Erosion Wear Behaviour of Bamboo/Glass Fiber Reinforced Epoxy Based Hybrid Composites

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Abstract- Now-a-days, there is an increasing interest in hybrid composites made by combination of two or more different types of fiber in a common matrix because these materials offer a range of properties that cannot be attained with a single type of reinforcement. The fibres are either natural or synthetic and both types of fiber have advantages and disadvantages. Therefore, in this work a new class of hybrid composite reinforced with a synthetic fiber and a natural fiber is developed to get the advantage of both the fibres in terms of superior tribological properties and economy. The present research work is undertaken to investigate the erosion behaviour of short bamboo and glass fiber reinforced epoxy based hybrid composites.

Keywords- composites; bamboo fiber; glass fiber

I. INTRODUCTION

Natural fibers have recently attracted the attention of scientists and technologists because of the advantages that these fibers provide over conventional reinforcement materials. The advantages of natural fibers include low price, low density, unlimited and sustainable availability, and low abrasive wear of processing machinery [1-3]. These natural fibers are low-cost fibers with low density and high specific properties. These are bio-degradable and nonabrasive, unlike other reinforcing fibers. However, certain drawbacks such as incompatibility with the hydrophobic polymer matrix, the tendency to form aggregates during processing, and poor resistance to moisture greatly reduce the potential of natural fibers to be used as reinforcement in polymers. A number of investigations have been carried out to assess the potential of natural fibers as reinforcement in polymers [4-6]. Natural fiber exists in the form of vegetable fiber, animal fiber or mineral fiber. The reason that many studies focus on bamboo is because it is an abundant natural resource in Asia, and its overall mechanical properties are comparable to those of wood. Bamboo is a naturally occurring composite material which grows abundantly in most of the tropical countries. This is one of the oldest building materials used by human kind [7]. It has been used widely for household products and extended to industrial applications due to advances in processing technology and increased market demand. The erosion of materials caused by impact of hard particles is one of several forms of material degradation generally classified as wear. Bitter [8] defined erosion as "Material damage caused by the attack of particles entrained in a fluid system impacting the surface at high speed" while Hutchings [9] wrote " Erosion is an abrasive wear process in which the repeated impact of small particles entrained in a moving fluid against a surface results in the removal of material from the surface". Solid particle erosion is a serious problem in gas turbines, rocket nozzles, cyclone separators, valves, pumps and boiler tubes**.**

Based on the literature a lot of research work has been done on the synthetic fiber reinforced or natural fiber reinforced polymer composites. However, very less work has been reported on both the synthetic and natural fiber reinforced polymer hybrid composites. To this end, the present work is undertaken to study the erosion wear behavior of both bamboo and glass fiber reinforced epoxy based hybrid composites.

II. EXPERIMENTAL DETAILS

A. Composite Fabrication

The short bamboo fiber which is taken as reinforcement in this study is collected from local sources. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. Wooden moulds having dimensions of 180 x 180 × 40 mm^3 were used for composite fabrication. The short bamboo fiber and E-Glass fibers are mixed with epoxy resin by simple mechanical stirring and the mixture was poured into various moulds, keeping in view the requirements of various testing conditions and characterization standards. The composite samples of four different compositions (EBG-1 to EBG-4) are prepared. The composite samples EBG-1 to EBG-4 are prepared in four different percentages of Glass and bamboo fibers (0wt.%, 15 wt %, 30 wt % and 45 wt %). This is done by varying the epoxy percentage (i.e. 100 wt % to 65wt.%). A releasing agent is used on the mould release sheets to facilitate easy removal of the composite from the mould after curing. The entrapped air bubbles (if any) are removed carefully with a sliding roller and the mould is closed for curing at a 24 h at a constant load of 50 kg. Finally, the composites are cut using diamond cutter for further characterization and erosion tests. The composition and designation of the temperature of 30°C for composites prepared for this study are listed in the Table 1.

TABLE 1. DESIGNATION OF COMPOSITES

Composites	Compositions
EBG-1	Epoxy (100 wt%)+Bamboo fiber (0wt%) +Glass fiber (0wt%)
EBG-2	Epoxy (75 wt%)+Bamboo fiber (7.5 wt%) +Glass fiber (7.5 wt%)
EBG-3	Epoxy (70 wt%)+Bamboo fiber (15 wt%) +Glass fiber (15 wt%)
EBG-4	Epoxy (65 wt%)+Bamboo fiber (22.5 wt%) +Glass fiber (22.5 wt%)

