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Analysis of Friction Wear Behaviour by taking 15% of Sic in Alsic Metal Matrix Composite using Taguchi Technique

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Abstract

The paper presents the results of tests carried out on Aluminium-SiliconCarbide composite by taking 15 percent of silicon carbide using Taguchi Technique. This experiment is conducted on this composite to successfully determined the optimum parameters for wear removal rate and coefficient of friction for 15% of SiC to the weight of the composite. In the experiment firstly input values are identified through which wear resistance and coefficient of friction optimum value comes, after identification the values are putting in the formula to find the theoretical calculated value and then experiment is being performed and confirmation test has been done to check whether the theoretical calculated value are experimentally feasible or not and after comparing given and calculated values. The aim of the experimental plan is to find the important factors and combination of factors influencing the wear process to achieve the minimum wear rate and coefficient of friction. The experiments were developed based on an orthogonal array, with the aim of relating the influence of sliding speed, applied load and sliding distance. These design parameters are distinct and intrinsic feature of the process that influence and determine the composite performance.

Keywords: Aluminium- silicon carbide; Taguchi technique; Coefficient of friction; Wear removal rate; Stir casting

Introduction

Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. Composites consist of one or more discontinuous phase (Reinforcement) embedded in a continuous phase (Matrix). Composites results in better properties than that of the constituent materials. The main part of the composite is known as matrix which holds the reinforcing phases [1]. Reinforcing material size and shape ranges from particle to continuous fibers (Figure 1).

Engineered composite materials must be formed to shape. The matrix material can be introduced to the reinforcement before or after the reinforcement material is placed into the mould cavity or onto the mould surface. The matrix material experiences a melting event, after which the part shape is essentially set.

Aluminium-silicon carbide metal matrix composite (Al-Sic)

Al-SiC, pronounced "alsick" is a metal matrix composite consisting of aluminium matrix with silicon carbide particles. It has high thermal conductivity (180-200 W/m K), and its thermal expansion can be adjusted to match other materials, e.g. silicon and gallium arsenide chips and various ceramics. It is chiefly used in microelectronics as substrate for power semiconductor devices and high density multi-chip modules, where it aids with removal of waste heat.

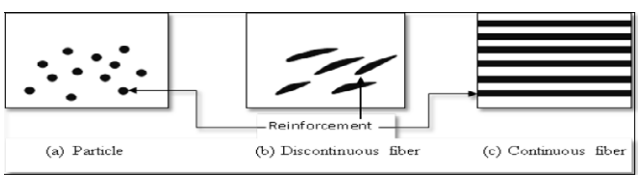

Figure 1: (a) Particles as reinforcement (b) Discontinuous fibers as reinforcement (c) Continuous fibers as reinforcement.

Taguchi technique

Taguchi technique is the statistical method developed by Genichi Taguchi to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology. Taguchi proposes an "off-line" strategy for quality improvement as an alternative to an attempt to inspect quality into a product on the production line. He observes that poor quality cannot be improved by the process of inspection, screening and salvaging. No amount of inspection can put quality back into the product. Taguchi recommends a three-stage process: system design, parameter design and tolerance design. In the present work Taguchi's parameter design approach is used to study the effect of operating parameters on the wear resisting behaviour of AlSic composite.

Experimental design strategy

Taguchi recommends orthogonal array (OA) for laying out of experiments. To design an experiment is to select the most suitable OA and to assign the parameters and interactions of interest to the appropriate columns [2]. The optimum condition is identified by studying the main effects of each of the parameters. The main effects indicate the general trends of influence of each parameter. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiments in determining the percent contribution of each parameter against a stated level of confidence. Study of ANOVA table for a given analysis helps to determine which of the parameters need control. Taguchi suggests two different routes

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to carry out the complete analysis. First, the standard approach, where the results of a single run or the average of repetitive runs are processed through main effect and ANOVA analysis (Raw data analysis). The second approach which Taguchi strongly recommends for multiple runs is to use signal- to- noise ratio (S/N) for the same steps in the analysis. The S/N ratio is a concurrent quality metric linked to the loss function.

Steps in experimental design and analysis

1. Select the quality characteristics.
2. Select noise factor and control factor.
3. Select orthogonal array.
4. Conduct the experiments.
5. Analyze the result and determine optimum factor-level combination.
6. Predict optimum performance.

