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Tribological properties of Aluminium Metal Matrix Composites (AA7075 Reinforced with Titanium Carbide (TiC) Particles)

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Abstract

In the present work aluminum matrix composites (AMMCs), AA7075 Alloy as the matrix metal and Titanium carbide (TiC) particles (2-10%) with an average particulate size of 2μm as reinforced material were processed by stir casting route. Computerized pin on disc wear tester was used for wear test with counter surface as EN32 steel disc (58-60 HRC) and cylindrical pin as the composite specimens. The wear rate in terms of weight loss per unit sliding distance, coefficient of friction and volume loss were obtained for the matrix metal and composites. The results of composite shows better wear resistance than matrix metal. The microstructural characterization of worn surface was investigated using SEM. Weight loss of samples was calculated and the variation of cumulative wear loss with sliding distance has been found to be uniform for both the matrix metal and the composites. It was also observed that the wear rate is low for composites compared to matrix metal. Further, it was noted from the experimentation that the wear rate decreases with increasing weight fraction of TiC and coefficient of friction decreases with increasing sliding velocity and weight fraction of TiC. SEM-XRD analysis revealed the presence of TiC and other phases. The better wear properties (wear rate, coefficient of friction and wear factor) was observed with 8 wt% TiC composite compared to other composites as well as matrix metal.

***Keywords**: Metal Matrix Composites, Al7075, TiC, Stir Casting, Wear, SEM*

1. Introduction

Particle reinforced metal matrix composites (MMCs) have been the most popular over the last few decades. The modern trend for potential applications is to optimize the mechanical properties and heat treatment of MMCs. Aluminum metal matrix composites (AMMCs) reinforced with discontinuous phases in the forms of whiskers, fibers, and particulates exhibit magnify strength values at higher temperatures, low coefficient of friction and thermal expansion, good wear resistance and stiffness compared to base alloys (1). The reinforcing material consists of discontinuous phase embedded in a continuous phase, whereas the matrix material consists of only continuous phase. The discontinuous phase much harder and stronger than continuous phase (2-3).

Several ceramic reinforcements have been identified for Aluminum (Al)-based metal matrix composites, but recently TiC has gained attention over others due to its high hardness, stiffness and wear resistance [4]. Ductility, toughness, electrical and thermal conductivity of the aluminum matrix adds to the properties of the Al–TiC composites [5]. In addition to being structural materials, now a days Al–TiC composites play a vital role as grain refiners for aluminum alloys in the automobile and aerospace industry [6]. TiC

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particulate reinforced MMCs are very interesting because TiC is thermodynamically stable and enhances the hardness and lightness of the composite. Al–TiC composites can be produced by various processes [7-8]. Casting route is particularly attractive as it is economical and practical.

Transition metal carbides, such as TiC, have more uniform distributions of electron density and the greatest metallic character of bonds and properties.It is thought that bringing clean metal and ceramic surfaces together in close proximity is sufficient to enable strong chemical bonds to be established [9].

In this study the composite is prepared by using stir casting method, which is one of the economic and commonly used methods in liquid metallurgy (10). Most of the studies made in automotive and aerospace field shows that the material used for components should possess good toughness with better tribological properties. Hence to meet the automotive application requirements an attempt has been made to develop the AA7075 based hybrid composite, having combination of both toughness and tribological properties like wear resistance. The greatest improvement in tribological properties of composite is generally obtained using particle reinforcement of Titanium carbide. The addition of magnesium alloy to composite during production ensures good bonding between the matrix and the reinforcement [11].

The uniform distribution of SiCp into AA7075 alloy matrix [12] and pre-aging of AA7075 at various retrogression temperatures improves the hardness, tensile properties and electrical resistivity [13].The hardness of aged AA7075 matrix material was improved than as cast condition material [14]. The mechanical, hardness and sliding wear resistance properties of heat treatment and forming composites were improved by adding SiC [15]. The superior mechanical properties were obtained with AA7075-SiC composites [16-17]. The densities of AA7075-Al_2O_3 composite are improved [18].

The present study is intended to investigate the tribological performance of aluminum matrix composites (AA7075-TiC) sliding against a pin-on-disk tester with the composites as the pins and stainless steel as the disk. The wear behavior was studied by detailed observations of the surfaces and sub surfaces of worn specimens. Low contact load and small sliding velocity were chosen to eliminate the thermal influence.

2. Experimental

2.1. Materials

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

Table 1. Chemical Composition of AA7075 Matrix Metal (wt. %)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.08	0.24	1.5	0.06	2.4	0.20	5.8	0.07	Balance

2.2. Fabrication of Composites

Pre weighted (AA7075) was fed into the electric furnace and was melted at 800^0C. The experimental setup is shown in Figure 1 (a). After melting of matrix metal, the magnesium ribbons are added to increase the wettability of AA7075 so that the reinforcement added to the metal is evenly dispersed. The TiC powder added to the molten metal was pre-heated up to 300^0C to remove the moisture, drift etc. (if any) in it. An appropriate amount (2% of the wt. of base metal) of Titanium Carbide (TiC) powder was then added slowly to the molten metal. The molten metal was stirred thoroughly at a constant speed of 300 rpm with a mechanical stirrer for a period of 15 minutes for uniform mixture of matrix and reinforced material. The metallic molds were preheated to a temperature of 400^0c.The molten composite (AA7075/TiC) was poured in the pre heated metallic molds and cooled to room temperature. Figure1 (b) Shown the castings were separated from the metallic molds. The same procedure was followed to get the AMMC's of different weight percentages - 4%, 6%, 8% & 10% .Formulation details of the composites are presented in Table 2.

