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Dry Sliding Wear and Mechanical Behavior of Aluminium/Fly ash/Graphite Hybrid Metal Matrix Composite Using Taguchi Method

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ABSTRACT

The experimental investigation of hybrid metal matrix composites with fly ash and graphite reinforced aluminium alloy (Al 6061) composites samples, processed by stir casting route are reported. The aluminium alloy was reinforced with 3 wt.%, 6 wt.%, 9 wt.% fly ash and fixed 3 wt.% of graphite to mixture the hybrid composite. Hardness of the hybrid composite were tested it was found that when the hardness of the hybrid composites can be increased when compared to (Al 6061). The parameters such as load, sliding speed, and reinforcement content were identified will affecting wear rate. The design of experiments (DOE) approach using taguchi method was employed to analyze the wear behavior of hybrid composites. Signal-to-noise ratio and analysis of variance (ANOVA) were used to investigate the influence of parameters on the wear rate.

***Key words*- Aluminium Alloy, ANOVA, DOE, Graphite**

1. INTRODUCTION

Conventional monolithic materials have limitations in achieving good combination of Strength, stiffness, toughness and density. To overcome these shortcomings and to meet the ever Increasing demand of modern day technology, composites are most promising materials of recent interest. Metal matrix composites (MMCs) possess significantly improved properties including high specific strength; specific modulus, damping capacity and good wear resistance compared to unreinforced alloys. There has been an increasing interest in composites containing low density and low cost reinforcements. Among various discontinuous dispersoids used, fly ash is one of the most inexpensive and low density reinforcement available in large quantities as solid waste by-product during combustion of coal in thermal power plants. Hence, composites with fly ash as reinforcement are likely to overcome the cost barrier for wide spread applications in automotive and small engine applications.

Mechanical properties of composites are affected by the size, shape and volume fraction of the reinforcement, matrix material and reaction at the interface. Wear is an important property in the selection of DRAMMCs. Wear is not an intrinsic material property but characteristics of the engineering system which depend on load, speed, temperature, hardness, and the environmental conditions .Wear performances of particulate reinforced aluminium matrix composites reinforced with various reinforcements ranging from very hard ceramic particulates such as SiC and Al_2O_3 to a very soft material such as graphite have been reported to be superior when compared with unreinforced alloys. It is therefore expected that the incorporation of fly ash particles in aluminium alloy has the potential for conserving energy intensive aluminium, and thereby reducing the cost of aluminium products, and at the same time causing a reduction in the weight of the products. Researchers have also reported significant improvements in properties and higher wear resistance by the incorporation of fly ash in aluminium alloy. Graphite and graphite powders are widely used in industrial applications for their excellent dry lubricating properties. So, if a solid lubricant like graphite is contained in the aluminium alloy, it can be released automatically during the wear process and can potentially reduce wear, increase the anti-seizure effects and improve thermal stability.

2. PLAN OF EXPERIMENTS

2.1 Material Selection

(Al6061) alloy is used as the matrix material in the present investigation and has the chemical composition as shown in Table 1. The aluminium alloy was reinforced with 3 wt.%, 6 wt.%, 9 wt.% fly ash and fixed 3 wt.% graphite to synthesize the hybrid composite through liquid metallurgy route. The fly ash and graphite particles with a size range of 53 to 75 µm were used. Fly ash particles being hard in nature improve the hardness, strength and stiffness of the hybrid composite. Graphite imparts excellent self lubricating property to the hybrid composite. A small amount of Mg (0.5 wt. %) was added to ensure good wettability of particles with molten metal. After mixing the melt was poured into a prepared mould for the preparation of specimen.

