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Dry Sliding Wear Behavior of TiC –AA7075 Metal Matrix Composites

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Abstract: The AA7075 matrix reinforced with 2 to 10 weight % of TiC particles were made by stir casting. Effects of load on the wear and friction of the worn surfaces of matrix and composite pins sliding against a rotating disc have been investigated under dry condition. The wear tests were carried out using a pin-on-disc type apparatus at three different loads (10, 20 and 30N) under a constant velocity of 2m/s for a sliding distance of 2Km. The coefficient of friction was recorded and wear rate of the Aluminum metal matrix composite (AMMC) pins calculated from mass loss measurement. Scanning electron microscope (SEM) equipped with energy dispersive X-ray spectroscopy (EDX) was used to investigated the worn surface. It is observed that higher load leads to higher wear rate and lower coefficient of friction for matrix as well as composites. The hardness was found to increase with the increase in wt. % of the reinforcement.

Keywords: Titanium carbide; wear behavior; metal matrix composites; AA7075.

1. Introduction

AA7075 alloys (Al-Mg-Zn-Cu) have been widely used as structural materials in aeronautic, defense and other industry sector due to their attractive properties. Aluminum based metal matrix composites have been emerged as an important class of materials for mechanical, wear, thermal and electrical applications, primarily as a result of their ability to exhibit superior strength to weight and strength to cost ratios when compared to equivalent monolithic commercial alloys[1-2]. The scope of availability of relatively cheaper reinforcements and growth of various processing routes, interest in metal matrix composites (MMC) for automotive, aerospace and other structural applications is increasing year after year. To characterize the mechanical behavior of reinforced metal matrix composites, a huge quantity of work were carried out by numerous researchers [3-4].

Some studies report that the wear and friction behavior of aluminum-based MMC, strongly depends on the reinforcement's particle, particle size and rate. If the rate of reinforcement particle in MMC is low, the coefficients of friction of the composites were high. Besides these, the wear resistance increases with increasing volume fraction of reinforcing particulates. If the reinforcement particle is well bonded to the matrix, the composite wear resistance increases continuously with increasing volume fraction of ceramics particles. This critical volume fraction depends on the load applied during the wear test [5].

Improvements in wear resistance by the incorporation of hard ceramic particles like sic, B_4C, Al_2O_3, TiO_2, TiB_2 and TiC into the aluminium-based alloys is well known. The literature survey

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regarding the above alloy systems and their composites are as follows. Chawala et al. [6] found that increasing volume fraction and decreasing particle size resulted in an increase fatigue resistance of Al-sic composites. Natarajan et al. [7] reported that A356/25SiCp aluminium matrix composites have considerable higher wear resistance than conventional grey cast iron. Shorowordi et.al [8] suggested that the transfer layer on Al-B_4C or SiC MMC acts as a protective cover and helps reduce both wear rate and friction coefficient. Ipek et al. [5] in the studies of Adhesive wear behaviour of B_4C and SiC reinforced 4147 Al matrix composites (Al/B4C–Al/SiC) concluded that a Al/SiC wear resist is high then Al/B_4C composite and the worn sample of Al/SiC only shows a light adhesive wear traces at the same conditions. Ramesha et al. [9] demonstrated the effects of wear behavior of Al6061–TiO2 composites and exhibited higher hardness, lower wear coefficient values when compared with the matrix alloy. However, they conclude that, increased loads and sliding distances resulted in higher volumetric wear loss but lowered the wear coefficient for both the matrix alloy and its composites. Kumar et al. [10] stated that Al–7Si/TiB2 in situ composites with significant improvement in hardness, yield strength, tensile strength, Young's modulus and wear resistance have been successfully synthesized by salt reaction route.

Kennedy and Wyatt [11] found that the interfacial bond strength in Al–TiC MMCs varies significantly with manufacturing method. Al–TiCp composites have been produced by reactingK_2TiF_6 and graphite in molten aluminum by many researchers. Jerome et al. [12] found that wear rate increases with the increase in applied load and decreases with increase in the weight percentage of TiC. Al 7075 possesses very high tensile strength, higher toughness at room temperature and are preferred in aerospace and automobile sectors [13]. But the mechanical properties of Aluminum alloys are reduced while temperature is increasing compare to the room temperature. A best way to avoid the problem is to introduce TiC particles in to the alloy [14]. Rao et.al.[15-16] produced Al7075-TiC composites by stir casting process and identified that increasing hardness of composites because of the presence of the increased TiC reinforced material and found that at heat treated (T_6) condition better wear properties obtained for 8 wt% TiC composite compared to other composites(2 to 10 wt%) as well as matrix material.

