

# Characterization of Wear Properties of Epoxy- SiC- Alumina Filled Polymer Matrix Composites

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## ABSTRACT

Nowadays, Polymer composites are frequently used for engineering applications such as aerospace, automotive and marine industries. The present research is on evaluation of wear properties of epoxy resin composite fabricated using alumina (Al<sub>2</sub>O<sub>3</sub>) in 5wt% and Silicon Carbide (SiC) in 5-15 wt% in steps of 5 wt% as fillers for testing purpose. The tribological properties such as dry sliding wear characteristics have been evaluated by conducting wear tests using Pin-on-Disc wear testing setup for sliding speed (200/300/400 rpm) and sliding load (20/30/40 N). The wear properties are analyzed using Taguchi's Design of Experiments and Analysis of Variance (ANOVA) techniques. From the statistical analysis it is found that the 15wt% of SiC is major factor influencing the wear resistance of the composite material. Finally regression analysis has been carried out to build regression model to predict the wear rate of the composite material under different sliding conditions.

**Keywords :** Alumina, Silicon Carbide, Taguchi's, ANOVA

## I. INTRODUCTION

The fast growing technology has created demand for newer materials particularly for structural applications which has improved physical and mechanical properties and which can be performed at highly corrosive environment, high temperature and pressure. Composites are the materials of choice, which are basically multifunctional materials having unprecedented physical and mechanical properties that can be tailored to meet the requirements of a particular application. There has been a tremendous achievement in the science and technology of composite material in recent times [1]. These materials have greatly improved since the 1970s and their use has expanded rapidly in the world of industry. Their contribution is essential to different

leading industry sectors. They are used because of their low mass and exceptional performance. Many composites used today are at the leading edge of materials technology with performance and costs justifying their ultra-demanding applications [2].

Among the thermosetting polymers, epoxy resins are the most widely used for high-performance applications such as, matrices for fiber reinforced composites, structural adhesive, coating and other engineering applications. Epoxy resins are characterized by excellent mechanical and thermal properties, high chemical, and corrosion resistance, low shrinkage on curing and the ability to be processed under a variety of conditions [3].

Rajesh et al. [4] fabricated the epoxy and polyester resin composites mixing aluminum oxide, silicon carbide with silicon carbide with different proportion of  $Al_2O_3$  and SiC along with GFRP. SiC remains one of the most explored conventional reinforcement for the development of AMCs [5]. Its suitability for weight saving structural and tribological applications, and appeal as coatings in metal substrates and heat sink components in microelectronics and electronic packaging applications [6–8] has helped to preserve it as first choice reinforcement material for AMCs. However, its relatively prohibitive cost and limited availability remain some concerns from a third world perspective.

Now-a-days specific fillers/additives are to enhance and modify the quality of composites as these are found to play a major role in determining the physical properties and mechanical behavior of the composites. For many industrial applications of filler reinforced epoxy composites are in use. Information about their mechanical behavior is great importance. Therefore, this work presents an experimental study of the evaluation of wear behavior of SiC-alumina filled polymer matrix composites.

## II. MATERIAL AND METHODS

Composites are made of reinforcing fibers or fillers and matrix materials. Matrix surrounds the fibers and thus protects those fibers against chemical and environmental attack.

The matrix material system selected is an Epoxy resin (LAPOX L-12 with density  $1.16 \text{ g/cm}^3$ ) supplied by Suntech Fibers, Bangalore, India. The two fillers chosen were Silicon- (SiC) and aluminum oxide ( $Al_2O_3$ ). The average particle size of SiC and  $Al_2O_3$  micro particles are about  $10 \mu\text{m}$  size.