Table 1 Chemical Composition

ELEMENT	Mg	Fe	Si	Cu	Mn	V	Ti	Al
Weight %	1.08	0.17	0.63	0.32	0.52	0.01	0.02	Remainder

2.2 Preparing Specimen

Fly ash / graphite reinforced Aluminium alloy (Al6061) composites, processed by stir casting route was used in this work. Liquid metallurgy route was used to synthesize the hybrid composite specimens. The matrix alloy was first superheated above its melting temperature and then the temperature was lowered gradually until the alloy reached a semisolid state. The required quantities of fly ash (3, 6 and 9 Wt. %) and graphite (3 Wt % fixed) were taken in powder containers. Then the fly ash and graphite was heated to 450^{o}C and maintained at that temperature for about 20 minutes. A vortex was created in the melt due to continuous stirring by a stainless steel mechanical stirrer with a rotational speed of 650 rpm.

At this stage, the blended mixture of preheated fly ash and graphite particles were introduced into the slurry and the temperature of the composite slurry was increased until it was in a fully liquid state. Small quantities of magnesium were added to the molten metal to enhance wettability of reinforcements with molten aluminium.

Stirring was continued for about 5 minutes until the interface between the particle and the matrix promoted wetting and the particles were uniformly dispersed. The melt was then superheated above the liquid us temperature and solidified in a cast iron permanent mould to obtain cylindrical samples. Sliding wear test specimens were machined from as-cast samples, to obtain cylindrical pins of diameter 10 mm and length 30 mm. The hardness tests were conducted in accordance with the ASTM E10.

2.3 Testing For Mechanical Properties

The Brinnel hardness tests were conducted in accordance with the ASTM E10. Hardness of the hybrid composite was tested. It was found that when the hardness of the hybrid composites can be increased when compared to aluminium alloy (Al 6061).

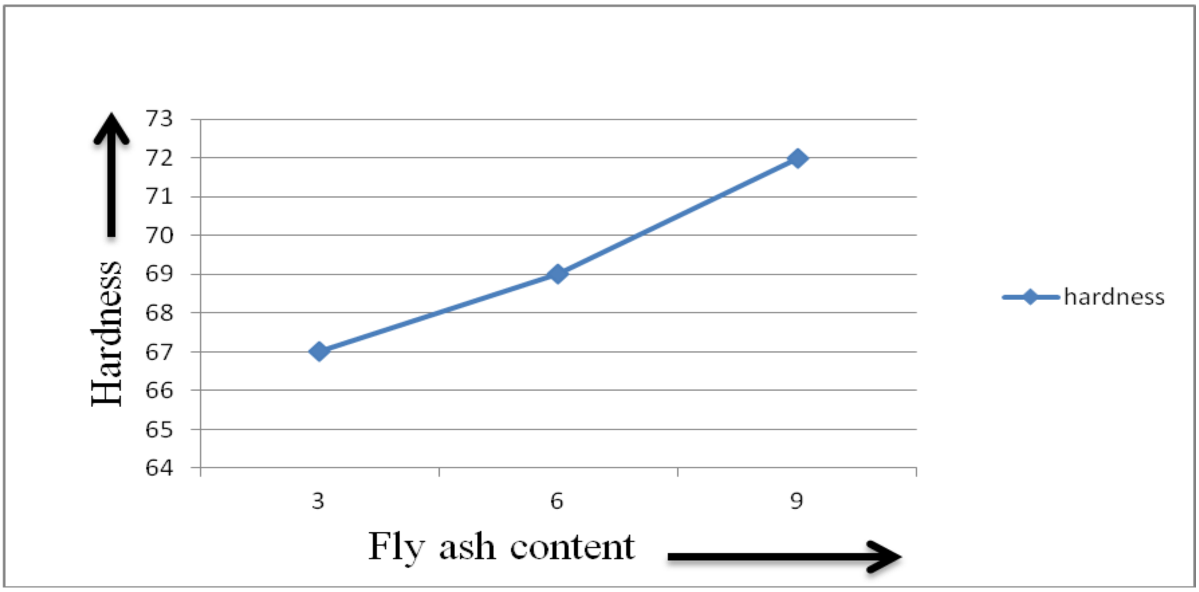

Fig .1 Hardness Level

From this figure 1, it can be clearly shown that when the fly ash content increases at the time hardness value will be increased.

