A Study on Tribological Behavior of Glass-Epoxy Composite Filled with Granite Dust

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Abstract: Granite powder is one of the solid wastes generated from stone processing industry used as organic filler replacing the conventional ceramic fillers in polymer matrix composite to increase the mechanical properties. The present work investigates the addition of granite powder on erosion wear properties of epoxy-glass fiber composite. The solid particle erosion wear rates of these hybrid composites are recorded considering various control parameters as impingement angles, erodent sizes and impact velocities following erosion resistance test in an air erosion test device at room temperatures. The test was conducted as per the Taguchi experimental design to minimize the erosion loss of material. The SEM views show the surface resistivity for the granite added specimens. The microscopic study also indicates various methods of material removal, crater wear and other subjective allocation during erosion experiment of the samples.

Keywords: Epoxy, Granite powder, Erosion wear, Taguchi design of experiment

1.INTRODUCTION

Fiber reinforced composite materials are made from two or more different constituent materials, which remain separate at micro and macroscopic level and possess different physical and chemical properties. Due to the addition of reinforcing material in the matrix; the properties of these samples are remarkably influenced [1]. Fiber reinforced polymer composites (FRP) are used in different sectors like automotive, railway, aerospace, aircraft, marine, wind, and etc. due to its desirable physical and mechanical properties over traditional monolithic materials. However, these materials are facing challenges and threats at different environments like high and low temperature, water, hydrothermal, alkaline, corrosive, and UV light exposure. Polymer composites operate in antagonistic environments where they are subjected to external attacks such as solid particle erosion. Application of such erosive situation are found in petroleum refineries carrying sand slurries in pipe, impeller blades of turbines, engine blades in aircraft and engineering structures exposed in desert environment etc. Erosion wear is occurred due to material loss on the exposed surface, while the solid particle strikes with certain speed. Impingement angle, impact velocity, size of the particle and targeted material highly influence the erosion rate.

Tsuda et al.[2] summarized wear mechanism and sand particle erosion behavior of different types of fiber reinforced composites. With increase in percentage of glass fiber content, erosion behavior of these composites are found to be changed from ductile to brittle, and reached maximum value at vertical impact.

Mohan et al. [3] reviewed erosion wear characteristics of glass fiber epoxy (G-E) composites. Erosion behavior of GE composite was highly influenced by addition of tungsten carbide powders as filler material. The effect of various impingement angles (30-90°) and impact velocities (40 and 80 m/sec) on the wear resistance of the composites were recorded. The erosion loss of both filled and unfilled composites in different experimental conditions were analyzed. The WC filled composite exhibited better erosion resistance as compared to that unfilled composites.
Barkoula and Karger-Kocsis [4] scrutinized the effect of fiber orientation and interfacial modification on the sand particle erosion of glass fiber reinforced epoxy composites. The erosion behavior of the composite were discussed at different impingement angles (30°, 60°, and 90°). The fiber orientation has negligible effect on wear rate.

Rajesh et al. [5] investigated the chemical structure of various polyamides on erosion loss characteristics by silica sand blasting apparatus at different angle and amount. The effect of impact velocity found more significant at an impingement angle (30°) than at normal striking (90°) on erosion rate.

Biswas and Satapathy [6] studied the erosion behavior glass-epoxy composite filled with red mud as per Taguchi experimental design. They suggested a mathematical model for calculating erosion rate and correlated with the experimental results. The result indicated the influence of filler content; erodent temperature, impact angle and velocity were more dramatic in determining the erosion loss from composite surface.

Srivastava and Pawar [7] studied the erosion loss of fly ash filled E-glass fiber epoxy composites. They found maximum erosion at 60° impact angle showing semi ductile behaviour of the developed composites. The erosion arte was highly influenced by the impact velocity. The composite filled with 4g fly ash shows minimum erosion loss, where as composite without filler shows maximum erosion wear property.

Tilly and Sage [8] conducted research on sand particle erosion characteristics and reported the effect of impact velocity on the erosion resistance. They conducted the particle erosion test on type 66 nylon with epoxy composites and concluded that the erosion resistance is highly influenced by the type of fiber used.

Tewari et al. [9] investigated the solid particle erosion test on unidirectional carbon and glass fiber reinforced composites. The erosion loss of those samples was calculated setting various impact angles with three different fiber orientations. The composites showed semi ductile nature at 60° impact angle causing maximum erosion wear. The erosion wear was influenced by the fiber orientations.

