Study of Dry Sliding Wear Behaviour of Aluminium-Silicon Alloy with Silicon Carbide (SiC) and Fly Ash Metal Matrix Composite

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Abstract— Performance of components subjected to relative motion is largely affected by tribological properties of the material. Over last few decades the interest of researchers has been shifted from conventional materials to metal matrix composite (MMC) as a material for components subjected to tribological applications. In the present work aluminium-silicon alloy (BS: LM6) was used as matrix and fly ash and silicon carbide (SiC) as reinforcements. The metal matrix composite was produced using stir casting. An attempt has been made to study the influence of operating parameters like applied load, sliding distance and temperature on dry sliding wear of aluminium alloy reinforced with different percentage of SiC particulate and fly ash is kept as constant 5% by weight. Experiments were designed based on taguchi technique. Based on ANOVA, load and sliding distance were found to have highest influence on the sliding wear of the specimens. Optimum values of parameters for which result is minimum mass loss were determined and confirmation test was conducted to verify the same.

Key words: MMC, LM6, SiC, Fly Ash, Stir casting, Taguchi, Pin on Disc

I. INTRODUCTION

The conventional materials do not always provide the required properties under all service conditions. Tribological characterization of materials is crucial for modern engineering applications. Common tribological components which are used in industrial applications, where wear is one of the influencing design parameters, include sliding and rolling contact bearings, seal, cams, gears and tappets, piston rings, electrical brushes, and cutting and forming tools. Adhesive and abrasive wear are the most common failure modes in the components operating under moderate contact stresses.

Composite materials are increasingly replacing traditional engineering materials because of their advantages over monolithic materials. The development of metal matrix composites has been one of the major innovations in the field of materials in the recent past [1]. A metal matrix composite (MMC) is normally fabricated using a ductile metal (e.g., Al, Ti or Ni) as the base material, which is normally reinforced by a ceramic material (e.g., mica, alumina, graphite, and SiC). Industrial wastes like Red mud and fly ash are also used as reinforced material now a day. Composites, exhibiting higher toughness, specific strength, and stiffness ad good wear resistance can be obtained by combining the metallic properties such as good ductility and toughness of the matrix with properties such as high strength, hardness and elastic modulus of the ceramic reinforcement. Use of fly ash as reinforcement material results in improvement of mechanical properties of composite. Fly ash in aluminium decreases the density of the composites and increases the wear resistance. Thus, in view of increased applications of composite materials in tribological components their characterisation is of major significance. The wear resistance of composites has received much attention in recent times. Research works concerning the un-lubricated sliding wear behaviour of such materials have examined the influence of variables such as the contact pressure (load), sliding velocity, temperature, reinforcement particle volume fraction, and particle size. A number of mechanisms proposed to explain the sliding wear behaviour of these composites [2]. Dry sliding wear study of Al 356 reinforced with SiC particulates showed better resistance to sliding wear compared with unreinforced alloy [3]. The wear rate was found to decrease initially, with sliding speed before showing an increasing trend. The wear resistance was found to increase with the volume percentage of reinforcement.

