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Polymer composites reinforced with short fibers obtained from poultry feathers

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Abstract

Short fibers obtained form poultry feathers are found to possess high toughness, good thermal insulation properties, non abrasive behavior and hydrophobic nature. Their low cost, low density and large aspect ratio can make them good reinforcing materials in polymer matrix composites. This paper reports the development of poultry feather reinforced epoxy composites. Randomly oriented short feather fibers are reinforced into epoxy resin to prepare composite slabs. Mechanical properties such as tensile strength, flexural strength, micro-hardness etc. are evaluated. Solid particle erosion tests are conducted on the composite samples to evaluate their wear resistance. A self developed air-jet type erosion test rig and dry silica sand particles are used for this purpose. It is found that the material loss from the composite surface depends greatly on operational variables like impact angle, impact velocity etc. Taguchi experimental design technique is used in this study to determine the relative significance of various control factors influencing the wear rate. The erosion response of the composite is compared with that of neat epoxy and the effect of fiber reinforcement on the wear rate is discussed.

Keywords: Poultry feather, Polymer composite, Erosion wear

1. Introduction

Natural fiber reinforced polymer composites have raised great attention and interest among materials scientists and engineers in recent years due to the considerations of developing an environmental friendly material and partly replacing currently used glass or carbon fibers in fiber reinforced composites[1]. They are high specific strength and modulus materials, low priced, recyclable and are easily available. Some experimental techniques, from micro scale to macro scale, such as single fiber pull-out test, single fiber fragmentation test, short beam shear test etc. have been employed to evaluate the interfacial performances of this kind of composites. It is known that natural fibers are non-uniform with irregular cross sections which make their structures quite unique and much different with man-made fibers such as glass fibers, carbon fibers etc. Many researches have been conducted to study the mechanical properties, especially interfacial performances of the composites based on natural fibers due to the poor interfacial bonding between the hydrophilic natural fibers such as sisal, jute and palm fibers and the hydrophobic polymer matrices. Worldwide laboratories have worked on this topic[2-5]. But reports on composites using bird feathers as reinforcing fibers are rare.

Materials derived from chicken feathers can be used advantageously as the reinforcing materials in polymer matrix composites. Such applications can potentially consume the huge quantity of feathers produced annually as a by-product of various poultry units worldwide. Chicken feathers are approximately 91% protein (keratin), 1% lipids, and 8% water[6]. The amino acid sequence of a chicken feather is very similar to that of other feathers and also has a great deal in common with reptilian keratins from claws[7]. The sequence is largely composed of cystine, glycine, proline, and serine, and contains almost no histidine, lysine, or methionine[8]. To aid the development of

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successful applications for chicken feather in composite making, this research work has been taken up. The objective of this investigation is to study the effect of poultry feather reinforcement on the erosive wear behavior of epoxy under multiple impact conditions. An attempt is made to optimize the process parameters for minimum erosion. For this an inexpensive and easy-to-operate experimental strategy based on Taguchi's parameter design has been adopted. This experimental procedure has been successfully applied earlier for parametric appraisal in erosion wear of polyester composites with different fiber and filler content [9-12].

2. Experimental Details

2 .1. Composite fabrication

The matrix material used for the fabrication of poultry feather reinforced composites consists of low temperature curing epoxy resin (Araldite LY 556) and corresponding hardener (HY951) supplied by Ciba Geigy India Ltd. Resin and hardener are mixed in a ratio of 10:1 by weight as recommended. Density of the epoxy resin system is 1.1 g/cc. The chicken feathers collected from poultry units are cleaned with a polar solvent, like ethanol, and are dried. The quills are removed and the short fibers (10-15 mm length) are obtained. To prepare the composite slabs, these fibers in pre-determined weight proportion (20%) are reinforced with random orientation into the epoxy resin. A block of size (300mm X 150mm X 8mm) is thus cast. The casting is put under load for about 24 hours for proper curing at room temperature. Specimens of suitable dimension are cut using a diamond cutter for physical characterization and erosion test.

