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# OPTIMIZATION OF VOLUMETRIC WEAR RATE OF AA7075-TiC METAL MATRIX COMPOSITE BY USING TAGUCHI TECHNIQUE

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**Abstract**

Aluminum Metal Matrix Composites (AMMCs), reinforced with particulates, have marked their importance in many engineering applications because of low wear rate and a significant hardness. In the present work, AA7075 metal matrix composite materials, varying in the particle percentage of TiC reinforcement, were prepared by stir casting procedure and optimized volumetric wear at different parameters such as particle percentage of TiC, sliding speed and sliding distance. The specimens were examined Scanning Electron Microscope (SEM). Through Taguchi's technique, a plan of experiment generated and it is used to conduct experiments based on $L_{27}$ orthogonal array. The developed ANOVA used to find the optimum wear under the influence of percentage of TiC, sliding speed, sliding distance. In all the cases, matrix material shows a higher volumetric wear rate than composites. 8 wt % of TiC composites show a lower volumetric wear rate (535.58 $mm^3$/sec) at minimum sliding distance and maximum sliding velocity of 1Km 2.61m/s, respectively.



**Keywords:** *AA7075- TiC, Taguchi optimization, metal matrix composites, stir casting, wear*.

## 1. Introduction

The permanent and rising demand for lightweight materials in automotive, aerospace, and defense applications has drawn the attention of researchers for improved fuel economy and cleaner emissions. Metal Matrix Composites (MMCs) are suitable for such applications provide good damping properties along with strength, thermal conductivity, and low coefficient of thermal expansion [1-3]. In the field of automobile, MMCs are used for cylinder block, brake drum, and pistons because of improved corrosion resistance and wear resistance [4-5]. MMCs have a stupendous benefit in producing materials with different combinations of stiffness and strength; where in particular, composites are extensively used due to easy fabrication and low cost. Among all, aluminum composites are utilized in many engineering fields because they possess a number of mechanical and physical properties that make them outstanding for automotive applications [6].

Even though MMCs offer superior properties than monolithic materials, they have not been widely applied in structural applications due to the difficulty of fabrication [7]. Fabrication of MMCs has several challenges, such as porosity formation, poor wettability and improper distribution of reinforcement. This can overcome by an attractive processing method for fabrication that is conventional stir casting, as it is moderately inexpensive and offers wide range of materials and processing circumstances. Due to stirring accomplishment of particles into melts, stir casting offers better matrix particle bonding [8]. Bhargavi et al. [9] successfully fabricated composite material through stir casting technique and identified the improved mechanical properties with uniform distribution of reinforced particles.

The quantity, a desired kind and distribution of the reinforcement components, depends on the selection of a suitable process engineering that is the matrix alloy and its application [10]. Thus, reinforcing aluminium with hard ceramic particulates, fibers, or whiskers for the development of Aluminium Metal Matrix Composites (AMMCs) has a series of excellent properties, i.e., high hardness, stability and low density [11]. Among the variety

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of aluminium alloys, Al7075 is quite an accepted choice as a matrix material to prepare metal matrix composites owing to its enhanced formability characteristics and the option of change of the strength of composites through heat treatment [12-14]. A modified stir casting method was engaged to manufacture Al7075 alloy with $TiB_2$ particles. The molten material, which is in semisolid state at near liquidus was stirred to disperse the particles that were added. It includes three-stage process where finally, the dissolution rate and the growth rate of a-Al reached equilibrium [15]. A Transmission Electron Microscopy (TEM) study of the electrochemical interactions between constituent particles and the alloy matrix was conducted on 2024-$T_3$ and 7075-$T_6$ aluminum alloys to improve understanding particle-induced pitting corrosion in these alloys. By using the stir casting method, Al7075-flyash composite was effectively made-up by adding Mg to improve the wettability of a flyash particle so that these composites could be used in those sectors where low weight and superior mechanical properties are necessary as such as in automobile and space industries [16]. The use of ceramic materials are as reinforcement for the matrix Al7075 in various properties can lead to more efficient MMCs, which enhanced mechanical and tribological properties [17]. Al7075 alloy and their composites have been effectively developed through the stir casting based liquid processing route with dispersion of basalt fiber, it significantly improves the hardness, yield strength and the ultimate tensile strength of Al7075 [18]. Aluminium metal matrix composites reinforced with graphite (Gr) and SiC particles fabricated by liquid materallurgy method. It shows that graphite particles are efficient agents in escalating dry sliding wear resistance of Al/SiCp composite [19]. MMCs are having more advantages because of better mechanical properties. The heat treatment specimens were generated hard and unbrittle phases in topcoat due to which an increase in hardness and wear resistance was observed and mass loss has been decreased when compared to untreated substrate [20]. The wear rate of quenched specimen is very low due to the existence of shielding oxide coating layer formed during heat treatment and due to the existence of acicular martensitic structure (retained beta) in its microstructure [21]. Dry Sliding Wear Behavior of Al7075 Reinforced with Titanium Carbide (TiC) was studied in a previous article [22].