## A. COMPOSITE FABRICATION

The fabrications of all composite specimens used in this work were manufactured by “Casting and Curing” technique. The process of manufacturing a composite product has been split into a number of different stages. Fabrication is done by mixing a measured amount of pure epoxy resin to a known amount of hardener in the ratio of 10:1.2 with gentle stirring to minimize formation of air bubbles. A releasing agent is used to facilitate easy removal of the composite from the mould after curing. The epoxy is mixed with calculated weight percentage of SiC and  $Al_2O_3$  with constant stirring. Then the mixture is poured into the moulds. Then the cast of each composite after 12 hr of impregnation and dried for 2 hr at  $100^\circ \text{C}$  in an oven after curing. The epoxy is mixed with calculated weight percentage of SiC and  $Al_2O_3$  with constant stirring. Then the mixture is poured into the moulds. Then the cast of each composite after 12 hr of impregnation and dried for 2 hr at  $100^\circ \text{C}$  in an oven. Specimens of suitable dimension are cut for physical characterization and mechanical testing. Utmost care has been taken to maintain uniformity and homogeneity of the composite. All composite samples with particulate fillers of fixed weight percentage are fabricated by the same technique. Composites having 0%SiC-5% $Al_2O_3$ , 5%SiC-5% $Al_2O_3$ , 10% SiC-5%  $Al_2O_3$  and 15% SiC-5%  $Al_2O_3$  are fabricated and prepared for conducting mechanical testing.

## III. RESULT AND DISCUSSION

### A. Evaluation of Wear Properties using Taguchi Method

The Taguchi technique is a powerful design of experiment tool for acquiring the data in a controlled way and to analyze the influence of process variable

over some specific variable which is unknown function of these process variables and for the design of high quality systems. This method was been successfully used by many researchers in the study of wear behavior of aluminum metal matrix composites [9-15]. Taguchi creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiment. The Taguchi method, which is effective to deal with responses, was influenced by multi-variables. This method drastically reduces the number of experiments that are required to model the response function compared with the full factorial design of experiments. The major advantage of this technique is to find out the possible interaction between the parameters. The Taguchi technique is devised for process optimization and identification of optimal combination of the factors for a given response. This technique is divided into three main phases, which encompasses all experimentation approaches. The three phases are:

- 1) The planning phase
- 2) The conducting phase
- 3) The analysis phase

Planning phase is the most important phase of the experiment. This technique creates a standard orthogonal array to accommodate the effect of several factors on the target value and defines the plan of experiments. The experimental results are analyzed using analysis of means and variance to study the influence of factors.

TABLE I. FACTORS AND THEIR LEVELS

Symbol	Factor	Level 1	Level 2	Level 3
L	Normal Load ( N)	20	30	40
S	Sliding Speed (rpm)	200	300	400
F	SiC content (Wt %)	5	10	15

TABLE II. L27 (313) ORTHOGONAL ARRAY OF TAGUCHI

Trail	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	1	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	2	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	2	1	2	1	1
17	2	3	1	2	2	3	1	1	2	3	3	2	2
18	2	3	1	2	3	1	2	2	3	1	1	3	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1

23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2
			A	A		A	A	B		A	B	B	C
			X	X		X	X	X		X	X	X	X
	A	B	B	B	C	C	C	C	D	D	C	D	D

In the present investigation, an L27 orthogonal array was selected and it has 27 rows and 13 columns. The selection of the orthogonal array is based on the condition that the degrees of freedom for the orthogonal array should be greater than, or equal to the sum of the variables. Each variable and the corresponding interactions were assigned to a column defined by Taguchi method. In the study of prediction of wear rate of the composite materials is carried out by selecting load (L), sliding speed (S) and wt% of SiC (Si) as control variables. The control variables and their levels are shown in table 3.1 and table 3.2 shows the standard L27 orthogonal array. The first column was assigned to load (L), the second column to sliding speed (S), the fifth column to SiC content (Si), and the remaining columns were assigned to their interactions. The response variable to be studied is wear rate. The experiments were conducted based on the rank order generated by Taguchi model and the results were obtained. The analysis of the experimental data was carried out using MINITAB 15 software, which is specially used in DOE applications. The experimental results were transformed into a signal to-noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise

factors. The S/N ratio for wear rate is calculated using 'smaller the better' characteristic, which can be calculated as a logarithmic transformation of the loss function, and is given in the equation 3.1.

$$\frac{S}{N} = -10 \log 1/n (\Sigma y^2) \tag{3.1}$$

Where, y is the observed data (wear rate) and n is the number of observations. The above S/N ratio transformation is suitable for minimization of wear rate. The experiments were conducted as per orthogonal array and the wear rate results obtained for various combinations of parameters are shown in Table 3.2. The experimental values were transformed into S/N ratios for measuring the quality characteristics using MINITAB 15. The S/N ratio obtained from all the experiments are shown in Table 3.3.