Table 2. Formulations of Different Composites used in the Study

code	C1	C2	C3	C4	C5
Matrix with % of reinforcement	Al7075-2%TiC	Al7075-4%TiC	Al7075-6%TiC	Al7075-8%TiC	Al7075-10%TiC

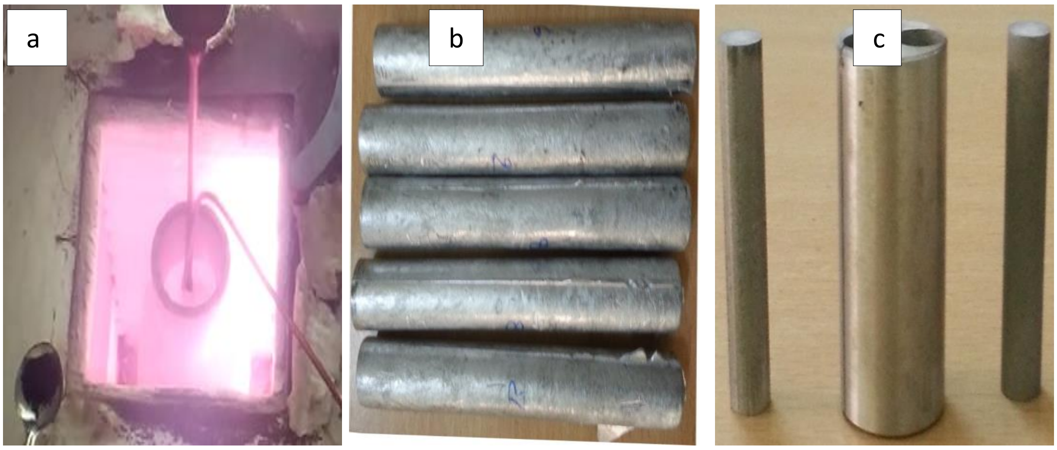


Figure 1. (a) Experimental Setup (b) As Cast Specimens (c) Wear Specimens

2.3. Heat Treatment (T_6)

Matrix metal and composites were heat treated and aged to T_6 condition. The T_6 temper is done by homogenizing the material at 450^0C for two hours, and then ageing at 121^0C for 24 hours. The wear specimens of 30mm length and Ø8mm were retrieved through wire cut EDM process from the thoroughly homogenized ingots of matrix metal and composites as shown in Figure1 (c).

2.4. Testing

Dry sliding wear tests for the matrix metal and composites were carried out using pin-on-disc machine (Model TR-20 LE supplied by M/s Ducom) in dry condition. Wear tests were conducted using cylindrical samples (Ø8mm X 30 mm) that had flat surfaces in contact region and the rounded corner. The pin is held stationary against the counter face of a (Ø100mm) rotating disc made of En-32 steel having a hardness of HRC60. The wear tests were conducted under the fixed normal load 19.62N and at three sliding velocities of 1.57m/s, 2.09m/s and 2.61m/s (300, 400 and 500 rpm). Each wear test has been carried out for a total sliding distances of 1, 2 and 3km. Pin weight before and after the test was measured to determine mass loss. Volume loss was determined (mass loss/density mm^3) using the density of Al7075 as 2.81g/cc and density of composites 2, 4, 6, 8 and 10 wt. % TiC contents as 2.82 ,2.83, 2.845, 2.8553 and 2.862 g/cc respectively. After each test run the pin is removed from the holder and disk was cleaned with acetone to remove wear debris.

Microstructure and SEM analysis of the post mechanical tests was carried out to study the worn out surfaces under different velocities and distances.

3. Results and Discussion

3.1. Hardness Behavior

Figure 2 shows, the hardness behavior of matrix metal and composites. Previously an attempt has been made for investigation on properties of TiC reinforced AA7075 metal matrix composites [19]. It can be observed that hardness shows increasing trend with increasing percentage of TiC particulates. However, declining of hardness was observed for C5 composite due to agglomeration and casting defect. This hardness increase was observed from 181 VHN for matrix metal to 202 VHN at 8 wt% TiC reinforced composite (C4) at T_6 condition. This could be due to the presence of TiC particulates which are hard in nature.

