Experimental Investigation of Wear Behaviour of Aluminium Metal Matrix Composite Reinforced with Titanium Carbide (TiC) Particulate

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Abstract – *The aim of the paper is to find the wear behaviour of Al LM6 Reinforced with titanium carbide (TiC). The strength to weight ratio of aluminium increases with addition of reinforcement and it makes most suitable material for application were high strengh to weight ratio required. Aluminium based metal matrix composites find varied applications in aerospace, defence, automobile, sports equipment and electronics due to their favorable properties viz. light weight, high strength and low coefficient of thermal expansion with addtion of reinforcement.The sliding wear behavior of aluminum matrix composites LM6–TiC have been investigated under dry sliding wear conditions. The aluminum metal matrix composites (AMMCs) are produced as LM6 matrix metal and TiC particulates of an average size of 44 µm as reinforced particles through stir casting. AMMCs studied are contained 4,6,8,10 wt.% of TiC particles for LM6. The wear tests were carried out at sliding velocity of 3,4,5 m/s, Temperature 75, 100, 125 °C and at Normal load of 20,30,40 N. The wear resistance of the composites increased with increasing weight percentage of TiC particles..*

Key Words: AMMC, TiC, Wear rate, Sliding Velocity, Reinforcement,composite

1. INTRODUCTION

Aluminium based composites are gaining increased applications in the transport, aerospace, marine, oil and gas, automobile & mineral processing industries, due to their excellent strength, wear resistance properties and light weight. However, their widespread adoption for engineering applications has been hindered by the high cost of producing components[4].

Hence much effort is been geared toward the development of composites with reinforcements that are relatively cheap, light weight & can compete favourably in terms of strength and wear characteristics.

Metals are normally alloyed with other elements to improve their mechanical properties and physical properties a wide range of alloy compositions is available in market. Final properties are highly influenced by thermal and mechanical treatments which determine the microstructure[3]

Recently, much interest has been in the automobile and aviation industries and many other industries to increase strength to - weight ratio of components & to improve the wear resistance of components, and enhance fuel efficiency as evidenced by extensive research into aluminium-based composites, due to light weight of aluminium it is most favour to use for the application were weight reduction is necessary [6]. One of such area being considered for potential weight reduction is the brake system because the conventional brake system has much weight and it has to be reducted to reduce the overall weight of the vehicle. Most Vehicles today are built with disc brake which consists of the caliper and a ventilated rotor. The caliper & rotor are typically made from ductile cast iron and grey cast iron respectively. Cast aluminium & aluminium based metal matrix composites (MMC) brake rotors give as much as 45-61% weight reduction in the braking system of the vehicle [7]. However, the major limitation of the use of aluminium alloys is its soft nature and its thermal expansion with high temperature, hence the need for its reinforcement with high strength-stiffness-strength materials such as TiC, SiC, TiB2, B4C, Al2O3, and Si3N4 [8].

Aluminium containing Reinforcement of TiC making it a potential candidate as a reinforcing agent for the production of metal matrix composite for wear applications, the TiC particles are hard and has a high melting point of 3160 °C . Wear is one of the most commonly encountered industrial problems that leads to the replacement of components and assemblies.

During the sliding action, the hard Particles (Reinforcement) are detached from the composite surface constitute a resisting barrier for reducing the wear rate of the composite material and result in long wear life of component which eventually increase the life of components and assemblies. The sliding wear resistance of the composites with respect to that of alloy varies with the process parameters in consideration[9].

The sliding and adhesive wear can be avoided by selection of dissimilar metals pairs for tribological applications. In a comparative study on wear resistance

MMC and Cast iron it is concluded that MMC are better Alternative materials as compared to cast iron for wear application [10]

2. EXPERIMENTAL PROCEDURE

A. MATERIALS

The material selected is Al LM6, the material finds application in aerospace, defense, automobile, sports equipment and in electrical equipments etc. because of its light weight and high strength, the chemical composition of the material is in Table 1

Table 1: Chemical Composition of LM6 [Wt. %]

Compound	Wt%	Compound	Wt%
Si	12.2491	Ti	0.0672
Co	0.0174	Zn	0.0944
Fe	0.4353	Ni	0.0264
Cu	0.0800	Sn	0.0632
Mn	0.1601	Cr	0.0199
Ca	0.0082	V	0.0146
Al	86.7654		

B. Reinforcement:

Fig 1: Titanium carbide (TiC) powder

Fig shows the TiC powder supplied by Cemal Gems and minerals, Bangalore Desity- 4.93 g/cm^3, melting temperature: 3160 °C, Boiling point: 4820 °C

