Effect of Alumina Particulate on Erosion Wear Behaviour of Short Bamboo Fiber Reinforced Epoxy Composites

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Abstract: Now-a-days, the use of natural fiber reinforced composites starts gaining popularity in engineering applications due to the fact that this material possesses characteristics that are comparable to conventional materials. Among natural fibers, bamboo has been widely used for many such applications due to its availability. Attempts have been made in this paper to explore the potential utilization of bamboo fiber in polymer matrix composites. Therefore, this work is focused on the erosion wear behavior of short bamboo fiber reinforced composites filled with Alumina (Al_2O_3) particulate obtained through experimentation. It further outlines a methodology based on Taguchi's experimental design approach to make a parametric analysis of erosion characteristics. Finally, the morphology of eroded surfaces is examined using scanning electron microscopy (SEM) and possible erosion mechanisms are identified.

Key words: Composites, Erosion wear, Bamboo fiber, Alumina particulate

1. Introduction

Recently, great attention has been devoted to the utilization of natural fibres as reinforcement for polymers by replacing glass and other synthetic fibers [1]. This is not only due to environmental concerns but also for providing a unique combination of high performance, availability, great versatility and processing advantages at favorable cost. In addition, particulate fillers can also be used to reduce cost and improve their dimensional stability. Studies on plastics and cements reinforced with natural fibers such as jute, sisal, coir, pineapple leaf, bamboo, banana, sun hemp, straw, and wood fibers have been reported. Among the natural fibers, bamboo finds widespread use in housing construction around the world, and is considered as a promising housing material in underdeveloped and developed countries. Bamboo shows mechanical properties comparable to those of wood and grows to maturity in only 6-8 months. In fiber reinforced polymer composites further addition filler improvers the performance of the composites reported by many investigators. Also the filler materials are used to reduce the material costs, to improve mechanical properties to some extent and in some cases to improve processability. Alumina (Al_2O_3) is an inorganic material that has the potential to be used as particulate filler material in various polymer matrices. It is hard, wear resistant, has excellent dielectric properties, high strength and stiffness, resistance to strong acid and alkali attack at elevated temperatures. Due to its many advantages and with a reasonable price, the fine grain technical grade

Al_2O_3 has a very wide range of engineering applications. To this end, the present research is carried out to study the erosion wear behavior of short bamboo fiber reinforced epoxy composites filled with alumina particulate.

1.1 Composite Fabrication

In this study, short bamboo fiber is taken as reinforcement is collected from local sources. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. Alumina (Al_2O_3) powders are obtained from NICE Ltd India in a range of 80-100 µm. A stainless steel mould having dimensions of 210 × 210 × 40 mm^3 is used for composite fabrication. The short bamboo fiber and alumina particulates are mixed with epoxy resin by the simple mechanical stirring. The composites are prepared in four different percentages of alumina particulates (0wt%, 5wt%, 10wt% and 15wt% of alumina) in the epoxy resin keeping bamboo fiber at a fixed percentage (45 wt%) and the mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. Figure 1 shows short bamboo fiber and bamboo fiber reinforced epoxy composite and the detailed composition and designation of the composites are presented in Table 1.

Figure 1 Short bamboo fiber and bamboo based composite

Table 1 The detail composition and designation of the composites

Composites	Composition
EBA-1	Epoxy+45wt% bamboo fiber+0wt% Alumina
EBA-2	Epoxy+45wt% bamboo fiber+5wt% Alumina
EBA-3	Epoxy+45wt% bamboo fiber+10wt% Alumina
EBA-4	Epoxy+45wt% bamboo fiber+15wt% Alumina

2. Erosion Test Apparatus

The solid particle erosion tests are carried out as per ASTM G76 using a standard erosion test rig (Figure 2). The test rig consists of an air compressor, a conveyor belt-type particle feeder, an air drying unit and an air particle mixing and accelerating chamber. The compressed and dried air is then mixed with the silica sand which is fed constantly by a conveyor belt feeder into the mixing chamber and then accelerated by passing the mixture through a convergent brass nozzle of 3 mm internal diameter. The set up is capable of creating reproducible erosive situations for assessing erosion wear resistance of the composite specimens. The erodent particles impact the specimen which can be held at different angles with respect to the direction of erodent flow. In the present study, dry silica sand of 450µm is used as erodent particle. The specimens are cleaned in acetone, dried and weighed to an accuracy of 0.1 mg before and after the erosion trials using a precision electronic balance. The weight loss is recorded for subsequent calculation of erosion rate. The ratio of the weight loss to the weight of the eroding particles causing the loss is then computed as a dimensionless incremental erosion rate. The process is repeated till the erosion rate attains steady state erosion rate.

