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Experimental Investigation of Wear Properties of Aluminium LM6-Al_2O_3-SiC Metal Matrix Composite

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ABSTRACT

Tribological properties are the primary factors which control the performance of components which are subjected to relative motion during the operation. In recent years, lightweight Metal Matrix Composites (MMC) have received wider acceptance as a material for components subjected to tribological applications. In the present study, an attempt has been made to observe the effect of operating parameters like applied load, reinforcement, temperature and sliding distances on the dry and wet sliding wear of LM6 aluminum alloy reinforced with different percentages of SiC particulates and constant percentage of aluminum oxide fabricated stir casting method. Experiments were designed based on Taguchi method. Microstructural studies were carried out using an optical microscope. The composites showed better wear resistance under the parameters tested, compared to the unreinforced alloy. ANOVA analysis is also carried out to find out most influencing input parameter among them all for dry sliding wear. From the experiment, it is predicted that sliding distance followed by reinforcement percentage is a most influencing factor in dry sliding wear. The sliding distance which contributes near about 52.60%, is the most influencing factor and the addition of SiC particulates helps in the reduction of wear rate.

Keywords: Metal Matrix Composites, Wear, Taguchi Technique, ANOVA, Dry sliding.

I. INTRODUCTION

Material's tribological characterization is important for modern applications of engineering. Wear is one of the significant design parameters for common tribological components which are used in the industrial applications, include rolling and sliding contact bearings, gears, seals, tappets and cams, electrical brushes, piston rings, and forming and cutting tools. Abrasive and Adhesive wear is most common failure modes in components operating under the moderate contact stresses. Composite materials are widely used traditional engineering materials due to their advantages on to monolithic materials. The metal matrix composite's (MMC's) development has been major innovations in materials science field in the recent years [1]. A metal matrix composite (MMC) is fabricated using a ductile metal such as Al, Ti or Nickel as the base material, which is normally reinforced by the ceramic material such as graphite, alumina or Silicon Carbide (SiC). Composites which are having higher toughness, stiffness, specific strength and good wear resistance can be achieved by combining the metallic properties such as toughness and good ductility of the matrix with properties such as hardness, high strength and elastic modulus of a reinforcement of ceramic. Thus, because of increased applications of the composite materials in the tribological components their characterization having a major significance. Composite's wear resistance has got much more attention in recent years. Research works libidinous the dry sliding wear behavior of such materials have examined a influence of variables such as the sliding velocity, contact pressure, temperature, reinforcement corpuscle volume fraction, and corpuscle size. A number of mechanisms have been proposed for explaining the sliding wear behavior of these types of composites [2]. Dry sliding wear study of Al LM6 reinforced with SiC particulates showed better resistance to sliding wear as compared with the unreinforced alloy [3]. The wear resistance was found to increase with the increase in volume percentage of the reinforcement. The wear rate was found to decrease initially, with the sliding speed before showing an increasing trend.

