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OPTIMIZATION OF TRIBOLOGICAL PROPERTIES IN A356/10SiC/5Gr HYBRID COMPOSITE USING TAGUCHI METHOD

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Abstract: *In present study, the tribological behavior of hybrid composites with A356 aluminum alloy matrix reinforced with 10 wt.% of SiC and 5 wt.% of graphite was investigated using the Taguchi method. The composites were produced by the compocasting procedure. The tribological properties were studied using block-on-disk tribometer under lubricated sliding conditions at different normal loads (40N, 80N and 120N), sliding speeds (0.25 m/s, 0.5 m/s and 1 m/s) and sliding distances (150 m, 300 m and 1200 m). Analysis of the wear rate results was performed using the ANOVA technique. The lowest level of wear rate corresponded to the contact conditions with normal load of 40N, sliding speed of 1.0 m/s and sliding distance of 1200 m.*

Keywords: *Aluminum hybrid composites, optimization, SiC, Graphite, wear, Taguchi method*

1. INTRODUCTION

Composites with metal matrix (MMCS) are materials which possess excellent possibilities for development and contemporary material sciences. Lately, especially particle reinforced aluminum matrix composites, attract considerable amount of attention because they have the potentials of satisfying the recent demands of advanced engineering applications, such as for example demands of automobile and aerospace industries [1, 2].

Hybrid composites can have engineering combination of two or more forms of reinforcement like fibers, short fibers, particulates and whiskers. It can have different materials as reinforcement like silicon carbide - graphite (SiC - Gr), silicon carbide - alumina (SiC - Al_2O_3), boron carbide - graphite (B_4C - Gr), graphite - alumina (Gr - Al_2O_3), and organic reinforcements are also used like fly ash etc [3, 4].

Just by choosing the right combination of particles for material reinforcement, their performance depends on it because some of the parameters for processing are directly connected with reinforcement particles. However, the final properties of the hybrid reinforcement depend on individual properties of the selected reinforcement and the matrix alloy. A few of such parameters are reinforcement type, size, shape, modulus of elasticity, hardness, distribution in the matrix among others [1-4].

The fabrication cost of aluminum metal matrix composites is low so it is manufactured on a large scale and is one of the most extensively used product worldwide. Aluminum metal matrix composites (AMMCs) have many advantages, including higher strength, abrasion and impact resistant, higher wear resistance, higher thermal conductivity and lower coefficient of friction and exactly for already mentioned advantages they became the substitute for conventional materials. The application area of AMMCs is very wide and it is usually used for production of engine pistons, cylinders barrel, connection rods, elements of vehicles braking systems, cardan shafts, gears, valves, turbines, belt pulleys, turbo-compressors housings of pumps and supporting parts and so on [5-8].

Numerous scientists and researchers have done extensive research on mechanical and tribological behaviours of composite materials for their characteristics. Researches of these behaviours are still in the process because of the increased use in aerospace, automotive, marine, electronic and manufacturing industries.

Shubhranshu Bansal and J. S. Saini have conducted a research on mechanical and wear properties of composite materials. As matrix material they used Al359 reinforced by silicon-carbide particles and silicon carbide/graphite manufactured in stir casting process. They concluded that the hardness of Al359-silicon carbide composite is better than that of Al359-silicon carbide graphite composite. And in tribological testing they showed that the wear resistance of Al359 alloy is increased by reinforcement of material silicon-carbide/graphite in high load conditions, sliding speed and sliding distance [9].

B. Pavithranetet al. have completed the studies of mechanical and tribological properties of hybrid composites with Al6061 matrix. Experiments of wear were conducted on disc dry sliding test rig with sliding velocity of 2 m/s and 4m/s under load of 30N and 50N. Varying the reinforcement percentage of SiC (0% and 8%) and Gr (0%, 2% and 4%) they noticed that by increasing reinforcement percentage, wear rate decreases. They also concluded that by increasing sliding velocity, wear rate also increases, whereas the influence of load is minimal on the applied load range on wear rate [10].