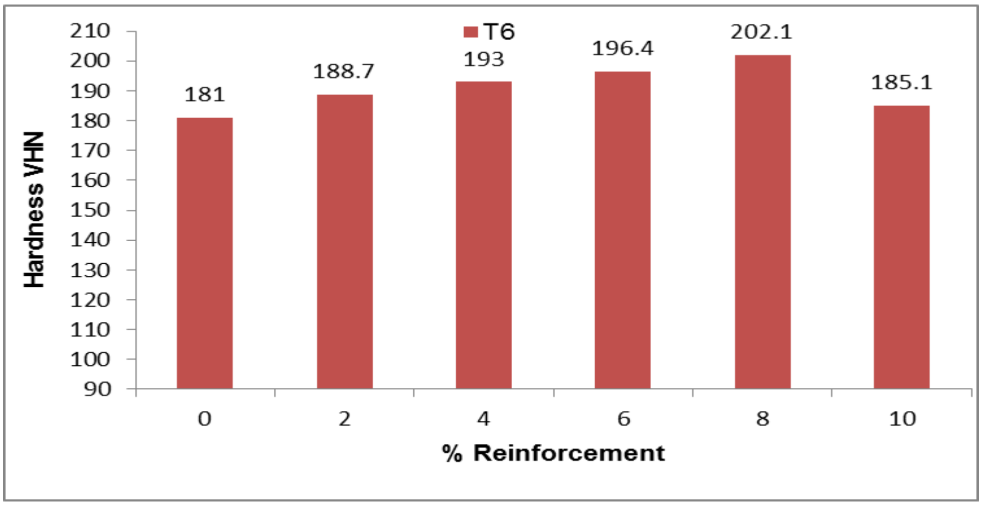


Figure 2. Hardness Behavior of Composites

3.2. Wear Study

Based on the results, various graphs are plotted and presented in Figure [3-14] for different wt%'s of TiC reinforcement at different velocities, sliding distances and constant load.

3.2.1. Effect of Wear Rate

Figure 3 (a-c) presents the variation of wear rate with sliding distance at different velocities and a fixed load of 19.62N for matrix metal and composites(C1,C2,C3,C4 and C5) respectively. It is noted that wear rate decreases with increasing sliding distance and also decreases with increasing weight percentage of TiC content. Thus it can be concluded that reinforcement of the TiC in matrix metal is very effective in improving its wear resistance. This increase in wear rate for higher weight fraction of TiC (10 wt %) might have happened due to agglomeration in the C5 composite, which leads to poor interfacial adhesion between the TiC and the matrix metal [20, 21].

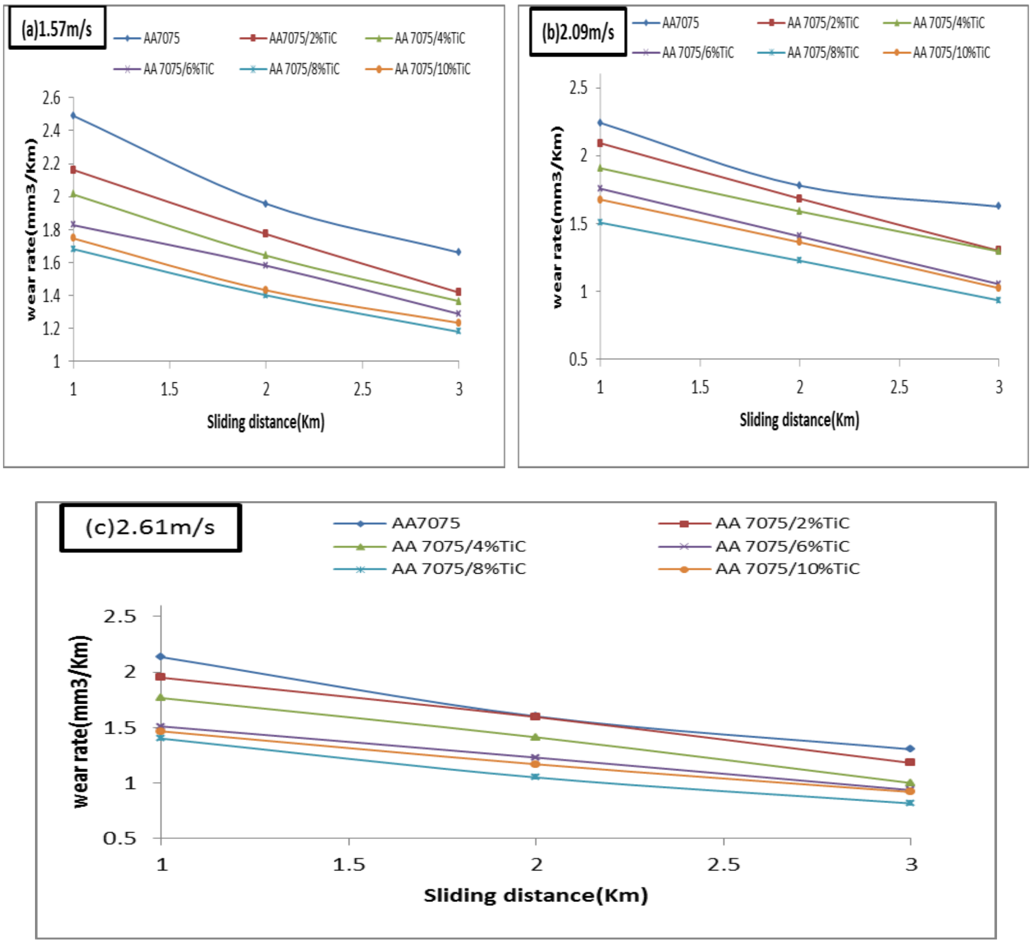


Figure 3. Variation of Wear Rate with Sliding Distance at a Velocity of (a)1.57m/s (b)2.09m/s (c)2.61m/s of Al7075,C1,C2,C3,C4&C5

The variation of wear rate with sliding distance is shown in Figure 4(a&b) for matrix metal and C4 composite at 1.57m/s,2.09m/s and 2.61m/s. It is observed that the Wear rate is low at higher value of sliding velocity and decreases with increasing Sliding distance due to of at higher velocities, the contact plateaus and coefficient of friction are low. So at lower velocities, increased wear rate is observed. For example, the wear rate of AA7075 matrix at load of 19.62N for 2.09m/s velocity at a sliding distance of 1Km is 2.241993mm^3/km which is reduced to 1.625148 mm^3/Km at a sliding distance of 3Km (fig.4a).when the velocity increased from 2.09m/s to 2.61m/s the wear rate of AA7075 matrix decreased from 2.241993mm^3/km to 2.135231mm^3/km for a fixed sliding distance of 1Km at load of 19.62N.

