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Taguchi Approach for Characterization of Three-Body Abrasive Wear Behavior of Granite Epoxy Composite with and Without SiC Filler

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Abstract:
The Granite-Epoxy (G-E) composites with Silicon carbide (SiC) and without Silicon carbide filler were prepared using the hand lay-up technique. Three-body abrasive wear tests with different loads/abrading distances were performed at room temperature by using a rubber wheel abrasion apparatus. The results showed that among the filled Epoxy composites tested, 20 wt. % granite and 10% SiC filled epoxy composites showed a better result. The systematic experimentation leads to identification of significant process parameters and material variables that predominantly influenced the specific wear rate. It is evident from Taguchi wear analysis that load plays a significant role followed by abrading distance, and material composition. Finally, the worn surfaces were examined using Scanning Electron Microscopy (SEM) to identify the various wear mechanisms.

Keywords*: Granite-Epoxy, Silicon carbide, Three-body abrasive wear, Wear mechanisms, Scanning Electron Microscopy*

1. Introduction

The increasing use of polymers and their composites in tribological applications convinced many researchers to study the wear behavior of polymeric composites. Generally, the mechanical load carrying capacity and specific wear rate of the materials determine their acceptability in practical applications. Wear was defined as damage to a solid surface, generally involving progressive loss of material, due to relative motion between contacting surfaces. The five main types of wear were abrasive, adhesive, fretting, erosion and fatigue wear, which were commonly observed in practical situations. Abrasive wear was the most important among all the forms of wear because it contributes almost 63% of the total cost of wear.

Polymer composites undergo abrasive wear in most of the situations like earth moving equipments, pipelines, rock drilling and ore crushers etc. The features that make composites so promising as industrial and engineering materials are their high specific strength, high specific stiffness and opportunities to tailor material properties through the control of fiber and matrix compositions. Composites are developed for superior mechanical strength and this objective often conflicts with the simultaneous achievement of superior wear resistance. As a result of this, composite materials are found to be used in mechanical components such as gears, cams, wheels, impellers, brakes, clutches, conveyors, transmission belts, bushes and bearings. In most of these services the components are subjected to Tribological loading conditions, where the likelihood of wear failure becomes greater. The use of fillers in the matrix, gives rise to many combinations that provide increasing load withstanding capability, reduced coefficient of friction, improved wear resistance and improved thermal properties. In addition to this, fillers in polymeric composite reduce the cost due to the less consumption of matrix material.

2. Literature Review

Polymer matrix composites are a special class of modern materials finding numerous applications. The literature survey carried out revealed only a few studies on the Tribological behavior of epoxy composites filled with either SiC or Granite particulates However, several other reports [1–9] show studies on epoxy composites filled with hybrid fillers, mainly constituting many combinations of both organic and inorganic fillers.

Among the thermosetting polymers, epoxy resins are the most widely used for high-performance applications such as, matrices for fiber reinforced composites, coatings, structural adhesives 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 [10].

Fillers and fiber reinforcements play an important role in determining the abrasive wear of the polymer matrix composites. Suresha et al [11] studied the three-body abrasive wear of graphite/SiC filled in glass fabric reinforced epoxy composites and concluded that the graphite filler increased the specific wear rate and SiC decreased the specific wear rate of glass-epoxy composite. Suresha et al [12]. studied the three-body abrasive wear of silicon carbide (SiC) filled in glass fabric reinforced epoxy (G-E) composites SiC decreased the specific wear rate of G-E composite. Patnaik et al [13]. investigated three-body abrasive wear of particulate filled glass-epoxy (G-E) composites and revealed that wear was more sensitive to variation in abrading distance. Majority of research studied the effect of one factor by keeping all other factors fixed, this approach is not advisable because in actual environment there will be combined effects of interacting factors influencing the abrasive wear. Hence, in this study an attempt is being made to study the interacting effects of factors along with the main effect. To achieve this, design of experiments based on Taguchi method is adopted [14]. Taguchi's technique uses special design of orthogonal arrays to study the entire parameter space with only a small number of experiments. It also helps in optimizing the critical parameters [15]. It is known from the literature that research works on composite materials concerning tribological studies may be very fruitful as it provides new opportunities of applications. The studies presented herein are for epoxy resin, filled with a highly abrasive type SiC in one case, and Granite filler in another case.

3. Experimental Details

3.1. Materials

The matrix material consist of epoxy resin of grade LAPOX L-12 and room temperature curing hardener of grade K-6 supplied by Yuje marketing ,Bangalore, India. Composites were fabricated by blending epoxy resin, Granite and SiC filler in certain wt. % reinforcement. Three different compositions of composites are prepared by varying SiC filler as well as granite filler reinforcement with fixed wt. % of epoxy matrix.