Wear is frequently appearing industrial problems, which leads to common replacement of components, mainly abrasion. Abrasive wear occurs when hard particles or asperities penetrate a softer surface, displaces material in the form of elongated chips, and slivers [23]. Wide range of studies on the tribological characteristics of aluminum MMCs containing different reinforcements such as short steel fiber, silicon carbide and alumina are already finished by many researchers [24-26]. The variables, such as interface between the particles and the matrix, composition of the matrix and particle distribution, affect the tribological behavior of metal matrix composites. These conditions consist of the type of environment, contact area, counter surface, applied load, sliding speed, and geometry [27]. The principle tribological parameters, such as applied load [28-30], sliding speed [31-32], and percentage of reinforce particles, control the friction and wear performance. The greatest development in tribological properties of composite is usually obtained by means of particle reinforcement of silicon carbide and boron carbide. The primary sliding distance require accomplishing mild wear decreased with increasing volume fraction and also wear rate decrease linearly with fraction of volume [33]. Daoud et al. [34] found that adding magnesium alloy to composite during production ensures fine bonding between the matrix and the reinforcement.

Taguchi method is the most useful tool for improving the performance of the product, process, design and system with a significant reduction in experimental time and cost [35]. Abbas et al. [36] established taguchi technique as a valuable technique to deal with responses influenced by multi-variables. It is meant for process optimization and finding of optimal combination of the parameters for a given response. This method significantly reduces the number of experiments that are necessary to model the response function compared with the full factorial design of experiments. This method defines at the lower-the-better, the larger-the-better and the nominal-the-better categories of eminence characteristics in the analysis of Signal/Noise ratio. The most significant advantage of this method is to find out the probable interaction between the factors. AA 6351-$T_6$ and AA 2024-$T_6$ alloys were fabricated by using friction stir welding process and applying ANOVA on the experimental investigations.

The influence of parameters, such as weight percentage of reinforcements, normal load, sliding distance and sliding speed on dry sliding wear, was discussed by incorporating an orthogonal array and Analysis of Variance (ANOVA) technique [37]. The percentage of contribution of FSW process levels was used and predicted tensile strength maximum at optimum parameters [38]. Chandrasekhar Rao et al. [39] studied the influence of grain refiners, modifier and refiner on wear - friction behavior of hypereutectic Al-15Si-4Cu cast alloy and reported that it depends on the size, shape and size distribution of α- aluminum grains and secondary phase particles in the matrix. Uthayakumar et al. [40] employed ANOVA to examine which design parameters considerably affect the wear behavior of the composite.

The present study is intended to look into the effects of sliding distance, sliding velocity and wt. % of reinforcement on volumetric wear rate of AMMCs (AA7075 as matrix material and Titanium Carbide (TiC) particulates as reinforced material on Pin on Disc apparatus and identify the most effective control parameter on reference variable by using Taguchi method. ANOVA was employed to investigate which design parameters significantly affect the wear behavior of the composite.

## Experimental Set-Up

### Materials and Methods

In the present investigation, dry sliding wear tests were performed on TiC particles of size 2μm reinforced Al-7075 alloy matrix composite. The reinforcement percentage varied from 2 to 10 wt. % in steps of 2%. The chemical composition of AA7075 Alloy is shown in Table1.

**Table 1**. Chemical composition of AA7075 matrix material (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 |

**Fabrication of Composites**

In manufacturing MMCs, stir casting technique is one of the popular liquid metallurgy process and is known as a very promising process for manufacturing at a normal cost and this is one of the vortex methods to create a good distribution of the reinforcement material in the matrix. Hence, for the present work, stir casting technique is used to fabricate Al 7075 alloys with varying weight percentages of TiC (2%, 4%, 6%, 8% and 10%) reinforcement. In order to achieve a good binding between the matrix and particulates, magnesium ribbons were added to increase the wettability of melted AA7075 matrix material. The experimental set up is as shown in Fig. 1.

In stir casting, furnace is mounted on the floor and the temperature of the furnace is precisely measured and controlled to achieve a good quality of composite. Two thermocouples and one PID controller are used for this purpose. Mild steel materials preferred as stirrer rod and impeller since they have high temperature stability. The stirrer is coupled to 1 HP DC Motor through flexible link and is used to stir the molten metal in semi-solid state. To bring the stirrer in contact with the composite material screw operator lift is used. The melt is maintained at the temperature of 800ºC for one hour and it is stirred thoroughly at a constant speed of 300 rpm for a period of 15 min and the vortex is produced by using a mechanical stirrer. TiC of 2,4,6,8 and 10 wt% with particulates size in range of 2 µm. The molten composite (AA7075/TiC) is poured in the materiallic molds which were preheated to $400^0$c and then cooled to room temperature and the castings were separated from the materiallic molds as shown in Figure 2. The same procedure followed to get the AMMCs of different weight percentages-4%, 6%, 8% and 10% [41].