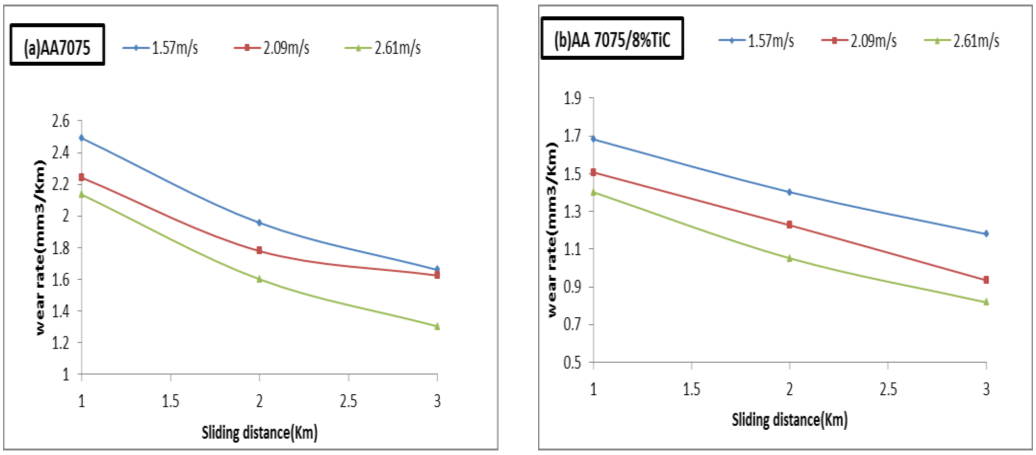


Figure 4. Variation of Wear Rate with Sliding Distance at Different Velocities of (a) AA7075 and (b) C4 Composite

The wear rate of the composites is lower than that observed in the matrix metal and decreases with increasing weight fraction of the TiC content in the composite as it is evident from Figure 5. It indicates that an increase in sliding velocity considerably affects the wear rate. The wear rate decreases sharply with increase in sliding velocity for composites with relatively higher weight fraction. However, even with increasing sliding velocity, the un-reinforced alloy showed higher wear rate compared to composites [22]. Figure 6 shows the variation of wear rate with weight fractions of TiC under different sliding distances at fixed velocity of 1.57m/s. It is clearly noted that the wear rate decreases with increasing TiC weight fraction and sliding distance. It should be observed that the effect of sliding distance and wt % of reinforcement over a wear rate is same nature at different conditions i.e., inversely proportional.

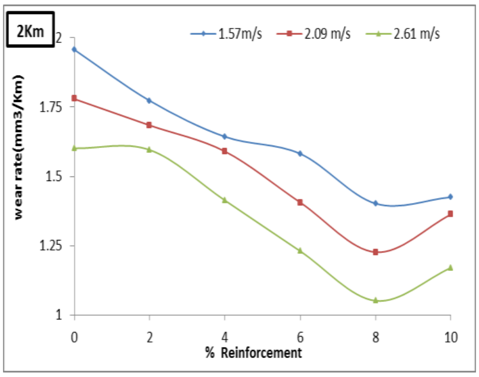


Figure 5. Variation of Wear Rate with Percentage of Reinforcement at a Sliding Distance of 2Km

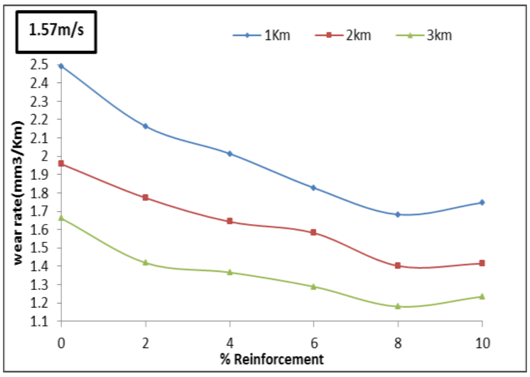


Fig.6.Variation of Wear Rate with Percentage of Reinforcement at a Sliding Velocity of 1.57 m/s

3.2.2. Effect of Coefficient of Friction

Figure 7(a-c) shows the variation in coefficient of friction with the variation of the sliding distance(1 to 3km) at different sliding velocities for theAA7075 matrix metal and composites (AA7075+TiC at 2,4,6,8 and 10 wt %). These curves show the result for velocities of 1.57, 2.09, and 2.61m/s respectively at a constant applies load of 19.62N. This shows coefficient of friction decreases with increase of sliding distance in all the cases. However, composite represents a lower coefficient of friction than that of as AA7075 matrix metal. Thus coefficient of friction decreases significantly with the incorporation of TiC in matrix. This trend is similar in all the materials investigated.

