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A COMPARATIVE STUDY ON EROSION WEAR BEHAVIOR OF COPPER SLAG FILLED BAMBOO-EPOXY AND GLASS-EPOXY COMPOSITES

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ABSTRACT

Copper slag is an industrial waste which is produced as a by-product during smelting and refining of copper. Rich in various metal oxides, it has tremendous potential to be used as fillers in polymeric matrices. The present investigation has been undertaken to study the wear characteristics of copper slag filled bamboo-epoxy composites and the results are compared with that of the glass-epoxy composites. Also, the influence of control factors on the erosion wear response of composites has been critically analyzed using Taguchi experimental design. Further, the morphology of eroded surfaces is examined and possible erosion mechanisms are discussed.

Key Words: Copper slag, Bamboo fiber, Epoxy resin, E-glass fiber, Taguchi method

1. INTRODUCTION

Polymers and their composites find increased applications in the areas where the surfaces are subjected to solid particle erosion. Hence, it has been considered as a serious problem for being responsible for many failures in engineering applications. Now-a-days specific fillers/ additives are added to enhance and modify the quality of composites as these are found to play a major role in determining the physical properties and erosive behaviour of the composites. This occurs not only due to environmental concerns but also for providing a unique combination of high performance, great versatility and processing advantages at favourable cost. Some research papers have reviewed the use of copper slag in the production of value added products such as abrasive tools, abrasive materials, cutting tools, tiles, glass, and roofing granules [1, 2]. They also reported the potential use of copper slag as a partial substitute of cement and aggregates in concrete and asphalt mixtures. The interest in natural fiber reinforced polymer composite materials is rapidly growing both in terms of their industrial applications and fundamental research [3]. Against this background, the present investigation is undertaken to study of the wear characteristics of copper slag filled bamboo fiber reinforced epoxy composites and to compare them with the existing results for similar set of glass-epoxy composites.

2. EXPERIMENTAL DETAILS

2.1 Composite fabrication and experimental set-up

Roving bidirectional bamboo fibers are reinforced in copper slag filled Epoxy LY 556. The epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. Copper slag collected from the plant site of Hindustan Copper Limited, at Ghatsila, India, was sieved to obtain particle size in the order of 70 µm. The average thickness of bamboo fibers is about 1.5 mm. The extracted fibers are dried in an oven at 105^0C for 72 h to remove moisture. Each ply of bamboo-fiber is of dimension 200 × 200 mm^2. A stainless steel mould having dimensions of 210 × 210 × 40 mm^3 is used. The solid particle erosion experiments are carried out as per ASTM G76 using a standard erosion test rig.

3. RESULTS AND DISCUSSION

Erosion behaviour of the composites is generally ascertained by correlating erosion rate with impingement angle, erodent velocity and erodent particle size. Erosion behaviour strongly depends on impingement angle. Ductile behaviour is characterized by maximum erosion rate and generally occurs at $15\text{-}30^0$. Brittle behaviour is characterized by maximum erosion rate at 90^0. Semi-ductile behaviour is characterized by the maximum erosion rate at $45\text{-}60^0$. Figure 1 shows the influence of impingement angle on steady-state erosion rate of epoxy and its composites. The results show that the peak erosion takes place at an impingement angle of 60^0 for the unfilled composites whereas for the copper slag filled glass-epoxy composites it occurs at 45^0 impingement angle. Hence, the erosion behaviour is semi-ductile. Similar observations have been also made in other polymers and composites [4, 5]. This clearly indicates that these composites respond to solid particle impact neither in a purely ductile nor in a purely brittle manner.