The present study is intended to investigate the sliding wear behavior and mechanism of AA7075 reinforced with TiC particulates using a pin on disc apparatus. The main aim has been to find out the effects of load on the wear and frictional behavior of the MMC worn surface.

2. Materials and Methods

2.1. Materials

The chemical composition of AA7075 matrix is shown in Table1. The TiC (Titanium Carbide) particulates of average particle size of 2 μm is used as reinforcement in the present investigation, supplied by Apex Enterprises, Secunderabad, Andhra Pradesh. Table 2 is presented the properties of AA7075 matrix material and reinforcing material (TiC) respectively.

Table 1. Chemical Composition of AA7075 matrix material by weight percentage

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.08	0.24	1.5	0.06	2.4	0.2	5.8	0.07	Balance

Table 2. Properties of AA7075

Properties	AA7075	TiC
Density (g/cc)	2.81	4.93
Poisson's Ratio	0.33	0.187
Hardness(VHN)	175	2900
Melting temperature(^{0}c)	477 - 635	3160
Tensile strength(Mpa)	505	118.6

2.2. method of Work

The composites examined in this study were consolidated via stir casting process. The AA7075 matrix was placed into the crucible and heated upto 800^{0}c for melting. 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. When the melting temperature reached to 800^{0}C, an appropriate amount (2% of the wt. of base metal) of Titanium Carbide (TiC) powder was then added slowly to the molten metal. The TiC powder added to the molten metal was pre-heated upto 300^{0}C to remove the moisture (if any) in it. Simultaneously, the molten metal was stirred thoroughly at a constant speed of 300 rpm with a stirrer under the organ gas atmosphere to avoid the oxidation. The high temperature molten metal was maintained at 800^{0}c and poured into the pre-heated (300^{0}C) cast iron moulds to get the required dimension of Ø15 x 150mm as shown in Figure 1(a). The same procedure was followed to get the AMC's of different wt. % - 4%, 6%, 8% & 10%. Standard wear specimens of 30mm length and 8mm diameter were retrieved through wire cut EDM process from the thoroughly homogenized ingots of matrix and composites as shown in Figure 1(b). The experimental setup is shown in Figure 2.

(a) (b)

Figure 1. Specimens of composite (a) cast (b) wear

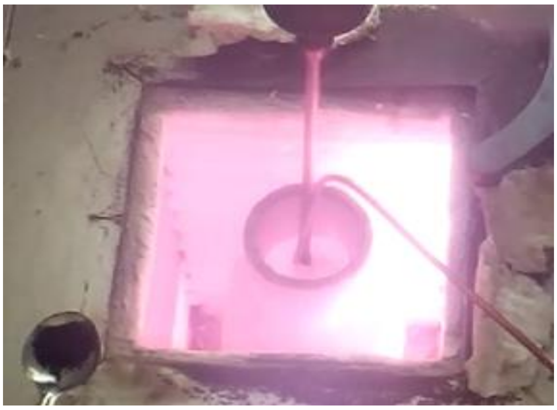


Figure 2. Molten metal in furnace

2.3. Testing

Vickers micro hardness studies were carried out for the polished samples of AA 7075 matrix material and AMMCs(AA7075 as matrix material and Titanium Carbide (TiC) particulates as reinforced material)using UHL IMS 4.0 Vickers Micro Hardness tester with 500 grams load. The diamond indentation time for the hardness measurement was 15 seconds. An average of five readings was taken for each hardness value at different locations to circumvent the possible effects of particle segregation.

The measured density of the AA7075 matrix material and AMMCs was measured by the Archimedes drainage method.

Dry sliding wear tests for the matrix and composites have been carried out using pin-on-disc machine (Model TR-20 LE supplied by M/s Ducom) as per ASTM standards. The surface of the disc and test pin was polished to a surface roughness of 0.1± 0.02 R_a using series of emery papers. Wear tests have been conducted using cylindrical samples that had flat surfaces in contact region and rounded a corner. The pin is held stationary against the counter face of a 120mm diameter rotating disc made of En-32 steel having a hardness of HRC60 as provided on pin-on-disc machine. The wear test have been conducted under the fixed velocity of 2m/s and at three different loads of 10, 20 and 30 N for a total sliding distance of 2km. Pin weight before and after the test was measured to determine mass loss. The coefficient of friction (Frictional force/load) and wear rate (volume loss/sliding distance) have been determined. Microstructure and SEM analysis was carried out to study the worn out surfaces under different parameters.

