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Optimization on Friction and Wear Process Parameters Using Taguchi Technique

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ABSTRACT

Novel LM24 hybrid composite materials varying in the percentage of SiC particulate reinforcement were fabricated by stir casting technique (liquid metallurgy route) and optimized at different parameters like applied load, sliding speed, sliding distance by taguchi method. The specimens were examined by Rockwell hardness test machine, Pin on Disc, Scanning Electron Microscope (SEM) and Optical Microscope. A plan of experiment generated through Taguchi's technique is used to conduct experiments based on L_9 orthogonal array. The developed ANOVA and the regression equations were used to find the optimum wear as well as co-efficient of friction under the influence of applied load, sliding speed, sliding distance. The dry sliding wear resistance was analyzed on the basis of "smaller the best". Finally, confirmation tests were carried out to verify the experimental results.

Keywords: *Hybrid metal matrix composites, Stir-cast, Dry sliding wear, Orthogonal array, Taguchi technique, analysis of variance.*

I. INTRODUCTION

In the recent past, research has shifted from monolithic materials to composite materials to meet the present global demand for light weight, high performance, eco-friendly, wear and corrosion resistant materials. The Al matrix composite reinforced with SiC and B_4C particulate are a new range of advanced materials. The best part of effort in Al matrix composite has been directed towards development of high performance composite with high strength and good tribological properties for using in automotive and aerospace application.

N. Natarajan, S. Vijayarangan and I. Rajendran [1] recommended SiC particulate reinforcement of metal matrix is more appropriate aspirant material for automobile purpose, but a new friction material is to be developed. S. Basavarajappa and G. Chandramohan [2] inspected in detail sliding speed, load, sliding distance, percentage of reinforcement and mutual effect of these factors, which manipulate the dry sliding wear performance of matrix alloy (Al2219) reinforced with SiC. N. Radhika, R. Subramanian and S. Venkat Prasat [3] found taguchi technique as a valuable technique to deal with responses influenced by multi-variables. It is formulated for process optimization and detection of optimal combination of the parameters for a given response. This method significantly reduces the number of trials that are required to model the response function compared with the full factorial design of experiments. The most important benefit of this technique is to find out the possible interaction between the factors. In view of the above article, an assessment is made to investigate the outcome of sliding speed, load, sliding time and volume fraction of reinforcement on the dry sliding wear behavior of the particulate reinforced Al-6061 alloy with a constant weight percentage (3%) of B_4C particulate and varying range (5,10,15%) of SiC particulate composites using taguchi method. The Analysis of variance was used to find the percentage contribution (Pr) of various process parameters and their correlations on dry sliding wear of the hybrid composite materials.

II. MATERIAL SELECTION

In the present investigation, Dry sliding wear tests were performed on SiC and B_4C particulates reinforced LM24 alloy matrix composite. Table1 shows the nominal composition weight percentage of matrix materials. The hardness measurements were made by applying a load of 100kg and the average is calculated from 10 different values of the experiments. The density measurements were all set according to the ASTM standard C1270-88. The value of hardness and density for matrix material were 85 BHN and 2.79 g/ cm^3 respectively in tempered condition. The particulate morphology study results such as shape of both reinforcements were angular-irregular and size of SiC (30-70μm) and B_4C (5-20 μm).

A. Manufacturing Of The Hybrid Composites Material

Stir casting technique is one of the popular Liquid Metallurgy Route (LMR) and also known as a very promising route for manufacturing near net shape hybrid metal matrix composite components at a normal cost [4]. In this present work, stir casting technique was used to fabricate LM24 alloy with constant weight percentages of SiC (10 %) and B_4C (4%) reinforcements. In order to achieve good binding between the matrix and particulates, one weight percent of magnesium alloy is added. The experimental set up was shown in figure 1. The stir casting furnace is mounted on the floor and the temperature of the furnace is precisely measured and controlled in order to achieve sound quality composite. Two thermocouples and one PID controller were used for this purpose. As mild steel materials are having high temperature stability, they are selected as stirrer rod and impeller.