Yang et.al. [10] studied the effect erosion of epoxy-glass fiber composites. They conducted the experiment using SiC particle with average size of 400-500 μm at various impingement angles (90°, 60°, and 30°) with a constant impact velocity of 42.5 m/s for 30, 60, 90 s.

Mahapatra et al.[11] studied the erosion wear rate of polyester glass fiber composites. They conducted the experiment as per Taguchi orthogonal array approach. They have developed a mathematical model for estimation of erosion loss and correlated with the experimental observations and found consistent values of mathematical prediction with experimental results.

The present study investigates the erosion wear behavior of granite dust filled (0%, 5%, 10% and 15 wt %) glass fiber reinforced epoxy composites. The test was conducted at various impact velocities (33, 43, 57, 68 m/s), different impingement angles (30°, 45°, 60°, 90°) and silica particles with average particle sizes of 70, 90, 110, 130 μm. However, Taguchi design of experiment was used for conducting the experiment at room temperature leading to minimum erosion loss of the composites.

2. EXPERIMENTAL PROCEDURE

2.1 Test Materials

In this present experimental study, marble particulates used with epoxy matrix. The epoxy resin as a matrix material and 2% HY 951 as a hardener mixed thoroughly prior to manufacture the composite specimen. The unmodified epoxy resin (LY 556) and hardener (HY 951) is supplied by Ciba Geigy India Ltd. Epoxy resin have a modulus of 3.42 GPa, and density of 1.10 gm/cc. Bidirectional glass fiber mats possesses a modulus of 72.5 GPa and density of 2.59 gm/cc to is supplied by Saint Govian Ltd. Granite waste is used as filler materials. The density of granite powder is 2.6 gm/cc [12]. The granite powder was arranged from School of Sculpture, KIIT University, India. The granite powders are kept in an oven for drying with a temperature of 100°C to remove water particle and sieved to a size of 90-100μm.

The chemical composition of the used granite powder as filler material based on weight percentage is presented in Table 1. Alkali treatment has been accepted to marginally improve the mechanical and tribological properties of the composites as stated by Jawaidet. al. [13]. This chemical treatment removes the surface impurities and O-H
groups so as to enhance the surface adhesion and hydrophobic characteristics of the fiber [14]. The prepared sample with their composition are presented in Table 2.

Table 1. Chemical content of used granite dust

| Ceramic Oxides (%) | SiO$_2$ | Al$_2$O$_3$ | Fe$_2$O$_3$ | CaO | MgO | SO$_3$ | Na$_2$O | K$_2$O |
|-------------------|---------|-------------|-------------|-----|-----|-------|--------|-------|
| Granite dust      | 53.2    | 14.1        | 12.3        | 9.1 | 8.3 | -     | 1.2    | -     |

Table 2. Designation of composite samples with their composition

| Designation of composites | Composition                                      |
|---------------------------|--------------------------------------------------|
| EGG0                      | Epoxy (60 wt %) + glass fiber (40 wt %) + filler (0 wt %) |
| EGG1                      | Epoxy (55 wt %) + glass fiber (40 wt %) + granite dust (5 wt %) |
| EGG2                      | Epoxy (50 wt %) + glass fiber (40 wt %) + granite dust (10 wt %) |
| EGG3                      | Epoxy (45 wt %) + glass fiber (40 wt %) + granite dust (15 wt %) |

2.2 Solid particle erosion test device

The erosion tests were conducted as per ASTM G 76 standard using solid particle erosion testing device (TR-470) supplied by DUCOM Ltd. as shown in Figure 1. The silica sand (erodent) are fed through the hopper and mixed with dry compressed air in air particle mixing chamber and subsequently passed through the brass nozzle of 3 mm diameter. These pressurized erodent bombard with the composite specimen, which can be held at various angles as per the requirement. The impact velocity can be controlled by varying the air pressure. The composites are cleaned with acetone and dried before weighing. The weight was recorded after each run. Micrographic views of the samples are studied showing the influence of filler addition.

Figure 1. Schematic description of solid particle erosion tester
3. Taguchi design of experiment

Impact velocity, filler content, impingement angle, erodent size, etc. are selected as control factors which highly influence the erosion rate of FRP composites as shown in Table 3. The effect of these four factors on erosion behaviour of polymer composites is therefore observed in this present work using an L16 orthogonal array design. Taguchi design of experiment is a simple approach used by the researcher to reduce the number of experiment [15]. To study the erosion rate by conventional approach, at least $4^4=256$ number runs of experiments are required in full factorial design considering four parameters at four levels, whereas in Taguchi experimental design approach required only 16 numbers of experiments, offering an advantage to cost and time of experiment. For minimum erosion rate ‘Lower is better’ characteristic study has been selected to find S/N ratio as presented in Equation 1. The tests were conducted as per the design presented in Table 4.

$$\frac{S}{N} = -10\log_{10}\left(\frac{1}{n}\sum (y^2)^{1/2}\right) \quad (1)$$

Where $n$ is the number of observations and $y$ is the observed data.

