composite (Fig. 6b) a partial agglomeration can be detected in some regions. However, by increasing the wt.% of reinforcement at both cast and heat treated conditions, the hardness and tensile strength of the



**Fig. 7 – Comparison of as-cast and heat treated condition of ultimate tensile strength with increasing % of reinforcement.**

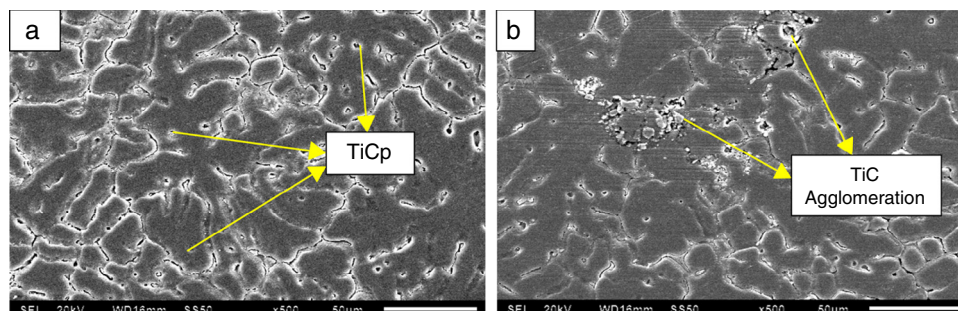


**Fig. 8 – Variation of percentage of elongation with % of reinforcement.**

10 wt.% TiC composite is not increased remarkably. This may be demonstrating that the effect of agglomeration at 10 wt.% TiC reinforced composite, which leads to the formation of pores [21].

#### 3.2. Tensile properties

The effect of TiC on the tensile strength and the percentage of elongation of the composite obtained from tensile test are shown in Figs. 7 and 8. The tensile strength was improved with adding TiC particle. About 130 MPa strength increase was determined for 8 wt.% TiC reinforcement following T<sub>6</sub> heat treatment. The percentage of elongation was reduced with increasing % of TiC particles in both the conditions. Result of tensile tests also revealed that the addition of reinforcement significantly decreased the percentage of the elongation from 8.341 to 7.140. The addition of TiC particles improves the mechanical properties mainly by stress transference from



**Fig. 6 – Scanning electron micrograph of TiC reinforced composite at (a) 8 wt.% and (b) 10 wt.%.**

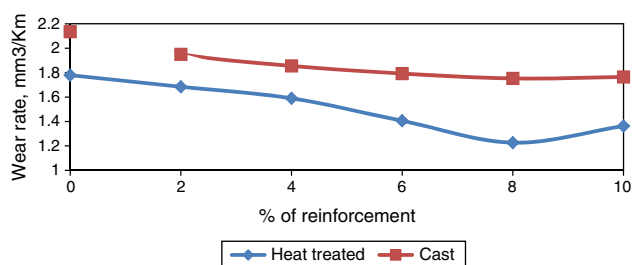


Fig. 9 – Effect of wt.% of reinforcement on wear rate.

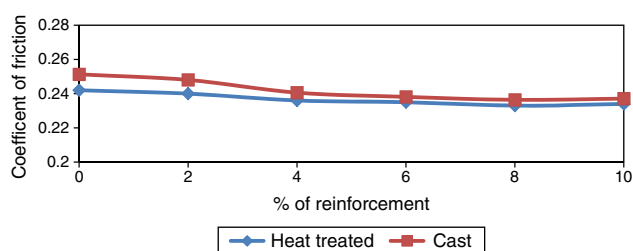


Fig. 10 – Effect of wt.% of reinforcement on coefficient of friction.

the aluminum matrix to the reinforced particles TiC. This is because of Orowan mechanism by which a dislocation bypasses impenetrable obstacles where a dislocation bows out considerably to leave a dislocation loop around a particle. A similar nature has been observed by Murali et al. [22] and Oñoro [23] by the stress transference from aluminum matrix to reinforced particles TiO<sub>2</sub> and TiB<sub>2</sub>, respectively. The interaction between the dislocations and TiC results in an improved in strength [24]. The tensile test results for as cast condition generally lower than the heat treated condition values of the same compositions due to the good hardness at heat treated condition.