U.prakash et.al [1] made an attempt to study the influence of operating parameters like applied load, sliding speed and sliding distance on dry sliding wear of A356 aluminium alloy reinforced with different percentages of 23 µm SiC particulates. Taguchi technique is used. Based on ANOVA, sliding distance and load were found to be highest influence on sliding wear of the specimens. K. V. Mahendra et.al [2] used Al-4.5% Cu alloy the matrix and fly ash and silicon carbide (SiC) as reinforcements. The hybrid composite was tested for fluidity, hardness, density, mechanical properties, impact strength, dry sliding wear, slurry erosive wear, and corrosion. There is an increase in hardness with increase in the particulates content. The density decreases with increase in fly ash and SiC content. The tensile strength, compression strength, and impact strength increases with increase in fly ash and SiC. The resistances to dry wear and slurry erosive wear increases with increase in fly ash and SiC content. Corrosion increases with increase in fly ash and SiC content. This material can be used as bearing material. Prashant Kumar Suragimath et.al [3] performed the work deals with fabricating or producing aluminium based metal matrix composite and then studying its microstructure and mechanical properties such as tensile strength, impact strength and wear behaviour of produced test specimen. Experiment has been conducted by varying weight fraction of Fly Ash (5% and 15%) while keeping SiC constant (5%). The result shown that the increase in addition of Fly Ash increases the Tensile Strength, Impact Strength, Wear Resistance of the specimen and decreases the percentage of Elongation. Vijay Kumar S Maga et.al [4], performed the study in which a modest attempt has been made to develop aluminium based MMCs with reinforcing material with an objective to develop a conventional low cast method of producing MMCs and to obtain homogeneous dispersion of reinforced material. Experiment has been conducted by varying weight fraction of Sic, Fly Ash, and Redmud. It appears from this study the wear resistance tends to increase with increase in addition of fly ash and red mud in LM6-Sic hybrid composite. Ajit Kumar Senapati [5] used fly ash from two different industries as reinforcement for fabricating aluminium composites. Results revealed that there is a great effect of reinforcing different fly ash in aluminium alloy matrix composites. Thus, selection of fly ash for reinforcement was found one of the most important criteria for fabricating aluminium matrix composite [6].

It is observed from the literature that the wear behaviour of composites is influenced by operating parameters like load, speed, sliding distance and temperature as well as the material parameters like particulate size and percentage composition of the reinforcement [7]. The task of studying the parametric influence and identifying the optimized values becomes difficult by conventional testing methods. Taguchi's parameter design offers a systematic method for optimization of various parameters with regard to performance, quality and cost. Taguchi's method utilizes tactically designed orthogonal arrays (matrices) 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 [8]. A unique feature of this method is the transformation of experimental data into special forms called S/N ratios. The S/N ratio is concurrent statistic. A concurrent statistic is able to look at two characteristic of a distribution and roll these characteristic into single number. Whenever the experimental investigation involves more number of parameters and the range of individual parameters is also large, the study becomes exhaustive. Under these circumstances, Taguchi's method minimizes the number of experiments while providing the reliable inference about the influence of parameters using statistical techniques such as Analysis of Variance (ANOVA) [9]. Analysis of variance is the decomposition of variance, which helps in getting a better feel of the relative effect of the different factors. The analysis of variance helps in deciding which factor is dominate over the other and the percentage contribution of particular independent variable [10].

In the view of above facts, the present work is taken up with the objective of studying the influence of normal load, sliding distance, temperature on the dry sliding wear behaviour of aluminium-silicon alloy (BS: LM6) reinforced with 3% and 6% by weight of silicon carbide (SiC) particles of size 20 µm and 5% by weight of fly ash constant, using taguchi technique. It is also intended to find optimum level of operating parameters to minimize the material loss under test conditions.

II. EXPERIMENTAL DETAILS

A. Materials

The composite specimen are fabricated using aluminium-silicon alloy (BS: LM6) as the matrix material the chemical composition of the alloy is given in table 1. The reinforcement materials used are a silicon carbide particles (SiCp) of 20µm size and fly ash particles of 100 µm size. Chemical composition of Fly ash is shown in table 2.

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

Table 1: Composition Details of Matrix Material

Compound	Wt%	Compound	Wt%
MgO	1.72	CaO	2.82
Al_2O_3	29.65	TiO_2	2.54
SiO_2	51.4	FeO	5.39
K_2O	1.57	CuO	4.56

Table 2: Composition Details of Fly Ash Reinforcement

B. Processing

The composites are fabricated by liquid metal stir casting technique. The aluminium LM6 is melted in graphite crucible using resistance-heated furnace. The required quantity of silicon carbide and fly ash was taken in powder container. The preheated particles were added to the melt with controlled feed rate, stirring speed and melt temperature. The stirring speed was in the range of 300 rpm and the processing temperature was 720-750℃. The SiC and fly ash particles were preheated at 750℃ and 350℃ respectively for one hour to remove the volatile contaminants on the particle surface and to artificially oxidize the surface to obtain a layer of SiO_2 which could promote better wetting. It has been found that addition of magnesium improves the wetting characteristics of aluminium based composites because of its lower surface tension also acts it acts as scavenge of oxygen, thereby increasing the surface energy of the particles. The melt at 650℃ was poured to create composite specimen. The prepared composite was subjected to machining to produce specimens 12mm in diameter and 25mm length to carry out the dry sliding wear test.