C. Stir Casting

After cleaning Al ingot, it was cut to proper sizes, weighed in requisite quantities and was charged into a vertically aligned pit type bottom poured melting furnace shown in Fig.2, Tic particle were preheated separately to 250°C ± 5°C before pouring in to the melt of Aluminium Alloy. This was done to facilitate removal of any residual moisture as well as to improve wettability. The molten metal was stirred with a BN coated stainless steel rotor at speed of 300-450 rpm. A vortex was created in the melt because of stirring where preheated TiC particle was poured centrally in to the vortex. The rotor was moved down slowly, from top to bottom by maintaining a clearance of 12mm from the bottom. The rotor was then pushed back slowly to its initial position. The pouring temperature of the liquid was kept around 700°C. Casting was made in cylindrical metal mould of 16 mm diameter and 100 mm height. To compare the desired characteristics, the AMCs were fabricated by repeating the same procedure with 0% (base material) 4%, 6%, 8%, and 10% Tic.

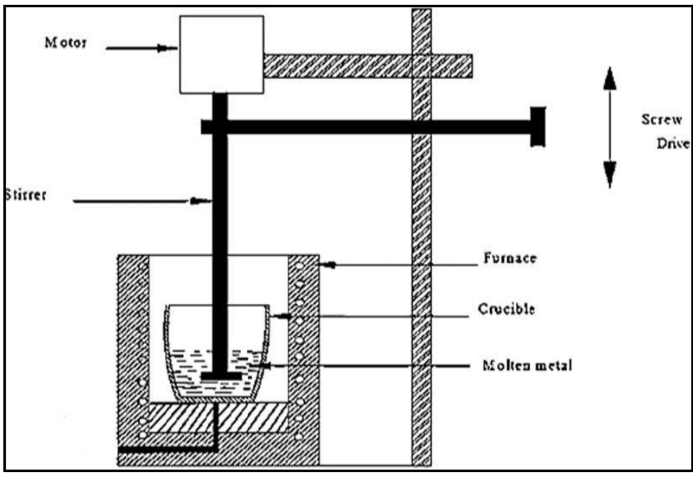

Fig 2-: Stir casting experimental setup

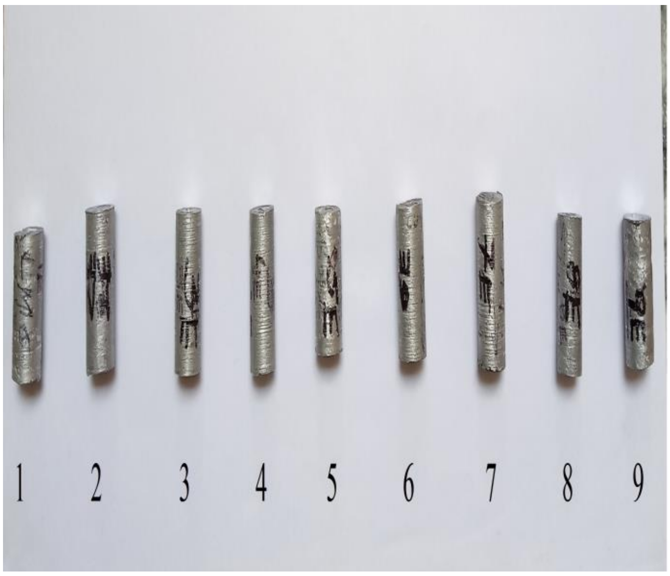

Fig: 3 Al LM6 pin

D. Scanning Electron Microscopy (SEM)

Scanning Electron microscopy images were taken at Central Facility Center, Dr. Babasaheb Ambedekar Marathwada University, Aurangabad. The Make of Scanning Electron Microscope was JEOL JSM-6510A as shown in figure

Fig 4: Scanning Electron Microscope Setup

In the following figures shows the SEM image of Al LM6 is show with titanium carbide (TiC) particle distribution for 6% Tic, 8% Tic, and 10% Tic