This stirrer was connected to 1HP DC Motor through flexible link and was used to stir the molten metal in semi solid state. The screw operator lift is used to bring the stirrer in contact with the composite material. The melt was maintained at a temperature between 750 to 800 ^oC for one hour. Vortex was created by using a mechanical stirrer. Weighed quantity of SiC (10wt.%) along with 4 weight percentage of B_4C particulate, preheated to 600ºC were added to the melt with constant stirring for about 10min at 500 to 650rpm . After complete addition of the particles to the melt, the composite alloy was tilt poured into the preheated (300ºC) permanent steel mould and allowed to cool in atmospheric air. The billet was then removed from the mould and machined for required dimensions. The uniform distribution of particulates reinforced in the matrix was examined with the help of SEM test. The SEM of unreinforced alloy and the composite are shown in figure 2.

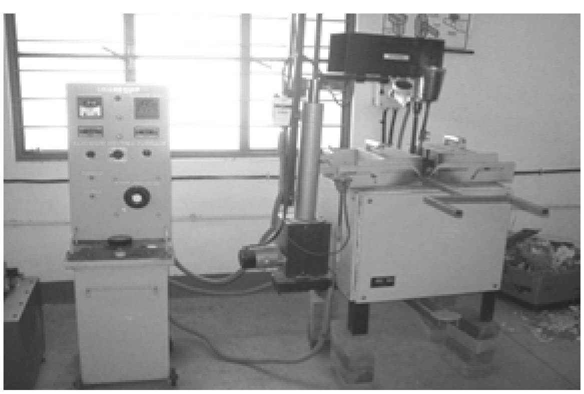
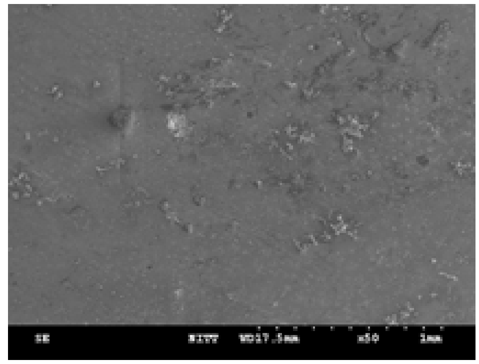
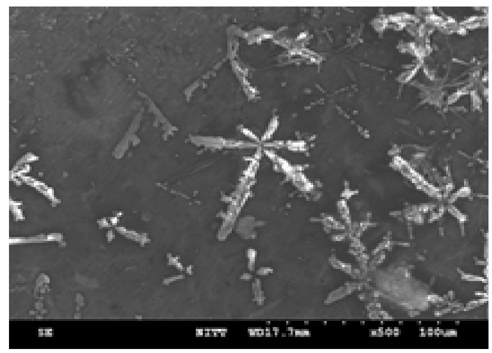


Figure 1: Stir casting setup



(a)



(b)

Figure 2: SEM of LM24/10%SiC/4%B_4C at (a) X50 and (b)X500 magnification

B. Mechanism of Wear Test

The composite specimens were rubbed against hardened steel. Dry sliding wear tests were carried out using pin - on- disc type wear tester at different parameters like sliding speed, applying load, Sliding time and percentage of reinforcement were varied in the range given in Table 1.

Table 1: Factor and Levels

Level	Load (N)	Speed (rpm)	Sliding distance (m)
1	10	200	1000
2	20	300	2000
3	30	400	3000

III. PLAN OF EXPERIMENT

The experiments were conduct as per the standard orthogonal array. 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 at least equals sum of those of wear parameters. In the present investigation an L_9 orthogonal array was chosen as shown in Table 2.

The wear parameters chosen for the experiment are (i) applied load (ii) sliding speed (iii) sliding distance. The experiment consists of 9 tests (each row in the L_9 orthogonal array) and the columns were assigned with parameters. The first column was assigned to the applied load (L), second column was assigned to the sliding speed (S), third column was assigned to the sliding distance (D). The experiments were conducted as per the orthogonal array with level of parameters given in each array row. The output to be studied is wear rate and coefficients of friction of the test samples are repeated three times corresponding to 27 tests. The experimental observations are further transformed into Signal to noise ratio. The response to be studied was the wear rate and coefficient of friction with the objective as smaller the best, which is calculated as logarithmic transformation of loss function as shown below,

$$(S/N) = -10^{*} \log 1/n (\sum Y_i^2) \qquad \text{-------Eqn (1)}$$

Where 'n' is the numbers of observations, 'Y_i' is the measured value of wear rate and coefficient of friction. It is suggested that quality characteistics are optimised when the S/N response is as smaller as possible.

