Application of Taguchi Method for Optimization of Process Parameters for Wear loss of LM25/Flyash Composite

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Abstract - Metal matrix composites (MMCs) are now gaining their usage in tribological industries because of their inherent properties like high strength to weight ratio, low wear rate etc. The present study deals with investigation relating to the influence of wear parameters like sliding speed, applied load, reinforcement wt% and sliding distance on the dry sliding wear. A pin-on-disc apparatus was used to conduct the dry sliding wear test. The design of experiment approach was employed to acquire data in controlled way using Taguchi method. Multiple regression analysis, Signal-to-Noise ratio and Analysis of Variance were employed to investigate the wear behaviour of aluminium composite. The incorporation of fly ash as reinforcement material in aluminium matrix material improves the tribological characteristics.

Keywords: Fly ash; Wear; Orthogonal Array; ANOVA; Taguchi Method; Regression.

I. INTRODUCTION

Metal matrix composites (MMCs) have received substantial attention due to their excellent strength, stiffness, lighter, and wear resistance in tribolgological, aerospace & marine industries. Though MMCs possess superior properties, they have not been widely applied due to the complexity of fabrication [4]. The conventional stir casting is an attractive processing method for fabrication, as it is relatively inexpensive and offers wide selection of materials and processing conditions. Stir casting offers better matrix particle bonding due to stirring action of particles into melts [5].

Wear is one of the most commonly encountered industrial problems, leading to frequent replacement of components, particularly abrasion. Abrasive wear occurs when hard particles penetrate a softer surface and displace material in the form of elongated chips. Extensive studies on the tribological characteristics of Aluminium MMCs containing various reinforcements such as silicon carbide, alumina, and fly ash already done by researchers [7–9]. The variables such as composition of the matrix, particle distribution, and interface between the particles and the matrix affect the tribological behaviour of metal matrix composites. The principle tribological parameters such as applied load [11–13], sliding speed [14, 15], and percentage of fly ash control the friction and wear performance.

Fly ash is one of the residues generated in the combustion of coal. The addition of fly ash leads to the increase in wear resistance, hardness, elastic modulus and proof stress compared to unreinforced alloy. The fly ash particle size and its volume fraction also significantly affect the wear properties of composites [16, 17].

The aim of the present study is to investigate the dry sliding wear of stir cast LM25 with 4, 8, and 12 wt.% fly ash reinforced MMCs, using a pin-on-disc type of wear machine. Furthermore, ANOVA was employed to investigate which design parameters significantly affect the wear behaviour of the composite.

II. TAGUCHI TECHNIQUE

The design of experiments (DOE) approach using Taguchi technique has been successfully used by researchers in the study of wear behaviour of MMCs. The DOE process is made up of three main phases: the planning phase, the conducting phase, and the analysis phase. A major step in the DOE process is the determination of the combination of factors and levels which will provide the desired information. Analysis of the experimental results uses a signal to noise ratio to determine the best process designs. The Taguchi technique is a powerful design experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable over some specific variable which is unknown function of these process variables and for the design of high quality systems. This method was been successfully used by researchers in the study of wear rate of aluminium metal matrix composites. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment. The experimental results are analyzed using analysis of means and variance to study the influence of parameters. A multiple linear regression model is developed to predict the wear rate of the hybrid composites. The major aim of the present investigation is to analyse the influence of parameters like load, sliding speed, reinforcement wt% and sliding distance on dry sliding wear of aluminium LM25/Fly ash metal matrix composites using Taguchi technique.

III. EXPERIMENTATION

3.1 Material details:

3.1.1 Matrix material- LM25 alloy

Matrix material LM25 (fig.1), which is commercially available, has advantage of lighter weight & major silicon content of alloy may helps to improve castability. Chemical composition of LM25 as per BS1490:1988 is given in table1.

