Experimental Investigation of Wear Properties of Aluminium LM6 Al_2O_3 Flyash Metal Matrix Composite

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Abstract— In the present study aluminium alloy LM6 metal matrix composites (MMCs) containing 4% & 8% Al_2O_3 and 5% fly ash particles have been fabricated by stir casting method. The tests were carried out using a pin-on-disk friction and wear tester by sliding these pin specimens at a constant speed of 1.1 m/s (300 r/min) against a steel counter disk at room temperature 100 °C, 125 °C and 150 °C, respectively at a load of 5,10 and 15. The design of experiments (DOE) approach using Taguchi technique has been used in the study of wear behavior of MMCs. It was found that the composites exhibit better wear resistance compared to unreinforced alloy up to a load of 15 N. Al2O3 and fly ash particle size and its volume fraction significantly affect the wear and friction properties of composites. With the increase of the reinforcement volume fraction of Al_2O_3, the wear resistance of the composites increases.

Key words: Aluminium, Metal Matrix, Wear Properties

I. INTRODUCTION

Recently, aluminum metal matrix composites (Al-MMCs) are widely used in the field of tribology, which have superior properties compared with the monolithic materials due to hard reinforcements. Many kinds of reinforcements, such as SiC, TiB2, Al_2O_3, SiCrFe and CrFeC, have been used to manufacture Al-MMCs. These composites can be used in high-speed rotating and reciprocating elements, such as pistons, connecting rods, drive shafts, brake rotors, and cylinder bores. Various aspects of the wear behavior of MMCs have been investigated, and detailed effects of the reinforcement type, reinforcement volume fraction, hybrid ratio, and different matrices on wear have been examined. The resistance increased with an increase in the Al_2O_3 particle content and size and decreased with an increase in the sliding distance, the wear load and the abrasive grit size. Also, they found that the effect of Al_2O_3 particle size on the wear resistance was more significant than that of the particle content[1]

In many engineering applications the use of aluminium alloy is inevitable because of its superior mechanical, thermal property and it also possesse slow wear resistance property. To increase the wear resistance of the aluminium, and its alloy, it is reinforced with different reinforcements. Reinforcements are usually fibers or particles of different orientation and shape as shown in figure number 1. The arrangement of the particles can be random, in most cases (Figure 1a), or preferred, in the shape of sphere, cube or any close to- regular geometrical form. A fibrous reinforcements are characterized by its length and diameter so we distinguish, long (continuous) fibers (Figures 1d and 1e) and short (discontinuous) fibers-

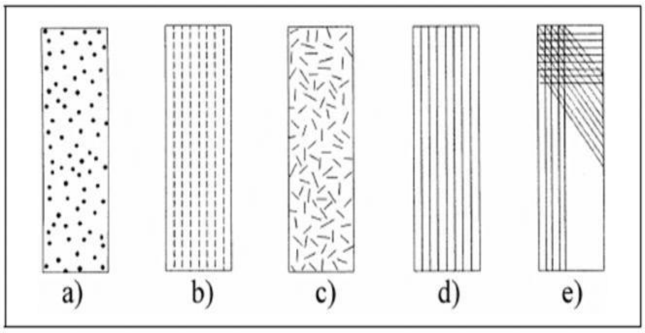

Fig. 1: Shape and Arrangement of Reinforcements in Composite Material [2]

whiskers (Figures 1b and 1c). Arrangement can be, as well, preferred (Figure 1b) and random (Figure 1c), and often the direction of fibers is changed from one layer to another. Among the different reinforcement particulates reinforcement is gaining more attention because of its excellent isotropic property during the fabrication of composite [2].

