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Analysis of Dry Sliding Behaviour of Aluminium Reinforced with Coated Both Sic and Gr Hybrid Composite using Design of Experiments

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ABSTRACT : Al6061 alloy- base matrix, reinforced with copper coated particles of silicon carbide and copper coated graphite powder, known as hybrid composite have been manufactured by stir casting technique and optimized at different control parameters like reinforcement content, load and sliding distance by Taguchi method. The friction and wear properties of hybrid composites have been studied by conducting dry sliding wear test using pin –on-disk wear test. The aluminium alloy is reinforced with 4wt%, 8wt% and 10wt% of Copper coated Silicon carbide and fixed 1wt% of copper coated graphite. A L_{27} orthogonal array is used for conducting the experiments through taguchi technique. ANOVA is used to investigate the influence of parameters on specific wear rate and coefficient of friction. It is observed from the test results that reinforcement content is the dominant parameter followed by load and sliding distance which influences specific wear rate and coefficient of friction. Finally confirmation test is conducted to verify the accuracy of the obtained results through optimization.

Keywords: ANOVA, Coefficient of friction, Hybrid composite, Specific wear, Taghuchi.

I. INTRODUCTION

Aluminium metal matrix composites containing hard ceramic particles such as SiC and Al_2O_3 combined with graphite powder has emerged as a potential material for wear resistance and weight critical applications, such as cylinder liners, pistons, connecting rods, brake drums and cylinder blocks [1-3]. To improve the wettability and uniform distribution of reinforcements such as SiC and Gr in an aluminium matrix, electroless copper coating is performed. Ghosh et al [4] studied the tribological behaviour of Al-7.5% SiCp MMC for varying parameters such as applied load, sliding speed and time using Taguchi orthogonal array method and concluded that time is the most significant parameter which influences the tribological behaviour of MMCs. Rajesh et al [5] studied the wear behaviour for Al alloy-5% SiCp MMC for varying parameters such as reinforcement content, sliding velocity, contact stress and sliding distance using Taguchi orthogonal array method and concluded that sliding velocity is the dominant parameter which influences the tribological behaviour of MMCs. Yusuf et al [6] performed the abrasive wear test of Al-15% SiC at varying process parameters such as applied load, sliding distances and reinforcement particles size using taguchi method and concluded that reinforcement particles size was dominant parameter which influences the abrasive behaviour of MMCs. Radhika et al [7] performed the wear test of Al/Al2O3/Graphite hybrid metal matrix composite at different control parameters such as applied load, sliding speed and sliding distance using Taguchi Method and found that sliding distance has the highest effect on wear rate followed by applied load and sliding speed. Basvarajappa et al [8] studied dry sliding behavior of Al/SiC/Graphite MMCs using taguchi technique and concuded that sliding distance is the control factor which has the highest influence on the wear of composites. For the present tribological study, Al6061 is used as a base metal and copper coated both SiC and Gr are used as reinforcements. The hybrid composite is prepared by stir casting process where coated SiC are added in 4wt%, 8wt% and 10wt% along with fixed 1wt% coated Graphite powder. The tribological tests are performed on the hybrid composites to study the wear and friction properties.

The obtained results are analysed by ANOVA and the dominant parameter which influences the specific wear rate and coefficient of friction are found. Finally regression equations are generated and confirmation test are carried out to verify the optimal process parameters combination.

II. MATERIAL SELECTION

Al6061 is used as matrix material and it is commonly used as automobile and aerospace material. The reinforcing material is silicon carbide which is one of the hardest materials is copper coated using electroless process and copper coated fine graphite powder which has low coefficient of friction and act as a self lubricant.

III. COMPOSITE PREPARATION

Al6061 is used as matrix material and it is commonly used as automobile and aerospace material. The reinforcing material is silicon carbide which is copper coated using electroless process and copper coated fine graphite powder which act as a self lubricant. In the present work, stir casting technique is used for manufacturing hybrid metal matrix composites consisting of Al6061 alloy with varying wt% of copper coated SiC (4%, 8% and 10wt%) and a fixed wt% of Gr (1wt%) . The temperature of stir casting furnace is precisely measured and controlled to achieve a good quality composite. Al6061 alloy is cut in to pieces and melted in a furnace at a temperature of 800 deg Celsius. The stirrer is used to stirr the molten metal when both preheated coated SiC and coated graphite are added in to molten metal. Constant stirring was carried out for about 10 mins.

Finally the molten metal is poured in to preheated moulds and allowed it to solidify.

IV. WEAR BEHAVIOUR

The pin on disc wear test setup has a slider disc which is hardened steel disc with hardness RC 60. The test pin samples were 9 mm dia and 30 mm height and its end surfaces are flat and polished metallographically prior to testing. A 80 mm wear track diameter was used for all the test and wear loss was measured by loss of height of specimen using LVDT. The obtained results are analyzed by using commercial software MINITAB 14.

V. PLAN OF EXPERIMENTS

Dry sliding wear test is conducted on three parameters such as reinforcement content, load and sliding distance which are varied at three levels as shown in the table1.