Experimental set-up

Experimental set-up is done after the problem formulation and set of the objective. The set-up for the present experimental study is discussed below:

Pin on Disc wear measuring instrument: The experiments were carried out on Pin on Disc wear measuring instrument installed at research and development Laboratory of Mechanical Engineering Department, Maharishi Markandeshwar University, Mullana, Ambala, Haryana, India [3].

The Pin on Disc wear measuring instrument (Figure 2) has the following main components:

1. Rotating Disc
2. Pin Holder
3. Load Pan

Further, the instrument is comprises of:

1) Controller (Figure 3); used to control the power supply of the instrument and the R.P.M. of the disc.

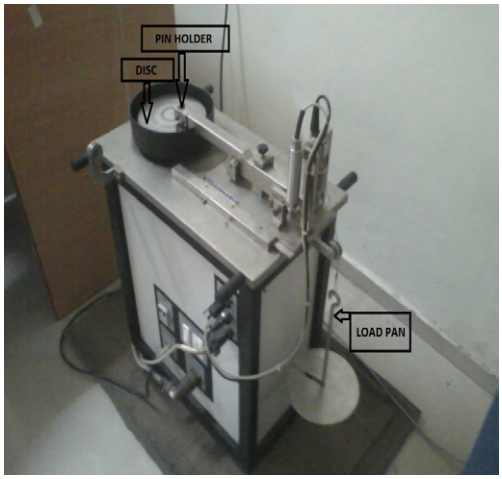

Figure 2: Pin on Disc wear measuring apparatus.

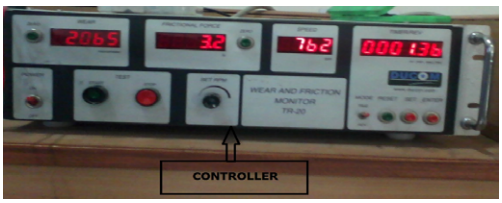

Figure 3: Controller.

Figure 4: Monitor.

2) Monitor (Figure 4); utilized to obtain the state of co-efficient of friction with respect to time as the specimen rotates over the disc.

Determination of Tribological Behaviour

Afterwards, the specimens of both the compositions i.e., 15 and 20% of the weight were subjected to the pin on disc wear measuring instrument to study the tribological properties such as wear rate as well as the co-efficient of friction. 9 pieces from both of the compositions were tested on the instrument. A graph showing the change in co-efficient of friction w.r.t. time was generated on the monitor as the specimen rotates over the disc.

The pin-on-disc tribometer serves for the investigation and simulation of friction and wear processes under sliding conditions. It can be operated for solid friction without lubrication and for boundary lubrication with liquid lubricants. Thus both material and lubricant tests can be executed.

Result and Analysis

The results for various combinations of parameters were obtained by conducting the experiment as per the orthogonal array.

a. Select the quality characteristics

There are three types of quality characteristics in the Taguchi methodology such as:

1) Smaller-the-better
2) Larger-the-better
3) Nominal-the-best

b. Select noise factor and control factor

Load (L), Sliding speed (S) and Sliding distance (D) had significant effect on wear behaviour. These factors are controllable factors. Table 1 shows all Taguchi design parameters and levels. One of the most

important considerable attributes of Taguchi parameter design was S/N ratio. It was differ at the different place.

Select orthogonal array

The selection of Orthogonal array depends on three items in order of priority, viz., the number of factors and their interactions, number of levels for the factors and the desired experimental resolution or cost limitations. A total of 9 experiments were performed based on the run order generated by the Taguchi model. The response for the model is wear rate and coefficient of friction. The general layout of L9 orthogonal array is shown in Table 2.

Experimental design with a L9 orthogonal array as suggested by Taguchi has been used to carry out experiments with three inputs parameters and for three levels of individual parameters. The inputs parameters used are Load (L), Sliding speed(S) and Sliding distance (D). As per Taguchi experimental design philosophy a set of three levels assigned to each process parameter has two degrees of freedom (DOF).

Controllable factors	A: Load, L (N)	B: Sliding speed, S (m/s)	C: Sliding distance, D (m)
Level 1	10	1.5	900
Level 2	20	2.5	1500
Level 3	30	3.5	2100

Table 1: Selected factor and level.

Experiment No.	Column 1	Column 2	Column 3
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 2: L9 Orthogonal array.