TABLE III.  
WEAR RATE AND S/N RATION OBTAINED AS PER TAGUCHI'S L27 ORTHOGONAL ARRAY

Sl No	load, N(L)	Speed, m/s (S)	SiC, wt% (Si)	Wear Rate Kg/m X 10 <sup>-5</sup>	S/N Ratio
1	20	1.05	3	3.0867	-9.78989
2	20	1.05	6	3.0194	-9.59841
3	20	1.05	9	3.0113	-9.57508
4	20	1.83	3	4.2575	-12.5831
5	20	1.83	6	3.786	-11.5636
6	20	1.83	9	3.585	-11.0898
7	20	2.62	3	4.4717	-13.0089
8	20	2.62	6	3.7923	-11.5781
9	20	2.62	9	3.6887	-11.3375
10	20	1.05	3	4.6403	-13.3309
11	20	1.05	6	3.8332	-11.6711
12	20	1.05	9	3.1752	-10.0354
13	20	1.83	3	5.3261	-14.5282
14	20	1.83	6	4.7157	-13.4709
15	20	1.83	9	3.869	-11.752
16	20	2.62	3	5.592	-14.9513
17	20	2.62	6	5.2443	-14.3938
18	20	2.62	9	4.5606	-13.1804
19	20	1.05	3	5.568	-14.914
20	20	1.05	6	4.7185	-13.4761
21	20	1.05	9	4.5796	-13.2166
22	20	1.83	3	6.4175	-16.1473
23	20	1.83	6	5.6392	-15.0243
24	20	1.83	9	5.3352	-14.543
25	20	2.62	3	6.5245	-16.2909
26	20	2.62	6	6.3447	-16.0482
27	20	2.62	9	5.498	-14.8041

**A. S-N Ratio Analysis**

The influence of control parameters such as load, sliding speed and SiC content on wear rate has been evaluated using S/N ratio response analysis. The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential was the control parameter. The S/N ratio response analysis, presented in Table 3.4 shows that among all the factors, load was the most influential and significant parameter followed by sliding speed and SiC content. Figure 3.1 shows the mean of wear rate graphically and figure 3.2 depicts the main effects plot for means of S/N ratio for wear rate. From the analysis of these results, it can be inferred that parameter combination of L = 20 N, S = 200 rpm and Si = 15% gave the minimum wear rate for the range of parameters tested.

TABLE IV. RESPONSE TABLE FOR S/N RATIOS - SMALLER IS BETTER (WEAR RATE)

Level	Load	Speed	SiC
1	3.633	3.959	5.098
2	4.551	4.77	4.566
3	5.625	5.08	4.145
Delta	1.992	1.12	0.953
Rank	1	2	3

