Experimental Investigation of Wear Properties of Aluminium LM25 Red Mud Metal Matrix Composite

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Abstract— The use of different kind of Metal-matrix composite materials is in constant growing over the years, because they have better physical, mechanical and tribological properties comparing to matrix materials. In automotive industry they are used for pistons, cylinders, engine blocks, brakes and power transfer system elements. Research attempts have been made in the past toreduce the cost of processing of composites, decrease the weight of the composites, and increase the desired performance characteristics. This paper presents the findings of an experimental investigation on the effects of applied load, RPM, Sliding distance and pin temperature in dry sliding wear studies performed on red mud-based aluminum metal matrix composites (MMC). Red mud is an industrial waste during the production of aluminum from bauxite ore. A pin-on-disc apparatus was used to conduct the dry sliding wear test. Taguchi-based L9 orthogonal array has been used to accomplish the objective of the experimental study. Analysis of variance (ANOVA) is employed to find the optimal setting and the effect of each parameter on wear rate.

Key words: MMC, LM25, Red mud, Stir-casting, Taguchi, Pin on disc

I. INTRODUCTION

Composite material is a mixture of two or morematerials or phases of the same material, insoluble inone another, possessing properties which are superior to any of the component materials.

Volume fraction of component materials should be above 5 % of total volume and their properties must be different from one another. Usually, volume fraction of one material is significantly higher than the volume fractions of the others and that material is called matrix. Matrix can be ceramic, metal and polymer[1]. The metal matrix composites exhibit the significant increase in mechanical strength, wear resistance and damping properties when compared to matrix alloy [2, 3].

In many engineering applications the use of aluminium alloy is inevitable because of its superior mechanical, thermal property and it also possesseslow wear resistance property. To increase the wear resistance of the aluminium, and its alloy, it is reinforcedwith different reinforcements.Reinforcements are usuallyfibers 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 closeto- regular geometrical form. [1]

A fibrous reinforcements are characterized by its length and diameter so we distinguish, long (continuous) fibers (Figures 1d and 1e) and short (discontinuous) fibers-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 (Figure 1e).

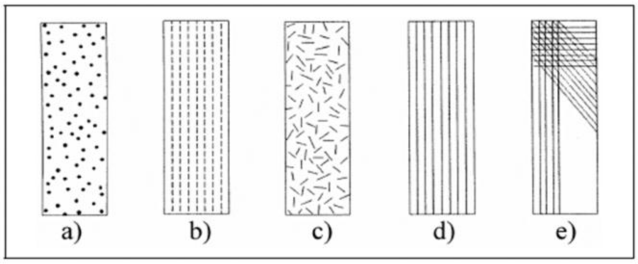

Fig. 1: Shape and Arrangement of Reinforcements in Composite Material[1]

Among the different reinforcement particulates reinforcement is gaining more attention because of its excellent isotropic property during the fabrication of composite [2].

II. LITERATURE REVIEW

Many researchers have been using Taguchi method to identify the effect of parameters on dry sliding wear behavior of the composites. There has been experimentalinvestigation using Taguchi and ANOVA to identify the significantfactors, while testing with Al 2219 SiC and Al 2219 SiC-graphite material shows that, the sliding distance, sliding speed, and load are having significant effect on wear [5].

S. Rajesh, et al. [4] investigated the effects of applied load, sliding velocity, weight % of reinforcement and hardness of the counterface material in dry sliding wear studies performed on red mud-based aluminum MMC.Taguchi-based L9 orthogonal array combined with multi-objective optimization based on ratio analysis (MOORA) is adopted to find the optimal combination of dry sliding wear parameter. MOORA revealed that optimal combination is load 20N, sliding velocity 3 m/s, % of reinforcement 20%, and counterface hardness of the material 58HRC.

Reddappa H.N et al. [6]conducted the experiments to investigate the effect of Load, sliding distance and weight percentage of reinforcement on sliding friction and wear of Al6061–beryl composites using pin on disc machine. The results reveal that wear rate and specific wear rate of the matrix as well as composite increases as the load increases. The composites have shown a lower rate of wear for Al6061-10% beryl composites as compared to that observed in Al6061-2% beryl and Al6061-6% beryl composites.

Sannino and Rack [7] reported that the particulates composites are good for industrial applications where performance along with cost is important. The effect of sliding velocity on the frictional and wear behavior of aluminium MMC sliding against ferrous counter body has been studied by a number of researchers.

