International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:9, No:6, 2015

Study of Tribological Behaviour of Al6061/Silicon Carbide/Graphite Hybrid Metal Matrix Composite Using Taguchi's Techniques

Mohamed Zakaulla, A. R. Anwar Khan

Abstract**—**Al6061 alloy base matrix, reinforced with particles of silicon carbide (10 wt %) and Graphite powder (1wt%), known as hybrid composites have been fabricated by liquid metallurgy route (stir casting technique) and optimized at different parameters like applied load, sliding speed and sliding distance by taguchi method. A plan of experiment generated through taguchi technique was used to perform experiments based on L_{27} orthogonal array. The developed ANOVA and regression equations are used to find the optimum coefficient of friction and wear under the influence of applied load, sliding speed and sliding distance. On the basis of "smaller the best" the dry sliding wear resistance was analysed and finally confirmation tests were carried out to verify the experimental results.

Keywords**—**Analysis of variance, dry sliding wear, Hybrid composite, orthogonal array, Taguchi technique.

I. INTRODUCTION

THE composite materials constitute a matrix phase and a reinforcement phase and they both work together to produce combination of material properties that cannot be met by the conventional materials [1]. Most of the research made in aerospace and automotive field shows that material used for the components should possess good tribological properties and better toughness. An attempt is made to develop the Al6061 based hybrid composite which is having combination of both tribological properties and toughness like wear resistance which will meet the automotive application requirements. Aluminium alloys possess a number of physical and mechanical properties which make them attractive for automotive applications, but they exhibit galling and extremely poor resistance to seizure [2]. N. Natarajan et al. [3] has recommended an aspirant material for automotive applications which is a SiC particulate reinforcement. It is reported that in aluminium matrix composite, addition of graphite reduces wear due to its solid lubrication property [4]. Yoshiro Iwai et al. [5] reported that wear rate decreases with increasing volume fraction. S.Basavarajappa et al [6] studied in detail load, sliding distance, sliding speed and percentage of reinforcement which manipulates the dry sliding performance of Al-2219 matrix alloy reinforced with SiC.N.Radhika et al. [7] determined that taguchi technique as a valuable technique to deal with responses influenced by multivariables. In present investigation, an assessment is made to investigate the outcome of load, sliding speed and sliding distance on the dry sliding wear behaviour of Al6061 alloy reinforced with 10 wt% SiC particles and 1wt% Graphite powder.

F. A. Mohamed Zakaulla is a Research scholar in Mechanical Department, Ghousia College of Engineering, Visvesvaraya technological university, Karnataka, India, (e-mail: mohd_zakaulla@yahoo.co.in).

S. B. Anwar khan is a professor in Mechanical Department, Ghousia College of Engineering, Visvesvaraya technological university, Karnataka, India, (e-mail Drark_gce@rediffmail.com).

II.MATERIAL SELECTION

Alloy Al6061 was selected as a matrix material. . The reinforcement was SiC (average size of 80-100microns) and a fine graphite powder.

III.COMPOSITE PREPARATION

The hybrid composite specimens were synthesized using the Liquid metallurgy route. The Al6061 alloy was super-heated above its molten state and vortex was created in the melt due to continuous stirring of a mechanical stirrer. At this stage both preheated SiC particles (10 wt %) and Graphite powder (1wt %) was introduced in to the molten metal and the temperature of a composite slurry was increased until it was in a fully liquid state. The composite slurry was stirred for 5 minutes and the hybrid composite melt was degassed using hexachloroethane tablets. Finally the hybrid composite melt was poured in a cast iron permanent mould to obtain cylindrical samples.

IV. WEAR BEHAVIOUR

To determine the sliding wear behavior of Al6061-10%SiC-1%Gr composite, a pin on disk type machine was used at different parameters like applying load, sliding speed and sliding distance. The test sample dimensions were 9 mm diameter and 30 mm height and specimen was held against a rotating hardened disk of die steel with Rc60 hardness. For all the tests, a fixed wear track diameter of 80 mm was used. A LVDT was used to measure the height loss of the specimen. MINITAB 14 was used for analyzing the measured results and also finds the important factors and combination of factors influencing the wear process.

V.PLAN OF EXPERIMENTS

The experiments were conducted as per L_{27} orthogonal array and it has 27 rows and 13 columns. The first column was assigned to applied load, second column was assigned to sliding speed and fifth column was assigned to sliding distance and interactions were assigned to their remaining columns. The objective of the model is to minimize wear rate and coefficient of friction and the responses are specific wear rate and coefficient of friction.