Gajendra Dixit and Mohammad Mohsin Khan investigated the impact of the change graphite particle dimensions in partial lubricated sliding wear behavior of 10 wt.% SiC reinforced aluminum composites with the help of a pin on disc wear testing machine. Composited were prepared in liquid metallurgy route method whereas the tests on wear were done on pin-on-disc machine. They noticed that wear rate increased with load and speed. They concluded that samples' testing in oil plus graphite lubricated conditions led to less wear rate than that in oil alone. Then, that by adding 5 wt.% graphite (7-10 µm) to the oil lubricant led to minimum wear rate, and composites reached the lowest wear rate value whereas matrix alloy reached the highest. In the work they showed that wear rate coefficient decreases especially on samples at low loads, and additionally it reduces wit addition of graphite to the lubricating oil [11].

T. Pratheep Reddy and N. Amara Nageswara Rao using Taguchi's technique studied the effect of applied load, speed and track diameter on wear rate intensity. They studied the properties of wear and friction of hybrid metal matrix composite with Al6061 alloy as base material and reinforcements of SiC and Gr. Using Taguchi's technique they concluded that considered factors have an impact on wear rate intensity and friction coefficient and they calculated the optimal variant for reaching minimal wear intensity: load 50N, speed 1000 rpm and track diameter 110 mm. Also, they concluded that composite wear resistance increases by addition of SiC and Gr particles and that the wear intensity is relatively lower for composites in relation to pure material matrix [12].

Taguchi optimization was used by many researchers in order to optimize tribological properties in aluminum hybrid composite. Design of experiments Taguchi method has in recent years become popular tool for engineering optimization due to its simplicity and robustness.

The aim of this work is to study tribological behavior of hybrid composites with A356 matrix reinforced with 10 wt.% of silicon carbide and with 5 wt.% of graphite. The experiments were conducted in lubricated conditions so as to find out new information and to carry out optimization of hybrid composites. The analysis of impact of load, sliding speed and sliding distance was performed using the Taguchi method.

2. EXPERIMENT

2.1 Materials and method of fabrication

In the present study, aluminum alloy A356 used as matrix, 10 wt.% of silicon carbide SiC (39 µm) and 5 wt.% of graphite (35 µm) as reinforcement. The composites were prepared in the compocasting process. A356 is an aluminum alloy of the following chemical composition: Si (7.20 wt.%), Cu (0.02 wt.%), Mg (0.29 wt.%), Mn (0.01 wt.%), Fe (0,18 wt.%), Zn (0.01 wt.%), Ni (0.02 wt.%), Ti (0.11 wt.%) and the rest is Al [13].

2.2 Wear analysis

The tests were performed in lubricated sliding conditions on the samples hybrid composites. Tribological tests are done on advanced and computer supported tribometer with block-on-disc contact pair in accordance with ASTM G77 standard. Samples are of 15.75 mm x 10.16 mm x 6.35 mm in size, whereas the counter body discs of 35 mm in diameter were made of steel 90MnCrV8 with the hardness of 62-64 HRC [14, 15].

Examinations were conducted according to the designed experiment plan where the values of loads are 40 N, 80 N and 120 N, of sliding speed are 0.25 m/s, 0.5 m/s and 1 m/s, and of sliding distance are 150 m, 300m and 1200m. The objective of the study is to achieve the minimum wear rate.

3. DESIGN OF EXPERIMENTS

The Design of the experiment (DOE) is used in Taguchi method to achieve the most significant data while conducting minimal number of experiments. Taguchi optimization is an experimental optimization technique that uses the standard orthogonal arrays for forming the matrix of experiments, which enables not only conducting minimal number of experiments but also reaching better value level of each parameter. Signal-to-noise (S/N) ratios are used in data analysis in Taguchi method. There are three basic categories to seek the best results of experiments; these are the nominal-the-better, the larger-the-better, and the smaller-the-better. The optimal setting is the parameter combination with the highest S/N ratio [16, 17, 18].