C. Test Procedure

Dry sliding wear test of the composite specimen were conducted using pin-on-disc test apparatus conforming to ASTM G99 standards. Figure 1 shows schematic diagram of apparatus test rig. Before conducting the test, the testing pin and the disc surface were polished with emery paper. EN-32 hardened steel disc with hardness of 60 HRC and Ra value of 1.6 µm was used as the counter surface. The details of test parameters are shown in table. The weight loss of the specimen at different operating conditions was measured using an electronic weighing machine with an accuracy of 0.1 mg. The dry sliding wear performance of the composite was studied as function of load, Sliding Distance, Contact temperature and Wt. % of SiCp.

Level	Load (L), N	Sliding Distance (SD), m	Temperature (T), ℃	Wt. % of SiCp (COMP), [5% Fly ash Const}
1	10	1000	100	0
2	15	1250	125	3
3	20	1500	150	6

Table 3: Process Parameters with Their Values at Three Levels

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

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

Where,
W_r= Wear Rate
Δm= Mass Loss
SD= Sliding Distance

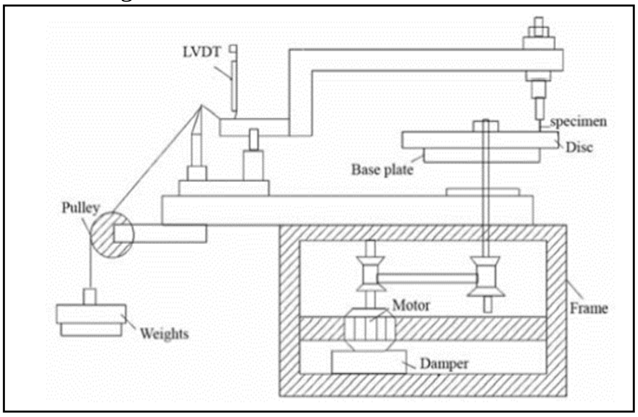

Fig. 1: Schematic Diagram of Pin on disc test rig

D. Design of Experiments

The test parameters selected for the experiment were based on Taguchi's standard $L_9(3^{4})$ orthogonal array. Orthogonal arrays allow 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 equal number of times. This is called balancing property and it imply Orthogonality. The $L_9(3^4)$ array contains 9 rows and 4 columns. The rows represent the number of trials and columns represent number parameters or factor that can be studied. Each parameter can be studied for three levels. Since the mass loss has to be minimized, smaller the better S/N ratio was chosen for the study. The wear test results wear analysed using ANOVA. This technique was used to find optimum values for each parameter so that mass loss is minimized. A linear regression model is developed to predict the wear rate of the composites

Sr. No	Load N	Sliding Distance m	Temperature	% SiCp	Wear Rate $\times 10^{-7}$, N/m	S/N Ratio
1	10	1000	100	0	0.1275	18.884
2	10	1250	125	3	0.1498	16.368
3	10	1500	150	6	0.1785	15.307
4	15	1000	125	6	0.1560	16.401
5	15	1250	150	0	0.2198	13.579
6	15	1500	100	3	0.2283	13.837
7	20	1000	150	3	0.1962	14.095
8	20	1250	100	6	0.1413	16.598
9	20	1500	125	0	0.2649	11.151

Table 4: Experimental Runs and Result

III. RESULTS AND DISCUSSION

It can be observed that the mass loss of all the materials increases steadily with increase in sliding distance. Also it can be seen that at most of the test conditions, mass loss is marginally higher for matrix alloy specimens compared to composite specimens. During the initial period of wear, there will be asperity contact between the contacting surfaces, and the asperities of the weaker material get sheared resulting in higher wear rate. With increase in sliding distance, asperities get evened out, the contact area increases and the surface gets work hardened, resulting in reduced wear rate of the test surface.