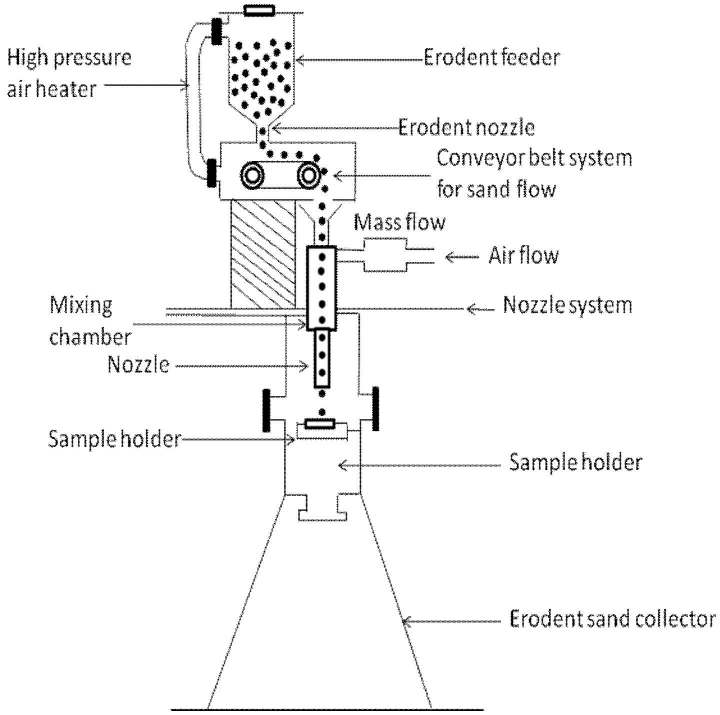


Figure 2 Schematic diagram of an erosion test rig

3. Plan of Experiments (Taguchi's Technique)

The Taguchi method has been generally adopted to optimize the design parameters because this systematic approach can significantly minimize the overall testing time and the experimental costs. Using the orthogonal array specially designed for the Taguchi method, the optimum experimental conditions can be easily determined. Accordingly, an analysis of the signal-to-noise (S/N) ratio is needed to evaluate the experimental results. Usually, three types of S/N ratio analysis are applicable: (1) lower is better (LB), (2) nominal is best (NB), and (3) higher is better (HB). Because the target of this study is to minimize the erosion rate, the S/N ratio with LB characteristics is required, which is given by

$$\frac{S}{N} = -10 \log \frac{1}{n} \sum Y^2 \qquad (1)$$

where ‘n’ the number of observations, and y the observed data.

In the design of experiment the most important stage lies in the selection of the control factors. Through exhaustive literature review on erosion behavior of polymer composites reveal that factors like impact velocity, filler content, erodent temperature, impingement angle, stand-off distance and erodent size etc. largely influence the erosion rate of polymer composites [2]. For elaboration of experiments plan the method of Taguchi for five factors at four levels is used, being understood by levels taken by the factors. Table 2 is indicated the factors to be studied and the assignment of the corresponding levels.

Table 2 Levels for various control factors

Control factor	Level			
	I	II	III	IV
A: Velocity of impact (m/sec)	35	45	55	65
B: Alumina content (wt%)	0	5	10	15
C: Impingement angle (°)	45	60	75	90
D: Stand-off distance (mm)	55	65	75	85
E: Erodent temperature (°C)	35	70	105	140

4. Results and Discussion

The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 14. The array chosen is the L_{16} (4^5) which has 16 rows corresponding to the number of tests with 5 columns at four levels, as shown in Table 3. In Table 3, the last column represents S/N ratio of the erosion rate which is in fact the average of two replications. Analysis of the result leads to the conclusion that factor combination of A_2, B_2, C_3, D_4 and E_3 gives minimum erosion rate (Figure 3). The response table for signal to noise ratios is given in Table 4.