2. 2 . Test apparatus

The set up used for the wear test is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. It consists of an air compressor, an air particle mixing chamber and accelerating chamber. Dry compressed air is mixed with the particles which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3mm internal diameter. These 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 clip. The velocity of the eroding particles is determined using standard double disc method[13]. In the present study, dry silica sand (spherical) of different particle sizes (300µm, 500 µm and 800µm) are used as erodent. The samples are cleaned in acetone, dried and weighed to an accuracy of $\pm$ 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 process is repeated till the erosion rate attains a constant value called steady state erosion rate. Hardness measurement is done with a Leitz Micro-hardness Tester using a load of 24.54 N. The tensile test is performed on flat specimens following ASTM test standard D 3039-76 in the universal testing machine Instron 1195. To evaluate the flexural strength, 3-point bend test is conducted on all the composite samples using the same universal testing machine. Span length of 40 mm and the cross head speed of 10mm/min are maintained. The surfaces of the specimens are examined directly by scanning electron microscope JEOL JSM-6480LV in the LV mode.

2 .3 . Experimental design

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The most important stage in the design of experiment lies in the selection of the control factors. Exhaustive literature review on erosion behavior of polymer composites reveal that parameters viz., impact velocity, impingement angle, erodent size and stand-off distance etc largely influence the erosion rate of polymer composites[14,15]. The impact of these four parameters are studied using L_9 (3^4) orthogonal design. The operating conditions under which erosion tests are carried out are given in Table 1. In conventional full factorial experiment design, it would require 3^4 = 81 runs to study four parameters each at three levels whereas, Taguchi's factorial experiment approach reduces it to only 9 runs offering a great advantage in terms of experimental time and cost. The experimental observations are further transformed into signal-to-noise (S/N) ratios. There are several S/N ratios available depending on the type of performance characteristics. The S/N ratio for minimum erosion rate can be expressed as "lower is better" characteristic, which is calculated as logarithmic transformation of loss function as shown below.

Smaller is the better characteristic: $\frac{S}{N} = -10 \log \frac{1}{n} \left(\sum y^2 \right)$ (9)

where 'n' the number of observations, and y the observed data. The plan of the experiments is as follows: the first column is assigned to erodent size (A), the second column to impingement angle (B), third column to impact velocity (C) and the fourth column to stand-off distance (D).

3 . Results and discussion

3 .1 . Mechanical properties of composite:

In the present investigation the reinforcement of poultry feather into epoxy resin has not shown any encouraging results in terms of mechanical properties. The tensile strength of the composite is measured to be 70.45 MPa where as that of neat epoxy is about 70 MPa. The incorporation of feathers has not caused any significant improvement in the flexural strength as well. However, the reinforcement has caused a reduction of about 13% in the composite density which leads to improvement in the strength to weight ratio. The density of the composite is measured to be 0.97 gm/cc which is less than the density of neat epoxy (1.12 gm/cc).

3 .2 . Surface morphology

Figures 1 and 2, the SEM micrographs of the eroded surfaces reveal that the matrix covering the fiber is chipped off due to repeated impact of hard silica sand particles. A crater thus formed shows an array of almost intact feather fibers. After the local removal of matrix this array of fibers is exposed to erosive environment. Small indentations on the epoxy matrix layer are also seen. The adhesion between the fibers and the epoxy matrix resists the wear due to erosion and the material loss therefore is reduced with the reinforcement of fibers. For the specimen eroded at lower impact angle (Figure 1), the wear magnitude is less as only the normal component of the impact velocity causes the wear. But in case of normal impact (i.e. at impingement angle 90^0), the erodent particles strike the composite surface with maximum kinetic energy and consequently the material loss is high (Figure 2). The broken fibers are mixed with the matrix micro-flake debris and the damage of the composite is characterized by separation and detachment of this debris.