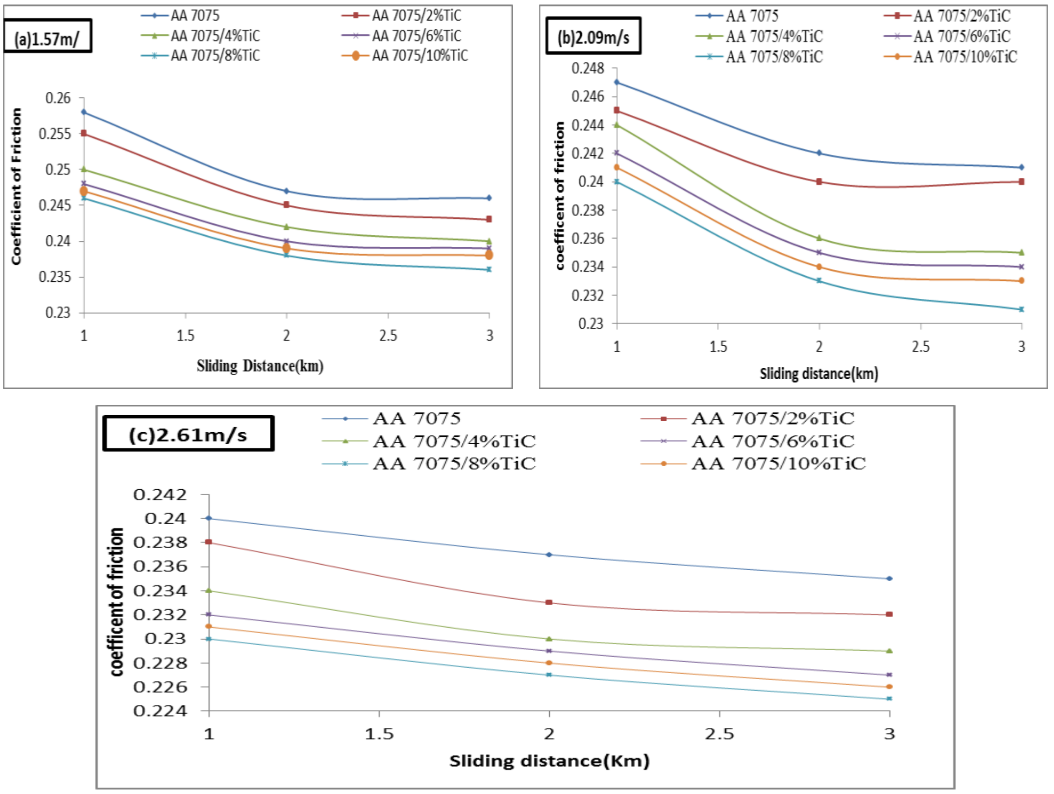


Figure 7. Variation of Coefficient of Friction with Sliding Distance at a Velocity of (a)1.57m/s (b)2.09m/s (c)2.61m/s of AA7075,C1,C2,C3,C4&C5

Figure 8 (a&b) shows the variation of average coefficient of friction of AA7075 matrix and C4 composite at 1.57m/s,2.09m/s and 2.61m/s velocities as function of sliding distance. It is observed that coefficient of friction decreases with increasing sliding distance and same trend with increasing velocity due to change in shear rate [23]. With increase Sliding velocity, the layer formation was more uniform i.e. less number of craters was observed [20].

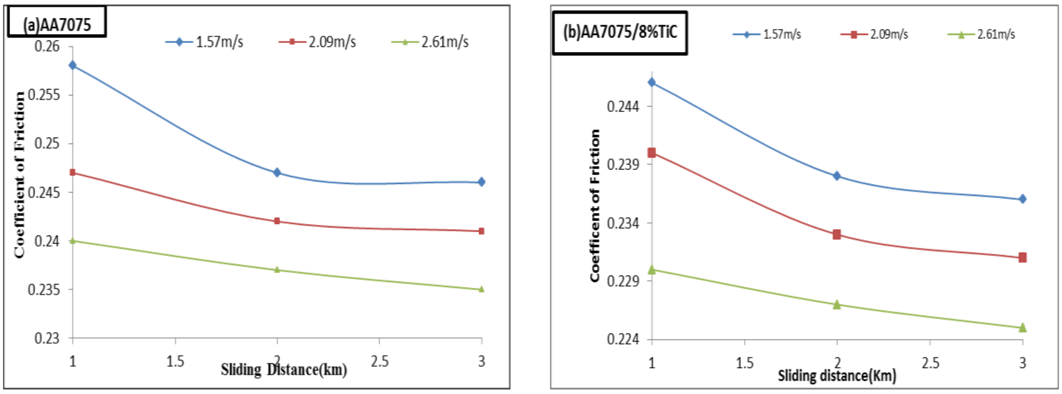


Figure 8. Variation of Coefficient of Friction with Sliding Distance at Different Velocities of (a) AA7075 and (b) C4 Composite

Figure 9 shows the variation of coefficient of friction of AA7075 and AA7075-TiC composites with increased percentage of reinforcement as a function of different velocities at a constant sliding distance of 1Km. It is observed that the coefficient of friction decreases steadily up to 8 weight percentage of TiC reinforced into AA7075 matrix material. With further increase in the percentage of TiC reinforcement a drastic increase in the coefficient of friction were observed for both the AA7075 matrix metal and its composites. The fluctuations in the coefficient of friction may be due to variation in contact between pin and disk.