H.B. Bhaskar and Abdul sharief [8] studied Tribological Properties of Aluminium 2024 Alloy–Beryl Particulate MMC's. They found that wear rate and coefficient of friction of the composites as well as the unreinforced material increases as the sliding distance and

applied load increases and as the percentage of reinforcement increases, the wear rate and coefficient of friction of the composite decreases.
Huda et al. [9] reported that selection of particular fabrication process depends on the type of the matrix and the reinforcement materials used to form theMMC. Particulates reinforcement can easily synthesize with matrix material using stir casting process.

Bharat admile [10] 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.

Deius et al. [11] showed that aluminium based MMCs containing hard particles offered superior operating performance and resistance to wear and abrasion compared to iron or nickel based alloys.

Yogesh kumar singla et al. [12] studied wear behavior of aluminium 6061 alloy reinforced with Sic, Red mud and Al2O3separately. Results of dry sliding wear test revealed that wear rate of composite decreases as compared to the matrix material.Lowest value of wear rate is observed for 10 weight % of Sic particles and highest value of hardness is observed for 7.5 weight % of Red mud. Therefore it is concluded that the wear rate is independent of the hardness.

V. Daniel Jebin et al.[13] studied wear behavior of AL6063 Alumina metal matrix composite at different sliding velocities (2.5,3,3.5and 4m/s) and constant load (20N) on pin on disc machine and found that the wear rate decreases with the increase in weight % (0%,4% and 8%) of alumina at all the sliding velocities.

Rohatgi et al. [14] studied the dry sliding wear behavior of Al 206 aluminium alloy containing silica sand reinforcement using three pins on disk rib meter against SAE 1045 steel. The result revealed that the addition of silica sand reduces the coefficient of friction of the composites.

Liu et al. [15] discussed the effect of fiber volume fraction, load applied, rotating speed and wear mechanics. It is found that the increasing weight % of reinforcement decreases the wear rate and the increasing in applied load increases thewear rate.

Iwai et al. [16] adopted powder metallurgy method to fabricate SiC whisker reinforced 2024 Al composites for varying weight % of reinforcements (0% to16%). Dry sliding wear test result revealed that the increase in weight % of reinforcement decreases the wear rate.

F.H. Stott [17] carried out numerous experiments on the high temperature sliding wear of metals and composite and found out that a transition from sever to mild wear occurs at ambient temperatures of 20-800˚C. This transition occurs due to compacted layers of wear debris particles. At higher temperatures oxidation, compaction and sintering lead to development of hard oxide glaze surfaces on these layers.

Sahin and Ozdin [18] developed mathematical model for the abrasive wear behavior of the SiCp reinforced aluminium MMC. From the experimentation result it was found that the wear rate of the composites is directly proportional to increasing the applied load and abrasive size.

A few attempts have been made to fabricate MMC to increase the wear resistance characteristics using low cost reinforcement like bauxite, corundum, granites, and sillimanite [19]. The ever-increasing demand for low cost reinforcement stimulated the interest towards the utilization low cost reinforcement like red mud. Red mud is the byproduct of Bayer's process during production of alumina [20]. It comprises of oxides of iron, titanium, aluminum and silica along with some other minor constituents. About 1-2 tons of red mud residues are produced for each ton of alumina. Storing of red mud is the major issue as it ishighly alkaline and it canlead to soil alkalization and water pollution, storing in dry land pollute the atmosphere. So, in this work an attempt is made to use red mud as reinforcement material. The present investigation has been carried out to optimize the wear rate of the red mud reinforced aluminiummetalmatrix composite fabricated through the stir casting process.

III. Experimental Procedure

A. *Materials:*

LM25 aluminumalloy and redmudwere used as matrix and reinforcement materials. LM25 aluminumalloy finds application in the electrical sliding contacts, cylinder blocks, cylinder heads, brakes, and other engine body castings.

Element	Si	Mg	Mn	Fe	Cu	Ni	Zn	Ti	Al
Wt %	7.11	0.51	0.2	0.12	0.2	0.04	0.08	0.01	Balance

Table 1: Chemical Composition of Aluminum LM25 Alloy.

