A STUDY ON EROSION RESPONSE OF FLY ASH FILLED SHORT BIO-FIBER REINFORCED EPOXY COMPOSITES

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Abstract: *This paper describes the processing, characterization and erosion wear response of fly ash filled epoxy composites reinforced with short fibers obtained from the scales of a typical fresh water fish (Lobea rohita). Erosion characteristics are studied using an air jet type erosion test rig employing the Taguchi's design of experiments approach. The findings show that the erosion rate is greatly influenced by various control factors. An optimal combination of these control factors is determined for minimization of erosion rate. A mathematical correlation is proposed as a predictive equation for estimation of erosion rate of these composites.*

Key Words: ***Polymer composite, Bio fibers, Fly ash, Taguchi method, Erosion***

1. INTRODUCTION

Fiber reinforced polymer composites have many applications in automobile, marine and aerospace industries. Due to operational requirements in dusty environments, the erosion characteristics of these composites are of vital importance. Since erosive wear of engineering components caused by abrasive particles is a major industrial problem, a full understanding of the effects of all system variables on the wear rate is necessary in order to undertake appropriate steps in the design of machine or structural component and in the choice of materials to reduce/control this wear. Various applications of polymers and their composites in erosive wear situations are reported by Pool et al. [1], Kulkarni and Kishore [2] and Aglan and Chenock [3] in the literature. A number of researchers Barkoula and Karger-Kocsis [4], Tewari et al. [5] have evaluated the resistance of various types of polymers and their composites to solid particle erosion. Tilly and Sage [6] have investigated the influence of velocity, impact angle, particle size and weight of impacted abrasives on nylon, carbon-fiber-reinforced nylon, epoxy, polypropylene and glass-fiber-reinforced plastic.

In recent years, a number of investigations have also been reported which prove the worth of natural fibers against their synthetic counter parts such as glass and/or carbon. Natural fibers are being used in polymers both in long and continuous form and also in the form of short fibers or flakes. The reported studies on short fiber reinforced composites by different investigators are found to have focused mostly on the strength properties of the composites. Beyerlein et al. [7] have described the influence of fiber shape in short fiber composites. Kari et al. [8] have evaluated numerically the effective material properties of composites with randomly distributed short fibers. Hine et al. [9] have presented a numerical simulation of the effects of fiber length distribution on the elastic and thermo-elastic properties of short fiber composites. Fu et al. [10] have studied the flexural properties of misaligned short fiber reinforced polymers by taking into account the effects of fiber length and fiber orientation. It is evident from the existing literature that polymer composites reinforced with natural fibers like jute, sisal etc. have long been used in various structural applications. Bio-fibers like animal whiskers and poultry feather have also recently drawn the attention of researchers [11].

Fish is one of the most abundantly available aqueous species and its scale, regarded as a waste material, can be gainfully converted to value added products. It is expected to contribute improved functional properties to the neat polymer apart from making the composite lighter and cheaper. Fish scales, the dermal derivatives of fish body, are important structures used as versatile research material in fisheries. They exhibit distinct pattern of dark and light bands corresponding to closely and widely spaced circuli that form annular zones depicting the age of fish in years. The engraved pattern of circuli on scale serves as a blueprint for the physiological epochs of fish life, narrating its growth history. Besides this established role of scales in fish biology, these have numerous hidden details in their sculptural design that contribute effectively to fish identification and classification. Fig. 1 presents the pictorial view of a single scale taken from the upper body of the fish. It is a typical cycloid type scale having a smooth outer edge and appears to be consisting of concentric layers. The surface of scale is divisible into anterior, lateral and posterior regions. Its centre is regarded as focus, around which the circuli are laid in a regular manner. These circuli are interrupted at regular intervals by transverse radii. Ikoma et al. [12] have studied the micro-structural, mechanical, and bio-mimetic properties of fish scales from Pagrus major. They have reported the tensile strength of the scale to be as high as ~90 MPa and have attributed this to the hierarchically ordered structure of mineralized collagen fibers. Although some earlier works studied fish body scales to strengthen their role in fish taxonomy [13], the available reports on fish scale research are relatively less.

Fig. 1 *Pictorial view of a single scale*

The potential use of fish scale fiber in composite making has not adequately been explored so far. Although Satapathy et al [14], in 2009, were the first to report on the processing of fish scale reinforced epoxy composites; so far no paper is available on such composites filled with particulate matters like industrial wastes.

Fly ash is such an industrial waste, the reinforcing potential of which needs to be explored. It is generated during the combustion of coal for energy production and is an industrial by-product which is recognized as an environmental pollutant. With rapid industrialization, it is but natural that the power generation will keep increasing in future. About 70% of total power generation in India is through thermal power plants where sub-bituminous coal and/or lignite are burnt in huge amount and consequently there is an estimated generation of about 80-90 million tons of fly ash per annum as the major solid waste. Fly ash consists of fine, powdery particles predominantly spherical in shape, either solid or hollow and mostly glassy (amorphous) in nature. It is generally grey in colour, abrasive, mostly alkaline and refractory in nature. Its utilization as a low cost adsorbent for the removal of organic compounds, light weight aggregate, road sub-base, construction material, mine and pit filler etc. has already been established. Due to increasing environmental concern and growing magnitude of the problem it has become imperative to manage fly ash.