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1224-1230 ISSN: 2249-6645

2.4 Conducting Design Of Experiment Using Taguchi Method

The experimental plan was formulated considering three parameters (variables) and three levels based on the Taguchi technique. The three independent variables considered for this study were load, sliding speed and fly ash content. Of these, the first two are process parameters, and the third is a material dependent parameter. The levels of these variables chosen for experimentation are given in Table 2.

Table 2 Parameter And Their Levels

Level				
Control factors	I	II	III	Units
A. Load	9.81	19.62	29.43	N
B. Speed	2	3	4	(M/S)
C. Fly ash	3	6	9	(wt.%)

3. RESULTS AND DISCUSSIONS

In the present investigation, a L27 orthogonal array was selected and it has 27 rows and 13 columns. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than, or equal to, the sum of the variables. Each variable and the corresponding interactions were assigned to a column defined by Taguchi method. The first column was assigned to load (L), the second column to sliding speed (S), the fifth column to fly ash content (F), and the remaining columns were assigned to their interactions. The response variable to be studied was wear rate.

www.ijmer.com Vol.2, Issue.3, May-June 2012 pp-1224-1230 ISSN: 2249-6645

Table 3 Wear Rate

Load (kg)	Speed (m/s)	Fly ash (Wt %)	Wear rate
1	2	3	0.937
1	2	6	0.7855
1	2	9	0.6322
1	3	3	0.7808
1	3	6	0.6284
1	3	9	0.4741
1	4	3	0.7808
1	4	6	0.4713
1	4	9	0.3161
2	2	3	1.561
2	2	6	1.256
2	2	9	0.9483
2	3	3	1.249
2	3	6	1.099
2	3	9	0.7903
2	4	3	0.937
2	4	6	0.6284
2	4	9	0.4741
3	2	3	2.03
3	2	6	1.571
3	2	9	0.9483
3	3	3	1.405
3	3	6	1.099
3	3	9	0.9483
3	4	3	1.249
3	4	6	0.9426
3	4	9	0.7903

3.1 S/N Ratio Analysis

The influence of control parameters such as load, sliding speed and fly ash content on wear rate has been evaluated using S/N ratio response analysis. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. The S/N ratio response analysis, presented in Table 3 shows that among all the factors, load was the most influential and significant parameter followed by sliding speed and fly ash content. The figure 2 shows the mean of S/N ratios for wear rate graphically and figure 2 depicts the main effects plot for mean wear rate. From the analysis of these results, it can be inferred that parameter combination of L = 9.81 N, S = 4 m/s and F = 9% gave the minimum wear rate for the range of parameter tested.