Aluminum matrix composites have been appeared as advanced materials for several major applications in automobile, aerospace, defense and other engineering sectors [8] due to their stiffness and high specific strength, superior wear and seizure resistance as compared to the alloy irrespective of sliding speed and applied load. Forsooth, these promising new materials have found a splay range of applications in automobile industries in last few years. Out of different automobile components, aluminum matrix composites have been found to be a much more promising material, in brake cylinder blocks, drums, connecting rods, cylinder liners, gears, pistons, drive shafts, valves, suspension components, etc. Attempts have been made to find out the effect of sliding velocity on the wear behavior of the aluminum alloy and composites.
From the available literature, we can conclude that the composite's wear behavior is influenced by operating parameters such as speed, load, temperature and sliding distance as well as the material parameters like percentage composition and particulate size of the reinforcement. The task of studying the parametric identifying and influence the optimized values to become difficult by using the conventional testing methods. Taguchi's design method proffers a methodical method for optimization of parameters with esteem to performance, cost, and quality. Taguchi's design method resort statistically designed orthogonal arrays to combine the various parameters and their individual levels in conducting the experiment. Taguchi's method uses a quadratic loss function to estimate the response characteristic. A unique ensign of this Taguchi system is the transformation of the experimental data into the special forms called as S/N ratios. The S/N ratio is nothing but the concurrent statistic. A concurrent statistic is able to look at the two characteristics of a distribution and coil these characteristics into a single figure of merit. If the experimental investigation involves more number of parameters and range of the individual parameters is also large, the study becomes exhaustive. Under this situation, Taguchi's Design method of investigation minimizes the number of experiments while providing the reliable inference about the influence of parameters using statistical techniques such as Analysis of Variance (ANOVA).
The organization of this document is as follows. In Section 2 (**Methods and Material**), I'll give detail of any modifications to equipment or equipment constructed specifically for the study and, if pertinent, provide illustrations of the modifications. In Section 3 (**Result and Discussion**), present your research findings and your analysis of those findings. Discussed in Section 4(**Conclusion**) a conclusion is the last part of something, its end or result.

II. LITERATURE SURVEY

Aluminum alloys have more importance as structural materials. For many applications, it is essential to ameliorate wear resistance. In the automotive applications use of aluminum alloys have been avoided Due to their low rigidity, strength and wear resistance, paragon with ferrous alloys [1]. Particulate-reinforced aluminum composites, offer reduced mass, nevertheless, high strength and stiffness, and improved wear resistance [2]. Specifically, the possibility of substituting iron-base materials for Al MMC,s, in automotive components, provides the potential for considerable weight reduction. Luminous developments have been derived in the system SiC/Al MMCs. A typical composite may have a volume fraction of ceramic phase of 20 vol. % SiC and an average particle size of around 10 mm. The strength of SiC/Al composites is increased by increasing the volume % of the ceramic phase, by decreasing the size of the ceramic reinforcement; ductility, nevertheless, diminishes and by increasing the strength of the Al matrix [3]. The Al matrix can be strengthened by mechanical alloying, a technique that can also refine ceramic powder particles [4].

Ramesh et al. [1] analyzed Al6061–Ni–P–Si3N4 composite revealed lower coefficient of friction and low wear rate compared to matrix alloy. The coefficient of friction for both matrix alloy and developed composite decreased with increasing load up to 80 N. Beyond this limit, with further increase in the load, the coefficient of friction increased slightly. However, with the increase in sliding velocity, the coefficient of friction of both matrix alloy and developed composite increases continuously. Wear rates of both matrix alloy and developed composites increased with increase in both load and sliding velocity.

Zhang et al. [2] also made an attempt at finding the effect of Al2O3 particle content on the steady-state wear rate of 6061 alloys through the use of the rule of mixture. After experimental validation, they suggested that if the reinforcement is strongly bonded with the matrix, wear resistance of composite would improve linearly with increase in reinforcement volume fraction. At the same time, they concluded that the counterpart will be subjected to more and more wear with an increase in the reinforcement content. Hence, one must consider a balance between these phenomena for developing wear resistant composite material.

Venkataraman and Sundararajan [3] examined that the transition load and wear or seizure resistance of the pure Al could be increased distinctly with increasing SiC content. They concluded that the transition loads are 45, 120 and 240 N for Al, Al–10% SiC and Al–40% SiC respectively. It is found by these investigators that even hardness of other Aluminium alloy is greater than that of the composite; transition load is noted to be less than that of composites.

