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Analysis on Dry Sliding Wear Behaviour of AA6061-B_4C-Gr Hybrid Composite-Taguchi Technique

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Abstract: Wear behaviour of AA6061-B_4C and AA6061-B_4C-Gr composites fabricated by stir casting process was investigated by performing the dry sliding wear test using a Pin-on-disc wear testing equipment. The influence of parameters such as material, sliding load and sliding velocity on the wear loss of specimens was investigated. Experiments were conducted based on the L9 Taguchi's technique. It was found that the sliding velocity was the most dominant factor influencing the wear loss followed by sliding load and material. Finally, confirmation tests were carried to verify the experimental results.

Key words: Wear, stir casting, sliding load, sliding velocity, Taguchi

INTRODUCTION

Composites are one of the most widely used materials in aerospace and automotive industries because of their adaptability to different situations and the relative ease of combination with other materials to serve specific purposes and exhibit desirable properties. Metal matrix composites have received more commercial attention due to their enhanced mechanical properties, wear resistance and low coefficient of thermal expansion (Prabu *et al*., 2006). In addition, metal matrix composites have an edge of better characteristics such as good strength to weight ratio, high specific stiffness, high hardness, light weight, high plastic flow strength, good thermal expansion, thermal stability, creep resistance and good oxidation and corrosion resistance (Cerit *et al*., 2008). In the area of automotive industries, key components are made by metal matrix composites because of better wear. Wear is the removal of material from one or both of two solid surfaces in a solid-state contact. Addition of hard ceramic particles improves wear resistance of the matrix material. The wear rate is associated to sliding velocity, applied load, particle size, hardness of material, reinforcement particle volume fraction and particle homogeneity (Toptan *et al*., 2012). Miyazaki *et al*. (1981) analyzed the wear resistance behaviour of graphite which is a solid lubricant that gives protection from damage during relative movement between the sliding elements and reduces the wear (Leng *et al*., 2009) observed that by the addition of graphite, the friction coefficient of Al-SiC composites decreases and the wear resistance is significantly increased. Ames and Alpas (1995) reported that the Al-Gr composites had higher wear resistance than the Al-SiC composite. Fabrication of MMCs through stir casting method has several challenges like porosity defects, poor wettability and improper distribution of reinforcement. Achieving uniform distribution of reinforcing particles in metal matrix plays a vital role in MMCs fabrication. Stir casting appears to be the most Capable Method for the production of metal matrix composites compared to other processing techniques, because of simplicity. Kundu *et al*. (2013) reported that wear is a characteristics of the engineering system which is influenced by applied load, sliding velocity, hardness of the material, sliding duration, sliding distance, temperature and the environmental conditions. The Design of Experiments (DOE) approach using Taguchi's technique is one of the most important and powerful statistical tool to study the effect of multiple variables simultaneously and involves series of steps which follows a defined sequence for the experiment to yield an improved understanding of process performance (Taguchi *et al*., 1987). Aim of this study is to analyze the influence of material, applied load and sliding velocity on dry sliding wear. The experiments were conducted based on a L_9 orthogonal array and to find the important factors influencing the wear of specimens to achieve the minimum wear rate.

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Design of Experiments (DOE): The DOE process is consisting of three main phases which are the planning phase, conducting phase and analysis phase. Major step in DOE process is the selection of the factors and levels which will provide the desired information. Analysis of the experimental results uses a signal to noise ratio to aid in the determination of the significant parameters. This technique has been successfully used by researchers in the study of dry sliding wear behaviour of composites. In the present study a plan of order for conducting experiments was generated by Gray Taguchi Method using orthogonal arrays and analysis of parameters was carried on by means of "ANOVA" technique. A Multiple Linear Regression Model is developed to predict the wear loss of composite.

MATERIALS AND METHODS

In the present investigation, AA6061 was chosen as matrix. First reinforcement was 10 wt.% of Boron Carbide (B_4C) of average particle size 20-50 μm. Second reinforcement was 3 wt.% of graphite particles of average particle size 20 μm. The chemical composition of the base matrix alloy AA6061 is given in Table 1.