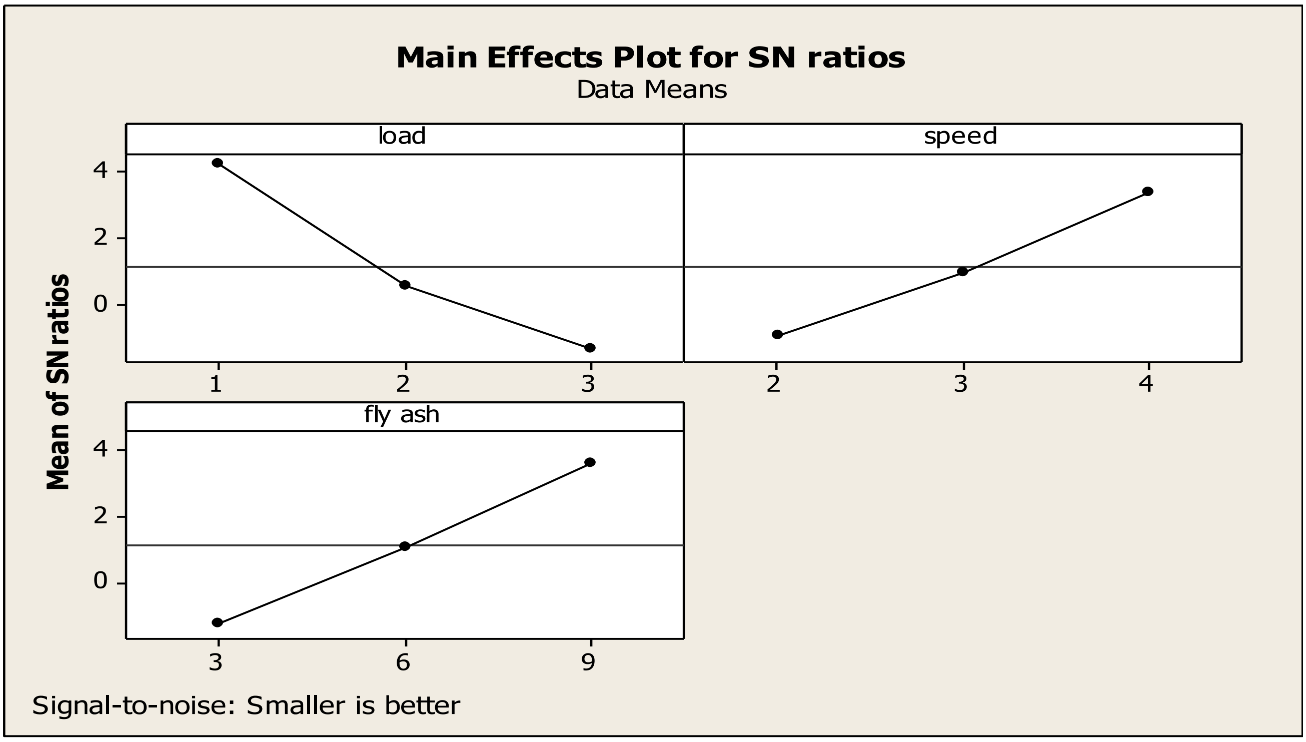

Fig.2 Mean of S/N ratios

Table 4 Response Table For S/N Ratios - Smaller Is Better (Wear Rate)

Levels	load	speed	Fly ash
1	0.6451	1.1855	1.2144
2	0.9937	0.9415	0.9424
3	1.2204	0.7322	0.7024
Delta	0.5753	0.4533	0.5120
Rank	1	3	2

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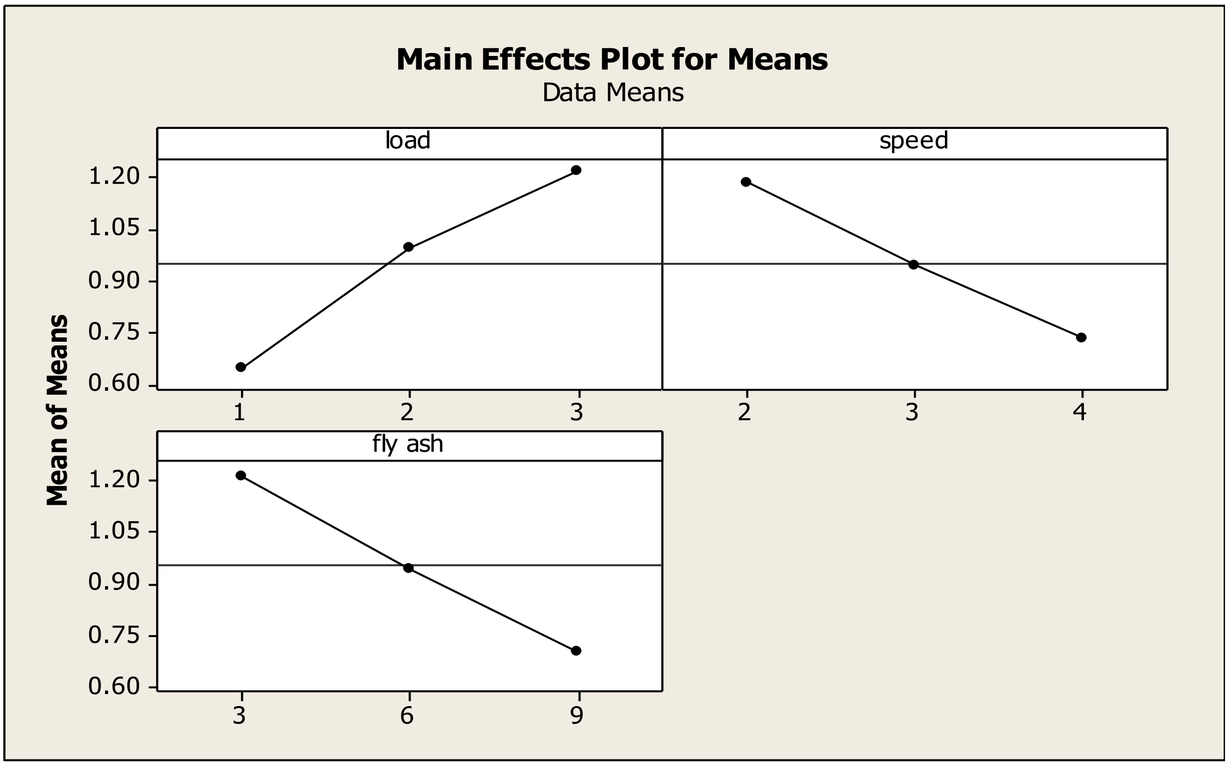