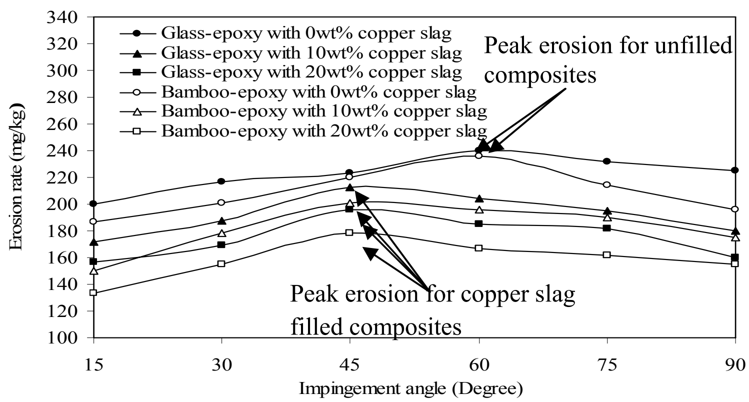

Figure 1. Effect of impingement angle on the erosion wear rate of the composites

Microstructures of the un-eroded surface of a copper slag filled bamboo-epoxy composite are presented in Figures 2a and 2b. Scattered copper slag particles are observed on the upper surface. In the case of the worn surface of the composite eroded at low impact speeds, however, the most visible dominant feature is fracture and often plastic deformation. Fiber fracture and failure inside the matrix is not clearly observed at an impingement angle of 30^0 although only matrix cracks and deformation are evident (Figures 2c and 2d). Similarly, for glass-epoxy composites as shown in Figure 2e presents the matrix is chipped off and the glass fibers are clearly visible beneath the matrix layer after the impact of dry silica sand particles (40^0C) of smallest grit size (300 µm) with a lower impact velocity (43 ms^{-1}) at a low impingement angle of 30^0. The micrograph with a higher magnification presented in Figure 2f distinctly illustrates a crater formed due to material loss and the arrays of broken and semi-broken glass fibers within. Due to repeated impact of hard and high temperature sand particles there was initiation of cracks on the fibers and as erosion progresses, these cracks subsequently propagate on the fiber bodies both in transverse as well as in longitudinal manner.

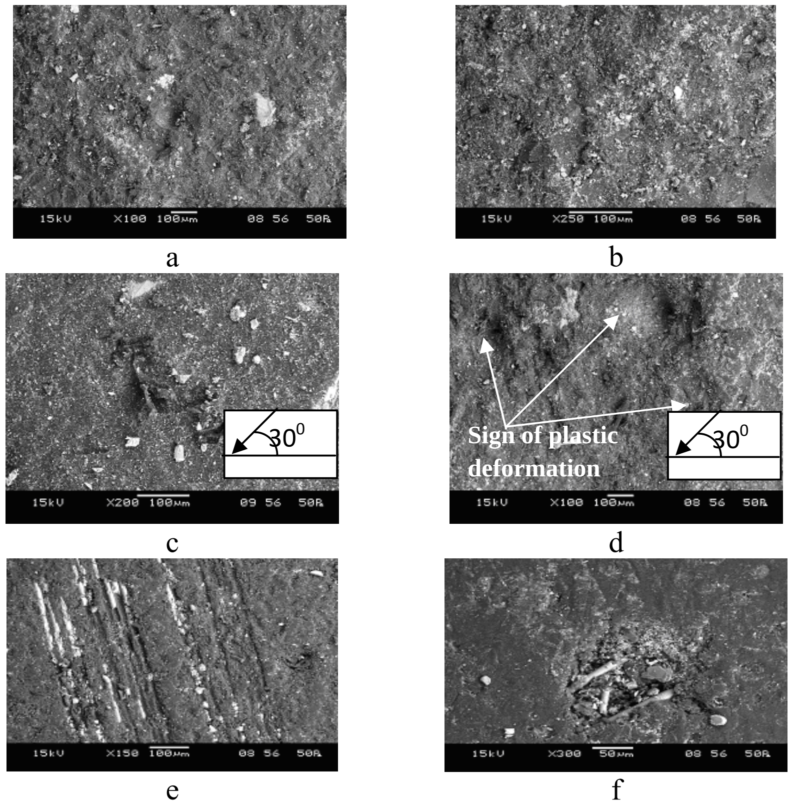

Figure 2. SEM images of the eroded bamboo/glass-epoxy composites filled with copper slag