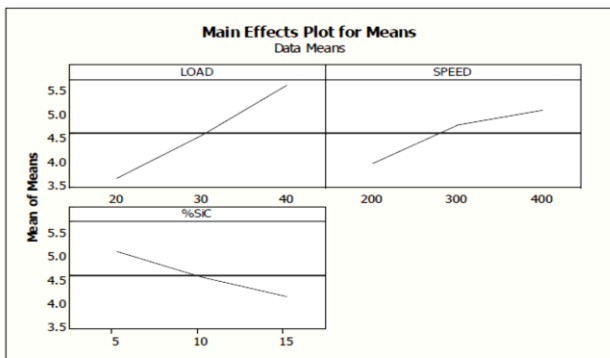


Figure 1: Main Effects plot for Means

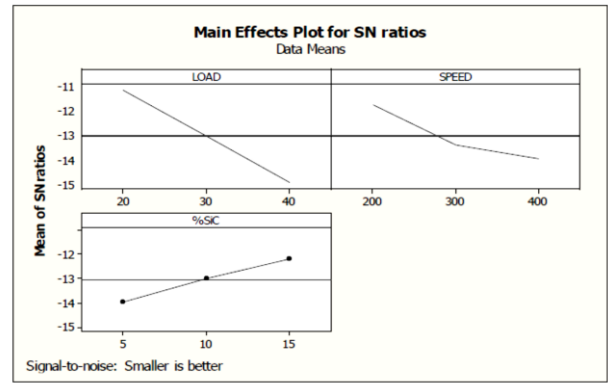


Figure 2: Main Effects plot for S-N Ratios

**B. ANOVA and Effects of Parameters on Wear Rate**

Analysis of Variance (ANOVA) was used to determine the design parameters significantly influencing the wear rate (response). The table shows the results of ANOVA for wear rate. This analysis was evaluated for a confidence level of 95%, that is for significance level of  $\alpha=0.05$ . The last column of Table 3.5 shows the percentage of contribution (P %) of each parameter in the response, indicating the degree of influence on the result.

TABLE V. ANOVA RESULTS FOR WEAR RATE

Source	D.F	Seq SS	Adj SS	Adj MS	F	P	P(%)
Load, N(L)	2	17.8907	17.89	8.945	209.230	0.000	61.38
Speed, m/s (S)	2	6.026	6.026	3.013	70.480	0.000	20.68
SiC, wt% (SI)	2	4.109	4.109	2.054	48.060	0.000	14.10
L X S	4	0.129	0.129	0.032	0.760	0.588	0.45
L X Si	4	0.555	0.555	0.138	3.250	0.007	1.90

<i>S X Si</i>	4	0.09 1	0.09 1	0.02 3	0.540	0.7 1	0.32
<i>Residual Error</i>	8	0.34 2	0.34 2	0.04 2			
<i>Total</i>	26	29.1 4					

Notes: DF, degree of freedom; SeqSS, Sequential sum of squares; Adj SS, Adjusted sum of squares; Adj MS, Adjusted mean squares; P, Percentage of contribution. S=0.2398 R-Sq=98.8% R-Sq(adj)=96.2%

It can be observed from the results obtained in the Table 3.5, that load was the most significant parameter having the highest statistical influence (61.38%) on the dry sliding wear of composites followed by sliding speed (20.68%) and SiC content (14.10%). When the P value for this model was less than 0.5, then the parameter or interaction can be considered as statistically significant. This is desirable as it demonstrates that the parameter or interaction in the model has a significant effect on the response. From an analysis of the results obtained in Table 3.3, it is observed that the load (L), sliding speed (S), SiC content (Si), the interaction effect of load with SiC content (L\* Si) is significant model terms influencing wear rate of composites, since they have obtained the P - value < 0.5. Although the interaction effect of load with sliding speed (L\*S) exerts some influence on the dry sliding wear, it may be considered statistically insignificant for its P-value is greater than 0.5, and hence it is neglected. The coefficient of determination (R<sup>2</sup>) is defined as the ratio of the explained variation to the total variation. It is a measure of the degree of fit. When R<sup>2</sup> approaches unity, a better response model results and it fits the actual data. The value of R<sup>2</sup> calculated for this model was 0.988, i.e., very close to unity, and thus acceptable. It demonstrates that 98.8% of the

variability in the data can be explained by this model. Thus, it is confirmed that this model provides reasonably good explanation of the relationship between the independent factors and the response. Statistical analysis is carried out for composite specimens having e-glass fiber in different wt%. Similar analysis is repeated for composites containing 3 wt%, 6 wt% and 9 wt% of e-glass fiber reinforced aluminum SiC composite materials and effect of different control variables on the wear rate of composites is analyzed using ANOVA.

### C. Worn surface morphology

To correlate the wear data effectively, SEM micrographs of worn surfaces of Epoxy Composite samples are shown in figure 3.3 to figure 3.5. Several mechanisms have been proposed to explain how material is removed from the surface during abrasion. Because of the complexity of abrasion, no one mechanism completely contributes to all the wear loss. In general, the abrasive wear process involves four different mechanisms namely microplothing, micro cutting, micro fatigue and micro cracking. Using SEM micrographs it is possible to identify qualitatively the dominant wear mechanisms under abrasion. Figure 5.7 to 5.9 show SEM micrograph of epoxy composite samples abraded during wear test. Figure 5.7 to 5.9 shows some ploughing marks on the surface, matrix damage and exposure of SiC. The matrix is heavily damaged by ploughing and cutting action by the higher sized SiC particles. The SEM micrograph also indicates the crack propagation of the matrix, deterioration of the matrix adhesion due to repetitive mechanical stress and some SiC pull-out from the matrix is also visible.