3. Results and discussion

3.1. Mechanical properties

The mechanical properties of the matrix and composites are presented in Table 3 and Figure 3.It shows the variation of hardness (VHN) of matrix and composites with weight percentage of TiC particles [15]. It is clearly evident that hardness increases with the increasing amount of TiC particles. The best results were obtained for the cast AA7075/TiC composite which contains 8 wt. % of TiC particles. This composite has exhibits higher hardness value than the other composites and as well as matrix material of the present investigation. A significant increase in hardness was observed when compared to monolithic alloy, which is due to the presence of TiC acts as a source for heterogeneous nucleation in the AA7075 melt, which leads to fine grain structure and presence of other phases like Al_3Ti and TiC acts as hardeners in the matrix [10]. Better bonding between reinforcement and matrix, clean and clear interface may also contribute to the hardness of the composites by increasing the load carrying capacity. Hardness of the AMMCs material increases by an amount of 21% as the content of TiC increases from 0 to 8 wt. %. However, declining of hardness was observed for 10 wt. % of TiC composite due to of agglomeration and casting defect [17].

Table 3. Mechanical properties of composites under study

Composition	Hardness (VHN)	Density(g/cc)
AA7075	98.4	2.810
AA7075/2 wt % TiC	102.2	2.820
AA7075/4 wt % TiC	106.1	2.830
AA7075/6 wt % TiC	115.2	2.845
AA7075/8 wt % TiC	118.6	2.853
AA7075/10 wt % TiC	115.9	2.862

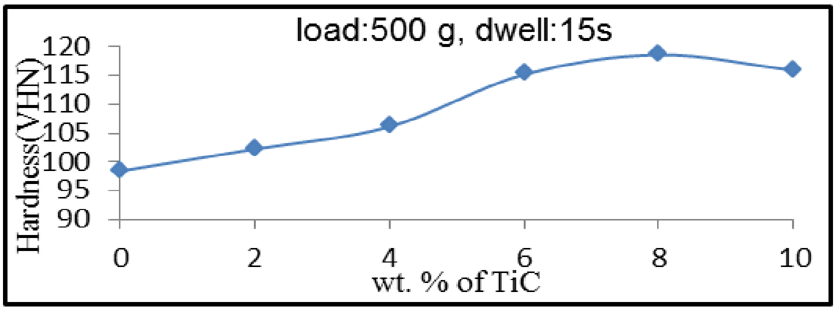


Figure 3. Hardness behaviour of AA7075 matrix and AA7075/TiC composites

3.2. Wear behavior

3.2.1. Effect of load and percentage of reinforcement on wear rate

Figure 4 shows the variation in wear rate of the AA7075 matrix material and AA7075/TiC composites with applied load. It is obvious from the figure that the wear rate of AA7075 matix material and AA7075/TiC composites increases with increase in applied loads at 10N, 20N and 30N under a constant sliding velocity of 2m/s for sliding distance 2Km. It can be seen that the wear rate increases almost uniformly with the applied load, irrespective of the percentage of composite [18]. The wear rate initially showed a short transient period and then reached a steady state behavior. For example the wear rate of AA7075 matrix material increased from 1.25 mm^3/Km to 2.14 mm^3/Km for a range of sliding distance 1 to 2 km and further increased from 2.14 mm3/Km to 2.18 mm^3/km for a range of sliding distance 2 to 3 Km. The wear rate behavior of the composites was dependent on reinforced weight percentage of TiC and applied load. The wear rate decreased with increased Weight percentage of reinforced material (TiC) and increased with increasing load [19].