The S/N ratio for wear rate using smaller-the-better characteristic given by Taguchi is as follows:

$$S/N = -10\log\frac{1}{n}\left(\sum_{i=1}^{n} y_i^{\,2}\right), \qquad (1)$$

where y_1, y_2.....y_n are the response of wear rate and n is the number of observations.

In this study, the experimental design was according to an L27 orthogonal array (OA) based on the Taguchi method, while using the Taguchi OA would significantly reduce the number of experiments. The control factors were load (L), sliding speed (S), and sliding distance (D) (table 1). For each process variable, three levels were considered.

Table 1. Control factors with their levels and SI units

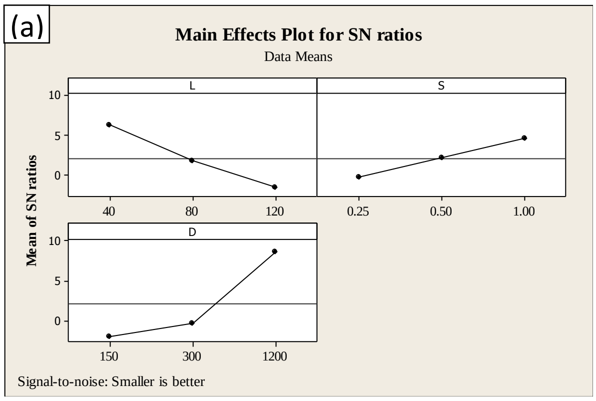
Control factors	Units	Level		
		I	II	III
Load (L)	N	40	80	120
Sliding speed (S)	m/s	0.25	0.50	1.00
Sliding distance (D)	m	150	300	1200

Experimental wear rate results, together with their transformations into S/N ratio, are shown in table 2.

The signal to noise ratio for each parameter is presented in figure 1 (a). In figure 1 (b) is shows interaction plot for each factor for which parallel plot denotes no interaction while crossing indicates significant interaction.

Table 2. L27 orthogonal array for experimentation

	Load	Sliding Speed	Sliding distance	Wear rate (mm^3 x 10^{-3}/m)	S/N ratio (db)
1	40	0.25	150	0.926	0.668
2	40	0.25	300	0.813	1.798
3	40	0.25	1200	0.273	11.277
4	40	0.50	150	0.680	3.350
5	40	0.50	300	0.713	2.938
6	40	0.50	1200	0.239	12.432
7	40	1.00	150	0.564	4.974
8	40	1.00	300	0.551	5.177
9	40	1.00	1200	0.202	13.893
10	80	0.25	150	1.879	-5.479
11	80	0.25	300	1.328	-2.464
12	80	0.25	1200	0.458	6.783
13	80	0.50	150	1.426	-3.082
14	80	0.50	300	1.033	-0.282
15	80	0.50	1200	0.372	8.589
16	80	1.00	150	1.093	-0.772
17	80	1.00	300	0.818	1.745
18	80	1.00	1200	0.299	10.487
19	120	0.25	150	3.158	-9.988
20	120	0.25	300	2.322	-7.317
21	120	0.25	1200	0.756	2.430
22	120	0.50	150	1.941	-5.761
23	120	0.50	300	1.588	-4.017
24	120	0.50	1200	0.561	5.021
25	120	1.00	150	1.207	-1.634
26	120	1.00	300	1.059	-0.498
27	120	1.00	1200	0.423	7.473