### 3.3. Wear behavior

The wear rate of the AA7075 matrix material and its composites with adding TiC particles at heat treated and as cast condition is shown in Fig. 9. The wear rate decreases with increasing TiC content and it was found to be minimum at 8 wt.% TiC as compared to other compositions. This may be attributed to the incorporation of hard TiC particles resulting in an improvement in the hardness and reduction in real area of contact. Since real area of contact is taken as the ratio of the normal load to the hardness of the pin material, therefore, wear rate decreases with decreasing real area of contact [25]. Beyond 8 wt.%, the wear rate increases and it was found to be less than that of the matrix material. This reduction in wear rate due to 10 wt.% of TiC content may be, thereby increasing the porosity and cracks and deterioration of mechanical properties [26]. In summary, for a given wt.% of reinforcement, the heat treated condition offers higher wear resistance.

### 3.4. Coefficient of friction

Fig. 10 shows the variation of average coefficient of friction over the sliding distance with percentage of reinforcement. It is observed that the average coefficient of friction decreases

with increasing wt.% TiC. However, the composites have shown a lower coefficient of friction as compared to that observed AA7075 matrix material. This may be due to the higher hardness of the composite resulting in lower real area of contact and therefore, smaller number of junctions which require less energy to get sheared during sliding as compared to the matrix. It should be observed that the effect of % of reinforcement at heat treated and cast condition over the coefficient of friction are of the same nature, i.e. inversely proportional.