Table 2: L_9 Orthogonal Array

S.No	Load (N)	Speed (rpm)	Sliding Distance (m)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 4: Response for S/N Ratio (Wear Rate)

Level	Applied Load (N)	Sliding Speed (rpm)	Sliding distance (m)
1	49.92	47.60	48.03
2	48.04	48.43	48.14
3	47.04	48.97	48.83
Delta	2.87	1.37	0.80
Rank	1	2	3

TABLE 3: OA & Results oF HMMC'S

Ex. No	Applying Load(N)	Sliding Speed (rpm)	Sliding Distance (m)	Wear Rate mm^3/m Wr	S/N Ratio for Wear (db)
1	10	200	1000	0.003681559	48.67936
2	10	300	2000	0.003240223	49.7885
3	10	400	3000	0.002727113	51.28594
4	20	200	2000	0.004293277	47.34422
5	20	300	3000	0.003788362	48.43097
6	20	400	1000	0.003824921	48.34755
7	30	200	3000	0.004581294	46.78024
8	30	300	1000	0.004427351	47.07712
9	30	400	2000	0.004328773	47.2727

V. RESULTS AND DISSUSSIONS

Experimental values of wear rate and the calculated values of signal to noise ratio for a given response using Equation 1, and are listed in table 3. The Taguchi's technique suggested that the analyzing of signal to noise ratio using conceptual approach that involves graphing the special effects and visually making out the significant aspects.

A. Results of Statistical Analysis of Experiments

The investigational results and calculated values were obtained based on the plan of experiment and then the results were analyzed with the help of commercial software MINITAB 14 as specially utilized for the design of experiment and statistical analysis of experiment appliances. The influence of controlled process parameters such as applied load, sliding speed and sliding distance has been analyzed and the rank of involved factors like wear rate which supports signal to noise response is given in tables 4 . It is evident from the tables that, among these parameters, load is a dominant factor on the wear rate. The influence of controlled process parameters on wear rate are graphically represented in figures 4 and 5. Based on the analysis of these experimental results with the help of signal to noise ratio, the optimum conditions resulting in wear rate and are also shown in figures 4 and 5. The figures clearly indicate that the first level of load and third level of both sliding speed and sliding distance are the optimum points. Hence the optimum conditions and the results are given in table 5.

Table 5: Optimum Level Process Parameters for Wear Rate

Ex. No	Applying Load(N)	Sliding Speed (rpm)	Sliding Distance (m)	Wear Rate mm^3/m Wr	S/N Ratio for Wear (db)
1	10	400	3000	0.002727113	51.28594