II. LITERATURE SURVEY

Many researcher have been using Taguchi method to identify the effect of parameters on dry sliding wear behavior of composite. There has been experimental investigation using Taguchi and ANOVA to identify the significant factors, WANG Yi-qi et al. [1] Al_2O_3 fiber and SiC particle hybrid metal matrix composite fabricated by squeeze casting. When the temperature increases, the SiC does not enhance the wear resistance. A. Baradeswaran, et al.[3] while studying on wear on Al_2O_3 composite with varying %reinforcement, load, sliding distance. The wear resistance of the composites increased with addition of the Al_2O_3 particle content. The wear rate at 6 wt. % Al_2O_3 is only 1/10th of the wear rate for the pure matrix material. T. Hariprasad, et al.[4] conducted the experiment to investigate the effect of B_4C and Al_2O_3 reinforcement upto 12% on different load, sliding distance. For Al_2O_3- B_4C 10% presence acts an excellent wear resistance. Bharath V. et al.[5] studied the addition level of Al_2O_3 reinforcement is being varied from 6 -12wt% in steps of 3wt%. with Al6061 for each composite, minimum weight loss was observed for (6061Al alloy +12% Al_2O_3). increase in hardness of the alloy matrix can be seen with addition of Al_2O_3 particles. Xiao-song JIANG et al. [6] studied the Al−5%Si−Al_2O_3 metal matrix composites for varying load, sliding distance. Results shown that with load increasing, wear loss and coefficient of friction increased. Pardeep Sharma et al. [7] carried parametric study of Al6082 alloy composites with varying % of Al_2O_3 from 0-12. Result showed that sliding distance is the most influential factor and percentage reinforcement is the factor which affects the wear least. Bharat admile [8] studied the dry sliding wear behavior of LM25 aluminium alloy containing Fly ash reinforcement using pin on disc machine with different input parameters viz, Load, Sliding velocity, sliding distance and weight percentage of reinforcement on wear rate of the composite. Results of the experiment revealed that load and sliding velocity are most influencing factors. Ravi MISHRA et al. [9] conducted experimental investigation of flyash reinforced aluminium alloy Al6061 composite, % Wt varying from 10,15and 20% with varying load, sliding distance. It is found that load and sliding velocity are most influential factor on wear, that are reduce by increase in % reinforcement. Ajit Kumar Senapati et al. [10] waste flyash is(two different kind) use in fabrication of aluminium alloy matrix composite, Results revealed that there is great effect of reinforcing different flyash in AMC. Sudarshan et al. [11] aluminium alloy (A356) composites containing 6 and 12 vol. % of fly ash particles have been fabricated, with different load. Composites exhibit better wear resistance compared to unreinforced alloy up to a load of 80 N. A few attempts have been made to fabricate MMC with Al_2O_3 to increase the wear resistance characteristics using low cost reinforcement like bauxite, corumdem, granite, sillimanite. The ever increasing demand for low cost reinforcement stimulate the interest towords the utilization of flyash with Al_2O_3 which is industrial waste. Al_2O_3 called a refractory ceramic oxide which is wear and corrosion resistant, used in metal cutting tools.

III. EXPERIMENTAL PROCEDURE

A. *Materials Used*

Eutectic Al–Si alloy LM6 containing 12.2491% Si was used as a matrix. The chemical compositions of the alloy are given in Table 1 Al_2O_3 and fly ash particle were used as a reinforcement material in this investigation. The chemical compositions of fly ash particle are given in Table 2.

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		

Table 1: Chemical Composition of Al-Si Alloy [Wt. %] Designated as Base Alloy

Compound	Wt%	Compound	Wt%
MgO	1.72	CaO	2.82
Al2O3	29.65	TiO_2	2.54
SiO_2	51.4	FeO	5.39
K_2O	1.57	CuO	4.56

Table 2: Chemical Composition of flyash

B. *Stir Casting*

After cleaning Al-Si 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.3. 4% Al_2O_3 +5% fly ash particle were preheated separately to $650^{o}C \pm 5^{o}C$ before pouring in to the melt of Aluminium-Silicon 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 Al_2O_3 and fly ash 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 $700^{0}C$. Casting was made in cylindrical metal mould of 16 mm diameter and 100 mm height. To compare the desired characteristics, two AMCs were fabricated by repeating the same procedure with 8% Al_2O_3 and 5% flyash.