### Table 3. Control factors with respective levels

| Control Factor | Level | II | III | IV | Units |
|----------------|-------|----|-----|----|-------|
| A: Impact velocity | 33 | 43 | 57 | 68 | m/sec |
| B: Filler | 0 | 5 | 10 | 15 | wt% |
| C: Angle of impingement | 30 | 45 | 60 | 90 | degree |
| D: Erodent size | 70 | 90 | 110 | 130 | m |

### Table 4. Orthogonal array for L16 Taguchi Experimental design

| Test Run | Velocity of impact A (m/sec) | Filler content B (wt%) | Impingement angle C (degree) | Erodent size D (m) |
|----------|-------------------------------|------------------------|-------------------------------|-------------------|
| 1 | 33 | 0 | 30 | 70 |
| 2 | 33 | 5 | 45 | 90 |
| 3 | 33 | 10 | 60 | 110 |
| 4 | 33 | 15 | 90 | 130 |
| 5 | 43 | 0 | 45 | 110 |
| 6 | 43 | 5 | 30 | 130 |
| 7 | 43 | 10 | 90 | 70 |
| 8 | 43 | 15 | 60 | 90 |
| 9 | 57 | 0 | 60 | 130 |
| 10 | 57 | 5 | 90 | 110 |
| 11 | 57 | 10 | 30 | 90 |
| 12 | 57 | 15 | 45 | 70 |
| 13 | 68 | 0 | 90 | 90 |
| 14 | 68 | 5 | 60 | 70 |
| 15 | 68 | 10 | 45 | 130 |
| 16 | 68 | 15 | 30 | 110 |
4. MICROGRAPHIC OBSERVATIONS

The eroded samples are cleaned with acetone and then dried. The morphological view was observed using SEM JEOL JSM-6480 LV. The cleaned specimens are mounted on stub using silver paste and coated with a thin film of platinum for better conductivity before examination. The SEM views are presented in Figure 2 (a), (b), and (c).

Fig. 2 (a) SEM views after solid particle erosion of EGG2 composite specimen (with erodent size of 110μm at 45° impingement angle and impact velocity 33m/s)

Fig. 2 (b) SEM views after solid particle erosion of EGG2 composite specimen (with erodent size of 130μm at 30° impingement angle and impact velocity 43m/s)

Fig. 2 (c) SEM views after solid particle erosion of EGG2 composite specimen (with erodent size of 70μm at 60° impingement angle and impact velocity 68m/s)

5. RESULT ANALYSIS

5.1 Experimental design analysis

In Table 5, the Taguchi experimental test run with their erosion rates and S/N ratios are presented. Three replications of each value was taken for better performance. The average S/N ratio of granite filled glass-fiber epoxy composites is found to be -54.7204dB. The design of experiment analysis was made by using MINITAB 16 software. The possible interaction between the control factors were studied before attempt was made to use this simple model for measuring the erosion performance. The factorial design establishes the interaction effects of control factors. Figure 3 shows the main effect plots for the granite filled composites. The analysis of result establishes the suitable factor combination for minimum erosion rate. In the present experimental condition, for granite filled composites A1 (velocity of impact=33m/s), B3 (granite content=10wt%), C1 (angle of impingement=30°) and D4 (particle size=130μm) provides minimum erosion rate.
Table 5. Erosion wear results for developed composite samples