Table 3 Experimental design using L_{16} orthogonal array

Sl. No.	Impact Velocity (m/sec)	Filler Content (wt %)	Impingement Angle (Deg.)	S.O.D (mm)	Erodent Temp. (°C)	Erosion rate (gm/gm)	S/N ratio (db)
1	35	0	45	55	35	2.8845E-04	70.7986
2	35	5	60	65	70	2.8579E-04	70.8791
3	35	10	75	75	105	3.1453E-04	70.0468
4	35	15	90	85	140	4.8749E-04	66.2406
5	45	0	60	75	140	3.6122E-04	68.8445
6	45	5	45	85	105	1.7473E-05	95.1527
7	45	10	90	55	70	5.2386E-04	65.6157
8	45	15	75	65	35	3.4341E-04	69.2836
9	55	0	75	85	70	5.9288E-05	84.5407
10	55	5	90	75	35	6.0474E-04	64.3686
11	55	10	45	65	140	7.1085E-04	62.9644
12	55	15	60	55	105	3.5208E-04	69.0671
13	65	0	90	65	105	2.8920E-04	70.7760
14	65	5	75	55	140	3.0700E-04	70.2572
15	65	10	60	85	35	9.7740E-04	60.1986
16	65	15	45	75	70	8.4680E-04	61.4444

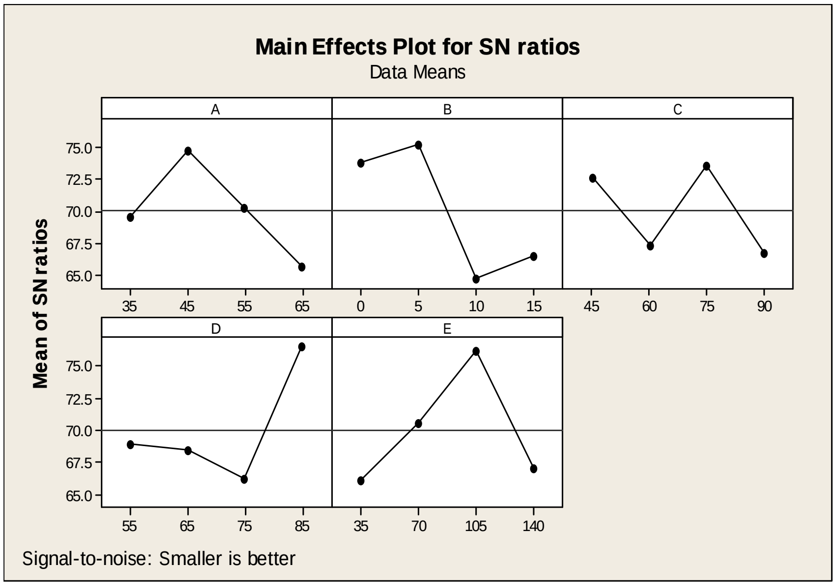


Figure 3 Effect of control factors on erosion rate

Table 4 Response table for signal to noise ratios

Level	Impact velocity (m/sec)	Filler content (wt %)	Impingement angle (°)	Stand-of-distance (mm)	Erodent temperature (°C)
1	69.49	73.74	72.59	68.93	66.16
2	74.72	75.16	67.25	68.48	70.62
3	70.24	64.71	73.53	66.18	76.26
4	65.67	66.51	66.75	76.53	67.08
Delta	9.06	10.46	6.78	10.36	10.10
Rank	4	1	5	2	3

4.1 Steady state erosion (Effect of impingement angle of erosion rate)

The erosion behavior of materials is broadly classified in the literature as ductile and brittle depending on the variation of erosion rate with impact angle. Ductile behavior is characterized by maximum erosion at low impact angles in the range of 10-30°. On the other hand, if maximum erosion occurs at impingement angle of 90°, then the behavior is brittle. However, reinforced composites have been found to exhibit semi-ductile behavior with maximum erosion rate at intermediate angles typically in the range of 45-60° [3]. In the present study, the variation of erosion rate of composites with impingement angle is studied by conducting experiments under specified operating conditions as shown in Figure 4.