Fig. 2: Stir casting set-up

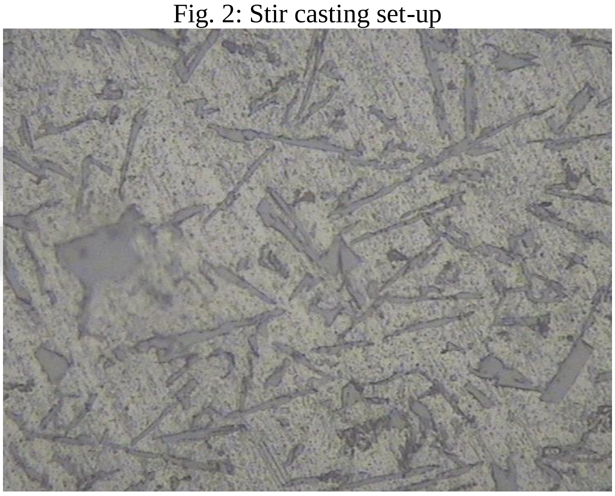

Fig. 3: Microstructure of 4% Al_2O_3 +5% fly ash at Magnification X500

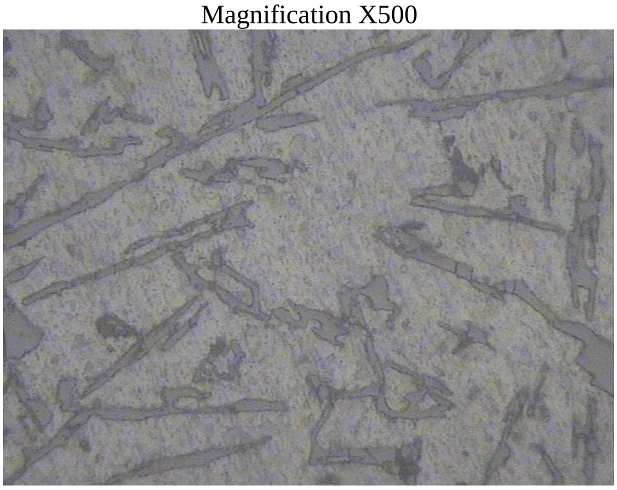

Fig. 4: Microstructure of 4% Al_2O_3 +5% fly ash at Magnification X1000

Compound	Wt%	Compound	Wt%

Cu	0.012	Zn	0.001
Mn	0.0005	Mg	0.0006
Si	11.51	Pb	0.012
Fe	0.19	Sn	0.010

Table 3: Chemical composition of LM6+4%Al_2O_3+5%Flyash

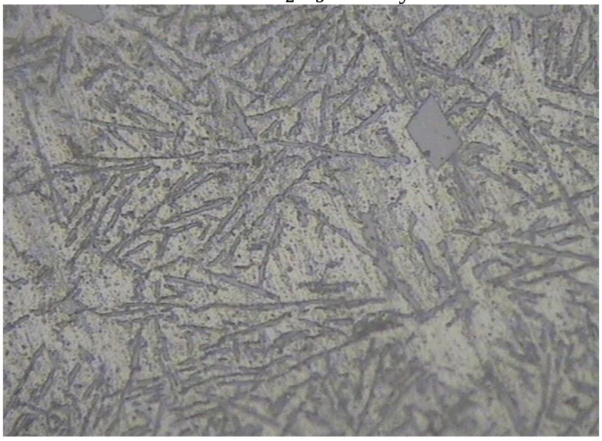

Fig. 5: Microstructure of 8% Al_2O_3 +5% fly ash at Magnification X500

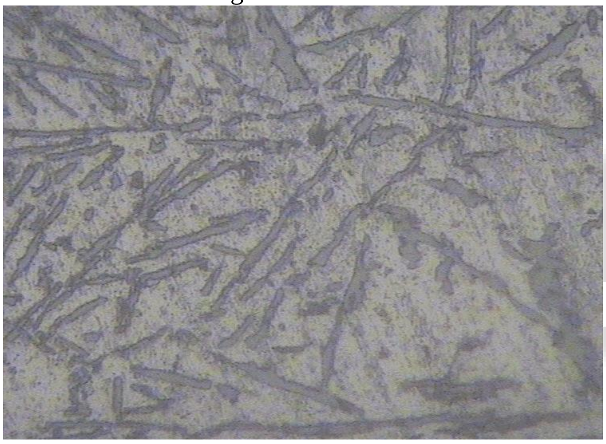

Fig. 6: Microstructure of 8% Al_2O_3 +5% fly ash at Magnification X1000

Compound	Wt%	Compound	Wt%
Cu	0.015	Zn	0.001
Mn	0.0005	Mg	0.0001
Si	11.09	Pb	0.012
Fe	0.21	Sn	0.006