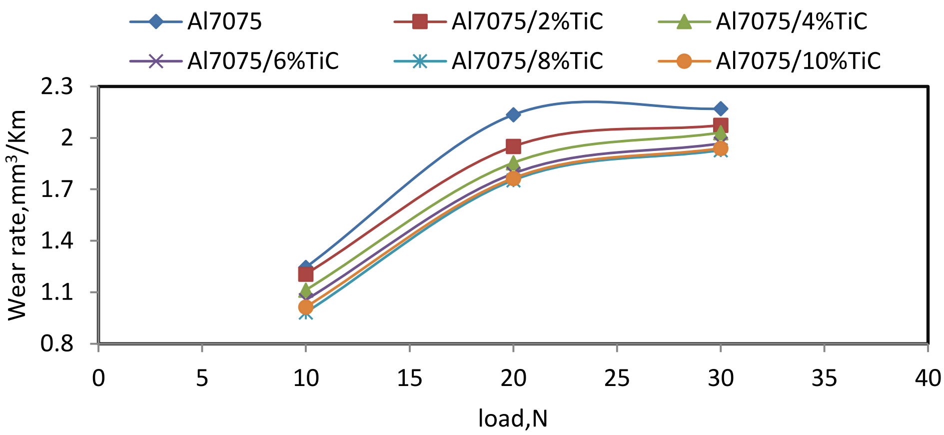


Figure 4. Variation of wear rate of AA7075 matrix material and AMMCs.

3.2.2. Effect of load and percentage of reinforcement on volume loss

Figure 5 presents the volume loss of the matrix material and AMMCs as a function of weight fraction of TiC particles at various loads. It can be seen that when the weight fraction of TiC particles increases, the volume loss of the matrix material and composites decreases. This reveals that the weight fraction of the reinforcement is proportional to the wear resistance of the composite [20]. It is also depicted that the volume loss at lower applied load 10N is considerably less as compared to that at higher load. The improvement in the wear resistance of the composites with increased contents of TiC reinforcement can be attributed to the improvement in the hardness of the composites. From these figures (Figures 4 & 5), it is observed that at wt. % 8 TiC composite shows better mechanical properties then matrix material and all other composites and improved hardness results in decrease in wear rate and volume loss [21]. The lower wear rates and volume loss in composites with higher amount of TiC particles can be attributed to the high peak hardness. The influence of TiC on wear resistance is more significant at lower load.

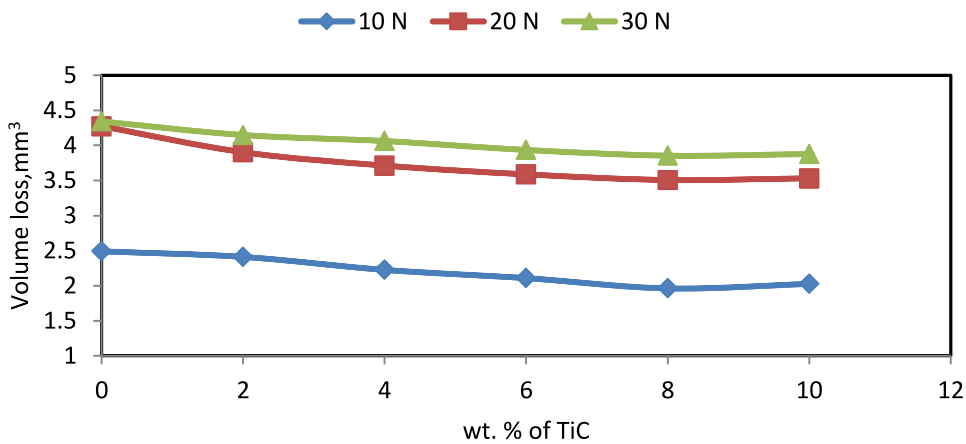


Figure 5. Variation of volume loss with increase in percentage of reinforcement of AA7075 matrix material and AMMCs

3.2.3. Effect of load and percentage of reinforcement on coefficient of friction

Figure 6 shows the variation of coefficient of friction (COF) with varying the loads (10N, 20N &30N) and weight percentage of reinforcements (AA7075 reinforced with 0 to 10 weight percentages of TiC). The COF of matrix material composites decreased linearly with applied load. It is observed that, the value of COF is high at low loads and tends to decease with increasing load [22]. It can be inferred from Figure 6 that the coefficient of friction also decreases with increasing wt. % of TiC in the AMMCs. The COF of composites is mainly affected by two factors. It increases as the amount of hard reinforcement in the matrix increases and it decreases with Fe phases present in the composite. It may be due to the formation of Fe rich transfer layers contributed in the AMMCs to decrease the overall COF [12, 23] and also 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 AA7075 matrix material [24].