In view of the above, the objective of the present investigation is to prepare fish scale reinforced epoxy matrix composites filled with different weight fractions of fly ash particles and to study the erosive wear behavior of these composites under multiple impact conditions.

2. EXPERIMENTAL DETAILS

Materials

The fish scales are collected from a fishermen's market in Rourkela, located in the eastern part of India. Labeo rohita (common local names are rohi, rui) is a typical fresh water fish normally located in weedy and slow flowing or standing waters of lakes, ponds, pools and rivers. It can be identified by the dark scales in its upper body, golden brown lower body and belly and dark brown dorsal fin and tail. It has pelvic, pectoral and anal fins with red tint. Mature fish scales are washed repeatedly with water to remove adhering dust and soluble impurities form their surface. The scales are allowed to dry in sunshine for two days and are then kept in an oven at 70^0C till they become crispy. The dried scales are then cut into short flakes of dimension, approximately 6–8 mm in length and 1 mm in width. These flakes are used as the reinforcing phase. Fly ash, used as the filler material in this work is collected from the captive power plant of National Aluminum Co. located at Angul (India).

Composite fabrication

The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. Composites of three different compositions (0, 10, and 20wt% fly ash filling) are made and the fiber loading (weight fraction of dried flakes of fish scales in the composite) is kept at 10% for all the samples. The castings are 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 and mechanical characterization.

Micro-hardness, Tensile and Flexural strength

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is used with a load of 24.54 N.

The tensile test is generally performed on flat specimens. During the test a uni axial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The length of the test section should be 200 mm. The tensile test is performed in the universal testing machine (UTM) Instron 1195 and results are analyzed to calculate the tensile strength of composite samples. The data recorded during the 3-point bend test is used to evaluate the flexural strength also. The test is conducted as per ASTM standard (D2344-84) using the same UTM.

Erosion Test apparatus

The erosion test set up confirming to ASTM G 76 is capable of creating reproducible erosive situations for assessing erosion wear resistance of the prepared composite samples. 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 3 mm 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 [3]. In the present study, dry silica sand (spherical) of different particle sizes (300 µm, 500 µm and 800 µm) are used as erodent. The samples 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 process is repeated till the erosion rate attains a constant value called steady state erosion rate.

Experimental design

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. Generally, a large number of factors are included so that non-significant variables can be identified at earliest opportunity. Five parameters viz., erodent size, angle of impingement, impact velocity, stand-off distance, and filler (fly ash) content, each at three levels, are considered in this study in accordance with L_{27} (3^{13}) orthogonal array design. Five parameters each at three levels would require 3^5 = 243 runs in a full factorial experiment. Whereas, Taguchi's factorial experiment approach reduces it to 27 runs only offering a great advantage. The various control factors and their selected levels taken for this study are given in Table 1.

Table 1 *Levels for various control factors*

Control factor	Level			
	I	II	III	Units
A: Erodent size	300	500	800	µm
B: Impingement Angle	30	60	90	Deg
C: Velocity of impact	32	44	58	m/s
D:Stand-off distance	120	160	200	mm
E: Filler (fly ash) content	0	10	20	wt%

3. RESULTS AND DISCUSSION

Mechanical Characterization

In this study, the hardness values of the composites with different fly ash content are found to be improving. For unfilled epoxy reinforced with 10 wt% of flakes, this value is found to be about 43 Hv, whereas with the incorporation of 10 wt% and 20 wt% of fly ash particles it is seen that the hardness is improved to 54 Hv and 69 Hv respectively. No significant change in tensile and flexural strength of the composites with the addition of fly ash is noticed.

Taguchi Analysis of the Erosion Test Results

The erosion wear rates of fly ash filled fish scale fiber reinforced epoxy matrix composites under various test conditions are given in Table 2. The experimental observations are transformed into a signal-to-noise (S/N) ratios. In this Table, the last column represents S/N ratio of the erosion rate which is in fact the average of two replications. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum erosion rate coming under *smaller-is-better* characteristic, which can be calculated as logarithmic transformation of the loss function as shown below.

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

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

The overall mean for the S/N ratio of the erosion rate is found to be – 46.79 dB. The analysis is made using the popular software specifically used for design of experiment applications known as MINITAB 14. The effects of individual control factors influencing the erosion wear rates of the composites are shown in Fig 2. The S/N ratio response is given in the Table 3, from which it can be concluded that among all the factors, impingement angle is the most significant factor followed by erodent size, fly ash content and impact velocity, while the stand-off distance has the least or almost no significance on erosion of these short bio-fiber reinforced composites. It also leads to the conclusion that factor combination of A_1, B_1, E_3 and C_1 gives minimum erosion rate.