Sr. No.	Load (N)	Sliding speed (m/s)	Sliding distance (m)
1	10	1.5	900
2	10	2.5	1500
3	10	3.5	2100
4	20	1.5	1500
5	20	2.5	2100
6	20	3.5	900
7	30	1.5	2100
8	30	2.5	900
9	30	3.5	1500

Table 3: L9 Orthogonal array for experiment.

This gives a total of six DOF for three process parameters selected in this work. The nearest three level orthogonal array available satisfying the criterion of selecting the OA is L9 having 26 DOF.

The details of experiments with parameters and levels are given in Table 3.

Conduct the Experiments

The work piece material used was AlSic composite in the cylindrical form having 10 mm diameter and 30mm length for both the compositions. These specimens were cut in the nine pieces by hand hacksaw. Wear rate and co-efficient of friction values were collected with the help of pin on disc wear measuring instrument. S/N ratio was calculated with the help of following Eq. (1).

$$\text{S/N}\ (\eta) = -10log\frac{1}{n}\sum_{i=1}^{n} y_i^2 \quad (1),$$

Where y_1, y_2...y_i are the response of friction and sliding wear; and n is the number of observations.

The result of L9 orthogonal array from Table 3 is shown in Table 4 for 15%. The wear behaviour of the work pieces obtained by the testing from pin on disc wear measuring instrument. Three responses were taken from each experiment e.g. R_1, R_2 and R_3 responses for each experiment. For the wear resisting feature, the signal-to-noise ratio should be small e.g. smaller the S/N ratio, better will be the wear resisting feature. The response table for signal to noise ratios show the average of selected characteristics for each level of the factor.

Analyze the Result and Optimum Factor-level Combination

The analysis of obtained result divided into the following three categories:

Analysis of raw data and S/N ratio

It is necessary to determine which parameter gives the lower wear rate. The smaller wear rate represents better or improved wear resisting condition and parameter. The average effect response Table 5 for the raw data and S/N ratio for 15% is shown below (Figures 5-8):

Determine optimum factor-level combination

Figures 5-8 shows three graphs, each of which contains a curve representing the mean and a curve representing the S/N ratio for 15% for wear and c.o.f. The values of the graphs are obtained from average effect response Tables 4-8 for the mean and S/N ratio. Every graph represents the values obtained from the response. Table 9 shown above it for both mean value and the S/N ratios. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Machining parameter settings with the

S. No.	Load (N)	Sliding speed (m/s)	Sliding distance (m)	c.o.f.	Wear rate (mm^3/m)	S/N ratio c.o.f. (db)	S/N ratio wear (db)
1	10	1.5	900	0.286	0.00476	10.87268	46.44786
2	10	2.5	1500	0.229	0.00347	12.80329	49.19341
3	10	3.5	2100	0.179	0.00165	14.94294	55.65032
4	20	1.5	1500	0.356	0.00415	8.971	47.63904
5	20	2.5	2100	0.33	0.00192	9.629721	54.33398
6	20	3.5	900	0.359	0.00356	8.898111	48.971
7	30	1.5	2100	0.358	0.00276	8.922339	51.18182
8	30	2.5	900	0.372	0.00347	8.589141	49.19341
9	30	3.5	1500	0.343	0.00239	9.294118	52.43204

Table 4: Results of L9 orthogonal array for 15% SiC.

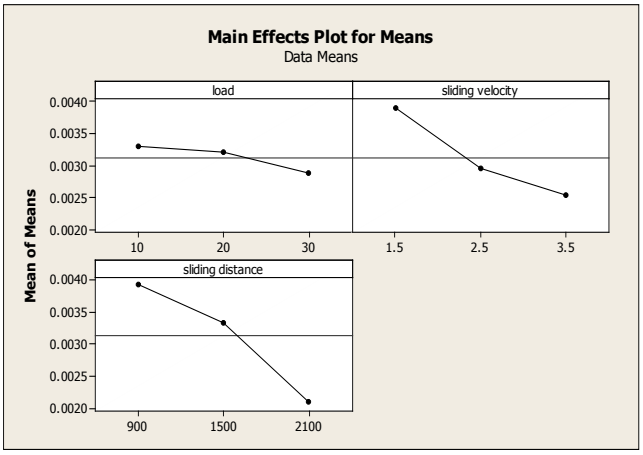

Figure 5: Response Graph for Mean values of wear for 15% SiC.