B. Erosion Test and Taguchi Experimental Design

The experimental set up for the solid particle erosion wear test (as per ASTM G76) used in this study is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared hybrid composites. The solid particle erosion test rig consists of a compressor, drying unit, a conveyor belt-type particle feeder which helps to control the flow of sand particle and an air particle mixing and accelerating chamber. The compressed air is then mixed with the selected range of silica sand which is fed constantly by a conveyor belt feeder into the mixing chamber and then passing the mixture through a convergent brass nozzle of 3 mm internal diameter. The erodent particles impact the specimen which can be held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample holder. The conditions under which the erosion tests are carried out are listed in Table 2. In the present study, pyramidal shaped dry silica sand of sizes 125μm are used as erodent. After each experimental run the eroded samples are cleaned in acetone and dried for 5 mins and then weighed to an accuracy of ± 0.01 mg before and after the erosion trials using electronic balance. The weight loss is recorded for subsequent calculation of erosion rate. The process is repeated till the erosion rate attains a constant value called steady state erosion rate.

TABLE 2. LEVELS FOR VARIOUS CONTROL FACTORS

Control factor	Level				Units
	I	II	III	IV	
A: Impact velocity	35	45	55	65	m/sec
B: Fiber loading	0	15	30	45	wt %
C: Impingement angle	45	60	75	90	°C
D: Stand-off- distance	55	65	75	85	mm
F:Erodent Temperature	35	70	105	140	Deg.

In the present work, the impact of five such parameters are studied using L_{16} (5^4) orthogonal design. The operating conditions under which erosion tests are carried out are given in Table 2. The tests are conducted at room temperature as per experimental design given in Table 3. Five parameters viz., impact velocity, fiber loading, stand-off distance, impingement angle and erodent temperature, each at four levels, are considered in this study. In Table 3, each column represents a test parameter and a row gives a test condition which is nothing but combination of parameter levels.

III. RESULTS AND DISCUSSION

A. Effect of Impact Velocity on Erosion Rate of Composites

The speed of erosive particle has a very strong effect on the wear process. If the speed is very low then the stresses at impact are insufficient for plastic deformation to occur and wear proceeds by surface fatigue. When the speed increases it is possible that subsurface cracking occurs as untreated composites are brittle in nature. Effect of impact velocity of particle on erosion rate is studied and the results are represented in Figure 1.

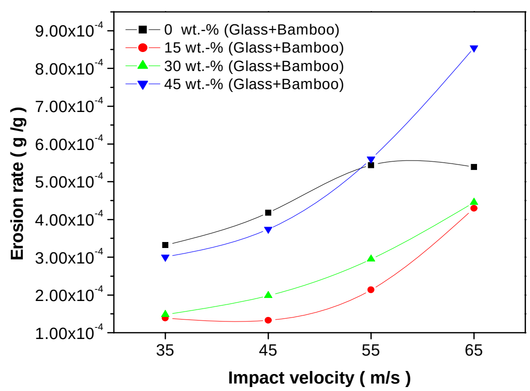


Figure1. Effect of impingement angle on erosion rate of hybrid composites

It is evident from the Figure 1 that at low impact velocity from 35m/sec to 45m/sec, there is not much variation in erosion rate. However, with the further increase in impact velocity, the erosion rate is significantly increasing i.e. up to 55m/sec. This may be due to the at higher impact velocity, the erosion rate is occurring due to plastic deformation and more amount of material is removed. On further increase in impact velocity all the composites show gradually increase in erosion rate except 0wt% bamboo/glass fiber reinforced epoxy composites shows quite reverse in trend as shown in Figure 1. This is due to the neat epoxy losses its properties and then starts melting. From Figure 1 it is also clear that neat epoxy shows maximum erosion rate and 15wt.% bamboo/glass fiber shows least erosion rate whereas 30 and 45wt.% hybrid composite lies in between the other two composites.

B. Effect of Impingement Angle on Erosion Rate of Composites

Impingement angle is one of the important parameters for the erosion behavior of composite materials. Dependence of erosion rate on the impingement angle is largely determined by the nature of the target material and other operating conditions. In the literature, materials are broadly classified as ductile or brittle, based on the dependence of their erosion rate with impingement angle [10]. The ductile behaviour is characterized by maximum erosion rate at low impingement angle i.e typically in the range of $15^0 < \alpha < 30^0$.