The variation of coefficient of friction with respect to sliding distance and wt. % of reinforcement is shown in fig.10.The coefficient of friction decreases with increasing sliding distance and decreased with increasing weight percentage of TiC reinforced material [7] .From these curves it is observed that the coefficient of friction is low at higher velocities and at maximum sliding distances. Hence, it can be concluded that at 8 wt% of TiC reinforcement into AA7075 matrix gives maximum reduction in coefficient of friction which in turn leads to minimum wear.

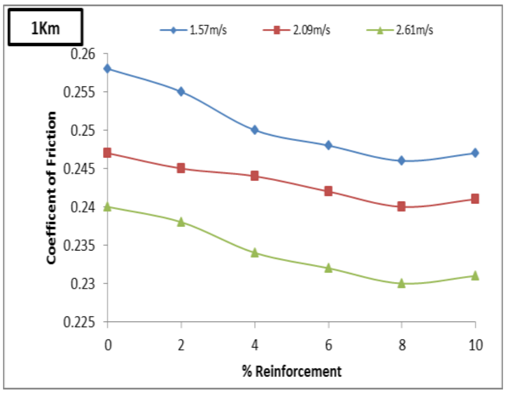


Figure 9. Variation of Coefficient of Friction with Percentage of Reinforcement at a Distance of 1Km

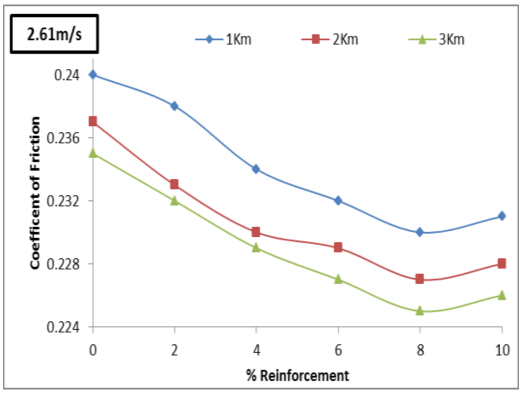


Figure 10. Variation of Coefficient of Friction with Percentage of Reinforcement at a Velocity of 2.61m/s

3.2.3. Effect of wear factor

Figure 11 (a&b) shows the variation in wear factor of the AA7075 matrix and composite with sliding distance at different sliding velocities of 1.57m/s and 2.61m/s under applied load of 19.62N. It is obvious from the figure that the wear factor of AA7075 matrix metal and composites decreases with increase in sliding distance. The wear factor of AA7075 matrix metal varies from 0.127 to 0.085 mm^3/N-Km for a range of sliding distance 1 to 3 km (Figure 11a). The wear factor typically shows an almost smooth variation with sliding distance. The wear factors of composites consistently showed lower wear factor compared to that of AA7075 matrix metal [18].

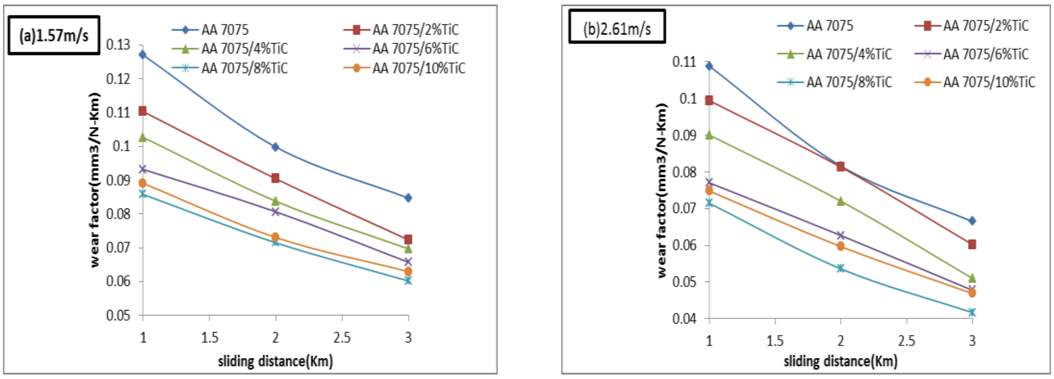


Figure 11. Variation of Wear Factor with Sliding Distance of AA7075 and Composites at (a) Sliding Velocity at 1.57m/s (b) Sliding Velocity at 2.61m/s

3.4. Microscopic Examination

3.4.1. Microscopic Examination of Composite

Figure 12 (a-b) shows microstructure of the polished and etched (etched with 2.5% HNO_3, 1.5% HCL, 1% HF, and 95% H_2O solution) C2 composite. Figure 12 (a) shows the fine inter-dendrite network due to rapid solidification. The black particles are observed inside grain and along the grain boundaries which could be the TiC particles. Figure 12(b) shows the SEM micrograph of C2 composite. Al_3Ti precipitate particles (marked by arrow) presented in the form of white color phase and black color phase corresponds to TiC particle segregated throughout the SEM microstructure [4]. Figure 13 shows EDS spectrum of C2 composite and also observed all the reinforced elements presented in the composite.