Table 1 Chemical Composition of LM25 alloy

Composition	Si	Fe	Cu	Mn	Zn	Mg	Ti
Range	6.5-7.5	0-0.55	0-0.2	0-0.35	0-0.1	0.2-0.4	0-0.2
Wt.%	7.24	0.26	0.17	0.24	0.10	0.43	0.05

A good matrix should possess ability to deform easily under applied load, transfer the load onto the reinforcement and evenly distributive stress concentration.

3.1.2 Reinforcement material- Fly ash

Fly ash (Fig.1), obtained from thermal power plant Parali (MH), which is actually industrial waste utilized to produce MMC. As Fly ash has low density, chances of having good wetability between fly ash & matrix Al alloy. Table 2 shows fly content analysis.

Table 2: Chemical composition of Fly ash

Compound	MgO	Al_2O_3	SiO_2	K_2O	CaO	TiO_2	FeO	CuO
Mass %	1.72	29.65	51.4	1.57	2.82	2.54	5.39	4.86

Fig.1 Ingots of LM25 alloy & Fly ash (53-106 micron)

3.2 Fabrication of MMC- Stir casting:

Stir casting (fig.2) is a liquid state method of composite material fabrication in which a dispersed phase (reinforcement) is mixed with matrix metal by means of mechanical stirring. Its advantages lie in its:

- Simplicity, flexibility and applicability for mass production.
- Allows a conventional metal processing route to be used and hence minimizes the final cost of the product.
- Allows very large sized components to be fabricated.

Fig.2 Stir casting set up

3.3 Wear test- Pin-on-disc Set up:

Wear samples are prepared with in the form of pin (Length 30 mm & diameter 5 mm as per as per ASTM G99-95 standards). Contact surfaces were prepared by grinding against 600-grit silicon carbide paper and cleaning with alcohol. Experiments have been conducted in the Pin-on-disc type Friction and Wear monitor (DUCOM; TL-20) with data acquisition system which was used to evaluate the wear behaviour of the composite, against hardened ground steel disc (En-32) having hardness 65 HRC and surface roughness (Ra) 0.5 µm. It is versatile equipment designed to study wear under sliding condition. Sliding generally occurs between a stationary Pin and a rotating disc. The disc rotates with the help of a D.C. motor having speed range 0-2000 rev/min with wear track diameter 50 mm which could yield sliding speed 0 to 10 m/sec. Load is to be applied on pin (specimen) by dead weight through pulley string arrangement.

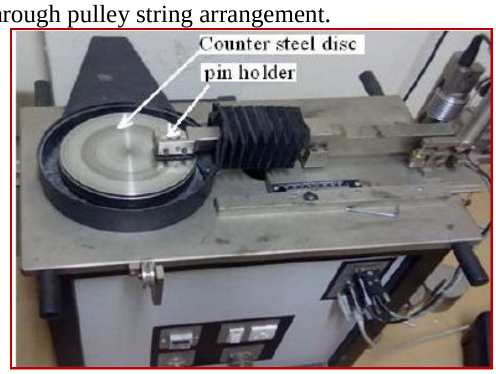

Fig.3 Pin-on-disc set up [COEP, Pune]

3.4 Plan of Experiment- L9 Orthogonal Array

The experiment specifies three principle wear testing conditions including Sliding distance (A), sliding speed (B), applied load (C) and percentage of fly ash (D) as the process parameters. The experiments were carried out to analyze the influence of above parameter on dry sliding wear of MMCs. Control factors and their levels are shown in Table 2. Table shows the L9 (3)4 orthogonal array. If the full factorial design were used, it would have 34 = 81 runs. The L9 (34) array requires only 9 runs, a fraction of the full factorial design. The standard Taguchi experimental plan with notation L9 (3)4 was chosen based upon the degree of freedom. The degrees of freedom for the orthogonal array should be greater than or at least equal to those of the process parameters.