The S/N ratio for specific wear rate and coefficient of friction using “smaller the better” characteristic given by taguchi is as follows

$$S/N = -10\, log\, [1/n\, (\Sigma y2)] \quad (1)$$

whereY_1, Y_2…..y_n are the response of sliding wear and n is the number of observations.

The levels of these variables chosen for experimentation are given in Table I.

TABLE I
PROCESS PARAMETERS AND LEVELS

Controllable factors	Load (L) (N)	Sliding speed (S)(m/s)	Sliding distance (D) (m)
Level 1	10	0.42	750
Level 2	20	0.84	1500
Level 3	40	1.68	3000

VI. RESULTS AND DISCUSSION

The calculated values of signal to noise ratio and experimental values of specific wear rate and coefficient of friction are shown in Table II. Commercial software MINITAB 14 was used for analyzing the measured results. The influence of process parameters such as applied load, speed and sliding distance on coefficient of friction and specific wear rate has been analyzed using signal to noise ratio table. From Tables III and IV it is clear that applied load is a dominant parameter on the specific wear rate and coefficient of friction followed by sliding speed and sliding distance. Figs. 1, 2 show graphically the influence of controlled process parameters on specific wear rate and coefficient of friction for Al6061-10%SiC-1%Gr composite.

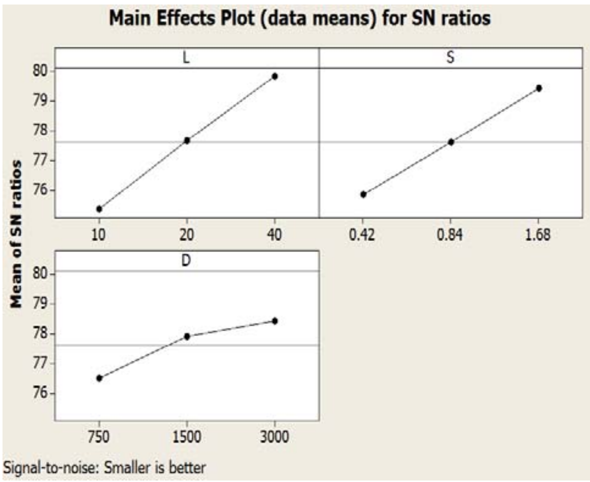

Fig. 1 Main effects plot for S/N ratios- specific wear rate

TABLE II
RESULT OF L_{27} ORTHOGONAL ARRAY

EXPT NO	Load (L)	Speed (m/s)	Distance (m)	Specific Wear rate K_s (mm^3/Nm)	S/N ratio (db)	Coefficient of friction	S/N ratio (db)
1	10	0.42	750	0.0002734	71.26403	0.376	8.496243
2	10	0.42	1500	0.0002512	71.99961	0.362	8.825829
3	10	0.42	3000	0.0001993	74.00985	0.35	9.118639
4	10	0.84	750	0.0001857	74.62376	0.342	9.31947
5	10	0.84	1500	0.0001605	75.8905	0.35	9.118639
6	10	0.84	3000	0.0001562	76.12638	0.342	9.319478
7	10	1.68	750	0.0001532	76.29482	0.354	9.019935
8	10	1.68	1500	0.0001135	78.90008	0.348	9.168415
9	10	1.68	3000	0.0001121	79.00789	0.344	9.268831
10	20	0.42	750	0.0001651	75.64506	0.368	8.683044
11	20	0.42	1500	0.0001613	75.84731	0.35	9.118639
12	20	0.42	3000	0.0001544	76.22705	0.338	9.421666
13	20	0.84	750	0.0001313	77.63471	0.356	8.971
14	20	0.84	1500	0.0001159	78.71833	0.34	9.370422
15	20	0.84	3000	0.0001109	79.10137	0.326	9.735648
16	20	1.68	750	0.0001428	76.90544	0.336	9.473214
17	20	1.68	1500	0.0001119	79.0234	0.331	9.60344
18	20	1.68	3000	0.0001012	79.89639	0.327	9.709045
19	40	0.42	750	0.0001174	78.60664	0.34	9.370422
20	40	0.42	1500	0.0001094	79.21965	0.328	9.682523
21	40	0.42	3000	0.0001041	79.65099	0.31	10.17277
22	40	0.84	750	0.0001377	77.22132	0.316	10.00626
23	40	0.84	1500	0.0001025	79.78552	0.33	9.629721
24	40	0.84	3000	0.0001094	79.21965	0.314	10.06141
25	40	1.68	750	0.0000965	80.30945	0.312	10.11691
26	40	1.68	1500	0.0000814	81.78751	0.296	10.57417
27	40	1.68	3000	0.0000743	82.58022	0.29	10.75204