A. Characterisation of Composites

Microstructure analysis is done to study the distribution of SiC and Fly ash particles in aluminium matrix. Figures numbers 2 (a) to 2(d) shows the micrographs of composites with different percentages of Sic and Fly ash. From the figure it is clear that the reinforcements are distributed in the matrix.

B. Analysis of Variance

Table 4 shows the orthogonal array and results obtained during the experimentation. Statistical analysis was performed using MINITAB 17 software. The analysed results are presented using ANOVA analysis and mean effects plot.

From the data obtained from the experimentation conducted as per table, the analysis of variance (ANOVA) has been carried out to analyze the influence of various operating parameters on the wear loss.


Fig. 2: (a) Microstructure of 3% Sic+5%Fly Ash at Magnification of × 500

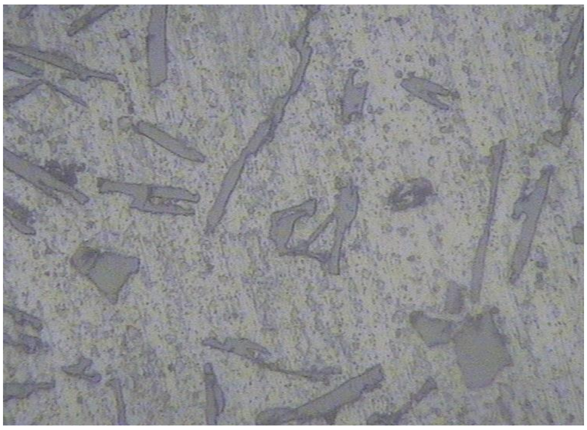

Fig. 2: (b) Microstructure of 3% SiC+5%Fly Ash at Magnification of × 1000

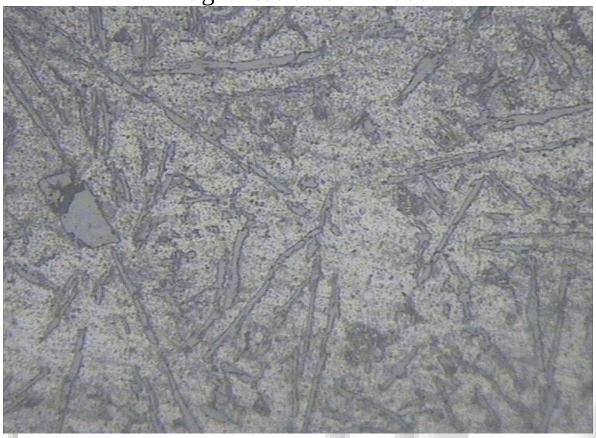

Fig. 2: (c) Microstructure of 6% SiC+5%Fly Ash at Magnification of × 500

This analysis was carried out for level of significance of 5% (i.e., the level of confidence 95%). Table shows the results of ANOVA analysis. The result shows that the load (31.77%) and sliding distance (40.97%) have the highest influence on wear of the composite.