3 .3 . Steady state erosion

The erosion wear rates of poultry feather reinforced epoxy matrix composites as a function of impingement angle (α) are shown in Figure 3. It can be seen that reinforcement of short feather fibers reduces the wear rate of the epoxy resin quite significantly. Both the neat epoxy and reinforced composites show maximum erosion at normal impact i.e. at $\alpha=90^0$. This implies the brittle nature of the composite. In Table 2, the last column represents S/N ratio of the erosion rate which is in fact the average of two replications. The overall mean for the S/N ratio of the erosion rate is found to be -48.45db. The analysis was made using the popular software specifically used for design of experiment applications known as MINITAB 14. The effects of individual control factors are shown in Figure 4. Analysis of the result leads to the conclusion that factor combination of A_1, B_1, C_1 and D_3 gives minimum erosion rate. Table 3 gives the signal to noise response table which shows that as far as the minimization of erosion rate is concerned; factors A, B, C have significant effect whereas factor D has the least effect. From this response table, it can be concluded that among all the factors, impingement angle is most insignificant followed by erodent size and impact velocity and the stand off distance has the least or almost no significant effect on erosion of the feather reinforced composite.

4 . Conclusions

Based on the studies made on erosion characteristics of the following conclusions are drawn:

1. Successful fabrication of poultry feather reinforced epoxy composites is possible by simple hand-lay-up techniques. Such composites have adequate potential for applications in highly erosive environments.

Although they exhibit poor tensile and flexural strength their erosion wear performance shows significant improvement with the reinforcement of short feather fibers.

2. The peak erosion rate for these composites occurs at normal impact (i.e. at impingement angle = 90^0). This indicates the brittle nature of the composites.
3. Erosion response of these composites can be successfully analyzed using Taguchi experimental design scheme. Factors like impingement angle, erodent size and impact velocity, in this sequence, are identified as the significant factors affecting the erosion rate. The effect of stand off distance on wear rate is negligible.
4. This study leaves wide scope for future investigations. It can be extended to newer composites using other reinforcing phases and the resulting experimental findings can be similarly analyzed.

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Table 1 Levels of the variables used in the experiment

Control factor	Level			
	1	2	3	Units
A: Erodent size	300	500	800	µm
B: Impingement angle	30	60	90	degree
C: Impact Velocity	32	44	58	m/sec
D: Stand-off distance	120	160	200	mm

Table 2 Experimental design using L_{27} orthogonal array

A	B	C	D	Er (mg/kg)	S/N Ratio
300	30	32	120	211.23	-46.4951
300	60	44	160	246.78	-47.8462
300	90	58	200	282.63	-49.0244
500	30	44	200	239.89	-47.6002
500	60	58	120	298.78	-49.5070
500	90	32	160	283.60	-49.0541
800	30	58	160	265.55	-48.4829
800	60	32	200	274.87	-48.7825
800	90	44	120	302.66	-49.6191

Table 3 Signal to noise ratio response table for erosion rate.

Level	A	B	C	D
1	-47.79	-47.53	-48.11	-48.54
2	-48.72	-48.71	-48.36	-48.46
3	-48.96	-49.23	-49.00	-48.47
Delta	1.17	1.70	0.89	0.08
Rank	2	1	3	4