Fig. 3 Main Effects Plot For Mean Wear Rate

3.2 Analysis Of Variance

ANOVA was used to determine the design parameters significantly influencing the wear rate (response). Table 5 shows the results of ANOVA for wear rate. The last column of Table shows the percentage of contribution (P %) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained in the Table 5, that load was the most significant parameter having the highest statistical influence (37.2%) on the dry sliding wear of composites followed by fly ash content (31%) and sliding speed (25.2%).

Table 5 ANOVA

Source of variation	DF	Seq SS	Adj SS	Adj Ms	F-test	P-value	P (%)
L	2	1.51125	1.51125	0.755700	52.472	0.000	37.2
S	2	0.92212	0.92212	0.463228	32.018	0.000	25.2
F	2	1.1701	1.1701	0.590496	40.6284	0.000	30.704
L*S	4	0.11803	0.11803	0.029508	2.04913	0.1800	3.5
L*F	4	0.07157	0.07157	0.017891	1.24253	0.3665	0.0035
S*F	4	0.06783	0.06783	0.016959	1.17760	0.38957	0.0025
ERROR	8	0.1152	0.1152	0.0144			3.1
TOTAL	26	3.9761					100

3.2.1Multiple Linear Regression Models

A multiple linear regression model is developed using statistical software "MINITAB 15".This model gives the relationship between an independent / predictor variable and a response variable by fitting a linear equation to observed data. The regression equation for wear rate is, Wear Rate = 1.57 + 0.288 load - 0.227 speed - 0.0853 fly ash Eq (1)

The above equation can be used to predict the wear rate of the hybrid composites. The constant in the equation is the residue. The regression coefficient (R^2) obtained for the model was 0.90 and this indicates that wear data was not scattered.

3.3 Confirmation Test

In order to validate the regression model, confirmation wear tests were conducted with parameter levels that were different from those used for analysis. The different parameter levels chosen for the confirmation tests are shown in Table 6.

Table 6 Confirmation Test

Experiments	Load (L)	Sliding speed (m/s)	Fly ash content (%)
1	1.5	2.5	3
2	2.25	3	6
3	2.75	3.5	9

Table 7 Wear Rate Level

Experiments	Experimental wear rate	Regression model – predicted wear rate (mm3/m)*10^-6	Error (%)
1	1.142	1.1786	3.20
2	0.972	1.0192	4.85
3	0.823	0.7998	2.81

4. CONCLUSION

The results obtained from S/N ratio response analysis depict that load was the most dominant parameter influencing the dry sliding wear rate of hybrid composites. ANOVA was used to determine the design parameters significantly influencing the wear rate, and it was calculated that load was the most significant parameter having the highest statistical influence (61.12%) on the wear rate of composites, followed by sliding speed (19.6%) and fly ash content (16.03%).A multiple linear regression model was developed and it can be used to predict the wear rate of the hybrid composites.

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