**Heat Treatment ($T_6$)**

The composite gets solidified in a die in the form of a cylindrical bar of diameter 8 mm and length of 30 mm. The solidified composite test sample is removed from the die and machined for required dimensions. The test AA7075 matrix material and AA7075/TiC composites were homogenized at $450^0$c for 2 hours and then aged at $121^0$C for 24 hours to $T_6$ condition. The wear specimens of 30mm length and Ø8mm were retrieved through wire cut EDM process from the thoroughly homogenized ingots of matrix alloy and composites as shown in Fig. 3 [41].

**Figure 1**. Electric furnace

**Figure 2.** Casting specimens

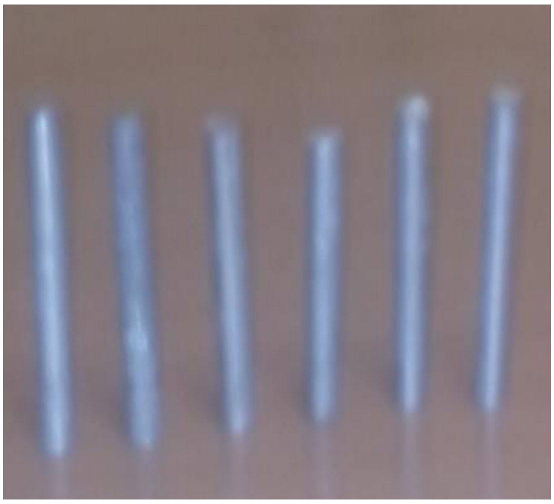

**Figure 3**. Wear specimens

### Testing Procedure

Cylindrical samples (Ø8mm x 30mm), having flat surface in contact region and rounded corner, were used to conduct wear tests under fixed normal load 20 N, at three sliding velocities (1.57 m/s, 2.09 m/s and 2.61 m/s) and at three sliding distances (1 Km, 2Km and 3Km) on pin-on-disc machine (Model TR-19.62LE supplied by M/s Ducom) in dry condition as per ASTM standards. The pin is detached from the holder and disk was cleaned with acetone to remove wear debris after each test run. The post mechanical tests (Microstructure and SEM analysis) were carried out to study the worn out surfaces under different velocities and distances.

### Calculation

The volumetric wear rate $W_v$ of the composite was calculated using relate to density (ρ), mass loss of the specimen after wear test (Δm)and the abrading time (t) by the following Eq.(1):

$$W_v = \Delta m/\rho t \ mm^3/sec \quad (1)$$

### Experimental Design

Design-of-Experiments (DoE) requires attentive planning, careful layout of the experiment, and professional analysis of results. Taguchi has standardized methods for each of these DoE application steps. The experiment specifies three principle wear testing conditions including percentage of TiC Particles, sliding distance and sliding velocity as the process parameters. The experiments were carried out to analyze the influence of volumetric sliding wear, specific wear rate and friction coefficient on the MMCs. Control factors and their levels are shown in Table 2. This Table shows that the experimental plan had three levels.

**Table 2.** Levels of the control parameters used in the experiments technique

| Control parameters | levels | | | units |
|---|---|---|---|---|
| | I | II | III | |
| Reinforcement | 0 | 8 | 10 | Wt.% |
| Sliding distance | 1 | 2 | 3 | Km |
| Sliding velocity | 1.57 | 2.09 | 2.61 | m/s |

Total 27 experiments ($L_{27}$) were conducted and the experimental combinations are determined using minitab15 software. The experimental result of volumetric wear rate is collected for each experiment and the same is analyzed to understand the influence of parameters [42].

### Results and Discussion

### Mechanical Properties

Table 3 shows the mechanical properties of AA7075 matrix material and composites at different wt. % of TiC. Previously, an attempt was made for the investigation on the properties of TiC reinforced AA7075 metal matrix composites [41]. It can be observed that hardness and measured density ($\rho_{MMC}$ = (m) / ((m-m1) X $\rho H_2O$)) show an increasing trend with increasing percentage of TiC particulates. The increase of hardness was observed from 181 VHN for matrix material to 202 VHN at 8 wt% TiC reinforced composite at T6 condition. However, declining of hardness was observed at 10 wt. % TiC composite due to the agglomeration and casting defect. The same trend was observed for tensile strength but significant decrement in percentage of the elongation from 8.341 to 7.14. From these results, it is observed that at wt. % 8 TiC composite shows better mechanical properties than the matrix material and all other composites.