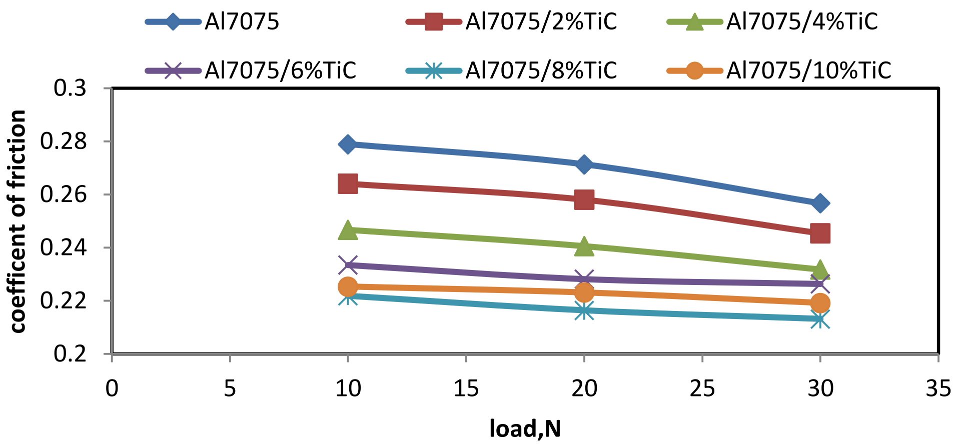
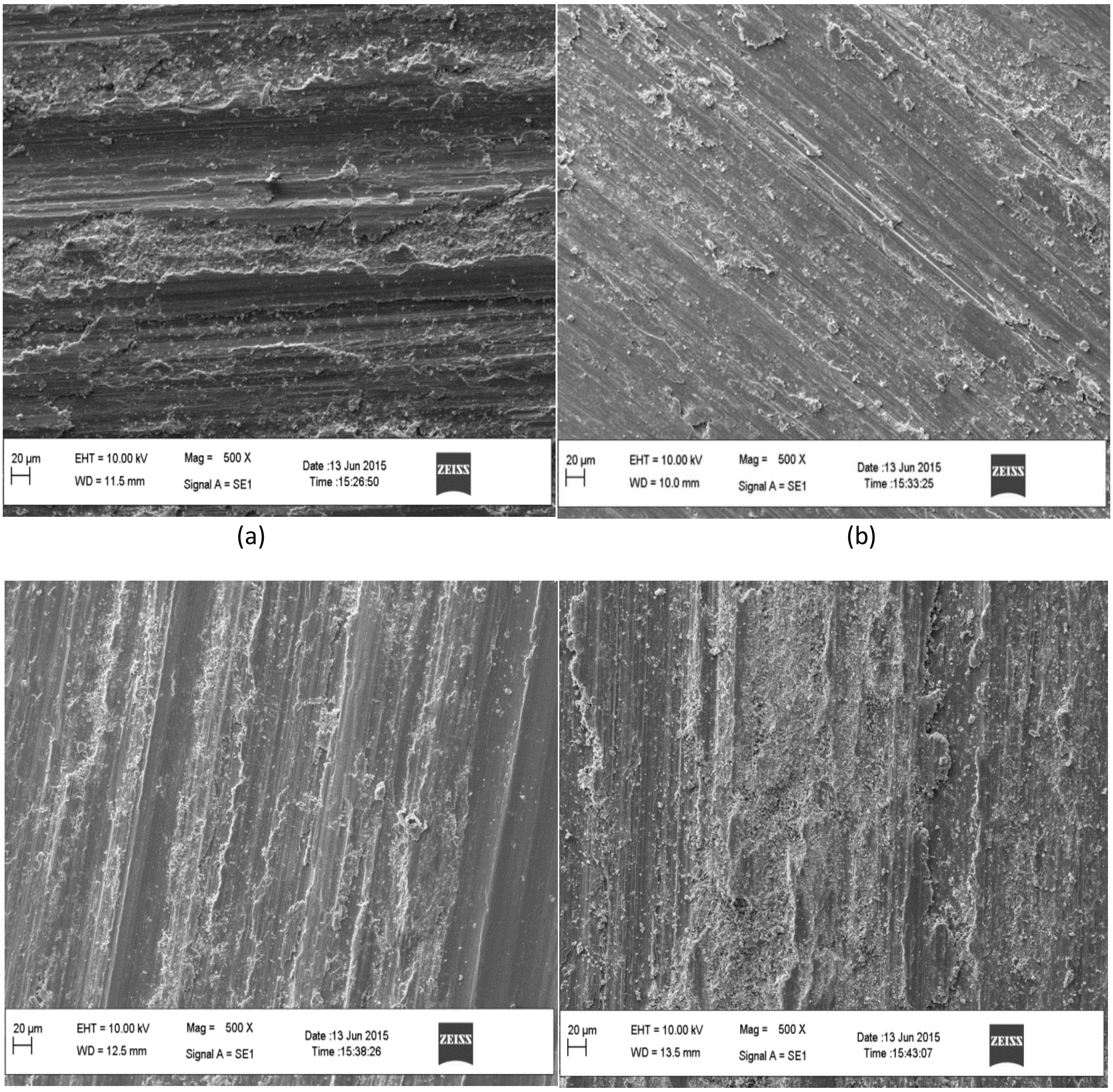