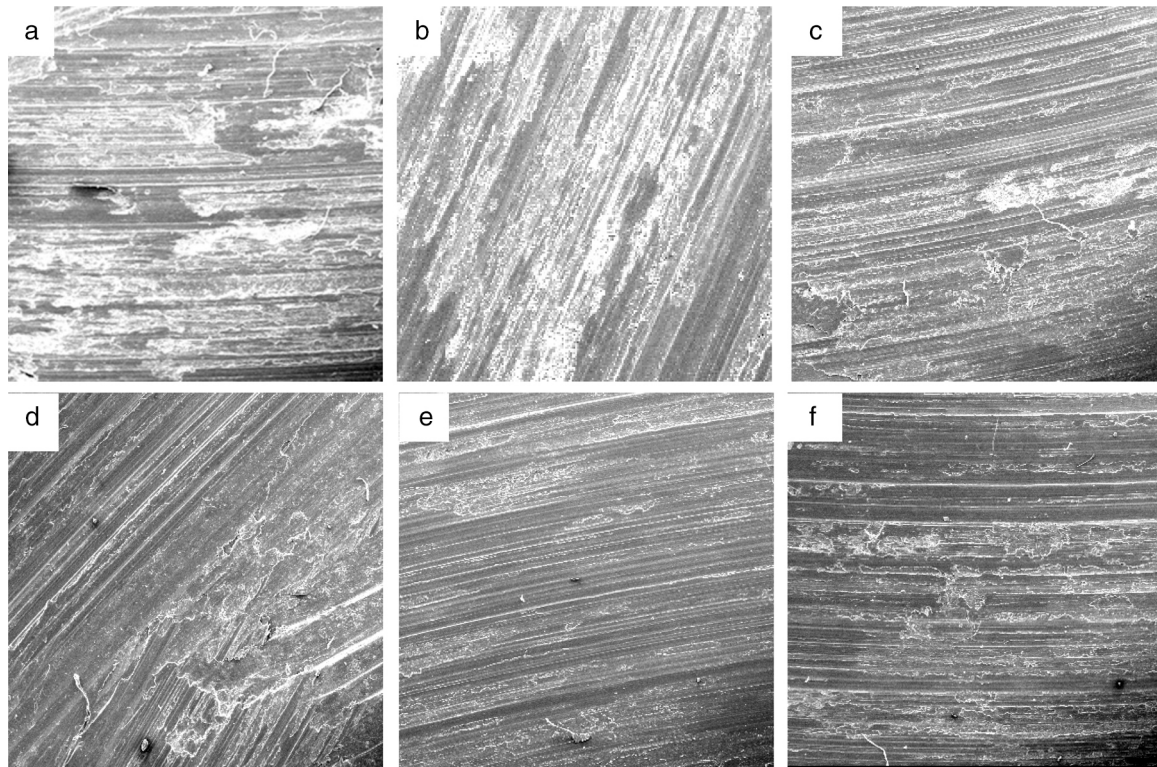
### 3.5. Wear surface analysis

Figs. 11 and 12 show SEM micrographs at 50 magnifications of the worn surfaces of AA7075 matrix material and AA7075/TiC composites in as cast and heat treated conditions. Wear rate is a function of the amount of TiC particles in composites and are effective to enhance the wear resistance of the composites in both the conditions.

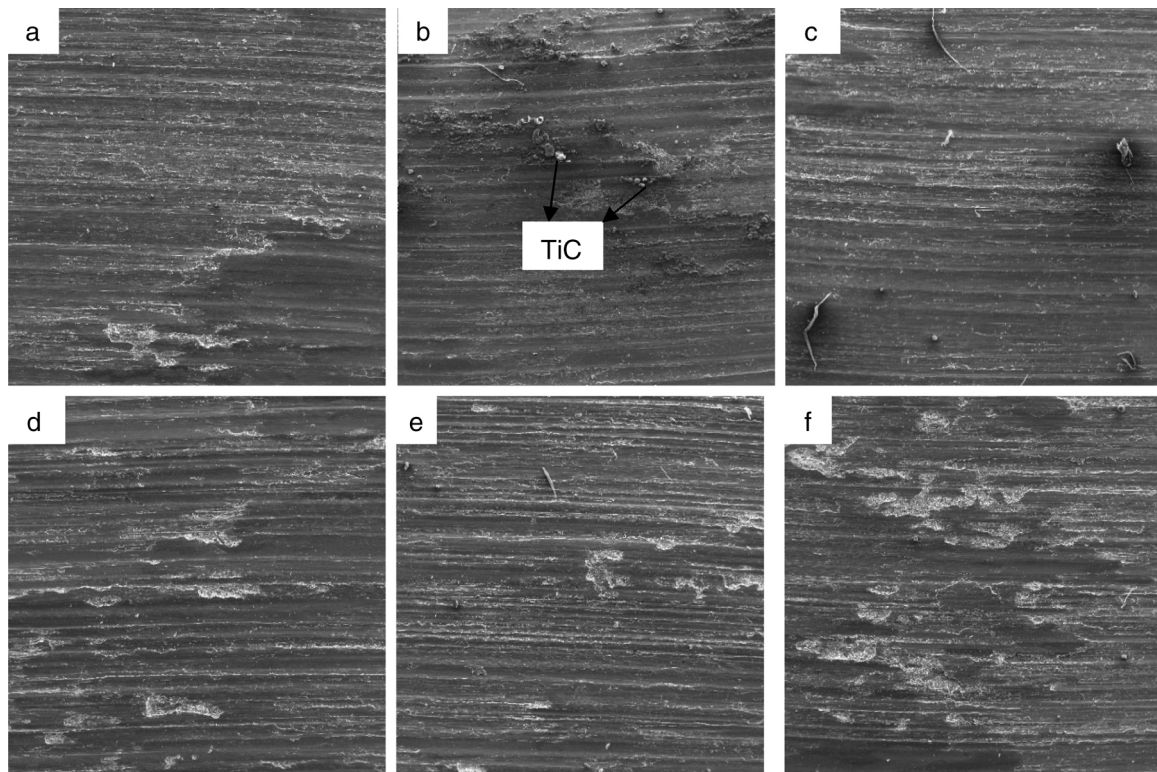
The interactions between dislocations and TiC particles resist the propagation of cracks during sliding wear. Strain fields are created around TiC particles due to the thermal mismatch between the aluminum alloy and TiC particle during solidification. Those strain fields offer resistance to the propagation of the cracks and subsequent material removal. The homogeneous distribution of TiC particles provides Orowan strengthening [27]. The clear interface and good bonding delay the detachment of particles from the aluminum matrix. Therefore, the wear resistance of the AMMCs is enhanced by TiC particles. The grain refining action of TiC particles can further be considered to play a role in lowering the wear rate.