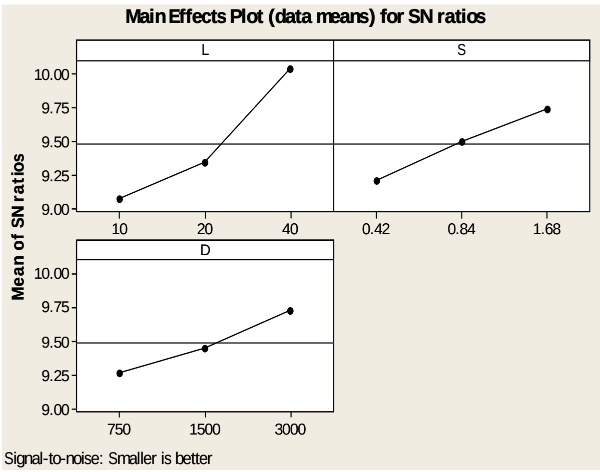

Fig. 2 Main effects plot for S/N ratios- coefficient of friction

TABLE III
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS- SPECIFIC WEAR RATE

Level	L	S	D
1	75.35	75.83	76.50
2	77.67	77.59	77.91
3	79.82	79.41	78.42
Delta	4.47	3.58	1.92
Rank	1	2	3

International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:9, No:6, 2015

TABLE IV
RESPONSE TABLE FOR SIGNAL TO NOISE RATIOS – COEFFICIENT OF FRICTION

Level	L	S	D
1	9.073	9.210	9.273
2	9.343	9.504	9.455
3	10.041	9.743	9.729
Delta	0.968	0.533	0.456
Rank	1	2	3

TABLE V
ANALYSIS OF VARIANCE FOR SPECIFIC WEAR RATE

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P(%)
L	2	90.108	90.108	45.054	174.68	0.000	47.71305
S	2	57.733	57.733	28.866	111.92	0.000	30.57018
D	2	17.846	17.846	8.923	34.60	0.000	9.449628
L*S	4	18.047	18.047	4.512	17.49	0.001	9.556059
L*D	4	0.513	0.513	0.128	0.50	0.739	0.271638
S*D	4	2.544	2.544	0.636	2.47	0.129	1.347072
Residual Error	8	2.063	2.063	0.258			1.092378
Total	26	188.854					100

TABLE VI
ANALYSIS OF VARIANCE FOR COEFFICIENT OF FRICTION

Source	DF	Seq SS	Adj SS	Adj MS	F	P	P(%)
L	2	4.48979	4.48979	2.24489	79.24	0.000	58.87832
S	2	1.28240	1.28240	0.64120	22.63	0.001	16.81717
D	2	0.94810	0.94810	0.47405	16.73	0.001	12.43322
L*S	4	0.35276	0.35276	0.08819	3.11	0.080	4.626033
L*D	4	0.08921	0.08921	0.02230	0.79	0.565	1.169884
S*D	4	0.23664	0.23664	0.05916	2.09	0.174	3.103256
Residual Error	8	0.22665	0.22665	0.02833			2.972249
Total	26	7.62554					100.0001

A. Analysis of Variance Results for Wear Test

Tables V and VI shows the results of analysis of variance on the specific wear rate and coefficient of friction for Al6061-10%SiC-1%Gr composite. This analysis is carried out at a level of 5% significance that is for a confidence level of 95%. The last column of both the table indicates the percentage contribution (Pr) of each factor on the total variation indicating the degree of their influence on the results. It is easily observed from Table V that applied load has a greater influence on the specific wear rate (P=47.71%). Hence applied load is an important process parameter to be taken in to account for wear process. Applied load is further followed by sliding speed (P=30.57%) and sliding distance (P=9.44%). Based on the interaction terms, the interaction between load and sliding speed have significance influence (P=9.55%). From Table VI, one can infer that the load has a greater control on coefficient of friction (P=58.87%). This parameter is followed by sliding speed (P=16.81%) and sliding distance (P=12.43%). The interactions between load and sliding speed (P=4.62%) have significant influence on coefficient of friction of Al6061-10%SiC-1%Gr composite.