Table 3: Control factor & their level

Symbol	Design parameter	Level1	Level2	Level3
A	Sliding distance (m)	636	1272	1909
B	Sliding velocity (m/min)	21	42	64
C	Applied Load (N)	10	20	30
D	Fly ash wt.%	4	8	12

Table 4: L9 (34) Orthogonal Array with wear

Experiments	Control factors				Wear (micron)
	A	B	C	D	
1	636	21	10	4	78
2	1272	42	10	8	133
3	1909	64	10	12	262
4	1272	21	20	12	113
5	1909	42	20	4	170
6	636	64	20	8	100
7	1909	21	30	8	110
8	636	42	30	12	111
9	1272	64	30	4	145

IV. RESULTS & DISCUSSION

4.1 Multiple Linear Regression Model

The parameters sliding distance, load, sliding speed and fly ash content were considered in the development of mathematical models for the wear rate. The correlation between these factors and wear rate on the LM25/fly ash composite were obtained by multiple linear regressions. The standard commercial statistical software package was used to derive the mathematical model in the form as:

Wear Loss = -12.5292 + (0.06625 * A) + (1.6196 * B) – (1.7833 * C) + (3.875 * D)

R2 = 0.8928

In multiple linear regression analysis, R2 is the regression coefficient (R2 = 90%) for the models, which indicate that the fit of the experimental data is satisfactory.

4.2 S/N Ratio Analysis

The influence of control parameters sliding distance, load, sliding speed and fly ash content on wear has been evaluated using S/N ratio response analysis. The wear rate was considered as the quality characteristic with the concept of "the smaller-the-better" and calculated by using following equation. Table 5 shows S/N ratio values of wear.

$$\text{S/N ratio} = -10 \text{ Log}_{10} \left[\frac{1}{n} \sum y^2 \right]$$

Here n is 1 (wear only) & y is response value (wear value).

Table:5 S/N ratio

Experiment	Wear (micron)	S/N ratio (dB)
1	78	-37.84
2	133	-42.47
3	262	-48.36
4	113	-41.06
5	170	-44.60
6	100	-40.0
7	110	-40.82
8	111	-40.90
9	145	-43.23

Table 5 shows S/N ratio analysis. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. 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. Higher the difference between the mean of S/N ratios, the more influential will be the control parameter.

Table: 6 S/N ratio values by factor level

Level ⇩	A	B	C	D
1	42.89	39.90	39.58	41.88
2	41.88	42.65	42.25	41.00
3	41.65	43.56	44.60	43.44
Delta	0.750	2.23	2.56	0.253
Rank	3	2	1	4