Element	Al_2O_3	Fe_2O_3	TiO_2	SiO_2	CaO	MnO	V_2O_5	Others
Wt %	45	25	2	1.6	1.8	0.16	0.067	Balance

Table 2: Chemical Composition of Red Mud

Reinforcement material is added to the LM 25 alloy to enhance the strength of the part being manufactured. Tables1 and Table2 show the chemical composition of aluminum alloy and red mud material. Theredmud used for the present investigation is collected from the NationalAluminum Company Limited (NALCO) Damanjodi, Odisha, India. The size of the red mud particles used for the study is in a range of 120–150 μm.The weighed quantity ofaluminum was melted in a crucible. The required quantity of red mud17.5% of weight of aluminium was taken in the powder container. The red mud was preheated in the furnace up to 350˚C and maintainedthe temperaturebefore mixing with aluminum melt. The weighed quantityof aluminum was melted to desired superheating temperature of 750±10˚Cusing crucible electrical resistance furnace with temperature controlling device. After melting was over, the temperature of the melt was lowered up to 650˚C to form slurry at lower temperature to have uniform mixing of red mud and to avoid the flow of red mud outside the matrix material. Required quantity of red mud particulates was added to the molten metal and stirred continuously by using mechanical stirrer to avoid segregation of the red mud particles. The stirring time was maintained 80s at an impeller speed of 300 rpm.Good wetting between the solid and liquid is essential for the formation of satisfactory bonds between them during casting. It has been found that the addition of magnesium improves the wetting characteristics of aluminium-based composites because of its lower surface tension also it acts as scavenger of oxygen, thereby increasing the surface energy of the particles.The melt at 650˚C was poured to prepare composite specimen. The prepared composite was subjected to machining to produce a size of Φ 12mm and 25mm length to carry out the dry sliding wear test.

B. Characterization of Composites:

Scanning electron microscope was used to study the distribution of red mud particles in aluminum matrix. Figures number 1(a) and 1(b) show the SEM images of 17.5% red mud reinforced aluminum MMC at different magnifications. From Figures number 1(a) and 1(b), it is understood that the mixing of red mud in aluminium matrix is uniform. Specimen was metallographically polished and etched with Keller's reagent prior to the microstructural characterization.

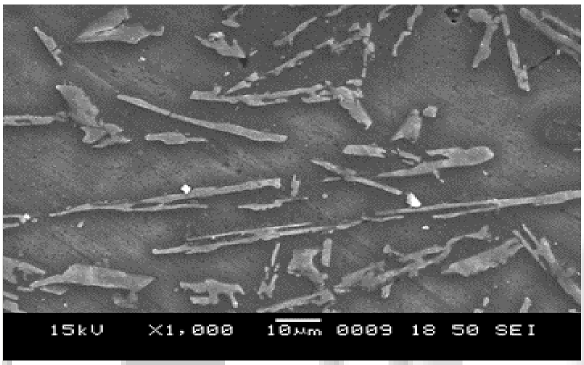

Fig. 2: (a) SEM at Magnification × 1000

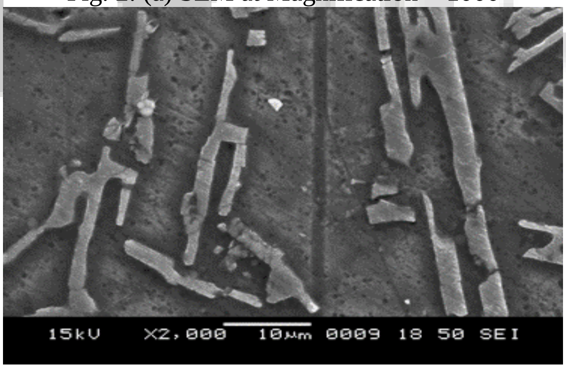

Fig. 2: (b) SEM at Magnification × 2000

C. Wear Test:

Pin-on-disc wear testing apparatus (ASTM G99-95 standard) was used for performing dry sliding wear test for evaluating wear rate of the fabricated composites. Figure 2 shows schematic diagram of pin on disc test rig. Before conducting the test, the testing pin and the disc surface were polished with emery paper. En31steel disc was used as counter face material with 60HRc hardness and surface roughness 1.6Ra. Samples were cleaned with acetone prior to experimental run. Prior to and after the wear tests, samples were weighed using weighing machine of accuracy 0.0001g to measure the mass loss. The dry sliding wear performance of the composites was studied as function of load, RPM, Sliding Distance, and Pin Temperature.

The dry sliding wear tests were carried out at controlled parameter levels. Parameters and levels of parameter are asshown in the table number 3. Wear rate of the composites was calculated from the ratio of mass loss to sliding distance.

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

Where,
Wr =Wear Rate
Δm =m1-m2
L = Sliding Distance

Sr. No.	Parameter	Level 1	Level 2	Level 3
1	Load (N)	10	15	20
2	RPM	300	400	500
3	Sliding distance (m)	1000	1250	1500
4	Temperature (˚C)	100	125	150

Table 3: Dry sliding wear test parameters and levels

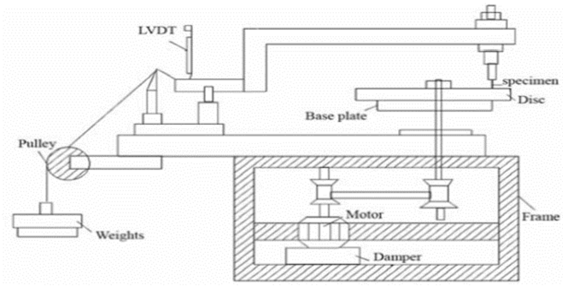

Fig. 3: Schematic Diagram of Pin on Disc Test Rig.