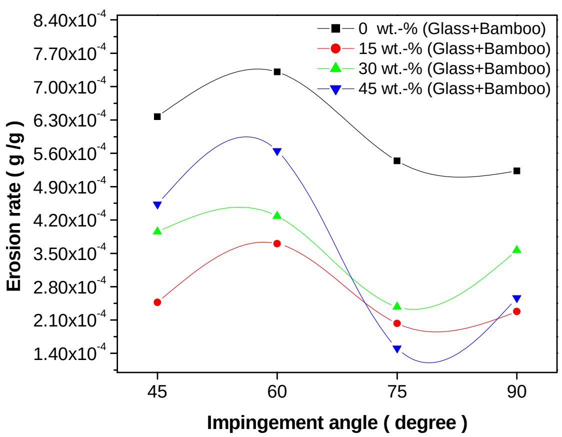


Figure 2. Effect of erodent temperature on erosion rate of hybrid composites

On the other hand, if the maximum erosion rate occurs at normal impact (*E*max at $\alpha=90^0$), the behaviour of material is purely brittle mode. The effect of impingement angle on erosion rate of untreated bamboo epoxy composite is studied and results are shown in Figure 2. The erosion rate increases with increase in fiber content. Sundararajan et al. [11] concluded that this behavior is attributed to the fact that the harder the material, larger is the fraction of the crater volume that is removed. In this investigation higher hardness values have been noted for composites with higher fiber loading and this is therefore the reason why the composites exhibit declining erosion resistance with the increase in fiber content. It is evident from the Figure 2 that impingement angle has significant influence on erosion rate and the maximum erosion is occurring at an impingement angle of 60° for all composite samples irrespective of fiber loading. So the mode of wear is neither a ductile erosion mode nor brittle erosion wear mode, it is behaving like semi-brittle mode of erosion wear.

C. Taguchi Analysis

Taguchi design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. Tables 3 show the erosion rates of different composites for all 16 test runs and their corresponding S/N ratios. Each of the values in these columns is in fact the average of two replications. The detail of the Taguchi experimental procedure was presented in our previous article [12]. The overall mean for the S/N ratio of the erosion rate is found to be 70.66db for the bamboo/glass hybrid composites. The analysis is made using the popular software specifically used for design of experiment (MINITAB 15). Before any attempt is made to use this simple model as a predictor for the measure of performance, the possible significant control factors are presented in Figure 3.

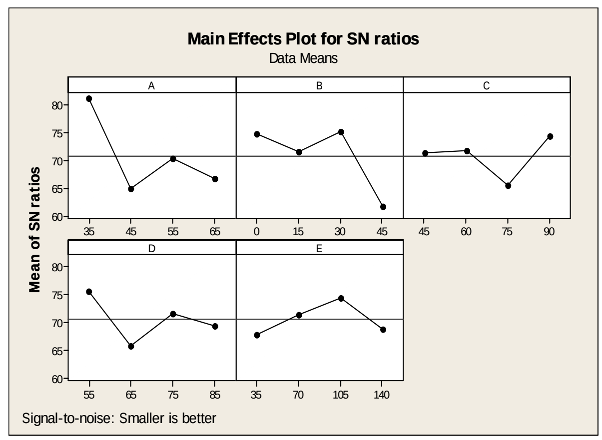


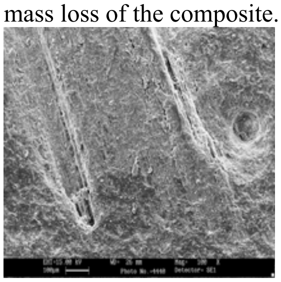
Figure 3. Effect of control factors on erosion rate for hybrid composites

TABLE 3. EXPERIMENTAL DESIGN USING L_{16} ORTHOGONAL ARRAY

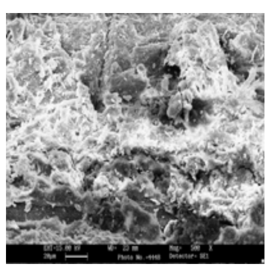
Sl. No	A (m/s)	B (wt %)	C Deg.	D (mm)	E (°C)	Er (gm/gm)	S/N
1	35	0	45	55	35	3.940E-05	88
2	35	15	60	65	70	1.167E-04	78
3	35	30	75	75	105	5.685E-05	84
4	35	45	90	85	140	2.363E-04	72
5	45	0	60	75	140	3.550E-04	68
6	45	15	45	85	105	3.670E-04	68
7	45	30	90	55	70	1.154E-04	78
8	45	45	75	65	35	7.239E-03	42
9	55	0	75	85	70	3.790E-04	68
10	55	15	90	75	35	2.256E-04	72
11	55	30	45	65	140	3.703E-04	68
12	55	45	60	55	105	2.856E-04	70
13	65	0	90	65	105	2.200E-04	73
14	65	15	75	55	140	5.392E-04	65
15	65	30	60	85	35	4.096E-04	67
16	65	45	45	75	70	1.001E-03	59