Factor Settings for Minimum Erosion Rate

In this study, an attempt is made to derive predictive equations in terms of the significant control factors for determination of erosion rate of these fly ash filled composites. The single-objective function requires quantitative determination of the relationship between erosion rates with combination of control factors. In order to express, erosion rate in the form of a mathematical model the following correlation is suggested.

$$Er = K_0 + K_1 \times A + K_2 \times B + K_3 \times E \tag{2}$$

Here, *Er* is the performance output term and K_i (i = 0, 1…3) are the model constants. The constants are calculated using non-linear regression analysis with the help of SYSTAT 7 software and the following relations are obtained:

$$E = 163.53 + 0.051 \times A + 0.696 \times B - 1.233 \times E \tag{3}$$

(r^2=0.997)

The correctness of the calculated constants is confirmed as high correlation coefficients (r^2) in the tune of 0.997 is obtained for Eq. (2) and therefore, the model is quite suitable to use for predictive purpose.

Table 2 *Erosion rates under various test conditions*

L_{27} (3^{13})	Erodent size (A) (m)	Angle of impingement (B) (deg)	Velocity of impact (C) (m/s)	Stand-off distance (D) (mm)	Filler (Fly ash) Content (E) (wt%)	Erosion rate (E_r) (mg/kg)	S/N ratio (dB)
1	300	30	32	120	0	183.45	-45.2704
2	300	30	44	160	10	176.98	-44.9585
3	300	30	58	200	20	170.56	-44.6375
4	300	60	32	160	10	206.76	-46.3093
5	300	60	44	200	20	192.50	-45.6886
6	300	60	58	120	0	234.87	-47.4166
7	300	90	32	200	20	219.57	-46.8315
8	300	90	44	120	0	244.65	-47.7709
9	300	90	58	160	10	230.45	-47.2515
10	500	30	32	160	20	176.98	-44.9585
11	500	30	44	200	0	198.54	-45.9570
12	500	30	58	120	10	186.45	-45.4112
13	500	60	32	200	0	245.31	-47.7943
14	500	60	44	120	10	238.33	-47.5436
15	500	60	58	160	20	230.38	-47.2489
16	500	90	32	120	10	236.42	-47.4737
17	500	90	44	160	20	231.23	-47.2809
18	500	90	58	200	0	247.82	-47.8827
19	800	30	32	200	10	220.67	-46.8749
20	800	30	44	120	20	206.61	-46.3030
21	800	30	58	160	0	253.65	-48.0847
22	800	60	32	120	20	212.78	-46.5586
23	800	60	44	160	0	235.98	-47.4575
24	800	60	58	200	10	225.07	-47.0464
25	800	90	32	160	0	258.11	-48.2361
26	800	90	44	200	10	241.87	-47.6716
27	800	90	58	120	20	239.81	-47.5973

Table 3 *Response Table for Signal to Noise Ratios*

Level	A	B	C	D	E
1	-46.24	-45.83	-46.70	-46.82	-47.32
2	-46.84	-47.01	-46.74	-46.87	-46.73
3	-47.31	-47.56	-46.95	-46.71	-46.34
Delta	1.08	1.73	0.25	0.16	0.97
Rank	**2**	**1**	**4**	**5**	**3**

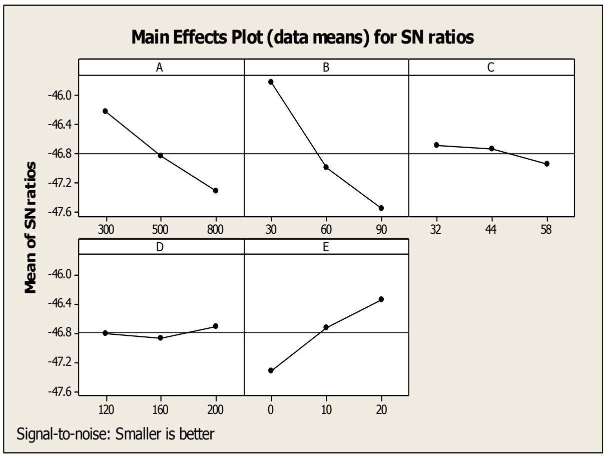

Fig. 2 *Effects of control factors on erosion rates*

4. CONCLUSIONS

Successful fabrication of epoxy matrix composites filled with fly ash particles and reinforced with short bio fibers derived from fish scale is possible by simple hand lay-up technique. Although these composites possess improved micro-hardness with the addition of fly ash, they do not exhibit any significant improvement in mechanical strengths as compared to those of the unfilled epoxy-fish-scale composites. These composites are found to have adequate potential for applications in highly erosive environments. They exhibit improved erosion wear performance than that of neat epoxy resin and the short bio fiber reinforced epoxy composites. Factors like impingement angle, erodent size, fly ash content and impact velocity, in this sequence, are identified as the significant factors affecting the erosion rate.

This study opens up a new avenue for utilization of a bio-waste like fish scale and an industrial waste like fly ash in fabricating a new class of bio-fiber reinforced composites which may find applications in conveyor belt rollers, pipes carrying pulverized coal in power plants, pump and impeller blades, household furniture and also as low cost housing material. .

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