3.4.2. Wear surface of Matrix and Composite

Scanning Electron Microscopic examinations of the worn pin surfaces were carried out at sliding over a distance of 2Km for an applied load of 19.62N and a sliding velocity of 2.61m/s to determine wear mechanism. Figure 14(a-d) shows the wear track photographs of the AA7075 matrix metal, C1, C3and C4 composites. The white arrows indicate the direction of sliding. AA7075 was presented with some large grooves with a size of 60µm. The examination of wear surface of AA7075 matrix metal tested at maximum sliding velocity shows a coarser and deeper grooves and ridges running parallel to one another, a typical characteristic of the sliding wear (Figure 14a). It is been observed that initially the wear happens to be adhesive wear and there is plastic flow of the material along with small cavity in the subsurface layer with a little smooth patch indicating severe wear[24]. However, the micrographs in Figure 14 (b to d) reveal that grooves are much shallower in composites than that of the alloy due to the presence of TiC particles. From Figure 14 (b), it is observed that with the addition of 2% of TiC reinforcement the craters are reduced and some smooth wear tracks are noticed. This clearly indicates that due to the reinforcement the hardness of the composite is enhanced. When percentage of reinforcement increases this adhesive wear turns out to be abrasive wear with more fine wear tracks and there exit a rough craters visible at 8 wt% of TiC reinforcement into AA7075 matrix in Figure 14 (d). Also, it is cleared from the figure that grooves are much finer and closely spaced in AA7075/8 wt % TiC due to the sliding action of a larger number of hard particles and debris. Few patches of oxygen-rich material were occurring evenly throughout the worn surface in all cases that eventually break off to form the loose debris [25]. Presence of craters in the tribo-layer are believed to be due to the cracking and breaking of delaminated layer into fragments, which might have resulted in the production of high aspect ratio wear debris or third body abrasives[26]. But further increase in reinforcement to 10% leads to the decrease in the wear resistance.

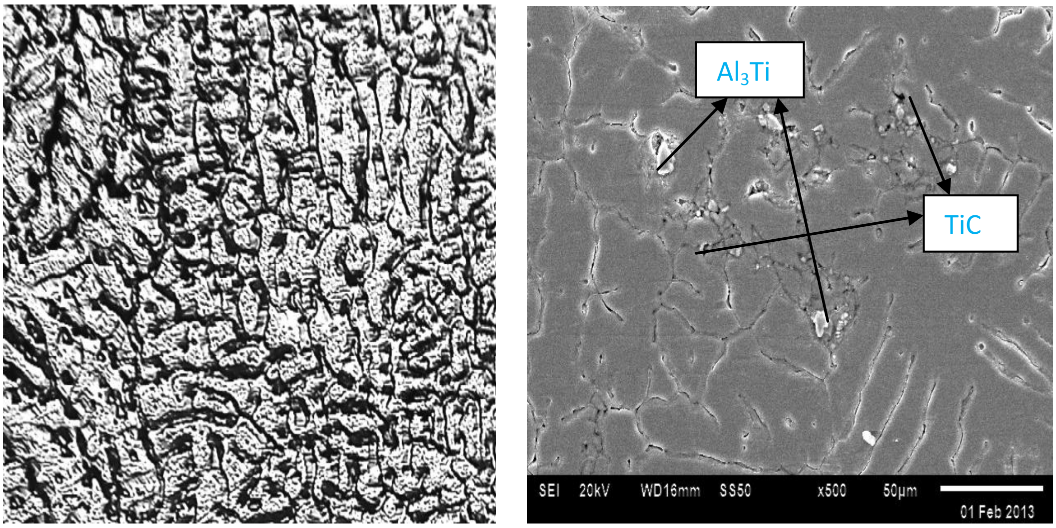
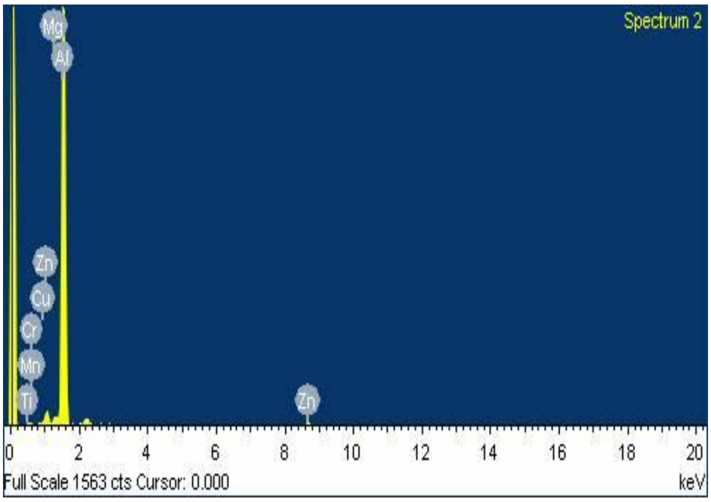


Figure 12. (a) Optical Micrograph (b) SEM Micrograph of 2 wt. % of TiC Reinforced into AA7075