D. Surface Morphology

The SEM observations explain the results presented in the Figure 4 for bamboo/glass fiber reinforced epoxy composites under steady state erosion rate studied at constant impact velocity 45m/sec, erodent size 125μm and stand-off distance of 65mm at controlled conditions with variations of impingement angle (30 to 90°). Figure 4 shows the SEM of surfaces of the hybrid composite eroded under various test conditions. In Figures 4(a) and 4(b) show the 15wt.% fiber loading at lower impingement angle, it appears that composites under consideration exhibit several stages of erosion and material removal process. Very small craters and short cracks are seen on the eroded surface of the composite at 30° impingement angle. On increase in impingement angle to 45° under similar operating conditions shows slightly increased in erosion rate as evident from Figure 4b for 30wt% fiber loading. This indicated that the initiation of matrix material loss from the surface and the matrix is chipped off and the fibers are slightly visible beneath the matrix layer after the impact of dry silica sand particles. But as the erosion tests are carried out with further higher impingement angle (60°) at constant impact velocity 45m/sec, erodent size 250µm and stand-off distance 65mm the morphology of the eroded surface becomes different as in Figure 4(c) .Such cracks are clearly noticed in Figure 4(c) and distinctly illustrate a crater formed due to material loss and the arrays of broken/semi-broken fibers. Due to repeated impact of hard silica sand and higher impingement angle the sand particles tries to initiation of cracks on the matrix body and as erosion progresses gradually, these cracks subsequently propagate on the fiber bodies both in transverse as well as in longitudinal manner. But on further increase in impingement angle from 60° to 75° almost all the composites showed maximum erosion rate (Figure 2) as shown in Figure 4(d) for 45wt% fiber loading. As discussed earlier for ductile materials, repeated impacts lead to plastic deformation processes and heavily strained regions on the composite surface. In the case of brittle materials on other hand, the propagation of cracks grows towards the surface and their intersection to form a wear particle separated from the surface leads to additional mass loss of the composite.



(a)



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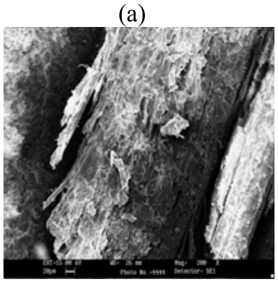
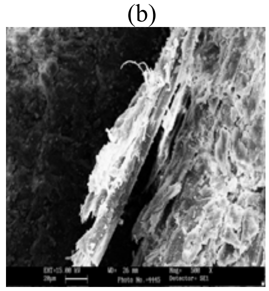


(c)



(d)

Figure 4. Surface morphology of eroded hybrid polymer composites

E. Analysis of Variance

Analysis of Variance (ANOVA) has been carried out from the experimental data for bamboo/glass fiber reinforced epoxy composites on erosion rate. Table 4 shows the ANOVA result for the erosion rate of hybrid composites under solid particle erosion. This analysis is undertaken for a level of confidence of significance of 5 %. The last column of the table indicates that the main effects are highly significant (all have very small p-values) [259]. From Table 4, it can be observed for the hybrid composites that impact velocity (p=0.120), fiber loading (p= 0. 142), stand-off distance (p= 0.564) and erodent temperature (p = 0.797) have great influence on erosion wear rate, whereas impingement angle shows least significant control factor in the present study.

TABLE 4. ANOVA TABLE FOR EROSION RATE OF HYBRID COMPOSITES

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	289.5	289.5	289.5	2.88	0.120
B	3	255.6	255.6	255.6	2.55	0.142
C	3	1.5	1.5	1.5	0.02	0.904
D	3	35.7	35.7	35.7	0.36	0.564
E	3	7.0	7.0	7.0	0.07	0.797
Error	0	1003.8	1003.8	100.4		
Total	15	1593.0				

IV. CONCLUSION

The experimental investigation of the present work has been lead to the following conclusions:

1. Successful fabrication of hybrid bamboo/glass fiber reinforced epoxy composites is possible by simple hand lay- up technique.
2. In steady state erosion rate is concerned with respect to impact velocity all the composites show gradually increase in erosion rate except 0wt% bamboo/glass fiber reinforced epoxy composites shows quite reverse in trend at higher impact velocity. This is due to the neat epoxy losses its properties and then starts melting. it is also clear that neat epoxy shows maximum erosion rate and 15wt.% bamboo/glass fiber shows least erosion rate whereas 30wt.% and 45wt.% hybrid composite lies in between the other two composites.
3. Similarly, as far as impingement angle is concerned all the hybrid composites show maximum erosion rate at 60° impingement angle irrespective of fiber loading. So the mode of wear is neither a ductile erosion mode nor brittle erosion wear mode, it is behaving like semi-brittle mode of erosion wear.
4. However, analysis of variance is concerned for hybrid bamboo/glass fiber composites impact velocity (p=0.120), fiber loading (p= 0. 142), stand-off distance (p= 0.564) and erodent temperature (p = 0.797) have great influence on erosion wear rate,

whereas impingement angle shows least significant control factor in the present study.

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