**Table 3**. Mechanical properties of AA7075 matrix and AA7075/TiC composites [41]

| Wt. % of Reinforcement | Hardness, VHN | Density, g/cc | Tensile strength, $N/mm^2$ | % of elongation |
|---|---|---|---|---|
| AA7075 | 181.0 | 2.810 | 471.3 | 8.34 |
| AA7075/2 wt.% TiC | 188.7 | 2.820 | 557.7 | 8.14 |
| AA7075/4 wt.% TiC | 193.0 | 2.830 | 563.9 | 7.86 |
| AA7075/6 wt.% TiC | 196.4 | 2.845 | 571.2 | 7.57 |
| AA7075/8 wt.% TiC | 202.1 | 2.853 | 602.0 | 7.14 |
| AA7075/10 wt.% TiC | 195.1 | 2.862 | 587.9 | 7.37 |

### Effect of Control Parameters on Volumetric Wear Rate

In Taguchi design, S/N ratio is a measure of robustness used to identify the control factors. The design matrix for three control factors, each at three levels, along with the results of the volumetric wear rates and S/N ratio are presented in Table 4. The effect of each control parameter on the volumetric wear rate can be analyzed with the main effects plot and interaction plot. The S/N ratio is calculated for each level of each parameter and then a plot is generated as show in Fig. 4. The level at which the S/N ratio is higher will give the higher signal for the required response, volumetric wear rate in this case. That particular level of each parameter is taken as the optimal parameter for volumetric wear rate, as per Taguchi optimization. It can be seen from the Fig. 4, that (i) as the wt. % of reinforcement increase, the volumetric wear rate decreases up to level 2(8 wt. %) and then increases slightly to level 3, (ii) as the sliding velocity increases, volumetric wear rate decreases and (iii) as the sliding distance increases, volumetric wear rate increases. It can be observed that the sliding velocity and sliding distance have a significant effect on the volumetric wear rate. The main effects plot (Figure 4) indicates that optimal values of the parameters for minimizing the volumetric wear rate occurred when the wt. % of reinforcement at level 2(8 wt. %), sliding velocity at level 3(2.61 m/s) and Sliding distance at level1 (1 Km). The interaction plot for volumetric wear rate is illustrated in Fig. 5. It is well understood that interactions do not occur when the lines on the interaction plots are parallel and strong interactions occur when the lines cross [43]. An observation of Fig. 5 reveals a small interaction between the test parameters.

**Table 4**. Experimental conditions and machining response

| Test number | Wt.% of Reinforcement | Sliding distance, Km | Sliding velocity, m/s | Volumetric wear rate, $mm^3/sec$ | S/N ratio |
|---|---|---|---|---|---|
| | 0 | 1 | 1.57 | 1584.34 | -63.997 |
| | 0 | 1 | 2.09 | 1071.67 | -60.6012 |
| | 0 | 1 | 2.61 | 815.66 | -58.2302 |
| | 0 | 2 | 1.57 | 4986.72 | -73.9563 |
| | 0 | 2 | 2.09 | 3405.69 | -70.6441 |
| | 0 | 2 | 2.61 | 2446.98 | -67.7726 |
| | 0 | 3 | 1.57 | 9520 | -79.5727 |
| | 0 | 3 | 2.09 | 6986.51 | -76.8852 |
| | 0 | 3 | 2.61 | 4486.12 | -73.0374 |
| | 8 | 1 | 1.57 | 1070.03 | -60.5879 |
| | 8 | 1 | 2.09 | 720.43 | -57.1519 |
| | **8** | **1** | **2.61** | **535.58** | **-54.5764** |
| | 8 | 2 | 1.57 | 3572.04 | -71.0583 |
| | 8 | 2 | 2.09 | 2348.05 | -67.4142 |
| | 8 | 2 | 2.61 | 1606.73 | -64.1189 |
| | 8 | 3 | 1.57 | 6764.49 | -76.6047 |
| | 8 | 3 | 2.09 | 4018.23 | -72.0807 |
| | 8 | 3 | 2.61 | 2811.78 | -68.9796 |
| | 10 | 1 | 1.57 | 1111.11 | -60.9151 |
| | 10 | 1 | 2.09 | 801.68 | -58.08 |
| | 10 | 1 | 2.61 | 560.59 | -54.9729 |
| | 10 | 2 | 1.57 | 3649.83 | -71.2455 |
| | 10 | 2 | 2.09 | 2608.18 | -68.3267 |
| | 10 | 2 | 2.61 | 1788.54 | -65.05 |
| | 10 | 3 | 1.57 | 7077.04 | -76.997 |
| | 10 | 3 | 2.09 | 4406.15 | -72.8812 |
| | 10 | 3 | 2.61 | 3163.31 | -70.0028 |