U. Prakash et.al [4] made an attempt to study the influence of operating parameters like applied load, sliding speed and sliding distance on the dry sliding wear of A356 aluminum alloy reinforced with different percentages of 23 μm Sic particulates. Taguchi technique is used based on ANOVA sliding distance and loads were found to be the highest influence on sliding wear of the specimens. Particulate-reinforced aluminum composites offer reduced mass, high stiffness, and strength, and improved wear resistance. Specifically, the possibility of substituting iron-base materials for Al metal-matrix composites (MMCs), in automotive components, provides the potential for considerable weight reduction [4]. Effect of SiC content on the aluminum matrix in sliding wear behavior was established for varying process parameters, and the results revealed that as the SiC content increases the wear rate and temperature decreases, but the reverse trend has been observed for the coefficient of friction [5].

K.V. Mahendra et.al. [5] Al-4.5% Cu alloy was used as the matrix and silicon carbide and fly ash as reinforcements produced by using conventional foundry techniques. The fly ash and SiC were added in 05%, 10%, and 15% by weight to the molten metal. The hybrid composite was tested for hardness, fluidity, mechanical properties, density, impact strength, slurry erosive wear, dry sliding wear, and Corrosion. The microstructure examination did use SEM to assess the distribution of the particulates in the Aluminium matrix. The results show that there is an increase in hardness with the increase in the particulates content. The density decreases with increase in fly ash and SiC content. The compression strength, tensile strength, and impact strength increases with the increase in SiC and fly ash.

Manoj Singla et al [6] performed an experiment by taking Al-SiC composites containing four different weight percentages of SiC have been fabricated by using liquid metallurgy method. Wear and friction characteristics of Al-SiC composites have been investigated under dry sliding conditions and compared with the pure aluminum. It was also observed that the wear rate varies linearly with variation in normal load but lower in composites as compared to that in the base material. The wear mechanism appears to be oxidative for both pure aluminum and composites under the given conditions of sliding velocity and load as indicated by scanning electron microscope analysis (SEM) of the worn surfaces.

Therefore, interest in Al-based MMCs continues to grow, especially from the transport industries, wherever component weight reduction is the main objective. While to an extent this has been successful, where a critical load exists during dry sliding, above which a ceramic-based composite offers little improvement in wear resistance compared to an unreinforced sample. Esteem, it was found that hard ceramics can actually increase the wear rate of the mating counter face, due to their abrasive action, and thus reduce the overall wear resistance of the tribosystem [6]. Particulate reinforced Al-MMCs exhibits better mechanical properties and improved wear resistance over other conventional alloys. Reinforcement fracture was observed both in areas further away in the bulk and at the worn surface, for particles which were in direct contact with each other. Thus, intermetallic reinforcements may have potential to replace reinforcements that are more abrasive to counter faces, such as SiC or Al2O3, while still providing adequate wear resistance for the Al alloy [8]. Experimental program using ball-on-cylinder tester has been conducted to investigate the effects of temperature, sliding speed, normal load, and type of lubricating oil on sliding wear mechanism. The debris and worn surfaces have been examined. Surface examination of the samples using SEM was used to study the wear surfaces. The results show that the temperature of the oils affects the probability of adhesion, wear rates, oxidation, and coefficient of friction. [10]. Due to this, the research work aims at reaching at beneficial sliding wear behavior of Al alloy in both dry and lubricated situations through stir cast technique so that the results are obtained for enhancing the wear resistance of the LM6 alloy. In this paper, we are mainly focusing on the dry sliding wear behavior.

III. EXPERIMENTAL PROCEDURE

A. Materials used

The composite specimen which was fabricated by using Al-Silicon alloy (BS: LM6) as a matrix material. The chemical compositions of alloys are given in Table I. SiC and Al_2O_3 were used as a reinforcement material in this work. The properties of Al_2O_3 are given in following Table II.