Composite preparation: Figure 1 two step stir casting route was adopted to fabricate the composites (Palanisamy *et al*., 2013). Both B_4C and graphite particulates were preheated at 300°C in a separate muffle furnace. AA6061 was charged into the crucible and the same was heated up to 650°C in order to melt the aluminium completely and then the stirring was done at 300 rpm.

Fig. 1: Stir Casting Method

Table 1: Chemical composition of the matrix alloy

Elements	Percentage
Si	0.359
Fe	0.221
Cu	0.21
Mn	0.032
Mg	0.901
Cr	0.053
Ti	0.141
Ca	0.013
Al	Bal

During stirring, degassing tablets were added to drive away the entrapped gases from the melt. Stirring was carried out for 3 min. During stirring, pre heated 10 wt.% B_4C and 3 wt.% graphite particulates were added. The melt temperature was brought down to 575°C to reach the semi-solid state. Stirring was done for 3 min at this stage. Composite slurry was again reheated to the temperature of 650°C and stirred at 300 rpm for 3 min. Finally the composite slurry was poured into the steel die cavity of 90×90×7 mm to solidify. Melting was done in an electrical resistive furnace (2 KW to 1 kg capacity). Temperatures were measured with a thermocouple with an accuracy of +/-3deg.K.

Wear behaviour: A pin on disc equipment was used to determine the sliding wear characteristics of the composite. Pin specimens of 6mm ^{2} for a height of 30 mm was prepared in EDM (Electric Discharge Machining). Two ends are sliced with high flatness accuracy in such a way that pin face is thoroughly butting with disc and is held with its axis perpendicular to disc surface while doing wear test. Moreover, wear testing equipment is having a split type holder to ensure proper alignment throughout the test run. Prior to wear testing, specimens were polished with abrasive paper of silicon carbide of grade 600 followed by grade 1000 and cleaned with ethanol and dried. Duration of wear test was conducted up to 30 min.

Plan of experiment: Dry sliding wear test was performed with three parameters viz., material, applied load and sliding velocity and varying them for three levels as shown in Table 2. According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters. The type of array that was chosen for this investigation being a L_9 orthogonal array which has 9 rows and 3 columns as shown in the Table 3.

The selection of orthogonal array depends on three items in the order of priority viz., the number of factors and their interactions, number of levels for the factors and

Table 2: Process parameters and levels

Levels	Materials	Load (N)	Sliding velocity (m sec^{-1})
1	1 (AA6061)	5.0	1
2	2 (AA6061-B_4C)	12.5	2
3	3 (AA6061-B_4C-Gr)	20.0	3

Table 3: Taguchi L_9 orthogonal array

Trials	Materials	Applied load (N)	Sliding velocity (m sec^{-1})
1	1	5.0	1
2	1	12.5	2
3	1	20.0	3
4	2	5.0	2
5	2	12.5	3
6	2	20.0	1
7	3	5.0	3
8	3	12.5	1
9	3	20.0	2

the desired experimental resolution or cost limitations. Totally, 9 experiments were performed based on the run order generated by Gray Taguchi Model. The response for the model is wear loss. In the orthogonal array, first column is assigned to material, second column is assigned to applied load and third column is assigned to sliding velocity. The aim of this model is to minimize the wear loss of the composites. The Signal to Noise ratio (S/N) which freezes the multiple points within a trial depends on types of characteristics being evaluated. The S/N ratio characteristics can be divided into three categories namely 'nominal is the best', 'larger the better' and 'smaller the better' characteristics. In this investigation 'smaller the better' characteristics was selected to analyze the dry sliding wear. S/N ratio for wear loss using 'Smaller the better' characteristics given by Taguchi is as follows:

$$\frac{S}{N} = -10 \log \left(\frac{1}{n}\right) (Y_1^2+Y_2^2+Y_3^2+...+Yn^2) \quad (1)$$

Whereas:

Y_1, Y_2, Y_3,..., Y_n = The response of sliding wear

n = The number of observations made

Response table for signal to noise ratio show average of selected characteristics for each level of factor. This table includes ranks based on the delta statistics which compares the relative value of the effects. S/N ratio is a response which consolidates repetitions and the effect of noise levels into one data point. Analysis of Variance (ANOVA) of the S/N ratio is performed to identify the statistically significant parameters.