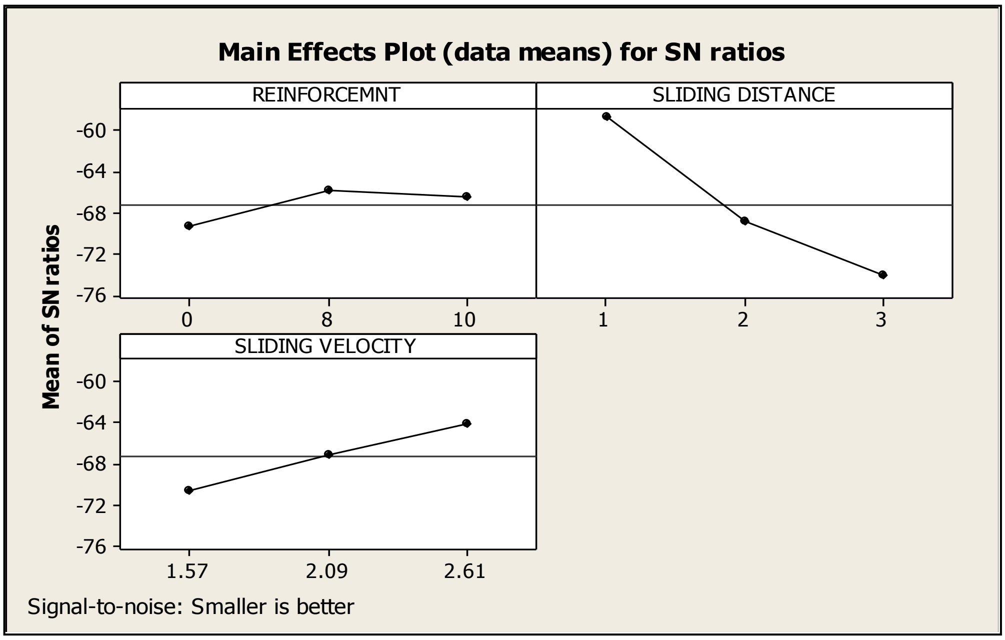


**Figure 4**. Main effects plot for volumetric wear rate of AA7075/TiC composites

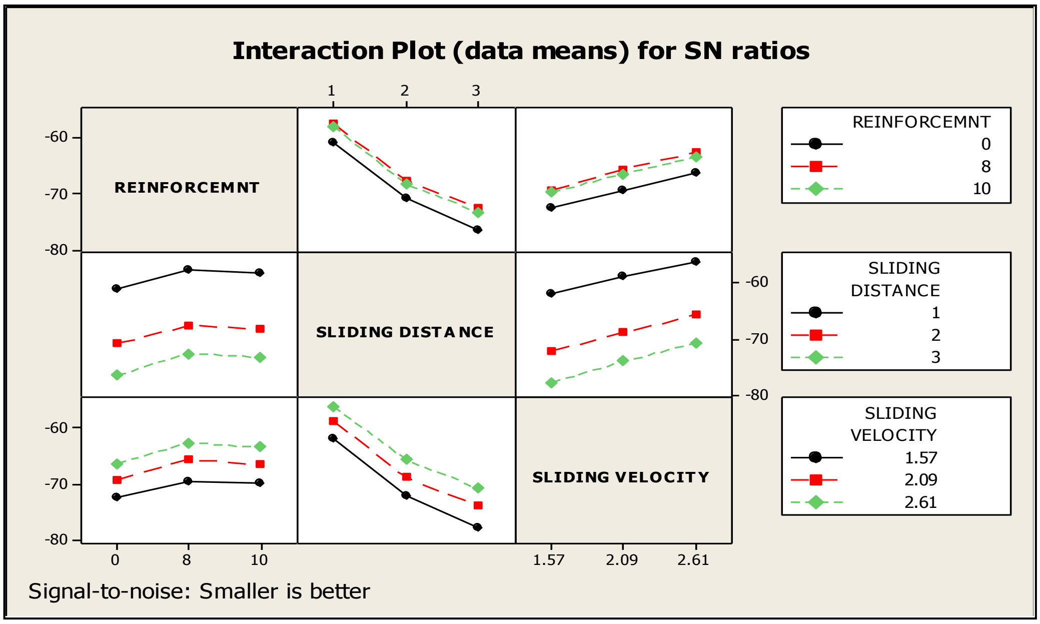


**Figure 5**. Interaction plot for volumetric wear rate ofAA7075/TiC composites

### Statistical Analysis of Variance (ANOVA)

ANOVA is a statistical technique which can infer some important conclusions based on the analysis of the experimental data. This method is rather useful for revealing the level of the significance of the parameters or their interaction on a particular response [44]. The ANOVA results for means of volumetric wear rate are given in Table 5. It can be observed that the percentage contribution on volumetric wear rate was sliding distance (80.99%) followed by sliding velocity (13.97%) and wt. % of reinforcement (4.82%). From the present analysis, it is also observed that sliding distance is the most influencing parameter for volumetric wear rate of AA7075-TiC particulate composites followed by sliding velocity and wt. % of reinforcement, respectively. The interaction between the sliding velocity and sliding distance (0.076) and wt. % of reinforcement and sliding velocity (0.041**)** are the significant interaction model terms. The interaction effect between wt. % of reinforcement and sliding distance (0.033) is only nominal.