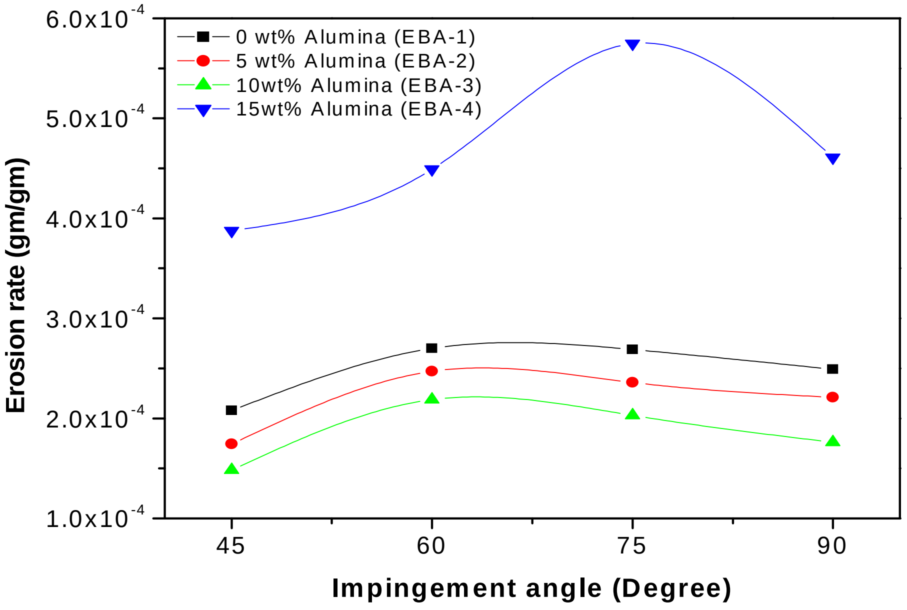
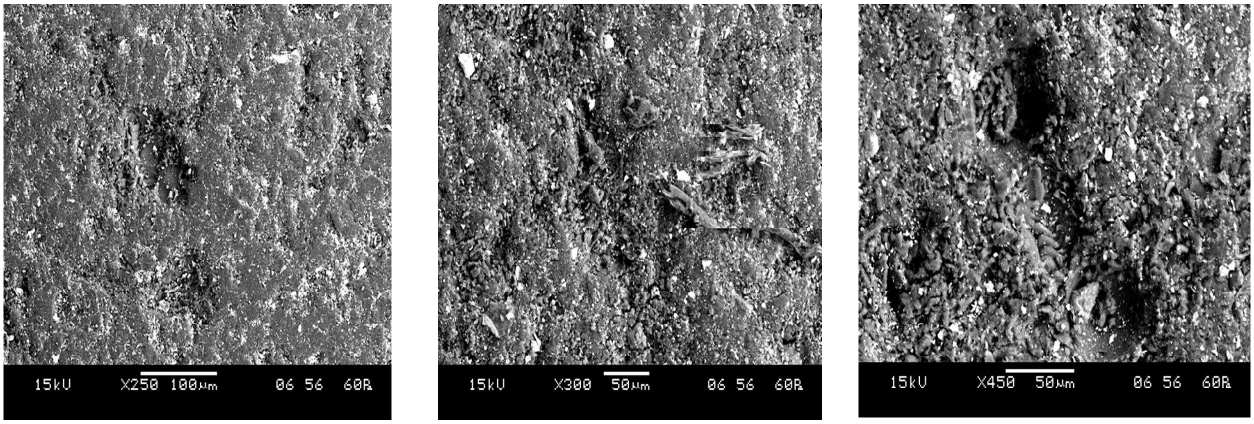


Figure 4 Effect of impingement angle on the erosion rate of the composites

The result shows the peak erosion taking place at an impingement angle of 60° for the unfilled and alumina filled bamboo-epoxy composites, except 15wt% alumina filled composite shows maximum erosion rate at 75° impingement angle. This clearly indicates that these composites respond to solid particle impact neither in a purely ductile nor in a purely brittle manner. This behaviour can be termed as semi-ductile in nature for all types of composites except 15wt% alumina filled composite which shows semi-brittle nature.

4.2 Surface Morphology

Figure 5 shows the SEM of the eroded bamboo fiber reinforced epoxy composites filled with alumina particulate. In Figure 5 (a) not much cracks or craters are seen on the composite surface after erosion due to impact of dry silica sand particles at low temperature (35°C) with a lower impact velocity (35 m/sec) at a low impingement angle of 45°. But as the erosion tests are carried out with higher impact velocity (55 m/sec) and higher erodent temperature of 70°C and 140°C, the morphology of the eroded surface becomes different as in Figure 7(b) and (c) respectively.



(a) (b) (c)

Figure 5 SEM of the eroded bamboo fiber-epoxy composites filled with alumina

5. Conclusions

The study on the erosion behaviour of alumina filled bamboo-epoxy composites leads to the following conclusions:

1. Alumina filled bamboo epoxy composites is successfully fabricated.
2. Impingement angle has significant influence on erosion rate. In this study it has been observed that these composites respond to solid particle impact neither in a purely ductile nor in a purely brittle manner. This behaviour can be termed as semi-ductile in nature for all types of composites except 15wt% alumina filled composite which shows semi-brittle nature.

3. Possible use of these composites in components such as pipes carrying coal dust, helicopter fan blades, industrial fans, desert structures, low cost housing, etc. is recommended.

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