3.2. Three-Body Abrasive Wear Tests

The three-body abrasive wear tests were conducted using a dry sand/rubber wheel abrasion tester as per ASTM G-65. The abrasive was fed at the contacting face between the rotating rubber wheel and the test sample. The tests were conducted at a rotational speed of 200 rpm. The feeding rate of abrasive was in the range of 235±5 g/min. The experiments were carried out at three different loads under different abrading distances. The wear was measured by the loss in weight, which was then converted into wear volume using the measured density data. The specific wear rate (Ks) was calculated from the equation:

$$K_s = \frac{V}{LxD} \quad m^3/Nm \tag{1}$$

Where V = volume loss in m^3, L= load in N and D = abrading distance in m.

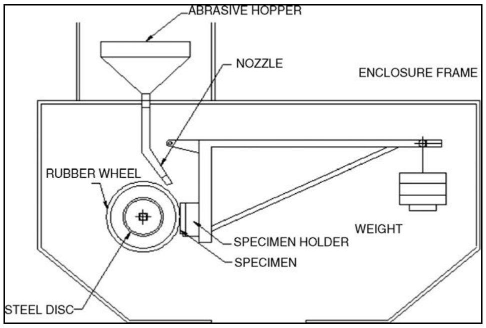

Figure 1: Dry sand rubber wheel abrasion test rig

3.3. Design of Experiments

Design of experiments (DOE) using Taguchi approach is a standardized form of experimental design technique. DOE is an experimental strategy in which effects of multiple factors are studied simultaneously by running tests at various levels of the factors. Factor is a variable or a parameter that has a direct influence on the output (wear characteristic). Levels are the descriptions that define the condition of the factor held while running the experiments. The wear tests are carried out under operating conditions given in Table 1.

Control factors	**Levels**		
	I	**II**	**III**
*Composition	A	B	C
Load(N)	20	30	40
Distance (m)	1500	2000	2500

Table 1: Operating conditions

**Composition A - 70% Epoxy 30% Granite, B – 70% Epoxy 25% Granite and 5% SiC,*
C – 70% Epoxy, 20% Granite and 10% SiC

In this present work the L9 array design is used as the experimental design. The experimental observations are transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate coming under smaller is better characteristic is given by

4. Results and Discussion

The experiment consists of 9 tests and three factors were assigned as shown in Table 2. The experimental results are analyzed using Taguchi method and the significant parameters affecting wear have been identified as shown in response Table 3.

Experiments	**Load (N)**	**composition**	**Abrading distance (m)**	**Weight loss (gm)**	**Specific wear rate (10^{-6}) (m^3/Nm)**	**S\N ratio (db)**
1	20	0	1500	0.064	1.3047	117.690
2	20	5	2000	0.074	1.1124	119.075
3	20	10	2500	0.085	1.0053	119.954
4	30	0	2000	0.172	1.753	115.124
5	30	5	2500	0.200	1.6330	115.740
6	30	10	1500	0.124	1.6295	115.759
7	40	0	2500	0.325	1.994	114.005
8	40	5	1500	0.241	2.4153	112.341
9	40	10	2000	0.273	2.0180	113.902

Table 2: standard orthogonal L9 array with control factors and output results

Level	**Load**	**Composition**	**Distance**
1	118.9	115.6	115.3
2	115.5	115.7	116.0
3	113.4	116.5	116.6
Delta	5.5	0.9	1.3
Rank	1	3	2

Table 3: Response Table for Signal to Noise Ratios

Analysis was made using minitab-15 software in order to find statistical significance of various factors like load, material and abrading distance. From Taguchi wear response (Table.3) it is evident that load plays a significant role followed by distance, and material plays least role.