Table 4: Chemical composition of LM6+8%Al_2O_3+5%Flyash

C. *Wear Test*

A single pin type pin-on-disc test apparatus was used to carry out dry sliding wear characteristics of the composite as per ASTM G99-95 standards. The tests are carried out at the elevated temperature under dry operating conditions. Wear specimen (pin) of size 12 mm diameter and 25 mm length was cut from as cast samples machined and then polished metallographically. A single pan electronic weighing machine with least count of 0.0001g was used to measure the initial weight of the specimen. The cylindrical pin flat ended specimens of size 12 mm diameter and 25 mm length were tested against EN31 steel disc by applying the load. After running through a fixed sliding distance, the specimens were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gave the sliding wear of the composite specimen and then the wear rate was calculated. The sliding wear rate of the composite was studied as a function of the load, rpm, sliding distance and temperature of the pin. The dry sliding wear tests were carried out at controlled parameter levels. Parameters and levels of parameter are as shown in the table number 5

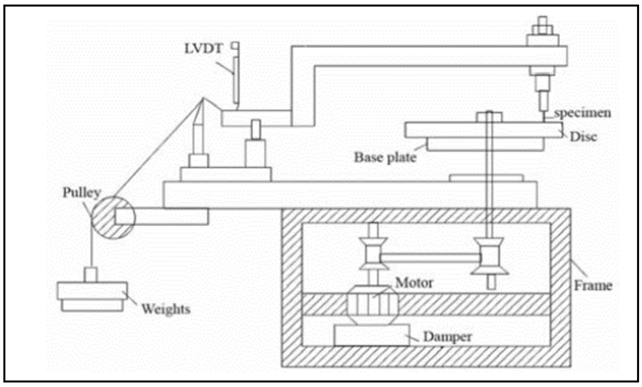

Fig. 7: Schematic Diagram of Pin on Disc Test Rig.

Wear rate of the composites was calculated from equation 1. the ratio of mass loss to sliding distance.

$$Wr = \frac{\Delta m}{L} \qquad (1)$$

Where, Wr = Wear Rate

Δm = m1-m2

L= Sliding Distance

Sr. No.	Parameter	Level1	Level2	Level3
1	Reinforcement	0	4	8
2	Load(N)	5	10	15
3	Sliding Distance (m)	1000	1250	1500
4	Temperature	100	125	150

Table 5: Dry sliding wear test parameter and levels

D. *Taguchi Experimental Design*

The design of experiments (DOE) approach using Taguchi technique has been successfully used by researchers in the study of wear behavior 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 load, RPM, Sliding distance and temperature of the pin on dry sliding wear rate of aluminium LM6, Al_2O_3 and flyash metal matrix composites using Taguchi technique.

Sr. No.	Load N	Sliding Distance m	Temperature °c	%Reinforcement	Wear rate$\times 10^{-7}$ N/m
1	5	1000	100	0	0.3413

					90
2	5	1250	125	4	0.350040
3	5	1500	150	8	0.369320
4	10	1000	125	8	0.317192
5	10	1250	150	0	0.331594
6	10	1500	100	4	0.349320
7	15	1000	150	4	0.361841
8	15	1250	100	8	0.352431
9	15	1500	125	0	0.372431

Table 6: Experimental Runs and Result

IV. EXPERIMENTAL RESULTS

Regression analysis is performed in order to find out the effect of load, rpm, sliding distance and pin temperature on wear rate of aluminum red mud composite. Statistical analysis was performed using MINITAB 16 software. The analyzed results are presented using ANOVA analysis and mean effects plots.