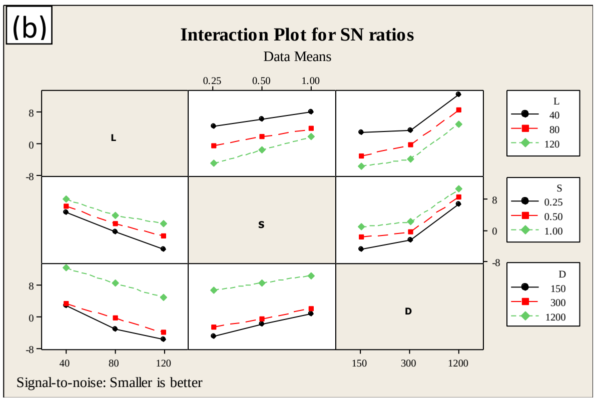


Figure 1. Graphical data of wear rate for smaller is better (a) main effects plot for S/N ratios (b) interaction plot for S/N ratios

According to signal to noise ratio for each parameter, factor levels can be determined for optimal wear rate base option. Factor optimal base option is L1S3G3, which means that the fist factor is on the first level, and the other two on the third.

4. RESULTS AND DISCUSSION

4.1 Wear analysis

Analysis of variance (ANOVA) is used for the analysis of experimental results and identification of factors which have significant impact on wear rate. The results of ANOVA analysis of considered factors and their interaction on wear rate ratio are given in table 3. The analysis was realized at 5 % significance level and a 95 % confidence level. The p values or probability values show the level of significance of each factor [19, 20]. In general the term having p-value less than 0.05 considered to have significant effect.

The percentage contribution by each of the process parameter in the total sum of the squared deviations was used to evaluate the importance of the process parameter change on the performance characteristic. From the sum of squares data contribution of each parameter was computed using equation (2).

$$\text{Contribution factor}(\%) = \frac{SS_f}{SS_T} \times 100 \qquad (2)$$

where SS_f is the sum of squares of factor and SS_T is the total sum of squares of all the parameters. This research was useful in achieving optimal value of considered factors so that the minimal wear rate value could also be achieved.

Analysis of Variance was carried out using Minitab 16. As it is given in table 3, the biggest impact on wear rate has the sliding distance with percentage contribution of 59.63%. Moreover, the impacts of the following factors can also be noticed: load (28.137%) and sliding speed (10.36%). To determine the model significance and individual parameter apart from probability (p-value), Fischer test (F-value) can also be applied. According to F-value the interaction between factors (load) x (sliding speed), (load) x (sliding distance) and (sliding speed) x (sliding distance) is also significant. The ranking of factors on the base of conducted analysis is given in table 4. The most influential factor is sliding distance, then follows load and finally sliding speed.

Table 4. Response table for signal to noise ratios

Level	L	S	D
1	6.279	-0.255	-1.969
2	1.725	2.132	-0.324
3	-1.588	4.538	8.709
Delta	7.867	4.793	10.679
Rank	2	3	1

According to conducted ANOVA analysis and results' analysis, the dependence among factors can be shown with respect to wear rate. Contour plots and 3-D surface plots were given so as to interpret results graphically.

Based on figures 2, 3, 4 (a) and (b) it is possible to calculate the parameter levels by which minimal wear rate values are achieved. More precisely, minimal wear rate value is achieved at lower load values and at higher sliding distance values. Wear rate depending on the sliding distance and sliding speed demonstrates that by increasing sliding speed wear rate decreases. The dependence between sliding speed and load clearly shows that at higher sliding speed values and at the lowest load value minimal wear rate value of hybrid composite is achieved.

Table 3. Analysis of Variance for S/N ratios

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr
L	2	280.779	280.779	140.390	1170.56	0.000	28.137
S	2	103.381	103.381	51.691	430.99	0.000	10.36
D	2	595.043	595.043	297.521	2480.71	0.000	59.63
L*S	4	8.975	8.975	2.244	18.71	0.000	0.899
L*D	4	5.592	5.592	1.398	11.66	0.002	0.561
S*D	4	3.168	3.168	0.792	6.60	0.012	0.317
Residual Error	8	0.959	0.959	0.120			0.096
Total	26	997.897					100