**Table 5**. ANOVA table for volumetric wear rate

| Source | DOF | Seq SS | Adj SS | Adj MS | F | % C |
|---|---|---|---|---|---|---|
| reinforcement | 2 | 64.98 | 64.98 | 32.491 | 300.53 | 4.82 |
| Sliding velocity | 2 | 188.37 | 188.37 | 94.186 | 871.18 | 13.97 |
| Sliding distance | 2 | 1091.18 | 1091.18 | 545.590 | 5046.4 | 80.982 |
| Wt.% of reinforcement * Sliding velocity | 4 | 0.56 | 0.56 | 0.140 | 1.29 | 0.041 |
| Wt.% of reinforcement * Sliding distance | 4 | 0.45 | 0.45 | 0.113 | 1.05 | 0.033 |
| Sliding velocity *Sliding distance | 4 | 1.03 | 1.03 | 0.258 | 2.39 | 0.076 |
| Error | 8 | 0.86 | 0.86 | 0.108 | | 0.063 |
| Total | 26 | 1347.44 | | | | 100 |

### Wear Analysis

Based on the results for AA7075 matrix material, 8 and 10 wt. % of TiC composites under constant load (20 N) conditions, various graphs are plotted and presented in Fig. [6-8]. Fig. 6 shows the variation of volumetric wear rate with wt. % of reinforcement for varying sliding distances (1, 2 and 3Km) at sliding velocity 2.09m/s. It indicates an increasing trend of volumetric wear rate with increasing sliding distance. The volumetric wear rate is higher for AA7075 matrix material than composites due to the increase in the hardness in the composites. During the running period, the volumetric wear rate increased very rapidly with the increasing sliding distance. It is obvious from the Figure that the nature of variation in volumetric wear rate for both the AA7075 matrix material and AMMCs with lead dispersion is similar, irrespective of their compositions. The 8 wt. % of TiC composite enchanting the highest tensile strengths showed the highest wear resistance amongst all. This is in agreement with the laws of adhesive wear and Archard's Equation [44]. It is known that as the tensile strengths of the alloys increase, their volumetric wear rate decreases [45]. In view of the above, the AA7075/8 wt. % would be expected to exhibit the lowest volumetric wear rate.

Figure 7 shows the variation in the volumetric wear rate with respect to the wt. % of reinforcement for varying sliding velocities (1.57 , 2.09 and 2.61 m/s) at sliding distance 1 Km. The result clearly indicates that an increase in the wt. % of reinforcement decreases the volumetric wear rate. The maximum volumetric wear rate is also observed for the unreinforced alloy. It is observed that the volumetric wear rate is low at higher value of sliding velocity due to of at higher velocities the contact plateaus and coefficient of friction are low. So at lower velocities, increased volumetric wear rate is observed.

Figure 8 shows the variation of volumetric wear rate for 8 wt. % TiC composite, having different sliding velocities (1.57, 2.09 and 2.61 m/s) with sliding distances (1, 2 and 3Km). The volumetric wear rate increases with increasing sliding distance, and it reaches a maximum value at a maximum sliding distance. It depicts clearly that the composite has a lower volumetric wear rate at higher sliding velocity(2.61 m/s) compared to lower sliding velocity(1.57 m/s).