B. Multiple Linear Regression Model

MINITAB R14 is statistical software which is used for developing a multiple linear regression models. This model gives a relationship between a predictor variable and a response variable by fitting a linear equation to the observed data. The regression equation developed for specific wear rate is

$$\text{Specific wear} = 0.000260 - (0.000002*L) - (0.000046*S) - (0.00000001*D)$$

The regression equation developed for Coefficient of friction is

$$CF = 0.394 - (0.00124*L) - (0.0154*S) - (0.000008*D).$$

C. Confirmation Test

Table VII shows the values used for conducting the dry sliding wear test and Table VIII shows the results of confirmation test and comparison was made between the computed values developed from 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 between 7.64% and 11.61% while for coefficient of friction it is between 4.88% and 6.95%. Thus the calculated coefficient of friction and specific wear rate from the regression equation and experimental values are nearly same with least error.

TABLE VII
CONFIRMATION EXPERIMENT FOR SPECIFIC WEAR RATE AND COEFFICIENT OF FRICTION

Expt No.	Load (L) (N)	Sliding speed (S) (m/s)	Sliding distance (D) (m)
1	14	0.62	750
2	28	1.04	1580
3	34	1.26	2200

TABLE VIII
RESULT OF CONFIRMATION EXPERIMENT AND THEIR COMPARISON WITH REGRESSION MODEL

Expt No	Expt Specific Wear rate(mm^3/Nm)	Regress model (2) specific wear rate (mm^3/Nm)	% error	Expt Coeff of friction	Regress model (3) coeff friction	% error
1	0.0002122	0.0001960	7.64	0.3821	0.3610	5.49
2	0.0001588	0.0001404	11.6	0.3553	0.3306	6.95
3	0.0001238	0.0001120	9.49	0.331	0.3148	4.88

VII. CONCLUSIONS

1) Results obtained from S/N ratio response analysis depict that applied load (47.71) was the most dominant parameter influencing the specific wear rate followed by sliding speed (30.57%) and sliding distance (9.44%) for Al6061-10%SiC-1%Gr composite and interaction term L*S (load*speed) (9.55%) was found most predominant among different interaction parameters.
2) Coefficient of friction for Al6061-10%SiC-1%Gr composite was highly influenced by the applied load

(58.87%) followed by sliding distance (16.81%) and sliding speed (12.43%).

3) Regression equations generated for Al6061-10%SiC-1%Gr composite has been used to predict the specific wear rate and coefficient of friction for the intermediate conditions with reasonable accuracy.
4) Confirmation experiment was carried out and a comparison was made between computed values and experimental values for the specific wear rate ofAl6061-10%SiC-1%Gr composite which showed the error ranging from 7.64% to 11.61% and for the coefficient of friction the error varied from 4.88% to 6.95% resulting in an conclusion that the design of experiments by Taguchi method was successful for calculating the coefficient of frictionand specific wear rate from the regression equation.

References

[1] S. J. Harris, 1988, Cast Metal Matrix composites, Materials Science and Technology, Vol. 4, No 3, pp. 231- 239
[2] S. V. Prasad and R. Asthana, 2004, Aluminum Metal-Matrix Composites for Automotive Applications, Tribology letters, Vol. 17, No. 3, pp. 445-453.
[3] N. Natarajan, S. Vijayarangan and I. Rajendran, 2006, Wear Behaviour of A356/25SiCpAluminium Matrix Composites Sliding against Automobile Friction Material," Wear, Vol. 261, No. 7-8, pp. 812-822.
[4] S.Suresha, B.K.Sridhara, 2010, Effect of addition of graphite particulates on the wear behaviour in aluminium –silicon carbide-graphite composites, Materials and Design, Vol 31, pp 1804-1812.
[5] Yoshiro. Iwai, H. Yonede and T. Honda, 1995, Sliding Wear Behaviour of SiC Whisker-Reinforced Aluminum Composite," Wear, Vol. 181-183, No. 2, pp. 594-602.
[6] S. Basavarajappa and G. Chandramohan, "Wear Studies on Metal Matrix Composites: A Taguchi Approach,"Journal of Material Science Technology, , Vol. 21, No. 6, 2005, pp. 845-850
[7] N. Radhika, R. Subramanian and S. Venkat Prasat, "Tribological behaviour of Aluminium/Alumina/Graphite Hybrid Metal Matrix Composite Using Taguchi's Techniques," Journal of Minerals & Materials Characterization & Engineering, Vol. 10, No. 5, pp. 427-443, 2011.