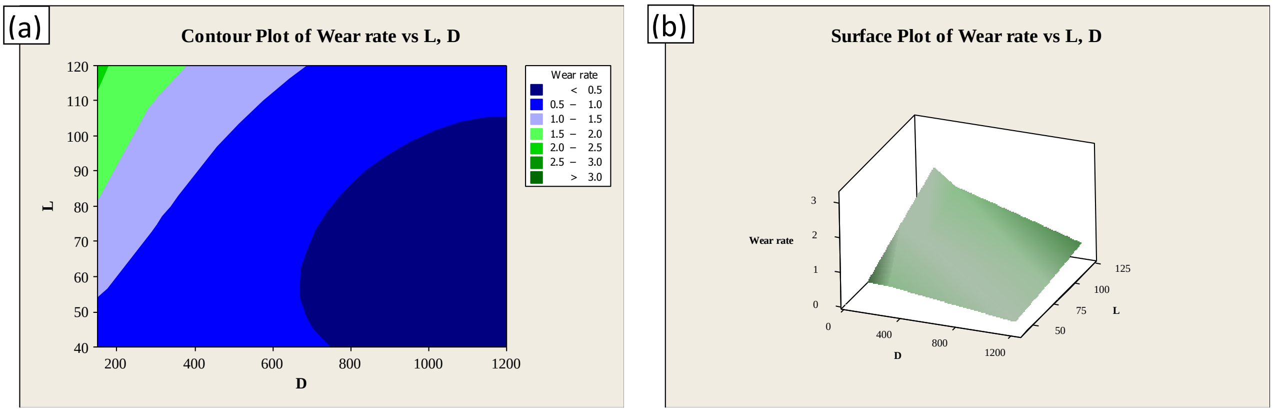


Figure 2. Dependence between wear rate of the load and sliding distance: (a) contour plot, (b) surface plot.

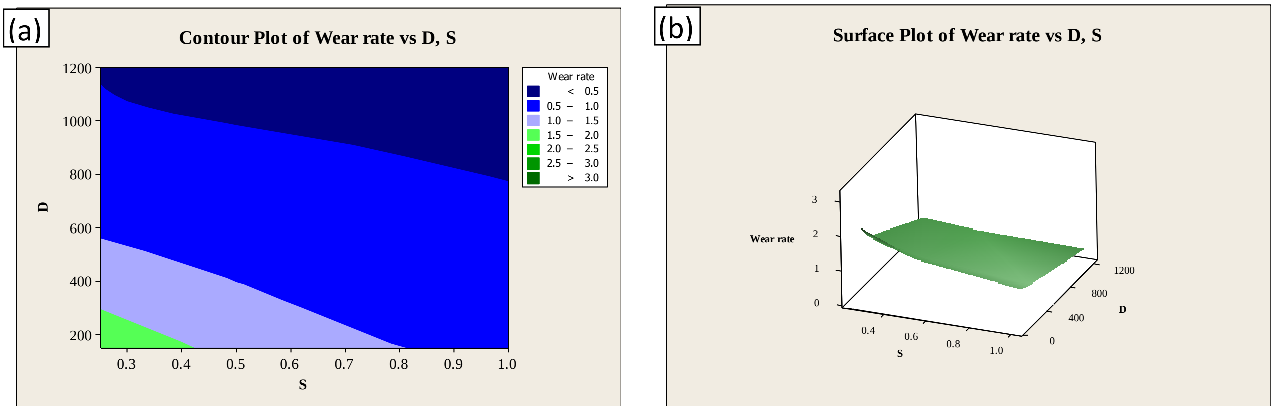


Figure 3. Dependence between wear rate of the sliding distance and sliding speed: (a) contour plot, (b) surface plot.