Table 1. Chemical Composition of Alloy (Weight %)

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 2. Properties Of Aluminum Oxide

Property	Minimum value S.I.	Maximum Value S.I.	Units S.I.
Density	3	3.98	Mg/m3
Melting point	2277	2369	k
Compressive strength	690	5500	MPa
Ductility	0.00018	0.0018	-
Hardness	5500	22050	MPa
Fracture Toughness	3.3	5	MPa.m$^{1/2}$
Thermal Conductivity	12	38.5	w/mk
Tensile Strength	69	665	MPa
Young's modulus	215	413	GPa

B. Stir casting

These MMC's are produced by using liquid metal stir casting method. The Al (LM6) is melted in the graphite crucible by the use of the resistance-heated furnace. The required quantity of alumina and SiC was taken in the powder container. The preheated particles of alumina and SiC were added in the melt with controlled stirring speed, feed rate, and melt temperature. The stirring speed was near about in the range of 300 rpm and the process temperature was 710-760°C. The SiC and Alumina particles preheated at 750°C and 350°C respectively for one hour to remove the volatile contaminants. It has been found that the addition of Mn improves the wetting property of Al-based composites due to its lower surface tension. To create composite specimen, the melt at 650°C was poured. The produced composite was subjected to machining process to produce specimens having size 12 mm in diameter and 25mm length to perform the dry sliding wear experiment. Following figure 1 show stir casting setup where as figure 2 to 5 shows microstructure of different composites used for the experimentation.

Figure 1. Set-up of Stir Casting

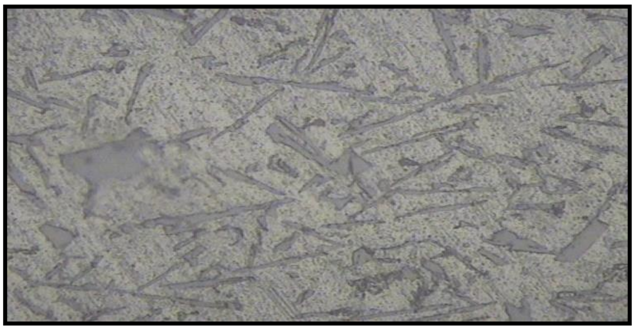

Figure 2. Microstructure of 5% Al_2O_3+3%SiC+LM6 at Magnification X-500

C. Wear Test

Dry sliding wear tests were carried out with the use of computerized Pin-on-disc wear testing machine by varying parameters such as normal load, sliding distance (SD) and Temperature for the MMC's. The tests are carried out under dry conditions. Wear specimen (pin) of size 12 mm diameter and 25 mm length was cut from the cast samples machined and then polished.