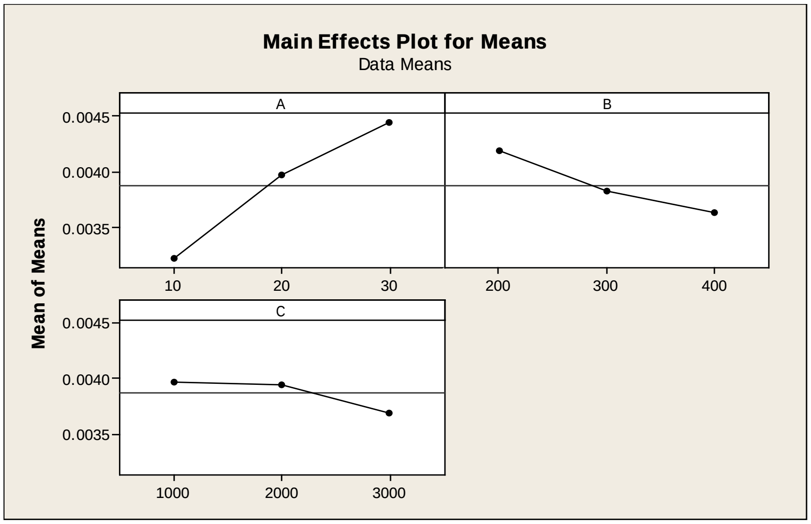


Figure 4: Main Effects plot for Means-Wr

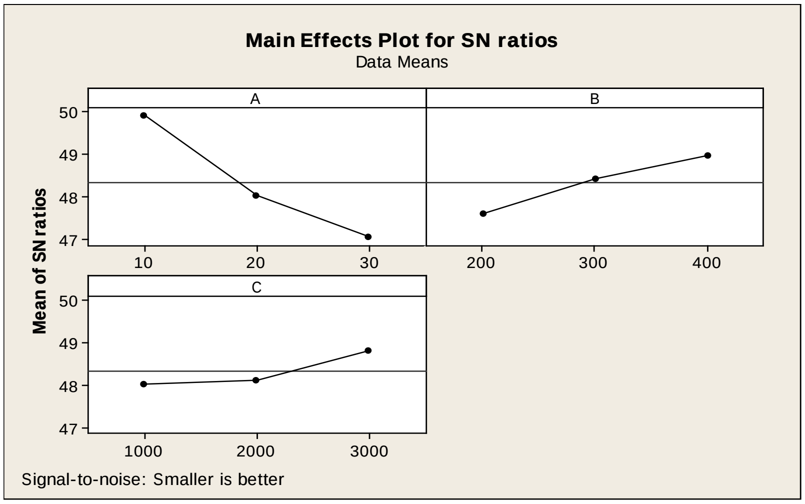


Figure 5: Main Effects plot for S/N ratios – Wr

B. Analysis Of Variance For Wear Rate

Tables 6 shows the results of the analysis of variance on the wear rate for SiC and B_4C particulates reinforced LM24 alloy matrix composite. This analysis is carried out at a level of 5% significance that is up to a confidence level of 95%. The last column of the table indicates the percentage of contribution (Pr) of each factor on the total variation indicating the degree of their influence on the results.

From the table 6, one can easily observe that the load factor has grater influence on wear rate (Pr-L=77.3798%). Hence applying load is an important control process parameter to be taken into account while wear process. Applied load is further followed by sliding speed (Pr-S=15.6615%), and sliding distance (Pr-D=4.1616%).

Table 6: Analysis Of Variance For Wear Rate (mm^3/m)

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr%
L(N)	2	0.000002306	0.000002306	0.000001153	111.6588	0.0125	77.3798
S(rpm)	2	0.000000483	0.000000483	0.000000242	23.3972	0.1416	15.6615
D(m)	2	0.000000144	0.000000144	0.000000072	6.9514	0.0812	4.1616
Error	2	0.000000021	0.000000021	0.0000000105			2.7971
Total	8	0.000002953					100

D. Multiple Linear Regression Models

Statistical software MINITAB R16 is used for developing a multiple linear regression equation. This developed model gives the relationship between independent / predictor variable and a response variable by fitting a linear equation to the measured data.

The regression equation developed for wear rate is,

$$Wr = 0.00376 + 0.000061\ L - 0.000003\ S - 0.000001\ D \quad \text{----Eqn(2)}$$

R-Sq = 96.6%

VI. CONFIRMATION EXPERIMENT

Finally, confirmation tests were performed to identify the optical parameter values from the experimental analysis as mentioned in table 7 and 8. The mathematical model was developed with the help of regression equations (2 & 3) and also the comparison result values obtained experimentally were analyzed.

Table 7: Confirmation Experiment for Wear Rate

Level	Load (N)	Speed (rpm)	Sliding distance (m)
1	16	220	1200
2	22	280	1800
3	28	360	2600

Table 8: Result of Confirmation Experiment and their Comparison with Regression Model

Exp. No	Exp. Wear Rate (mm^3/m)	Reg. model equ(1), Wear Rate(mm^3/m)	% Error
1	0.002942	0.002876	2.24
2	0.002492	0.002462	1.20
3	0.0019091	0.001788	6.34

From the analysis, the actual wear rate is found to be varying from the calculated one using regression equation and the error percentage ranges between 1.20% to 6.34% for wear rate. As these values are closely resembling the actual data with minimum error, design of experiments by Taguchi method was successful for calculating wear rate from the regression equation.

VII. CONCLUSIONS

Taguchi's method is used to find the optimum conditions for dry sliding wear of the hybrid metal matrix composite materials. The following are the conclusions drawn from the present study.

1. Optimum wear rate was obtained from the experiment using Taguchi's method.
2. The wear rate is dominated by different parameters in the order of applied load, sliding speed, sliding distance. The ANOVA test

concluded that as applied load increases the wear rate also increases significantly.

3. 400rpm sliding speed, 10N applied load, 3000m sliding distance are the optimum conditions for wear rate.
4. Applied load (77.379%) is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear rate of the composites among the other factors such as sliding speed (15.6615%) and sliding distance (4.1616%).
5. From confirmation tests, the errors associated with wear rate ranges between 1.20% to 6.34% resulting in the conclusion that the design of experiments by Taguchi method was successful for calculating wear rate from the regression equation.

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