Element	Weight%	Atomic%
Mg K	2.16	2.01
Al K	80.04	73.84
Si K	0.58	0.51
TiC K	10.21	20.91
Cr K	0.23	0.11
Mn K	0.31	0.14
Cu K	1.55	0.61
Zn K	4.92	1.87
Totals	100.00	

Figure 13. EDS Spectrum and Analysis of AA7075-2%TiC Composite

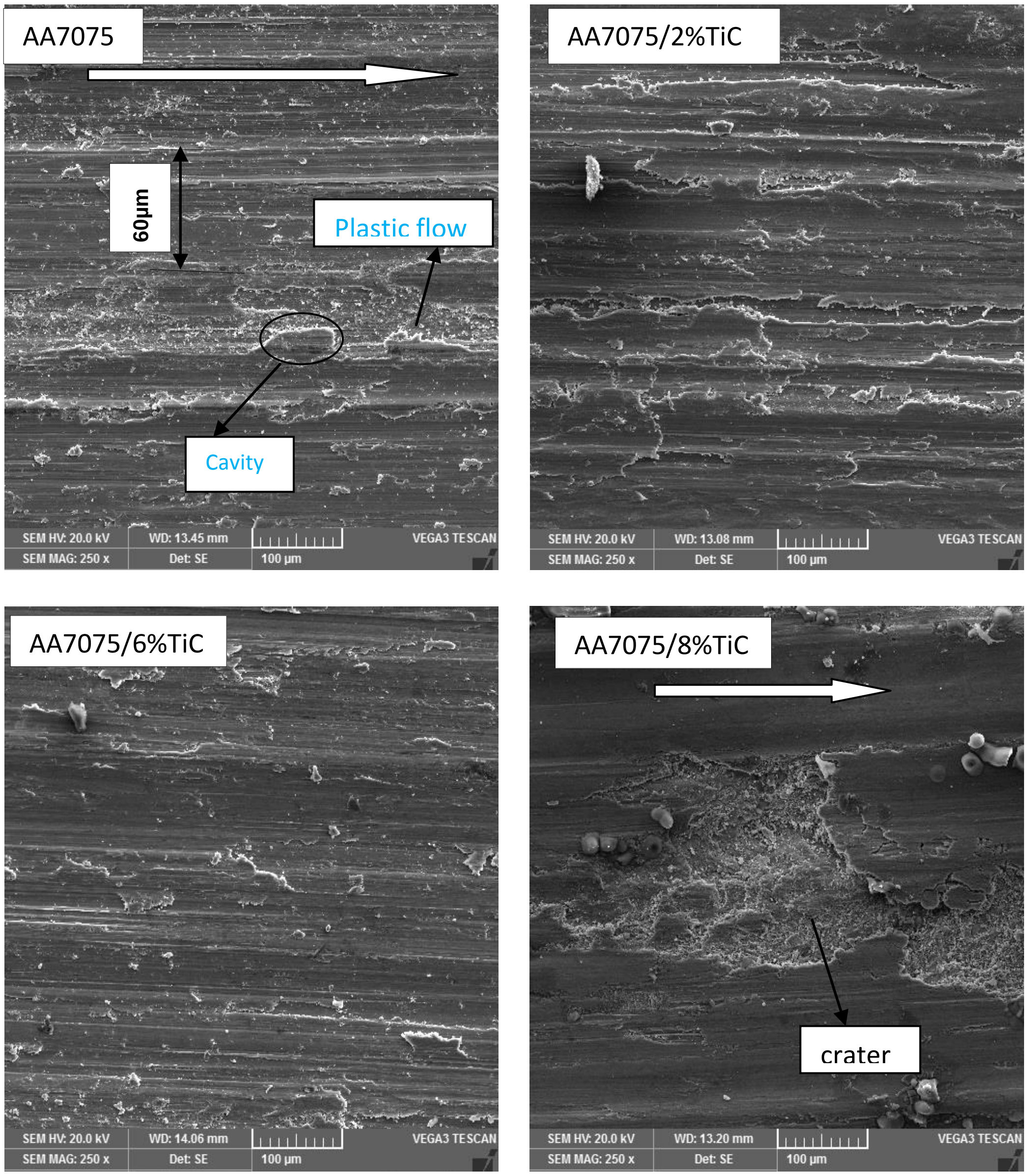


Figure 14. SEM Micrographs of Worn Surfaces of (a) AA7075 Matrix Metal (b) AA7075/2% TiC (c) AA7075 /6% TiC (d) AA7075/8%TiC

4. Conclusions

Friction and wear behavior of AA7075/TiC composites have been studied against pin on disc. Results of the study show:

- The weight percentage of reinforcement was most significant parameter affecting the hardness of composites produced by stir-casting process. ThusAA7075 matrix containing 8% of TiC particulates exhibited the highest micro-hardness.
- The wear rate, coefficient of friction and wear factor varying with the sliding distance and the percentages of reinforcement are of same nature.
- The wear resistance of TiC reinforced composite increases with increase in the TIC content. However, the addition of 10% TiC does not improve the wear resistance considerably.

- The wear rate of the composites decreased with increasing the weight percentage of Titanium carbide (TiC) particulates than the base alloy.
- From the studies in overall it can be concluded that AA7075-TiC exhibits superior mechanical and tribological properties.

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