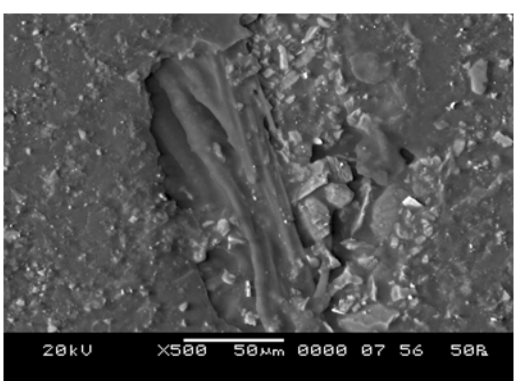

Figure 1 SEM Micrograph of composite eroded at α=30^0

Figure 2 SEM Micrograph of composite eroded α=90^0

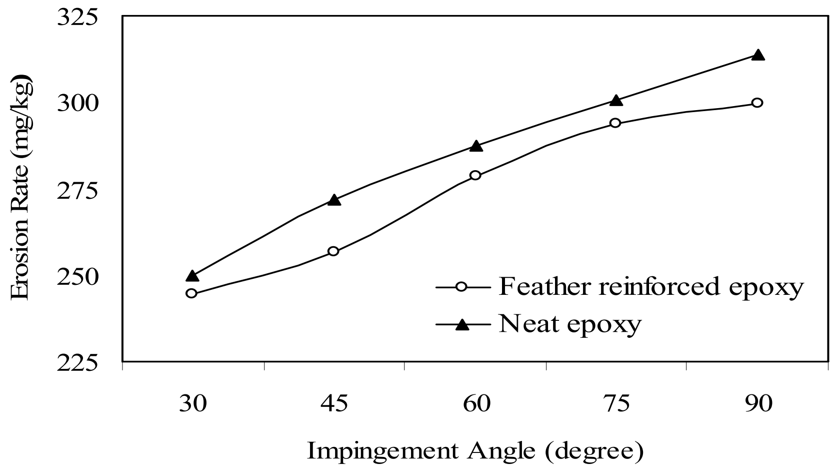

Figure 3 Variation of erosion wear rate with impingement angle

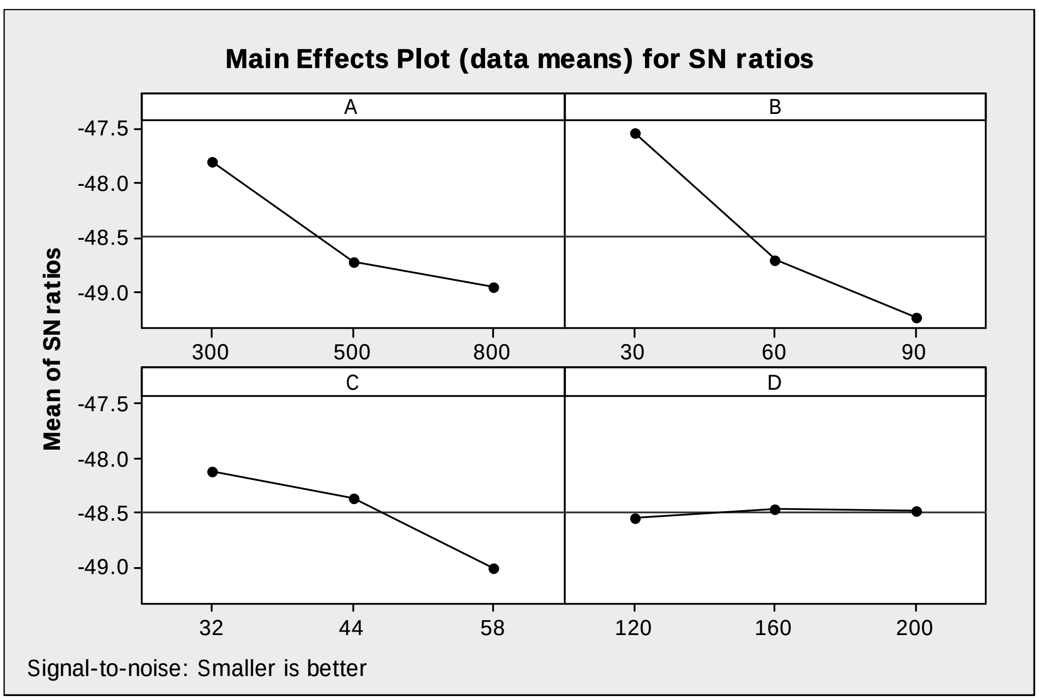

Figure 4 Effect of control factors on erosion rate

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