RESULTS AND DISCUSSION

Results of statistical analysis of experiments: The results of various combinations of parameters were obtained by conducting the experiment as per the L9 orthogonal array. The measured results were analyzed using the commercial software 'MINITAB 16' specifically used for Design of Experiments (DOE) applications. Table 4 shows the average outcome of experiments three trials of wear loss. Experimental results are converted into noise to signal ratio primarily to measure quality characteristics. Using signal to noise ratio response table, wear loss have been analyzed to find the influence of control parameters such as material, applied load and sliding velocity. The ranking of process parameters using signal to noise ratios obtained for different parameter levels for wear loss is given in Table 5. It can be inferred from Table 5 that the sliding velocity is a dominant parameter followed by applied load and the material on wear loss of specimens. The analysis of these experimental results using S/N ratios gives the optimum conditions resulting in minimum wear rate. Main effects plot for SN ratios-wear loss is shown in Fig. 2. It was found that the optimum parameters are (AA6061-B_4C-Gr) material, applied load (5 N) and sliding velocity (1 m sec^{-1}).

Table 4: Results of L_9 orthogonal array

Material	load (N)	Sliding velocity (m sec^{-1})	Wear loss (µm)	S/N ratio (db)
1	5.0	1	64.0	-36.1236
1	12.5	2	174.5	-44.8359
1	20.0	3	315.0	-49.9662
2	5.0	2	82.5	-38.3291
2	12.5	3	221.5	-46.9075
2	20.0	1	112.3	-41.0076
3	5.0	3	112.1	-40.9921
3	12.5	1	50.0	-33.9794
3	20.0	2	150.8	-43.5680

Material A = AA6061 alloy; Material B = AA6061+B_4C; Material C-AA6061+B_4C+Gr

Table 5: Response table for S/N ratios

Levels	Material	Applied load (N)	Sliding velocity (m sec^{-1})
1	-43.64	-38.48	-37.04
2	-42.08	-41.91	-42.24
3	-39.51	-44.85	-45.96
Delta	4.13	6.37	8.92
Rank	3.00	2.00	1.00

Table 6: Analysis of variance (wear loss)

Source	df	Seq.SS	Adj.MS	F-values	p-values	Pr. (%)
Material	2	9711.5	4855.8	22.49	0.043	16.96
Applied load	2	17183.3	8591.6	39.79	0.025	30.01
Sliding velocity	2	29918.2	14959.2	69.29	0.014	52.26
Residual error	2	431.8	215.9	-	-	0.754
Total	8	57244.8	-	-	-	100

DF = Degree of Freedom; Seq.SS = Sequential Sums of Squares; Adj.MS = Adjusted sums of squares; Pc = Percentage of contribution

Analysis of variance results for wear test: ANOVA was performed for a level of significance of 5% to study the influence of the parameters. In the ANOVA analysis (Table 6), there is a p-value for each independent parameter in the model. The p-value is used to test the significance of each parameter. When the $p<0.05$ then the parameter can be considered as statistically highly significant. It was observed that sliding speed, applied load and materials have <0.05 which means that they are highly significant at 95% confidence level.

It can be observed from Table 6 that sliding velocity has the highest influence (52.26%) on wear loss.