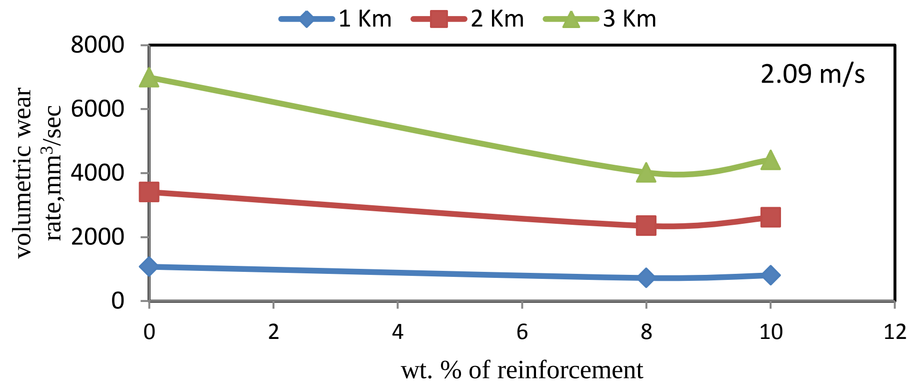


**Figure 6**. Variation of Vol. wear rate with wt. % of reinforcement at sliding velocity 2.09 m/s

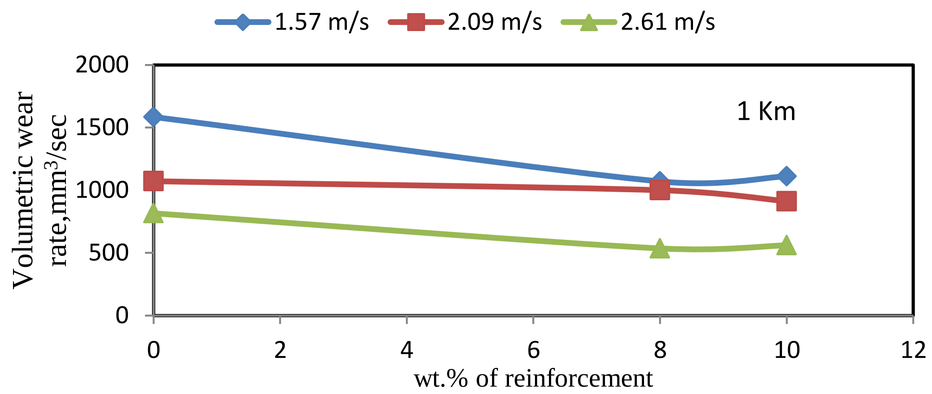


**Figure 7**. Variation of Vol. wear rate with wt. % of reinforcement at the sliding distance 1Km

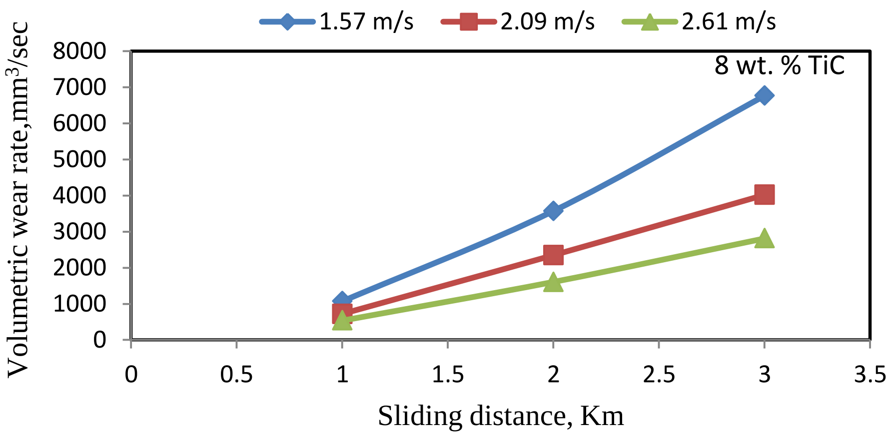


**Figure 8**. Variation of Volumetric wear rate with sliding distance of 8 wt. % of TiC composite

**SEM Analysis**

The examination of the wear surfaces of the AA7075 and AA7075/TiC composites at a presented magnification 50X reveals a well-defined pattern of grooves and scratches running parallel to one another in the sliding direction (indicated by the white arrows) as shown in Fig. 9. It can be seen that the grooves are deeper in the matrix alloy as compared to the composites tested under similar conditions (19.62N, 2.61m/s and 3 Km) due to the absence of hard TiC particles. The examination of wear surface of AA7075 matrix alloy tested at above conditions was characterized by smearing and scratches, a typical characteristic of the sliding wear (Figure 9a) [46]. However, the worn surfaces (Figure 9b-c) reveal that grooves are much shallower in composites than that of the matrix alloy due to the presence of TiC particles. In addition, it, as evident in Figure 9c, exhibits a comparatively smooth worn surface and grooves are much finer and closely spaced in AA7075/8 wt. percentage TiC particles due to the sliding action of a larger number of hard particles and debris. Due to the increase in TiC particle on the surface of matrix, the plastic deformation of matrix can be resisted with the presence of TiC that acts as a barrier to the moment of dislocation, which causes the more wear resistance than matrix alloy [47]. This clearly indicates that with the improving weight percentage of reinforcement, the hardness of the specimen greatly improves resulting in improving the wear resistance of the reinforced component. Figure 9d shows the worn surface of the AA7075/10 wt. % TiC composite with small cavities visible on the surface. However, a further increase in the reinforcement to 10 wt. % leads to the decrease in the wear resistance.