3.1 Confirmation experiment

The final step in any design of experiment approach is to predict and verify improvements in observed values through the use of the optimal combination level of control factors. The confirmation experiment is performed by taking an arbitrary set of factor combination $A_2 B_3C_3 D_2E_1F_3$, for bamboo based epoxy composites. Similarly, for glass based epoxy composites the arbitrary set of factor combination $A_2B_2C_2D_2E_3$, but factor F has been omitted and factor D has also least effect on performance characteristics. The estimated S/N ratios for erosion rate are calculated with the help of **Taguchi L_{27} (3^6)** orthogonal array design [6] and the estimated predictive equation as follows:

$$\hat{\eta}_{bamboo-epoxy} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_3 - \bar{T}) + [(\bar{A}_2\bar{B}_3 - \bar{T}) - (\bar{A}_2 - \bar{T}) - (\bar{B}_3 - \bar{T})] + (\bar{C}_3 - \bar{T}) + [(\bar{B}_3\bar{C}_3 - T) - (\bar{B}_3 - \bar{T}) - (\bar{C}_3 - \bar{T})] + (\bar{D}_2 - \bar{T}) + (\bar{E}_1 - \bar{T}) + (\bar{F}_3 - \bar{T}) \quad (6)$$

$$\hat{\eta}_{Glass-epoxy} = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_2 - \bar{T}) + [(\bar{A}_2\bar{B}_2 - \bar{T}) - (\bar{A}_2 - \bar{T}) - (\bar{B}_2 - \bar{T})] + (\bar{C}_2 - \bar{T}) + [(\bar{B}_2\bar{C}_2 - T) - (\bar{B}_2 - \bar{T}) - (\bar{C}_2 - \bar{T})] + (\bar{D}_2 - \bar{T}) + (\bar{E}_3 - \bar{T}) \quad (7)$$

$\bar{\eta}_{bamboo-epoxy}$ and $\bar{\eta}_{glass-epoxy}$: Predicted average for bamboo fiber reinforced epoxy composites and glass fiber reinforced epoxy composites respectively.

A new combination of factor levels A_2, B_3, B_2, C_2,C_3, D_3, E_1, E_3 and F_3 is used to predict deposition rate through prediction equation and it is found to be $\bar{\eta}_{bamboo-epoxy} = -45.1397\,db$ and $\bar{\eta}_{glass-epoxy} = -45.1182\,db$ respectively.

For each performance measure, an experiment is conducted for a different factors combination and compared with the result obtained from the predictive equation as shown in Table 1.

Table 1. Results of the confirmation experiments for erosion rate

	Optimal control parameters (For composites with bamboo-fiber reinforcement)		Optimal control parameters (For composites with glass-fiber reinforcement)[7]	
	Prediction	Experimental	Prediction	Experimental
Level	$A_2\,B_3C_3\,D_2\,E_1F_3$	$A_2\,B_3C_3\,D_2\,E_1F_3$	$A_2\,B_2C_2D_2E_3$	$A_2\,B_2C_2D_2E_3$
S/N ratio for Erosion rate (db)	-45.1397	-42.9007	-45.1182	-42.1268

The resulting model seems to be capable of predicting erosion rate to a reasonable accuracy. An error of 4.96 % (bamboo-epoxy) and 6.63 % (glass-epoxy) for the S/N ratio of erosion rate is observed. However, the error can be further reduced if the number of measurements is increased.

4. CONCLUSIONS

The present investigation of erosion rear characteristics of copper slag filled epoxy composites with bamboo and glass reinforcement leads to the following conclusions:

1. The erosion wear performance of these composites greatly influenced by addition of copper slag filler. Erosion characteristics of these composites can be successfully analyzed using Taguchi experimental design scheme. The study reveals that for similar test conditions bamboo based composites exhibits much better wear resistance than those by glass-epoxy composites. This establishes bamboo as a better candidate for reinforcement as compared to glass fibers from the view point of erosion performance.
2. Erosion process involved different mechanisms depending on the type and arrangement of fiber and filler content in the matrix. For bamboo fiber composite, severe deterioration of both fiber and matrix, micro-ploughing in the matrix, transverse shearing, stripping, and fibrillation of fibre are identified and composite debonding, pulling, and fibre fracture are the characteristic features of damage in glass fiber.

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