Figure 3: SEM Micrographs of 5wt% Al<sub>2</sub>O<sub>3</sub> and 5wt% SiC Epoxy Composite

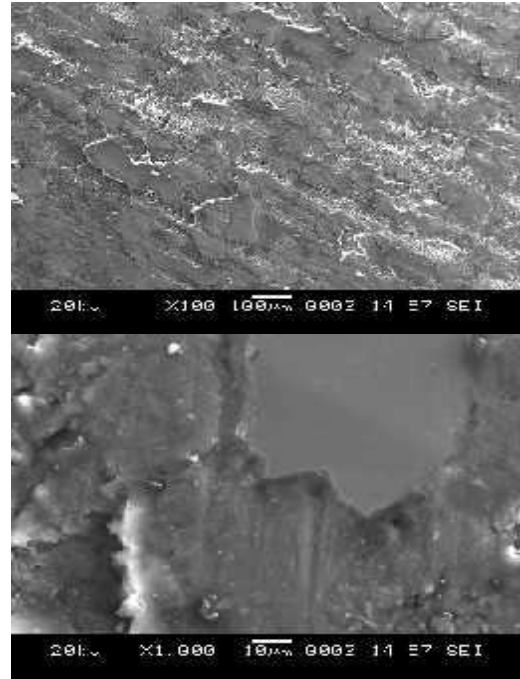


Figure 5: SEM Micrographs of 5wt% Al<sub>2</sub>O<sub>3</sub> and 15wt% SiC Epoxy Composite

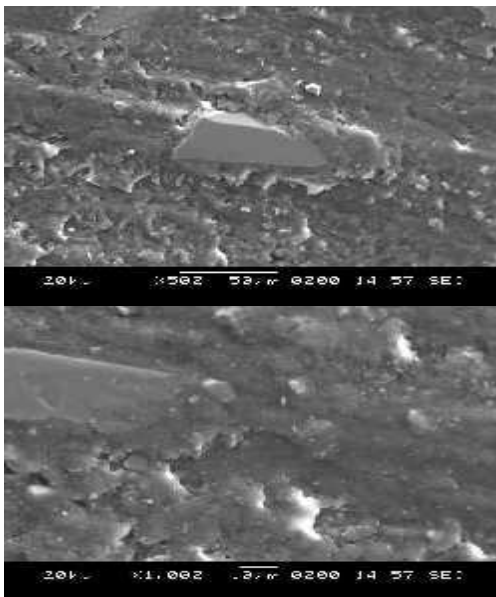


Figure 4: SEM Micrographs of 5wt% Al<sub>2</sub>O<sub>3</sub> and 10wt% SiC Epoxy Composite

#### IV. CONCLUSION

The following conclusions can be made by the study of SiC and Al<sub>2</sub>O<sub>3</sub> filled epoxy polymer matrix composites:

- Wear rate decreases with increasing abrading distance and grit size. Further, the wear volume increases with increasing abrading distance. Al<sub>2</sub>O<sub>3</sub> filled composite showed better abrasion resistance as compared to that of unfilled composites.
- There has been an observed marked improvement in wear resistance as seen in Al<sub>2</sub>O<sub>3</sub> and SiC filled composite sample. Higher wear resistance was noticed for 5 wt. % of Al<sub>2</sub>O<sub>3</sub> and 15 wt% SiC filled composite than unfilled composites.
- SEM micrographs revealed that the microploughing and micro cutting are the dominant wear mechanisms characterized by the

formation of deep grooves with extruded filaments of matrix at the edges of the grooves.

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- Cite this article as :** Mohammed Asif Kattimani, D. H. Pachchinar, Bhimanagouda Patil, "Characterization of Wear Properties of Epoxy - SiC - Alumina Filled Polymer Matrix Composites", International Journal of Scientific Research in Science and Technology (IJSRST), Online ISSN : 2395-602X, Print ISSN : 2395-6011, Volume 6 Issue 5, pp. 163-170, September-October 2019. Available at doi : <https://doi.org/10.32628/IJSRST196516>  
Journal URL : <http://ijsrst.com/IJSRST196516>