As shown in Fig. 11a, exhibits deep long grooves along the direction of sliding and material delamination were observed on the worn surfaces of matrix material (AA7075). At 2 and 4 wt.% of TiC particles composites (Fig. 11b and c) would confirm that micro-ploughing and delamination are the two main dominant wear mechanisms. Ploughing is the processes of displacing material from groove to sideways to form ridges adjacent to the groove produced and thus repeated sliding of hard asperity leads to metal loss [18]. By increasing the weight percentage of TiC to 6 and 8 wt.%, less deep grooves can be observed (Fig. 11d and e) and the surface is much smoother compared to the one it was observed (Fig. 11a-c). The surface of AA7075 reinforced by TiC of 10 wt.% demonstrates rougher worn surface than AA7075/8 wt.% TiC. At this amount of TiC the debris are able to easily separate out from the surface which can be justified by the presence of pores, as shown in Fig. 11f. This can be the main reason for increasing of wear loss and COF at high weight percentage of TiC [8].

Fig. 12a shows with coarser and the large grooves in the matrix material indicating an abrasive wear. By increasing reinforced material TiC from 2 to 4 weight percentage, the grooves are reduced and some smooth wear tracks could also be seen in Fig. 12b and c. In the composite with 6 and 8 wt.% of reinforcement, small size grooves are seen with oxide patches and discontinuous ridges (Fig. 12d and e) [28]. It is further evident from the figure that the depth of subsurface deformation reduces when TiC particulate content is increased. But further increases in reinforcement to 10 wt.% (Fig. 12f) leads to the decrease in the wear resistance.



**Fig. 11 – SEM micrographs of worn surface of (a) AA7075, (b) 2 wt.% TiC, (c) 4 wt.% TiC, (d) 6 wt.% TiC, (e) 8 wt.% TiC, and (f) 10 wt.% TiC composites at cast condition.**



**Fig. 12 – SEM micrographs of worn surface of (a) AA7075, (b) 2 wt.% TiC, (c) 4 wt.% TiC, (d) 6 wt.% TiC, (e) 8 wt.% TiC, and (f) 10 wt.% TiC composites at heat treated condition.**

#### 4. Conclusions

In the present work, AA7075/TiC AMMCs were prepared by the stir casting process and the effect of TiC particulate content on mechanical and tribological properties of the prepared AMMCs were investigated both as cast and heat treated conditions. The results can be summarized as follows:

- The composites at cast condition exhibits less hardness, tensile strength and wear resistance than heat treated ( $T_6$ ) condition, due to failure to form good hardening.
- The mechanical (hardness, tensile strength and percentage of elongation) properties for the TiC reinforced composite specimens are better than AA7075 matrix material in both conditions.
- The high content of TiC particles in AMMCs lead to high wear resistance up to 8 wt.%.
- The wear rate of AA7075/8 wt.% TiC composite at  $T_6$  condition was found to be optimal wear rate compare to the cast conditions and AA7075 matrix material.
- Wear rate and coefficient of friction decreases with increase of wt.% of TiC reinforced particle.

#### Conflicts of interest

The author declares no conflicts of interest.

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