Table 1: Process parameters and levels.

Controllable factors	Reinforcement Content (wt%) (R)	load (N) (L)	sliding distance (m) (D)
Level 1	4	10	500
Level 2	8	20	1000
Level 3	10	40	1500

An L_{27} orthogonal array having 27 rows and 13 columns was selected to optimize the control parameters. In an orthogonal array first column is assigned to reinforcement content, second column to load applied and fifth column to sliding distance and remaining columns are assigned to the interactions. The main aim of the model is to minimize specific wear rate and coefficient of friction.

The S/N ratio for specific wear rate and coefficient of friction are determined by "smaller the better" characteristics given by taguchi is as follows

S/N = -10 log [1/n (Σy2)] **(1)**

Where Y_1, Y_2.....y_n are the responses of dry sliding wear and n is the observations.

VI. RESULTS AND DISCUSSION

A. Results of statistical analysis of experiments

Table 2 illustrates the experimental values of specific wear rate and coefficient of friction and computed values of signal to noise ratio for a given response using equation (1).

Minitab 14 which is commercial software is used for analyzing the measured results. Signal to noise ratio table is used for determining the influence of reinforcement content, load and sliding distance on specific wear rate and coefficient of friction. Table 3 and 4 depicts the process parameters ranking for specific wear rate and coefficient of friction. The process parameters are statistically significant in the signal to noise ratio and it is observed that reinforcement content is a dominant parameter on the coefficient of friction and specific wear rate followed by load and sliding distance. Fig. 1-2 shows the influence of process parameters on specific wear rate and coefficient of friction graphically.

Table 2: Result of l_{27} orthogonal array of taguchi matrix for specific wear rate and coefficient of friction.

Expt No	Reinforcement wt%	Load	sliding distance	specific wear	SN wear	CF	SN CF
1	4	10	500	0.0002568	71.80842	0.380	8.404328
2	4	10	1000	0.0002420	72.32492	0.376	8.496243
3	4	10	1500	0.0002078	73.64535	0.370	8.635966
4	4	20	500	0.0002217	73.08588	0.370	8.635966
5	4	20	1000	0.00017	75.1	0.3	8.706

6	4	20	1500	0.0001567	76.10051	0.364	8.777972
7	4	40	500	0.0001920	74.3345	0.350	9.118639
8	4	40	1000	0.0001602	75.9046	0.346	9.218478
9	4	40	1500	0.0001483	76.57722	0.342	9.319478
10	8	10	500	0.0001918	74.34458	0.356	8.971
11	8	10	1000	0.0001729	75.24246	0.350	9.118639
12	8	10	1500	0.0001655	75.62352	0.348	9.168415
13	8	20	500	0.0001593	75.95476	0.346	9.218478
14	8	20	1000	0.0001261	77.98318	0.340	9.370422
15	8	20	1500	0.0001144	78.83165	0.336	9.473214
16	8	40	500	0.0001605	75.8891	0.330	9.629721
17	8	40	1000	0.0001334	77.49548	0.326	9.735648
18	8	40	1500	0.0001206	78.37144	0.323	9.81595
19	10	10	500	0.0001638	75.71527	0.350	9.118639
20	10	10	1000	0.0001486	76.55799	0.344	9.268831
21	10	10	1500	0.0001485	76.56791	0.340	9.370422
22	10	20	500	0.0001315	77.62063	0.328	9.682523
23	10	20	1000	0.0001142	78.84374	0.326	9.735648
24	10	20	1500	0.0001062	79.47832	0.321	9.869899
25	10	40	500	0.0001454	76.74782	0.322	9.842883
26	10	40	1000	0.0001239	78.14124	0.316	10.00626
27	10	40	1500	0.0000954	80.40903	0.31	10.17277

Table 3 : Response table for signal to noise ratios- smaller is better (specific wear rate).

Level	Reinforcement content (R)	Load (L)	Sliding distance (D)
1	74.32	74.65	75.06
2	76.64	77.00	76.40
3	77.79	77.10	77.29
Delta	3.46	2.45	2.23
Rank	1	2	3

Table 4: Response table for signal to noise ratios- smaller is better (coefficient of friction).

Level	Reinforcement content	Load	Sliding distance
1	8.813	8.950	9.180
2	9.389	9.275	9.295
3	9.674	9.651	9.400
Delta	0.862	0.701	0.220
Rank	1	2	3

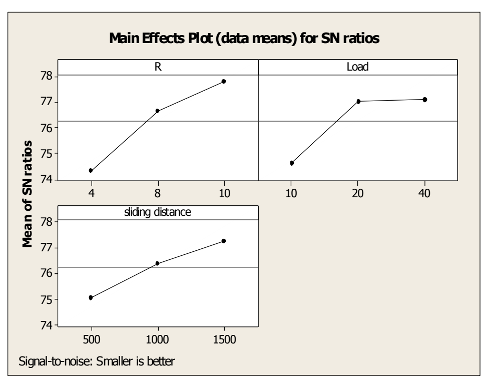

Fig. 1. Main effects plot for S/N ratios- specific wear rate.