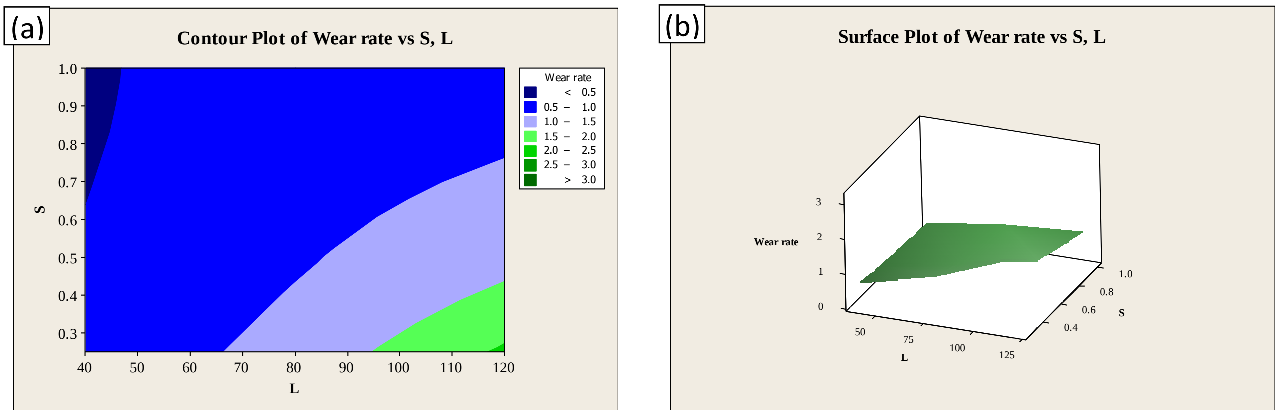


Figure 4. Dependence between wear rate of the sliding speed and load: (a) contour plot, (b) surface plot.

4.2 Linear regression

The relationship between control factors and response for wear rate in term of S/N ratios was analyzed using Taguchi method. The 95% confidence level was achieved by accounting the complete experimental design data. The regression equation developed for the wear rate is as follows:

$$SNRA1 = 0.840 - 0.098L + 6.165S + 0.010D \quad (3)$$

Equation (3) can be used for prediction of response wear rate at given levels of parameters. Table 5 demonstrates the estimation of linear model coefficients for S/N ratios in term of statistical parameters, standard error, T-test and probability value. Data given in this table clarify that the model was significant at the 95% confidence level since some p-values were less than 0.05.

Ratio with negative sign in equation is next to load factor, which means that wear rate decreases by increasing sliding distance. However, wear rate increases when load and sliding speed increase.

Table 5. The equation of regression coefficients

Term	Coef	SE Coef	T	P
Constant	0.840	0.688	1.222	0.234
L	-0.098	0.006	-16.110	0.000
S	6.165	0.639	9.643	0.000
D	0.010	0.000	23.548	0.000

By substituting the predicted optimum factor levels in the regression equation the estimated optimum Wear rate = 0.173356 $mm^3 \times 10^{-3}$/m. Further validation experiments were conducted for the predicted optimum conditions and wear rate from the validation experiments was obtained as 0.202 $mm^3 \times 10^{-3}$/m. The percentage error was also calculated and found to be 14.18% confirming the success of statistical analysis.

5 CONCLUSION

In this research work, the effect of various factors levels and factors (load, sliding speed and sliding distance) on wear rate hybrid composite was studied using Taguchi orthogonal array. Conclusions drawn from this experimental work are as follows:

- The hybrid composites have been successfully fabricated by compocasting process for the study of tribological properties.
- Taguchi's robust design method is suitable to analyse the wear rate as described in the present work.
- According to ANOVA analyses, the percent contributions of the L, S, and D factors on the wear rate were found to be 28.137%, 10.36% and 59.63%, respectively. Sliding distance (factor D) was found on the wear rate most effective parameter.
- It is concluded that combinations for minimum wear rate is L1S3D3 i.e. 40N load, 1 m/s sliding speed, and 1200 m sliding distance. Optimum wear rate is determined as 0.202 $mm^3 \times 10^{-3}$/m.

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