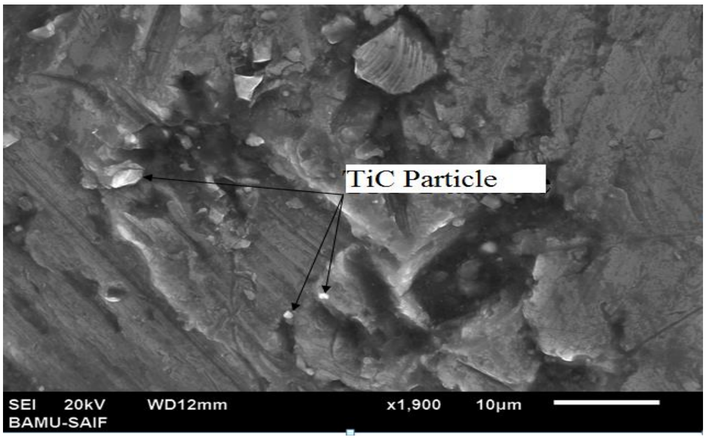

Fig 5: SEM images of LM6 6% Tic

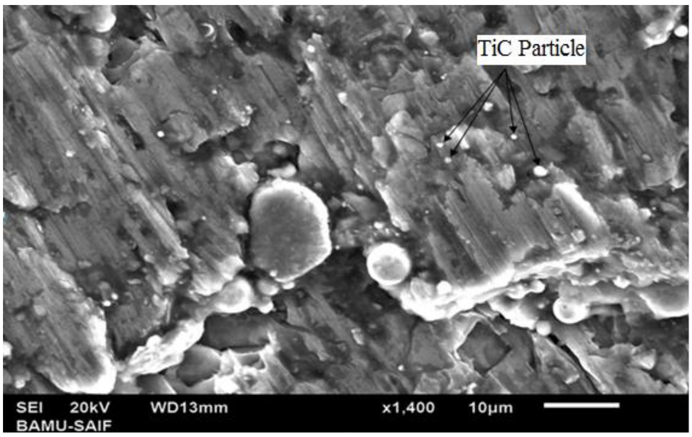

Fig 6: SEM images of LM6 8% Tic

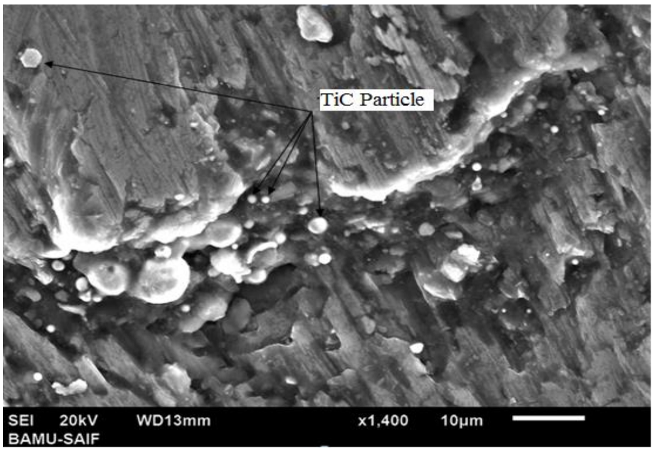

Fig 7: SEM images of LM6 10% Tic

E. Wear Test

Wear test is carried out to find the wear rate of Aluminium metal matrix LM6. The wear test is performed on a pin on disc machine make of DUCOM. The cylindrical pin is prepared of 12 mm and height 30 mm. the surface of the material is polished and surface roughness is about 0.1µm. All samples and disc are clean with help of sand paper. Selected parameters are Normal load 20 N,30 N,40 N, sliding velocity 3,4,5 m/s ,percent reinforcement 0% (base material) 4%, 6%, 8%, 10%. Temperature 75 (ºc), 100(ºc), 125(ºc).

From the Pre-experimentation it was found out that the wear rate of reinforcement 0% (base material) and 4% is more as compared to the other percentage of reinforcement therefore for experimentation 6%, 8%, 10% reinforcement (TiC) is selected and SEM images of 6,8,10% Wt% of TiC shown. The levels of experiment are selected by OVAT analysis.

Wear rate calculations:

Wear rate in mm^3/N-m
ρ: Density of LM6 in gm/cc
L: Sliding distance in the meter.
F: Load in Newton.

Wear rate = (Δm*(10^3))/ρLF

Fig 8 : Pin on Disc set-up

3. Taguchi Experimental Design

The design of experiments (DOE) approach using Taguchi technique has been successfully used for wear behavious by researchers for study of MMCs. A major step in the DOE process is the selection of control factors and levels which will provide the desired information. Taguchi creates a standard orthogonal array to accommodate the effect of several parameters on the output parameter and defines the plan of experiment. Four process parameters at three levels led to the total of 9 dry sliding wear tests. The experimental results are analyzed using analysis of variance (ANOVA) to study the influence of parameters on wear rate. A linear regression model is developed to predict the wear rate of the composites. The major aim of the present investigation is to analyze the influence of parameters like % Reinforcement, Load, Sliding velocity and temperature of the pin on dry sliding wear rate of aluminium LM6, Titanium Carbide (TiC) used as reinforcment. Taguchi technique is used to find the optimum levels using MINITAB software.