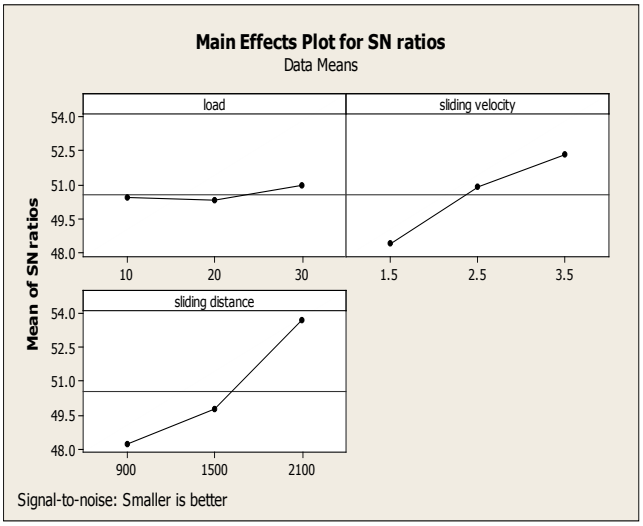

Figure 6: Response Graph for S/N Ratio of wear for 15% SiC.

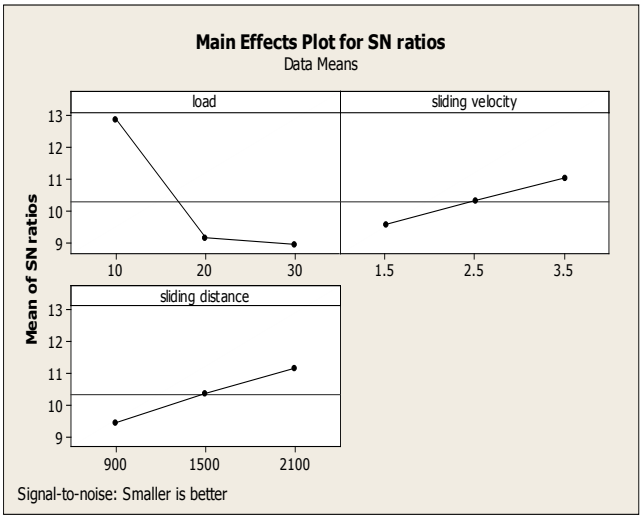

Figure 7: Response Graph for S/N ratio of c.o.f. for 15% SiC.

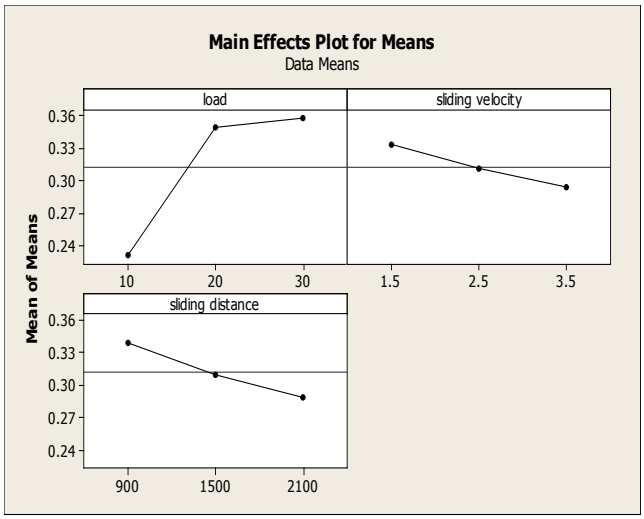

Figure 8: Response Graph for mean values of c.o.f. for 15% SiC.

Level	Load (A)	Sliding velocity (B)	Sliding distance (C)
1	0.00329	0.00389	0.00393
2	0.00321	0.00295	0.00333
3	0.00287	0.00253	0.00211
Delta (Δ)	0.00042	0.00136	0.00182
Rank	3	2	1

Table 5: Average effect response Table for mean values of wear for 15% SiC.

Level	Load (A)	Sliding velocity (B)	Sliding distance (C)
1	50.43053	48.422	48.204
2	50.31467	50.906	49.754
3	50.93575	52.351	53.722
Delta (Δ)	0.621	3.929	5.518
Rank	3	2	1

Table 6: Average effect response Table for S/N ratio of wear for 15% SiC.