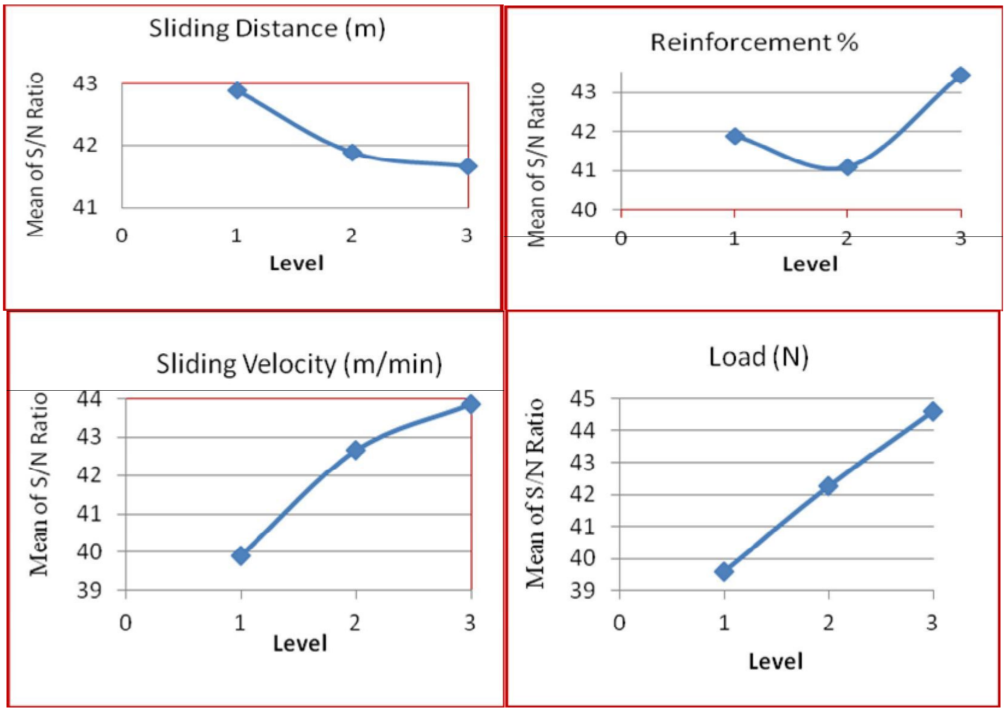

Fig.4 Effect of process parameter on wear loss

4.3 Analysis of Variance (ANOVA):

Table 7 shows results of ANOVA for wear rate obtained by using MiniTab software.

Table: 7 ANOVA results

Source of variation	DOF	Sum of Square SS	F-Value	P- Value	%
A	2	1907	3.01	0.158	9.04
B	2	7061	11.15	0.029	33.50
C	2	10668	16.84	0.015	50.60
D	2	1441	2.28	0.206	6.85
Error	2				
Total	8				100

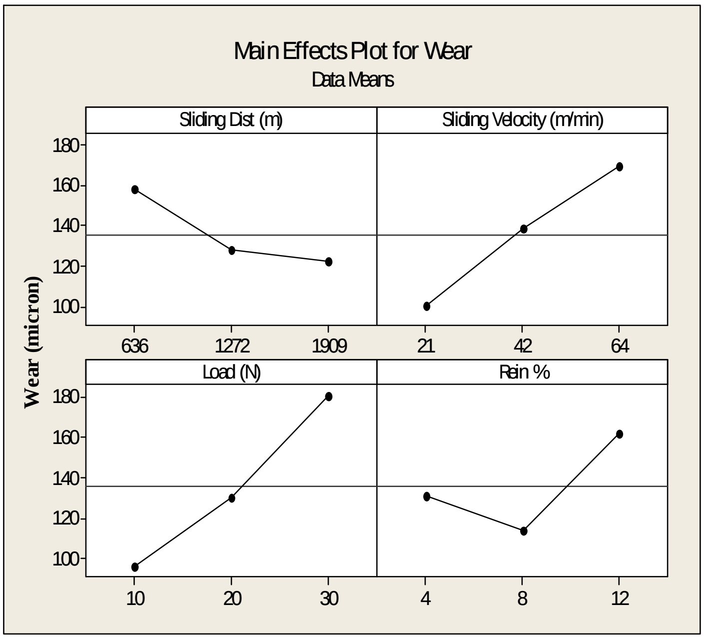

Fig.5 Main effect plots for Wear

ANOVA was used to determine the design parameters significantly influencing the wear rate (response). Table 7 shows the results of ANOVA for wear. This analysis was evaluated for a confidence level of 95%, that is for significance level of α=0.05. The last column of Table 7 shows the percentage of contribution (%) of each parameter on the response, indicating the degree of influence on the result. It can be observed from the results obtained that Load C was the most significant parameter having the highest statistical influence (50.60%) on the dry sliding wear of composites followed by sliding velocity B (15.6%) and sliding distance A (9.04%).When the P-value for this model was less than 0.05, then the parameter or interaction can be considered as statistically significant. This is desirable as it demonstrates that the parameter or interaction in the model has a significant effect on the response. From an analysis of the results obtained in Table 7, it is observed that the interaction effect of load C & sliding speed B is significant influencing wear rate of composites.

V. CONCLUSION

1. Aluminium matrix reinforced with 4, 8 and 12 wt. % fly ash was successfully prepared by stir-casting process, and the wear behaviour of the composites was investigated using pin-on-disc machine.
2. L9 orthogonal array was adopted to investigate the effects of operating variables on the abrasive wear of various composites.
3. The applied load and sliding speed are the most influencing factors, and it is observed that their contributions to wear behaviour are 50.60% and 15.60%, respectively.

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