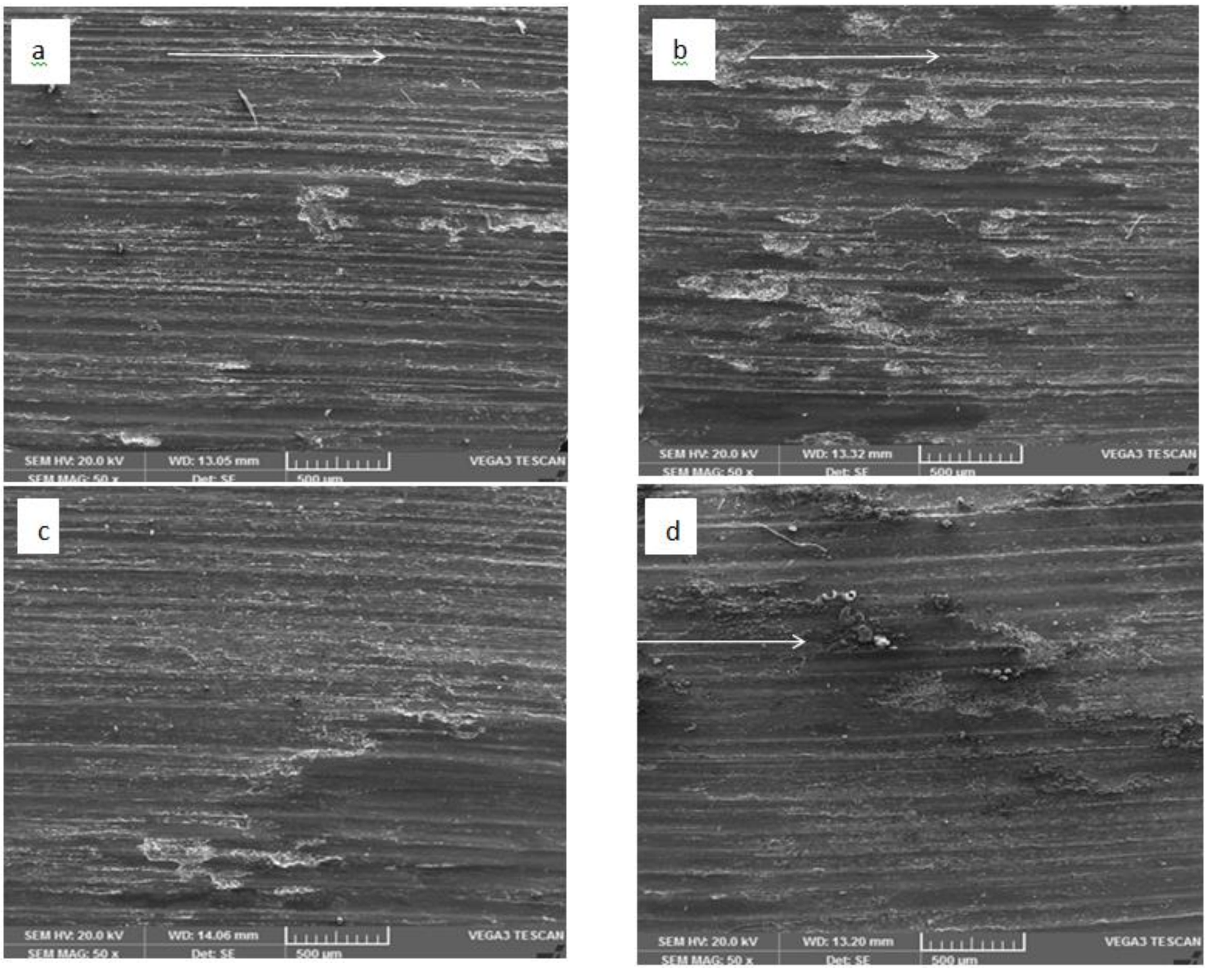


**Figure 9**. SEM micrographs of worn surfaces at sliding velocity 2.61m/s, sliding distance 3km and normal load 19.62N of (a)AA7075 (b)AA7075+2%TiC (c)AA7075+8%TiC (d)AA7075+10%TiC

**Conclusions**

For all heat treatment conditions, AA7075 reinforced with 2μm TiC particle showed better mechanical and tribological properties than those of the AA7075 matrix material and the increased weight percentage of TiC content increased the density, hardness and wear resistance of the composites. The degree of improvement of wear resistance of AMMC is strongly dependent on the kind of reinforcement as well as on its weight fractions. The volumetric wear rate of AA7075 and AA7075 reinforced with TiC composites increased with increasing sliding distance and decreased with increasing of wt. % of reinforcement and sliding velocity. From the ANOVA table it is seen that the parameter sliding distance is the most significant parameter influencing the volumetric wear rate, while the other parameters sliding velocity and wt. % of reinforcement are also significant within the specific test range.

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