Figure 6. Variation of coefficient of friction with load

However, the 10 wt. % of TiC composite have shown a higher wear rate and coefficient of friction as compared to that observed 8 wt. % of TiC composite. This may be due to the wear test is higher at the interface between the counter face and the 10 wt. % TiC composite [20]. Consequently, the presence of higher amount of TiC hard particles between two surfaces causes an increase in the wear rate and the coefficient of friction of the composite.

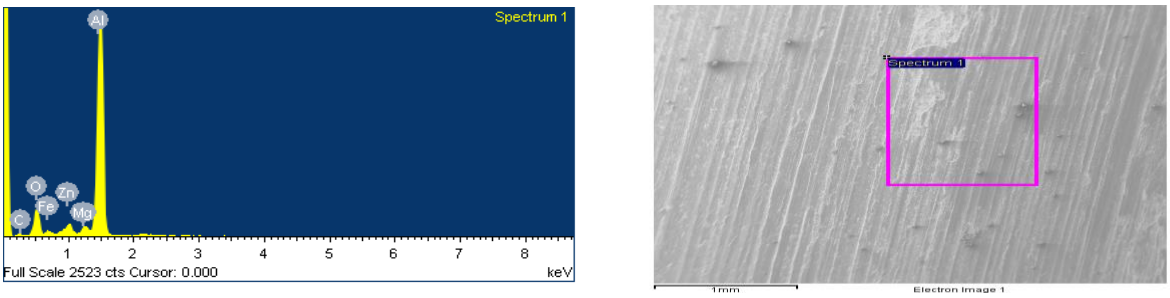
3.3. Optical micrograph of contact surface

The SEM micrographs of the worn surface of AA7075 matrix material and AMMCs(2, 8 and 10 wt.% of TiC) under sliding distance of 2 Km, sliding velocity of 2 m/s and a normal load of 20 N at room temperature were shown in Figure 7(a)–(d). It can be observed that the wear tracks are layered with compacted wear debris eventually forming the transfer layer. Figure 7(a) shows the wear tracks of AA7075 matrix material, it shows heavy delamination and fracture of the transfer layer due to the abrasive action of the hardened transfer particles resulting in cutting with subsequent delamination and fracture of the compacted layer. In Figure 7(b) and 7(c) shows distinct grooves and ridges running parallel to one another in the sliding direction as shown with red mark. It can be seen from the micrographs that the grooves are wider and deeper in matrix as compared to the composites tested under similar conditions. In Figure 7(d) Ploughing can also be seen on the worn-out surface of the 10wt. % of TiC composite, which may be due to sliding of oxide particle in the composite. From the analysis of EDS result shown in Figure 8 consist of oxides of Fe and it is confirmed. In the case of composites, a thick transfer layer could be seen, which protects the underlying matrix from being in contact with the sliding counterpart and thereby reducing the wear rate. This transfer layer formed on the composites provides a protective cover to the underlying material thus inhibiting the metal–metal contact. Therefore, less wear rate has been observed [12]. The less wear is noticed in Figure 7(c), it helps to infer that the AA 7075/8%TiC composite exhibits the superior wear resistance compared to other AMMCs and matrix alloy.