Table 6 shows the orthogonal array and results obtained during the experimentation. Figure 3show the wear rate ratio main effect plot for the output performance characteristics. From Figure 5 it was understood that the optimal parameter combination for wear rate was as shown in table number 7.

A. *Analysis of Wear Rate*

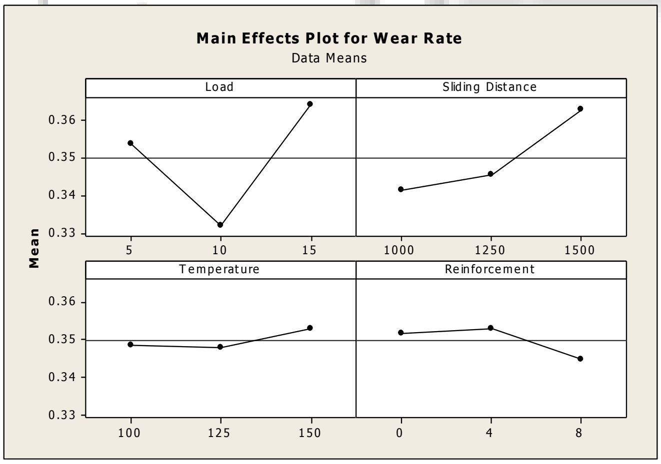

Fig. 8: Main Effect Plot Wear Rate

Sr. No.	Parameter	Optimum level
1	Load	10
2	Sliding Distance	1000
3	Temperature	125
4	Reinforcement	8

Table 7: Optimum Level of Parameters

V. 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 8 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 (63.22%) on the dry sliding wear rate of composites followed by sliding distance (15.27%) .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 8, it is observed that the effect of load & sliding distance is influencing wear rate of composites.

Source	DF	SS	MS	F Value	P Value	%
Load	2	0.0032337	0.0016169	102.56	0.000	61.54
Sliding Distance	2	0.0015335	0.0007668	48.64	0.000	29.18
Temperature	2	0.0000989	0.0000495	3.14	0.092	1.8
Reinforcement	2	0.0002463	0.0002463	7.81	0.011	4.68
Eror	9	0.0001419	0.0001419			
Total	17					

Table 8: ANOVA for Wear Rate

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

A. *Model summary*

S	R-Sq	R-Sq(adj)	R-Sq(Pre)
0.00397055	97.30	94.90	96.12

Table 9:

B. *Regression Equation*

Wear Rate= 0.277 + 0.00106 Load + 0.000043 Sliding distance + 0.000093Temperature -0.00088 Reinforcement Analysis of variance (ANOVA) is carried out using MINITAB 16 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. The obtained R square value is 97.30%.

VI. CONFIRMATION EXPERIMENT

A. *Predicted Optimum Condition*

The predicted values of analysis of varience at the optimum levels are calculated by using the relation:

$$\breve{n} = nm + \sum_{i=1}^{o} (nim - nm) \qquad (2)$$

Where, $\breve{n}$ = Predicted value after optimization

nm = Total mean value of quality characteristic

nim = Mean value of quality characteristic at optimum level of each parameter

o =Number of main wear parameters thet effect the wear rate. The purpose of this confirmation experiment is to verify the improvement in the quality characteristics.

Parameter	Model value	Experimental value	Error
Wear rate	0.32999	0.317192	3.878%

Table 10:

VII. CONCLUSION

The use of the Taguchi method and analysis of response variables to optimize the dry sliding wear parameters of the Al_2O_3 flyash aluminium based metal matrix composite has been reported in this paper.

1) Aluminium LM 6 matrix reinforced with 4% Al_2O_3 + 5% flyash and 8% Al_2O_3 + 5% flyash was successfully prepared by stir casting process and the behavior of the composite was investigated using pin-on-disc machine.
2) It is observed that applied load is found to be most significant parameter with 61.54% contribution to wear rate. Sliding Distance was found next significant parameter with 29.18% contribution to wear rate.
3) In investigation of Al_2O_3 flyash aluminium based metal matrix composite it is found as increase in reinforcement of Al_2O_3 flyash the wear resistance also increase.

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