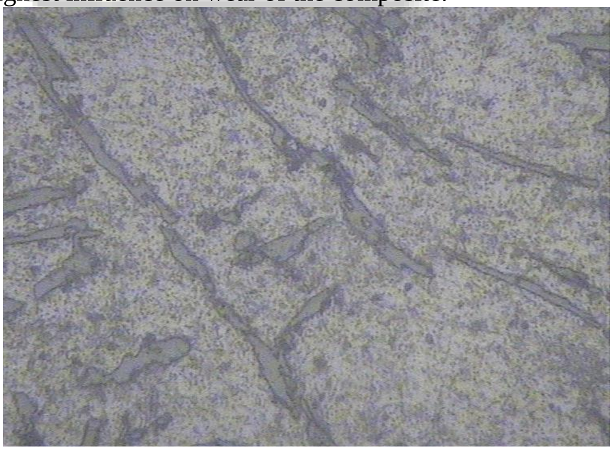

Fig. 2: (d) Microstructure of 6% Sic+5%Fly Ash at Magnification of × 1000

Optimum value of each factor to obtain minimum loss is found using the response table for S/N ratios. In the present investigation, the requirement is to minimize the mass loss or maximization of S/N ratio. Hence the level having maximum average S/N ratio value is optimum for the corresponding factor. Average S/N ratios for the factor levels are tabulated in table. Fig shows the main effects plot for S/N ratios. The mean in the main effects plot is average of S/N ratio for the factor levels in table. From the table 4 considering the maximum average S/N ratio value, the optimum levels of parameters chosen are (i) Normal load of 10N (ii) Sliding distance of 1000m (iii) Temperature of 100°C and (iv) Composite with 6 wt.% of SiCp. A confirmation sliding wear test was conducted applying the optimized test parameters and the mass loss under these conditions was found to be 0.00089 gm (Specific wear rate 0.0875×10^{-7}N/m), which was found to be the least among all the test results recorded

Source	DOF	Sum of Squares	Mean of Squares	F Value	P Value	% Contribution
Load	2	0.0129945	0.0064972	49.31	0.000	31.77
Sliding Distance	2	0.0167577	0.0083789	63.59	0.000	40.97
Temperature	2	0.0037413	0.0018707	14.20	0.002	9.15
Wt. % of SiCp	2	0.0062259	0.001130	23.62	0.000	15.22
Error	9	0.0011859	0.0001318			2.99
Total	17	0.0409054				100

Table 5: Results of ANOVA

S	R-sq	R-sq (adj.)	R-sq (Pred)
0.0114791	97.10	94.52	96.12

Table 6: Model Summary

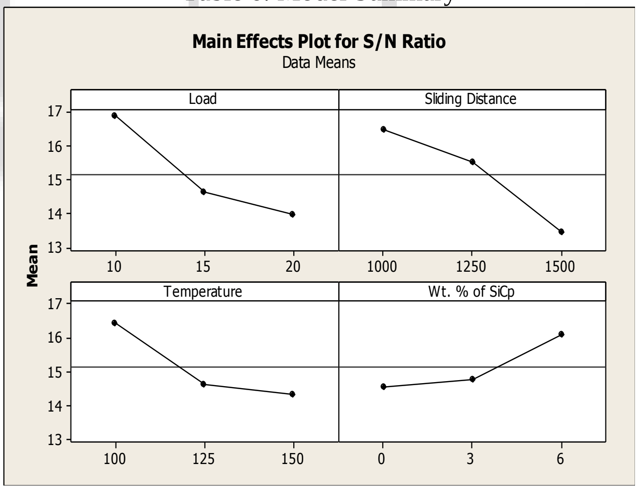

Fig. 3: Main Effects Plot for S/N ratios

C. Regression Equation

Regression analysis is performed in order to find out the effect of load, sliding distance, temperature and wt.% of SiCp on the wear rate alloy and composites. It gives functional relationship between response wear rate and input parameters.

Wear Rate = 0.621289 + 0.309533 Load + 0.0355867 Sliding Distance + 0.0151333 Temp – 0.021345 Wt. % SiCp

IV. CONCLUSIONS

Dry sliding wear tests have been conducted on aluminium-silicon alloy (BS: LM6) and its composites with 3% and 6% SiCp and 5% Fly ash (Constant) by weight at different operating parameters. Following conclusions can be drawn based on the test results.

- Addition of SiC and Fly ash reinforcement has been found to reduce the wear rate, compared to matrix alloy
- Mass loss due to sliding wear increases with sliding distance, but the wear rate is found to decrease with sliding distance, because of flattening of asperities as well as work hardening of the surface
- Within the operating range, temperature is found to influence the wear rate only marginally
- Mass loss due to sliding is found to increase initially with load, but the rate of wear if found to decrease at higher loads, mostly due to work hardening effect on sliding surface

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