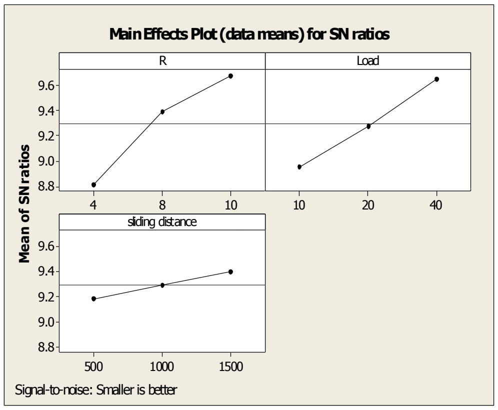

Fig. 2. Main effects plot for S/N ratios- coefficient of friction.

B. Analysis of variance results for wear test

Table 5 & 6 shows the ANOVA results for specific wear rate and coefficient of friction for three factors varied at three levels and their interactions. This analysis is carried out for a confidence level of 95%, i.e a significance level of α = 0.05.

Table 5: Analysis of variance for specific wear rate.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr (%)
Reinforcement	2	55.982	55.982	27.991	106.32	0.000	47.1
Load	2	34.672	34.672	17.336	65.85	0.000	29.2
Sliding distance	2	22.774	22.774	11.387	43.25	0.000	19.1
Error	20	5.265	5.265	0.263			
Total	26	118.693					

Table 6 : Analysis of Variance for coefficient of friction.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	Pr (%)
Reinforcement	2	3.46761	3.46761	1.73380	1774.19	0.000	57.5
Load	2	2.21424	2.21424	1.10771	1132.91	0.000	36.7
Sliding distance	2	0.21836	0.21836	0.10991	111.72	0.000	3.49
Reinforcement *load	4	0.09674	0.09674	0.0241	24.75	0.000	1.59
Error	16	0.01564	0.01564	0.0009			
Total	26	6.01258					

It is observed from the table 5 and 6 that reinforcement content (Pr = 47.1% & Pr = 57.5%) is an important control parameter which affects both specific wear rate and coefficient of friction followed by applied load (Pr = 29.2% & Pr = 36.7%) and sliding distance (Pr = 19.1% & Pr = 3.49 %). For specific wear rate the interaction terms are not statically significant and for coefficient of friction the interaction between reinforcement content and load alone have significant influence (Pr = 1.59%).

C. Multiple linear regression models

Statistical software MINITAB 15 is used for developing a multiple linear regression model and this model gives the relationship between a predicted variable & a response variable by fitting a linear equation to observe data. The regression equation for specific wear rate

Specific wear rate = 0.000310 - 0.000011 (R) - 0.000001 (L) - 0.0000001 (D)

The regression equation for coefficient of friction

CF = 0.415 - 0.00572 (R) - 0.000896 (L) - 0.000009 (D)

D. Confirmation test

In a design process, confirmation experiment is the final step. Table 7 shows the values used for conducting confirmation test for the dry sliding wear and table 8 shows the results of confirmation test and comparison was made between the computed values developed from the regression model and experimental values.

The experimental value of specific wear rate is found to be varying from specific wear rate calculated from regression equation by error percentage between 5.12% to 10.71%, while for Friction coefficient it is between 2.84% to 7.05%

Table 7 : Confirmation experiment for specific wear rate and coefficient of friction.

Expt No.	Reinforcement (%)	load (N)	Sliding distance (m)
1	2	16	500
2	6	24	750
3	10	32	1250

Table 8 : Result of confirmation experiment and their comparison with regression model.

Expt No	Expt Specific Wear rate (mm^3/Nm)	Regress model eqn(2) specific wear rate (mm^3/Nm)	% error	Expt Coeff of friction	Regress model eqn(3) coeff friction	% error
1	0.0002340	0.0002220	5.12	0.396	0.384	2.84
2	0.0001624	0.0001450	10.7	0.374	0.352	5.76
3	0.0000472	0.0000430	8.89	0.342	0.317	7.05

VII. CONCLUSIONS

1) The specific wear rate is dominated in the order of reinforcement content, applied load, and sliding distance.
2) Reinforcement content (47.1%) is the process parameter which has highest influence on the specific wear rate in compare to other factors such as applied load (29.2%), and sliding distance (19.2%). The interaction between the parameters does not have any statistical influence on specific wear rate.
3) The coefficient of friction is influenced in the order of reinforcement content, applied load, and sliding distance.
4) Reinforcement content (57.5%) is the process parameter which dominates on coefficient of friction in compare to other factors such as applied load (36.7%), and sliding distance (3.49%). The interaction between reinforcement content and load will contribute (1.59%) than other interactions.
5) From confirmation tests, the errors associated with specific wear rate ranges between 5.12% to 10.71 % and 2.84% to 7.05 % for coefficient of friction resulting in the conclusion that the design of experiments by Taguchi method was successful for calculating specific wear rate and coefficient of friction from the regression equation.

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