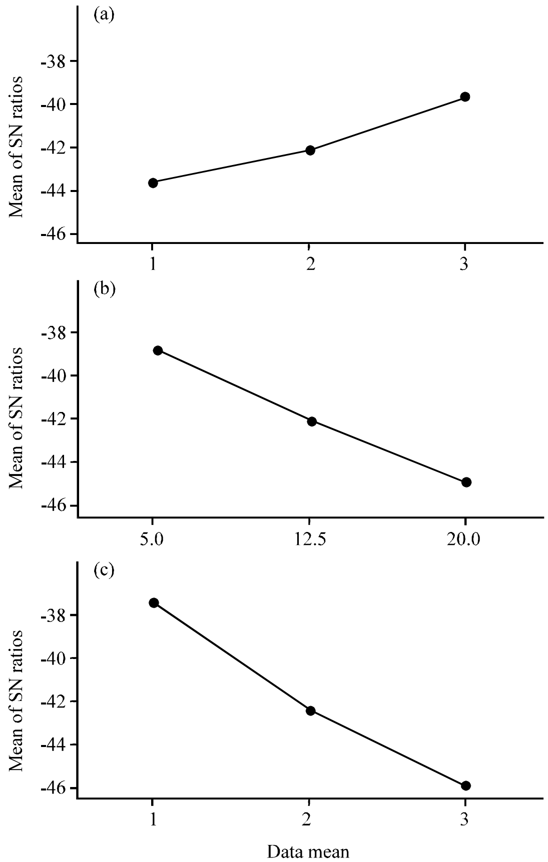

Fig. 2: Main effects plot for SN ratios-wear loss. a) Material; b) load and c) sliding velocity

Hence, sliding velocity is significant factor to be taken into consideration during wear process followed by applied load 30.01% and Material 16.96%.

Multiple Linear Regression Model analysis: A regression equation was generated to establish correlation among the parameters namely materials, applied load and sliding velocity. The value of regression coefficient, R^2 (0.9925) is in good agreement with the adjusted R^2 (0.9698). The regression equation developed for wear loss is:

$$\text{Wear rate} = -6.8-40.1(A)+7.10\,(B)+70.4\,(C) \qquad (2)$$

From the Eq. 2, it is observed that the sliding velocity (C) is a significant parameter on wear loss followed by the applied load (B) and material (A). The above equation can be used to predict the wear loss of the composites. It can be observed from Eq. 2 that the coefficients associated with sliding velocity (C) and applied load (B) are positive. It indicates that the wear loss of the specimens increases with increasing sliding velocity and applied load.

Table 7: Confirmation experiment for wear loss

Experiment	Materials	Applied load	Sliding velocity
1	1	10	1.5
2	3	15	2.5

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

Experiment No.	Reg. model wear (μm)	Exp. wear (μm)	Error (%)
1	129.7	136.2	4.8
2	165.4	174.3	5.1

Confirmation experiment: To validate the regression analysis, a dry sliding wear test was conducted using a specific combination of the parameters and levels. The important aspect is the determination of the preferred combination of the levels of the factors indicated to be significant by the analytical methods and also to validate the conclusions drawn during the analysis phase. Table 7 shows the values used for conducting the dry sliding wear test and Table 8 shows the result of confirmation test and comparison was made between the experimental values and the computed values developed from the Regression Model. The experimental value of wear loss is found to be varying from the wear loss calculated in regression equation by about 5%. Thus, the calculated wear rate from the regression equation and experimental values are nearly same with least error.

CONCLUSION

Following are the conclusions drawn from the study on dry sliding wear test using Taguchi's technique. Sliding velocity has the highest influence on wear followed by applied load and material. Incorporation of graphite as reinforcement increases the wear resistance of composites by forming a protective layer between pin and counter face and the inclusion of B_4C increases hardness. Regression equation generated for the present model was used to predict the wear loss of with reasonable accuracy. Confirmation experiment was carried out and made a comparison between experimental values and computed values showing an error associated with dry sliding wear of composites being 5%. Thus, design of experiments by Taguchi Method can be successfully used to predict the tribological behaviour of composites.

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