4.1. Main effect and interaction plots

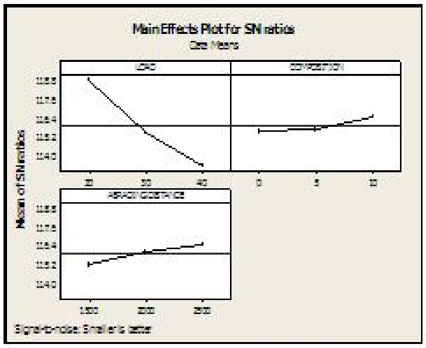

Figure 2: Main effect plot for SN ratios

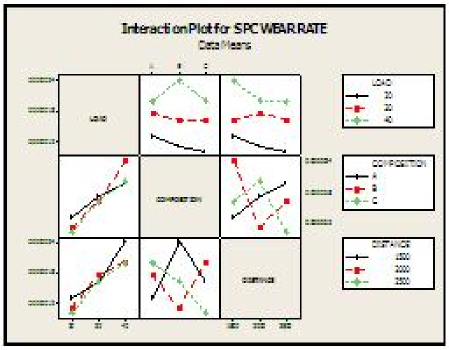

Figure 3: Interaction plot for Sp. Wear rate

The main effects plot generated by MINITAB 15 software pertaining to ANOVA is shown in Fig.2 which shows graphically the effect of the three control factors and their levels on wear rate of the composite specimens. A main effect is seen when different levels of a factor affect the response differently. When the line is horizontal, then there is no main effect present. When the line is not horizontal, then there is a main effect present. The steeper the slope of the line, the greater is the magnitude of the main effect on the wear rate. For each control factors, a level with maximum value of mean of S/N ratio will give minimum wear rate. At load 20N, for material A (G-E) and at distance 1500 m observed minimum specific wear rate [16].

When the effect of one factor depends on the level of the other factor, interaction plot can be used to visualize possible interactions. Parallel lines in an interaction plot indicate no interaction. Greater is the difference in slope between the lines, higher is the degree of interaction. From the interaction plot shown in the Fig. 3, it is observed that the interaction between abrading distance and composition shows significant effect on the wear rate of the composite samples [17].

4.2. Analysis of variance

The results of ANOVA analysis are shown in Table 4, the last column of the table shows the percentage contribution of each factor on the specific wear rate of the composites.

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution
Load	2	1.50673	1.50673	0.75337	47.19	0.021	89.97
Composition	2	0.04766	0.04766	0.02383	1.49	0.401	2.84
Distance	2	0.08830	0.08830	0.04415	2.77	0.266	5.27
Error	2	0.03193	0.03193	0.01597			1.90
Total	8	1.67462					

Table 4: Analysis of Variance for sp. wear rate.
R-Sq = 98.09% R-Sq(adj) = 92.37%

Considering the ANOVA for the wear results of granite– epoxy composite, it was observed that, the load was the major factor that contributed (89.97%)on the abrasive wear loss of the composite followed by abrading distance (5.27%) and composition contributed comparatively less (2.84%), the pooled error associated was approximately about 1.90%

4.3. Effect of applied load, abrading distance and composition on specific wear rate

From Fig. 4 it is observed that for all the composites tested, the specific wear rate decreases with the increasing abrading distance, increases with increasing applied load. Specific wear rate is lower for 10 wt % SiC filled G-E composite compare to other two compositions. This is attributed to the fact that, in 10wt % SiC filled G-E composite, the dispersion of filler is uniform and a better adhesion is established between the matrix and the filler (SEM images Fig. 7 a & b). The SiC filled composite showed less damage to matrix. This is due to the incorporated hard SiC particles present along with matrix on surface of the composite specimen, which acts as anti-wear additive and hence retard the wear loss [18].

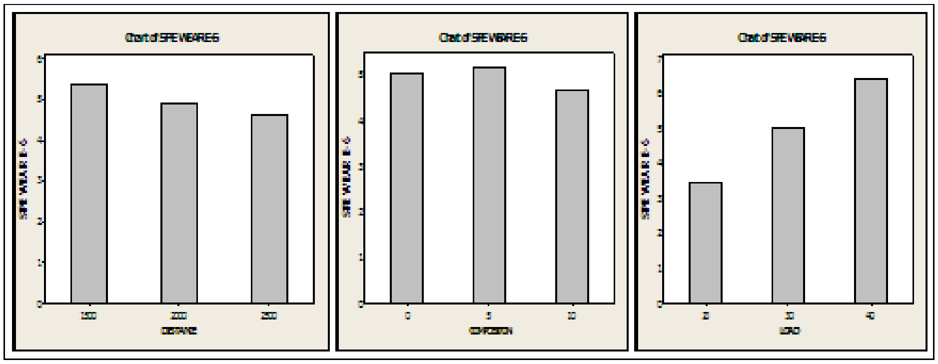

Figure 4: Variation of Specific Wear Rate with different parameters

4.4. Worn surface morphology

To correlate the wear data better, SEM photo micro- graphs of abraded samples were taken at different loads to find out predominant wear mechanisms. The SEM features of the worn surfaces of G-E and SiC filled G-E composite samples at loads 20 and 40 N were shown in Figs. 5, 6 & 7 respectively. In Fig. 5, G-E composite shows features characteristic of typical unmodified resin casting, the composite surface exhibits resin rich (marked as R) surface layer with less voids and debris. The presence of resin layer improved the bonding and surface integrity with high matrix adhesion (19). The abrasive wear loss of G-E composite is higher than the GE-SiC composite because of the soft matrix exposed to abrasion force further the G-E composite showed severe matrix failure at the initial stage of abrasion, hard abrasive particles was in contact with soft matrix resulting in severe matrix damage and the rate of material removal was very high [20].