(c) (d)

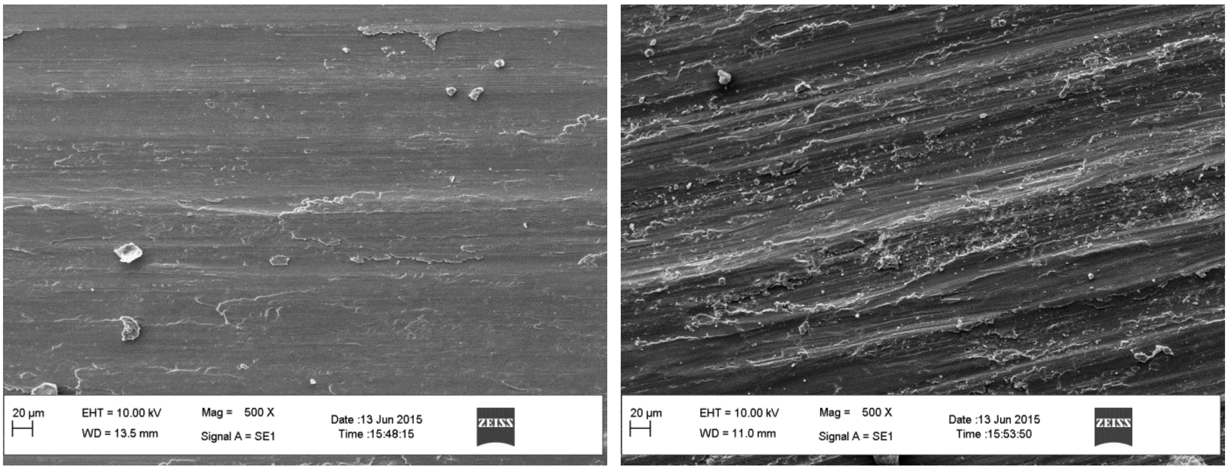
Figure 7. Morphologies of the worn surface at a load of 20N (a) AA7075 matrix material (b) AA7075/2%TiC, (c) AA7075/8%TiC and (d) AA7075/10%TiC composite.



Element	Weight%	Atomic%
C K	8.63	16.81
O K	16.07	23.49
Mg K	1.93	1.86
Al K	61.10	52.97
Fe L	7.81	3.27
Zn L	4.47	1.60
Totals	100.00	

Figure 8. EDS result of worn surfaces of 10 wt. % of TiC composite at sliding distance 2Km, sliding velocity 2 m/s and normal load 20 N.

These 8 wt. % of TiC composite Pins tested at different loads of 10 N and 30 N under a constant sliding velocity 2 m/s and sliding distance 2 Km, the wear mechanism have been related to the process of delamination is shown in Figure 9. This is a fatigue-related wear mechanism in which repeated cyclic stresses, impact, and so on can cause layers to separate, forming a mica-like structure of separate layers, with significant loss of mechanical toughness [25]. At low load (10 N), the light delamination marks appear and the worn surfaces become rather smooth when viewed at the same magnification [Figure 9(a)]. Delamination is observed to be more extensive under the higher load of 30N [Figure 9(b)]. Earlier researchers have mentioned increasing dominance of delamination with load [26]. At high load (30 N), degree of grooves formed at the worn surface of the 8 wt. % TiC composite undergo severe plastic deformation leading to severe wear. The SEM [Figure 9(b)] shows the presence of heavy wear debris particles on their worn surfaces [21].



(a) 10 N (b) 30N

Figure 9. Delamination of worn surfaces of 8 wt.% of TiC composite specimens under a load of (a) 10N and (b) 30N

4. Conclusions

The wear behaviors and coefficient of friction of AA7075 and AA7075/TiC composites have been investigated using pin on- disk wear tester. The following conclusion can be made:

1. AA7075 reinforced with TiC particles can improve dry sliding wear resistance and also increase in the weight fraction of particles leads to improvement in the wear resistance.
2. The wear rate increases with increasing of load for all the matrix and composites.
3. The coefficient of friction (COF) of the AMMCs found to be decreased with added TiC filler content. COF of the AMMCs decreases by an amount of 20% as the filler content of TiC increases from 0 to 8 wt. %.
4. Different wear mechanisms were found to operate under the test conditions of variation in load and % TiC particles. They are adhesive, abrasive and delamination.
5. The wear resistance of TiC reinforced particles increases with increase in the TiC content. However, the addition of 10 wt. % TiC does not improve the wear resistance considerably.
6. The SEM Morphologies of worn surfaces of AA7075 matrix material and AMMCs clearly indicated that the amount of grooving in the worn surfaces of the composites is reduced with increased content of TiC, indicating lower material removal.

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