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 ofthe composites. The major aim of the present investigation is to analyze the influence of parameters likeload, RPM, Sliding distance and temperature of the pin on dry sliding wear rate of aluminium LM25 Red Mud metal matrix composites using Taguchi technique.

Sr. No.	Load N	RPM	Sliding Distance m	Temperature ˚C	Wear rate×10^-7 N/m
1	10	300	1000	100	0.1300
2	10	400	1250	125	0.1560
3	10	500	1500	150	0.0800
4	15	300	1250	150	0.0400
5	15	400	1500	100	0.1800
6	15	500	1000	125	0.0200
7	20	300	1500	125	0.3310

8	20	400	1000	150	0.3866
9	20	500	1250	100	0.1180

Table 4: 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 17 software. The analyzed results are presented using ANOVA analysis and mean effects plots.

Table 4 shows the orthogonal array and results obtained during the experimentation. Figure 2 show the S/N ratio main effect plot for the output performance characteristics. From Figure 2 it was understood that the optimal parameter combination for wear rate was as shown in table number 5.

A. *Analysis of wear rate:*

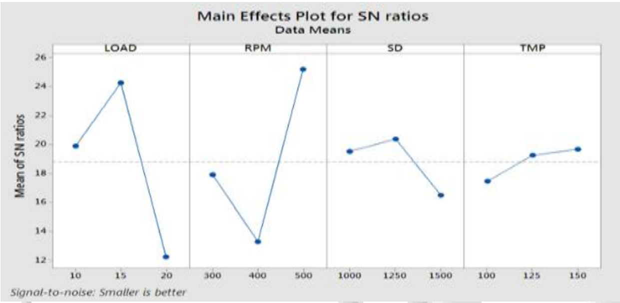

Fig. 2: Main Effect Plot Wear Rate.

Sr. No.	Parameter	Optimum level
1	Load	15N
2	RPM	500
3	Sliding distance	1250m
4	Temperature	150˚C

Table 5: Optimum Level of Parameters

V. ANOVA FOR WEAR RATE

ANOVA was used to determine the design parameters significantly influencing the wear rate. Table 6 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 6 showsthe 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 wasthe most significant parameter having the highest statistical influence (52.39%) on the dry sliding wear rate of composites followed by RPM (36.08%) and sliding distance (8.92%).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 6, it is observed that the effect of load A & RPM B is influencing wear rate of composites.

Source	DF	SS	MS	F Value	P Value	%
Load	2	0.135799	0.067899	197.49	0.000	52.39
RPM	2	0.093519	0.046760	136.00	0.000	36.08
Sliding distance	2	0.023128	0.011564	33.64	0.000	8.92
Temperature	2	0.003647	0.001823	5.30	0.030	1.40
Error	9	0.003094	0.000344			1.19
Total	17	0.259187				100

Table 6: ANOVA for Wear Rate

– DF: degree of freedom, SS: sum of squares, V: variance, F: test, P: contribution.

1) Model summary:

S	R-sq.	R-sq(adj)	R-sq(pred)
0.0185421	98.81%	97.74%	95.22%

2) Regression equation:

Wear rate = 0.031 + 0.01723 Load - 0.000536 RPM + 0.000018 Sliding distance + 0.00046 Temperature

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. The obtained R square value is 98.81%.

VI. CONFIRMATION EXPERIMENT

In order to validate the result, confirmation experiment has been conducted at the optimal setting of process parameters as shown in table number 5.

Parameter	Model value	Experimental value	Error %
Wear rate	0.1129	0.1093	3.29

Table 5: Confirmation Experiment

CONCLUSION

The use of the Taguchi method and analysis of response variables to optimize the dry sliding wear parameters of the red mud based aluminum metal matrix composites has been reported in this paper.

The following conclusions were made.

1) Aluminium LM 25 matrix reinforced with 17.5% red mud was successfully prepared by stir casting process and the wear behavior of the composites was investigated using pin-on-disc machine.
2) It is observed that applied load is found to be a most significant parameter with 52.39% contribution to wear rate. Of three, RPM was found next significant parameter compared to sliding distance and pin temperature. Contribution of RPM to wear rate is 36.08%.

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