For 4 Parameters and 3 levels the design in the MINITAB becomes saturated when total degreed of freedom for an array becomes equal to the sum of the degrees of freedom of each parameter. Total degrees of freedom are given by

fLN = N-1. Degrees of freedom for residual error can be calculated as follows

DF= (fLN) – (Sum of DF of all the terms included in the model)

In the present investigation standard L9 orthogonal array with 3 levels of four parameters is used. The parameters selected in this study are reinforcement, load, sliding Velocity, temperature i.e. four process parameters. Total degrees of fLN= N-1= 9-1=8

DF for residual error = 8-(2+2+2+2) = 0. The adjusted mean square in ANOVA is calculated by dividing the sum of squares by degrees of freedom. The degrees of freedom of residual error is zero therefore it is not possible to calculate mean square for error i.e. (MSE). ANOVA uses fisher test to analyze the variance present in the experiment Hence MINITAB fails to calculate F test and ultimately the p value column in the ANOVA. To overcome this situation of saturated design repeat response measurement method is used.

Table 2: Parameters and levels

Sr no	Parameter	Level 1	Level 2	Level 3
1	Reinforcement (%)	6	8	10
2	Load (N)	20	30	40
3	Sliding Velocity (m/s)	3	4	5
4	Temperature (ºC)	75	100	125

Table 3: Experimental Run & Result

Run	%Tic	Load(N)	Sliding velocity (m/s)	Temp (ºC)	Specific Wear rate×10^{-3} (mm^3/N-m)	S/N Ratio
1	6	20	3	75	0.07552	20.7224
2	6	30	4	100	0.09202	16.7607
3	6	40	5	125	0.14520	22.2342
4	8	20	4	125	0.07732	21.3912
5	8	30	5	75	0.08520	20.7992
6	8	40	3	100	0.09121	22.2095
7	10	20	5	100	0.07754	21.6028
8	10	30	3	125	0.08315	20.9036
9	10	40	4	75	0.09012	20.7224

4. Experimental Results

Statistical analysis has to be performed in order to find out the effect of Reinforcement (TiC), Load, sliding velocity, and pin temperature on wear rate of aluminum composite of LM6. Statistical analysis was performed using MINITAB 17 software. The analyzed results are presented using ANOVA analysis and main effects plot.

Table 2 and Table 3 shows the orthogonal array and results obtained during the experimentation. Figure 9 show the wear rate ratio main effect plot for the output performance characteristics. From Figure 9 it was understood that the optimal parameter combination for wear rate was as shown in table number 4

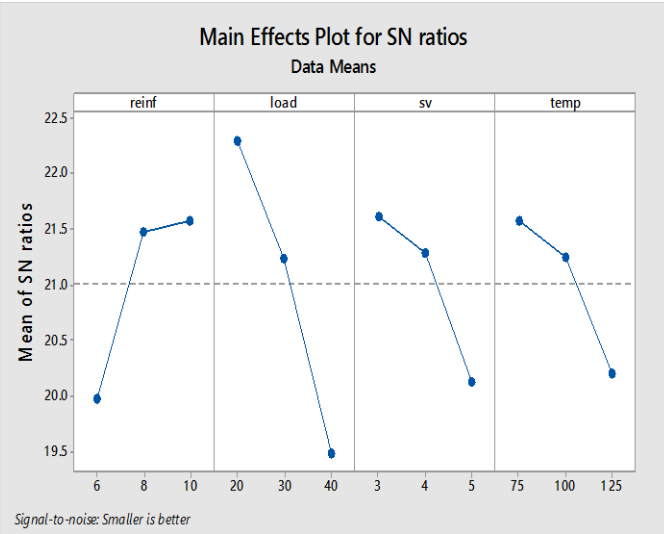

Fig. 9: Effect of various parameters on S/N ratios For wear rate (LM6)