Level	Load (A)	Sliding velocity (B)	Sliding distance (C)
1	12.873	9.589	9.453
2	9.166	10.341	10.356
3	8.935	11.045	11.165
Delta (Δ)	3.938	1.456	1.712
Rank	1	3	2

Table 7: Average effect response Table for S/N ratio of c.o.f. for 15% SiC.

highest S/N ratio always yield the optimum quality with minimum variance. The level that has a higher value determines the optimum level of each factor.

Wear for 15%: Here, third level for load (A3=30N) has the highest S/N ratio value (Figure 6), which indicated that the working performance at such level produced minimum variation of the wear removal. The lower wear removal value had a better working performance. Furthermore, third level for load (A3=30N) has indicated the optimum situation in terms of mean value (Figure 5). Similarly, the third levels of both sliding velocity (B3=3.5 m/s) and sliding distance (C3=2100 m) have also indicated the optimum situation in terms of S/N ratio and mean values and ultimately results in optimum wear removal rate.

Level	Load (A)	Sliding velocity (B)	Sliding distance (C)
1	0.231	0.333	0.339
2	0.348	0.310	0.309
3	0.357	0.293	0.289
Delta (Δ)	0.126	0.04	0.05
Rank	1	3	2

Table 8: Average effect response Table for mean values of c.o.f. for 15% SiC.

Wear removal rate	Predicted value of optimum levels	Experimental result of optimum levels	Percentage change
1.	For 15% A3B3C3=0.00126 mm^3/m	For 15% A3B3C3=0.00107 mm^3/m	0.019%
Coefficient of friction	Predicted value of optimum levels	Experimental result of optimum levels	Percentage change
1.	For 15% A1B3C3=0.189	For 15% A1B3C3=0.249	6%

Table 9: Experimental and Optimal results.

Co-efficient of friction for 15%: Here, third level for load (A1=10N) has the highest S/N ratio value (Figure 7), which indicated that the working performance at such level produced minimum variation of co-efficient of friction. The lower co-efficient of friction value had a better working performance. Furthermore, first level for load (A1=10N) has indicated the optimum situation in terms of mean value (Figure 8). Similarly, the third levels of both sliding velocity (B3=3.5 m/s) and sliding distance (C3=2100 m) have also indicated the optimum situation in terms of S/N ratio and mean values and ultimately results in optimum co-efficient of friction.

- **Predict optimum performance**

The optimum values of wear and co-efficient of friction could be predicted using the following Taguchi equation:

Wear rate for 15%, Predicted mean=A3 + B3 + C3 – 2× (Y)

= 0.00287+0.00253+0.00211-(2×0.003125)

= 0.00751-0.00625

= 0.00126 mm^3/m.

Here, predicted mean=0.00126 mm^3/m which show that the parameter we used is within the range of specified machining conditions.

Co-efficient of friction for 15%, Predicted mean=A1 + B3 + C3 – 2× (Y)

= 0.231+0.293+0.289-(2×0.312)

= 0.813-0.624=0.189

Here, predicted mean=0.189 which show that the parameter we used is within the range of specified machining conditions.

- **Confirmation test:** The confirmation test is conducted to verify that, the optimal setting factors derived previously will actually yield an improvement in quality characteristic under study and how close are the respective predictions with the real ones. After performing experiment again as per given optimum levels following results were obtained for both the wear removal rate and coefficient of friction.

Conclusions

Following are the conclusions drawn from the study on dry sliding wear test using Taguchi's technique:

1) Taguchi parameter design successfully determined the optimum parameters for wear removal rate and coefficient of friction for 15% of SiC to the weight of the composite. (A3, B3, C3) for wear removal rate in case of 15% SiC and (A3, B2, C1). (A1, B3, C3) for co-efficient of friction in case of 15% SiC. Where, A-LOAD (N), B-SLIDING SPEED (m/s), and C- SLIDING DISTANCE (m).

2) Taguchi parameter design can provide a systematic procedure that can effectively and efficiently identify the optimum wear rate and coefficient of friction of the composite. This research demonstrates how to use Taguchi parameter design for optimizing wear rate with minimum cost.

3) Incorporation of silicon carbide as primary reinforcement with increasing composition increases the wear resistance of composite.

4) Confirmation experiment was carried out and made a comparison between experimental values and computed values showing a change associated with dry sliding wear of composites is 0.019% and 6% for co-efficient of friction. Thus, Design of experiments by Taguchi method was successfully used to predict the tribological behaviour of composites.

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