| Test Run | Velocity of impact A (m/sec) | Filler content B (wt%) | Impingement angle C (degree) | Erodent size D (m) | Erosion wear rate (mg/kg) | S/N ratio (dB) |
|----------|-----------------------------|-----------------------|-----------------------------|-------------------|--------------------------|---------------|
| 1        | 33                          | 0                     | 30                          | 70                | 514.12                   | -54.2213      |
| 2        | 33                          | 5                     | 45                          | 90                | 445.94                   | -52.9855      |
| 3        | 33                          | 10                    | 60                          | 110               | 447.21                   | -53.0102      |
| 4        | 33                          | 15                    | 90                          | 130               | 390.45                   | -51.8313      |
| 5        | 43                          | 0                     | 45                          | 110               | 540.94                   | -54.6630      |
| 6        | 43                          | 5                     | 30                          | 130               | 474.63                   | -53.5271      |
| 7        | 43                          | 10                    | 90                          | 70                | 514.25                   | -54.2235      |
| 8        | 43                          | 15                    | 60                          | 90                | 521.19                   | -54.3399      |
| 9        | 57                          | 0                     | 60                          | 130               | 657.62                   | -56.3595      |
| 10       | 57                          | 5                     | 90                          | 110               | 611.41                   | -55.7267      |
| 11       | 57                          | 10                    | 30                          | 90                | 501.94                   | -54.0130      |
| 12       | 57                          | 15                    | 45                          | 70                | 582.93                   | -55.3123      |
| 13       | 68                          | 0                     | 90                          | 90                | 723.94                   | -57.1941      |
| 14       | 68                          | 5                     | 60                          | 70                | 713.21                   | -57.0643      |
| 15       | 68                          | 10                    | 45                          | 130               | 571.94                   | -55.1470      |
| 16       | 68                          | 15                    | 30                          | 110               | 624.29                   | -55.9077      |

Table 6. ANOVA table for erosion rate

| Source | DF | Seq SS  | Adj SS  | Adj MS  | F       | P      |
|--------|----|---------|---------|---------|---------|--------|
| A      | 3  | 98,941  | 98,941  | 32,980  | 70.61   | 0.003  |
| B      | 3  | 22,767  | 22,767  | 7587    | 16.23   | 0.021  |
| C      | 3  | 7752    | 7752    | 2581    | 5.53    | 0.096  |
| D      | 3  | 6641    | 6641    | 2213    | 4.72    | 0.116  |
| Error  | 3  | 1402    | 1402    | 476     |         |        |
| Total  | 15 | 1,37,503|         |         |         |        |

Figure 3. Effect of control factors on erosion wear rate

5.2 Mathematical model for confirmation of experiment

The optimal factor combination for minimum erosion rate is found in the result analysis. The confirmation of experiment was done by considering arbitrary set of combination factor $A_1 B_2 C_2 D_3$ for the experimental observation. A prediction of mathematical model was developed and correlated with the experimental values. The predicted result was estimated using the following equations.

$$\eta_s = \bar{T} + (\bar{A}_1 - \bar{T}) + (\bar{B}_3 - \bar{T}) + (\bar{C}_1 - \bar{T}) + (\bar{D}_4 - \bar{T})$$  \hspace{1cm} (2)
Where $\eta_x$ is the predicted averages, $T$ is overall experimental average, and $A_1, B_2, C_1$ and $D_4$ is the mean responses for factors at the designated levels.

By combining similar terms, the equation can be formulated as:

$$\eta_x = A_1 + B_2 + C_1 + D_4 - 3T$$

(3)

The S/N ratios for both the cases are compared. The comparative error was found to remain within tolerance limit as shown in Table 7. Therefore the model is suggested for prediction of erosion rate with a suitable accuracy.

### Table 7. Results of the confirmation experiments for the erosion rate

| Filler material | Control factor setting for optimal values | $S/N$ ratio, Predictive values (dB) | $S/N$ ratio, experimental values (dB) | Error (%) |
|-----------------|------------------------------------------|-------------------------------------|--------------------------------------|-----------|
| Granite         | $A_1B_2C_2D_3$                           | -53.711                             | -51.462                              | 4.18      |

### 6. CONCLUSIONS

The paper has presented the experimental and analytical observation on erosion rate of granite dust filled epoxy-glass fiber composites draws the following conclusions:

1. Fabrication of hybrid epoxy glass fiber composite filled with granite dust is possible by simply hand layup technique at room temperature.
2. Erosion wear test was conducted considering optimum values of control parameters for minimum erosion rate as per Taguchi experimental design. The effect of control factors found to be significant for the erosion rate. Filler percentage enhanced the erosion resistance of the developed composites.
3. Scanning electron microscopy observation of the eroded composites have analyzed at various experimental conditions. The study reveals various erosion mechanism such as carter formation, clustering of fiber, micro ploughing, breakage of fiber, plastic deformation etc.
4. The predictive ANOVA model and experimental values are compared. This is observed that this model provides the suitable factor combination for the erosion loss, and their predictive results as per mathematical model remains consistent with the experimental values.
5. These composites may be recommended for engineering applications, which are exposed to erosive situations like desert environment and also can be used in general applications like false ceiling, pipe lines carrying raw materials for steel insturities, industrial rotor blades etc.

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