- Reinforcement: with increase in reinforcement the wear resistance of the pin is increasing upto 10% TiC. The wear resistance increase because During the sliding action, the hard TiC particles detached from the composite surface constitute a resistance barrier in reducing the wear rate of the composite material [19,9,22]
- Load : with increasing of load from 20N to 40N wear rate increases because with increase in load coefficient of friction increased , further the size of wear debris increased with increasing the load resulting in large wear rate at higher load [17]
- Sliding velocity: the wear rate increase as the sliding velocity increases from 3m/s to 5m/s as the SV increased the disc speed increases , the material removal ability of disc material will increase and it will eventually remove the material from pin surface & there is quick plastic deformation of material [17]
- Temperature: the wear rate increases with increase in temp from 75 ºC to 125 ºC because increase in temperature increases the intermolecular distances between the adjacent molecules, & With increase of temperature the wear rate increases because of the thermal softening of matrix let to more wear [20]

Table 4: Optimum level of parameters for LM6 with Titanium Carbide (Tic) reinforcement.

Sr. No.	Parameter	Optimum level
1	%Tic	10 %
2	Load	20 N
3	Sliding Velocity	3 m/sec
4	Temperature	75◦C

5. ANOVA For Wear Rate

ANOVA was used to determine the design parameters significantly influencing the wear rate. Table 8 shows the results of ANOVA for wear rate. This analysis was evaluated for a confidence level of 95% that is for significance level 0.05. The last column of the table number 5 shows the percentage of contribution of each parameter on the wear rate, indicating the degree of influence on the result. It can be observed from the results obtained that Load was the most significant parameter having the highest statistical influence (46.91%) on the sliding wear rate of composites followed by Reinforcement (21.58%),Sliding velocity (15.76%) and Temperature (10.81%) .When the P-value for this model is less than 0.05, then the parameter can be considered as statistically significant. From an analysis of the results obtained in Table 5, it is observed that the effect of load & percentage of Reinforcement (TiC) is influencing wear rate of composites

Table 5: ANOVA result of TiC Composite for Wear

Source	DF	Adj SS	MS	F Value	P Value	%
Reinforcement	2	7.638	3.8191	19.41	0.001	21.51
Load	2	16.652	8.3261	42.32	0.000	46.91
Sliding Velocity	2	5.594	2.7970	14.22	0.002	15.76
Temperature	2	3.839	1.9197	9.79	0.006	10.81
Error	9	1.771	0.1967			4.98
Total	17	35.494				100

DF: degree of freedom, SS: sum of squares, V: variance, F: test, P: Contribution

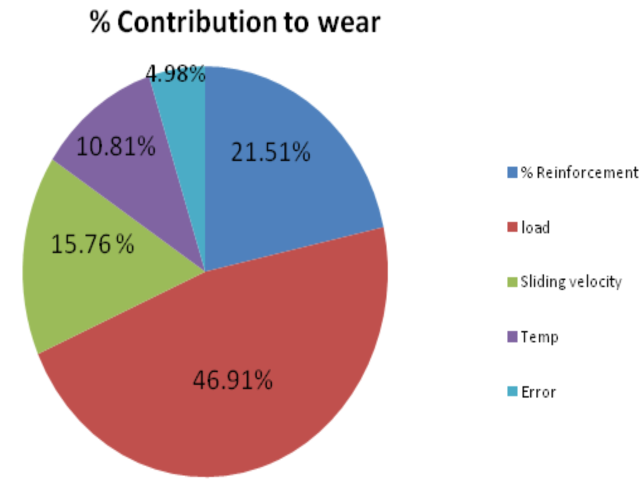

Fig 10: Percentage contribution of factors to wear

A. Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.443536	95.01%	90.58%	80.05%

B. Regression Equation

Specific wear rate = 0.0088 - 0.00516 reinf + 0.001602 Load + 0.00968 sv + 0.000366 temp

.Analysis of variance (ANOVA) is carried out using MINITAB 17 software to investigate difference in average performance of the factors under test. ANOVA breaks total variation into accountable sources and helps to determine most significant factors in the experiment.

6. CONFIRMATION EXPERIMENT

Table 6: Predicted vs Experiemntal value

Parameter	Model value	Experimental value	Error %
Wear rate	0.04573	0.04742	3.69%

7. CONCLUSION

Titanium Carbide (Tic) aluminium based metal matrix composite has been reported in this paper.

1. Al LM6 reinforced with TiC particles improves dry sliding wear resistance
2. The wear resistance of the composite increases with addition of TiC particles (by weight %) , it increases upto 10% TiC.
3. It is observed that applied load is found to be most significant parameter with 46.91% contribution to wear rate. Reinforcement was found next significant parameter with 21.51% contribution to wear rate, sliding velocity 15.76%, temperature 10.81%

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