The GE-SiC composite at 20N showed smooth surfaces because of less matrix damage and matrix is well bonded, where as SEM images at higher load 40N showed rough surface. This result clearly indicates as load increases wear loss also increases.

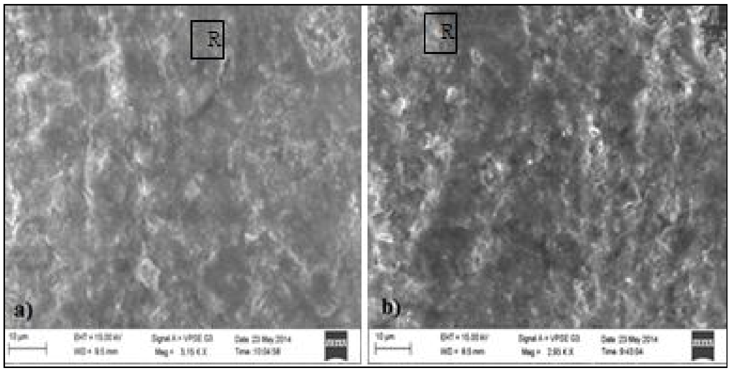

Figure 5: SEM micrographs of abraded G–E composite at (a) 20 N (b) 40N load

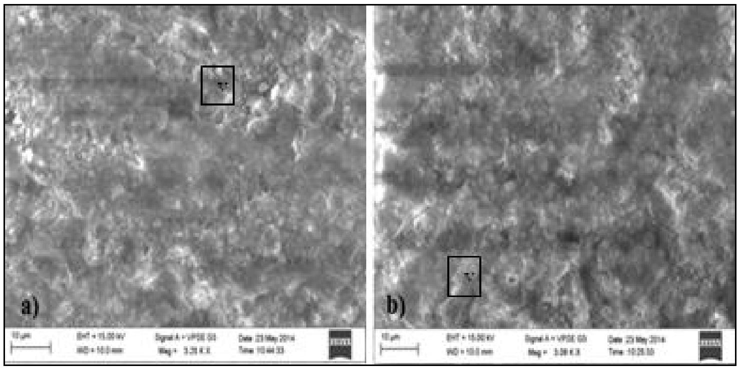

Figure 6: SEM micrographs of abraded 5 wt. % of SiC filled G-E composite at a) 20N b) 40N load

The 5% SiC filled G-E composites (Fig.6) shows granular fracture features with surface waves of lesser depth separated by frequent tracks, indicating the brittleness introduced due to the incorporation of the hard SiC particles into the relatively more ductile epoxy matrix. Smooth surface of the matrix and at some regions voids (marked as v) are evident from the photo-micrograph. This is attributed to the finer abrasive particles get crushed as the abrading distance and load increases.

The 10 % SiC filled G-E composites (Fig.7) shows granular fracture features with surface waves of very lesser depth separated by frequent tracks, indicating the more brittleness introduced due to the incorporation of the hard SiC particles into the relatively more ductile epoxy matrix.

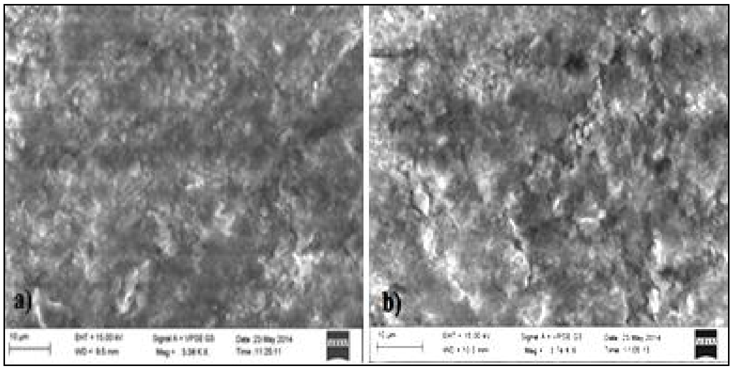

Figure 7: SEM micrographs of abraded 10wt % of SiC filled G-E composite at a) 20N b) 40N load

5. Conclusion

Based on the studies the following conclusions are made.

- Specific wear rate increased with increase in applied load and decreased with increasing abrading distance. 10% SiC filled G–E composite showed better abrasion wear resistance as compared to that of other two compositions.
- From the ANOVA analysis, for wear resistance it has been found that; load is the dominating factor (89.97%) followed by abrading distance (5.27%) and composition (2.84%).
- The G-E composite worn surface features exhibits severe matrix damage. However, SEM studies revealed that in SiC filled GE composite severity and the extent of damage on the surface become less as noticed in the softer region owing to the presence of hard SiC particles phase.
- SEM studies of worn surfaces support the involved mechanisms and indicate damage to the matrix, exposure of fillers and removal of the fillers.

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