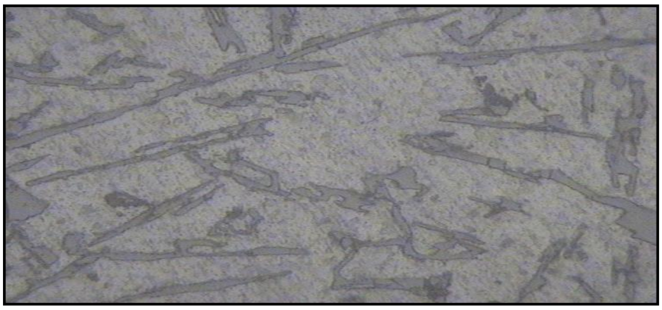

Figure 3. Microstructure of 5% Al_2O_3+3%SiC+LM6 at Magnification X-1000

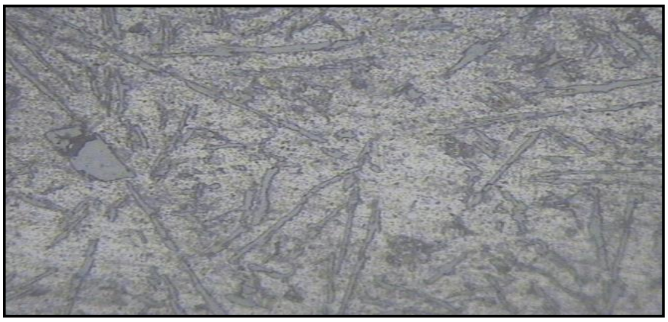

Figure 4. Microstructure of 5% Al_2O_3+6%SiC+LM6 at Magnification X-500

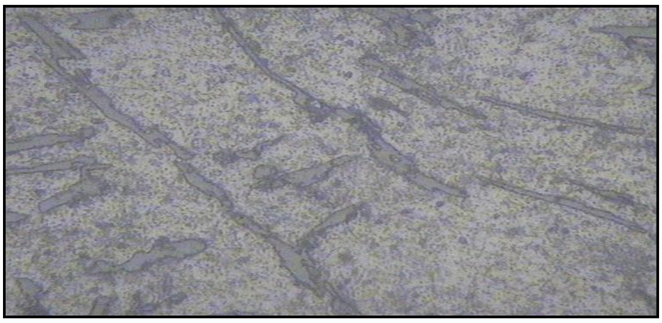

Figure 5. Microstructure of 5% Al_2O_3+6%SiC+LM6 at Magnification X-1000

A single pan electronic weighing machine having least count of 0.0001gram was used for the measurement of the initial weight and final weight of the specimen. The cylindrical pin of size 25 mm length and 12 mm diameter were tested against the EN31 steel disc. After running through a certain sliding distance, the specimens were removed and cleaned with acetone. Then measure the final weight to calculate weight loss due to wear. The differences in weight measured before and after test give sliding wear of composite specimen and then the wear rates were calculated for different samples. The dry sliding wear tests were carried out at controlled parameter levels. The set up of Pin on Disc machine shown in figure 6.

Figure 6: Setup of Pin on Disc Machine

Wear rate of the composites was calculated from the equation I.

$$WR = \Delta m / L \qquad (I)$$

By using this equation we had calculated the wear rate.

D. Taguchi Experimental Design

For the experiment, the test parameters selected were based on the Taguchi's standard L9 orthogonal array. Orthogonal arrays allow a rapid estimation of individual factor effects (or main effects), without the fear of distortion of results by the effect of other factors. In orthogonal arrays, for any pair of columns, all combination of factor levels occur an equal number of times. This is called balancing property and it implies orthogonality. Parameters and levels of the parameter are as shown in the table number IV.

Table 3. Parameters And Levels

Parameters and Levels	Load (N)	Sliding Distance (m)	Temp (°C)	%Reinforcement (Wt% SiC)
Level-1	5	1000	100	0
Level-2	10	1250	125	3
Level-3	15	1500	150	6

In the present investigation, the test parameters chosen are load, sliding distance, temperature and the weight percentage of reinforcement. Details of wear parameters with their levels are shown in Table 2.

Since the mass loss has to be minimized, smaller the better S/N ratio can be chosen for the study. Here larger the better S/N ratio approach was selected and then optimum parameters were observed from the means plot or S/N ratio plots. The wear test results were analyzed using ANOVA method.

IV. RESULTS AND DISCUSSION

Following the table, V shows the orthogonal array and results obtained during the dry sliding wear experimentation which is performed on a pin on disc machine.

Table 4. Experimental Results

Sr. No	Load (N)	Sliding Distance (m)	Temp (°C)	Wt% of SiC	Wear rate× 10–7 N/m (Dry)
1	10	1000	100	0	0.1317
2	10	1250	125	3	0.1471
3	10	1500	150	6	0.1826
4	15	1000	125	6	0.1371
5	15	1250	150	0	0.1921
6	15	1500	100	3	0.2422
7	20	1000	150	3	0.1763
8	20	1250	100	6	0.1234
9	20	1500	125	0	0.2516

Following figure 6 shows the main effect plots for the mean. From this, we can find out the optimum process parameters with respect to input variables such as load, Temperature and sliding distance for dry sliding wear for the Dry sliding wear rate. The optimum level parameters obtained from this main effect plot are shown in the following table.

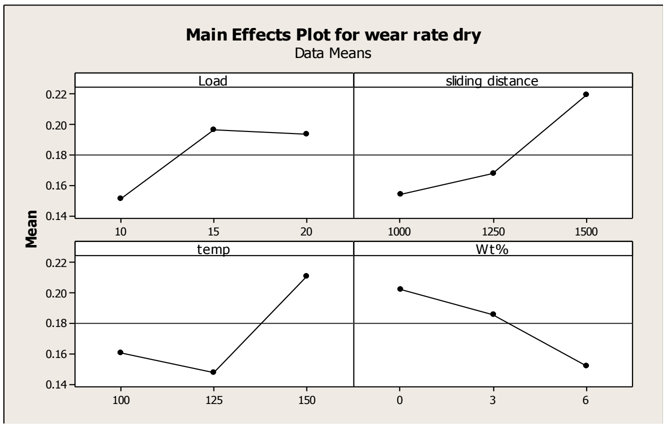

Figure 6. Main Effect Plot for Means

From this graph, we can find out the optimum process parameters. This graph indicates the load 10N, Sliding distance 1000m, Temperature 125°C, and 6% SiC are the optimum process parameters for dry sliding wear.

V. ANOVA ANALYSIS

From the data obtained from the experimentation conducted, the analysis of variance (ANOVA) has been carried out to analyze the influence of various operating parameters on the wear loss. This analysis was carried out for a level of significance of 5% (i.e., the level of confidence 95%). Table VI shows the results of ANOVA analysis. It can be observed from the results obtained that Sliding Distance was the most significant parameter having the highest statistical influence (52.60%) on the dry sliding wear rate of composites while Temperature (10.01%) is the least influencing parameter in dry sliding wear.

Table 5. Anova Table

Source	DF	SS	Adj MS	F Value	P Value	%
Load	2	0.00603	0.0028	30.76	0.0010	17.44
SD	2	0.01820	0.0063	69.26	0.0020	52.60
Temp	2	0.003	0.001	11.74	0.003	10.0

		5	1		0	1
Wt%	2	0.0061	0.0031	33.95	0.0030	17.60
Error	9	0.0009	0.00001			
Total	17	0.0346				

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

The following table shows the model summary.

Table 6

S	R-Sq	R-Sq (adj)	R-sq (Pre)
0.009465	97.65%	95.58%	96.61%

A. **Regression Equation**

The regression equation for dry sliding wear rate is given as follows:

Wear rate dry = - 0.0865 + 0.0038 Load + 0.00013 sliding distance + 0.001 temp 0.0076 Wt%

ANOVA is carried out by using MINITAB software to investigate the 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 for the Dry condition is 97.65 %.

VI. CONFIRMATION TEST

To test the efficiency of the model the confirmation tests were performed by selecting the set of optimum process parameters. Table 7 gives the arithmetic values of confirmation test.

Table 7. Confirmation Test

Parameter	Model value	Experimental value	Error %
Wear rate	0.1057	0.1006	4.79

VII. CONCLUSION

Following conclusion can be drawn based on test results.

1. From the experiment, it was observed that in dry sliding wear, sliding distance most significant factor and contributes (52.60%) followed by the percentage of reinforcement and load, while the least influencing factor is a temperature which is having the contribution of 10.01 %. Because as the sliding distances increases temperature increases causes fatigue failure of the material after some interval of time. This fatigue failure occurs because of localized tensile stresses.
2. Addition of SiC content has been found to be reducing wear rate, compared to matrix alloy. Because the addition of SiC causes an increase in hardness of the composite. The hardness of the wear material, or more particularly, the hardness of the work surface, is an important parameter in determining the resistance of a material to abrasion. An increase in the surface hardness of the wear material reduces the depth of penetration by the abrasive particle, leading to lower wear rates.
3. Within the operating range, the temperature is found to influence wear rate marginally.
4. With the increase in speed, load, and sliding distance due to the formation of pits and surface elimination wear rate has increased under dry condition.

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