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Erosive Wear Behavior of Glass-Epoxy Hybrid Composites Reinforced with Blast Furnace Slag

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ABSTRACT

This paper depicts the processing, mechanical characterization and erosion response of a new class of multi-phase hybrid composites consisting of epoxy resin reinforced with glass fiber and filled with blast furnace slag (BFS) obtained from iron and steel industries. Such glass fiber reinforced epoxy (GFRE) composites are fabricated incorporating BFS as the particulate filler in them with an objective to improve their wear resistance in erosive operating conditions. The effects of slag particles as filler in modifying the physical and mechanical properties of glass-epoxy composites have been studied. It is found that the incorporation of blast furnace slag modifies the mechanical properties like tensile, flexural and inter-laminar-shear strengths of the glass-epoxy composites. The micro-hardness and density of the composites are also greatly influenced by the presence of these fillers. By incorporating these particulate fillers, synergistic effects, as expected are achieved in the form of modified mechanical properties. Inclusion of glass fibers in neat epoxy improved the load-bearing capacity (tensile strength) and the ability to withstand bending (flexural strength) of the composites. Experiments are carried out to study the effects of BFS content and other control factors on the solid particle erosion behavior of these GFRE composites. The erosion rates (E_R) are evaluated at different impingement angles ranging from 30^0 to 90^0 at different impact velocities.

Key words: Hybrid Polymer Composites; Blast Furnace Slag, Solid Particle Erosion, Taguchi Method

Introduction

Polymers find wide engineering applications due to their low density, reasonably good strength and wear resistance as compared to monolithic metal alloys. For weight sensitive uses, undoubtedly they are the most suitable materials but prohibitive costs and stability of properties pose challenge for the researches in the process of development of composites. In order to bring down the cost, cheap and easily available fillers are a viable option. However, mechanical properties of the composites should not be degraded in the attempt of reducing the cost. Therefore, purpose of using fillers is twofold: first, to improve the mechanical, thermal or tribological properties, and second, to reduce the cost of the component. Specifically, in polymers, a large number of materials such as minerals and inorganic oxides (alumina and silica) are mixed with thermoplastics like polypropylene and polyethylene [1]. Through judicious control of reinforcing solid particulate phase, selection of matrix and suitable processing technique, composites can be prepared to tailor the properties needed for any specific application. In past two decades, ceramic filled polymer composites have emerged as a subject of extensive research. But due to high cost of conventional ceramic fillers, it has become important to explore the potential of cheap materials like mineral ores and industrial wastes for utilization in preparing particle-reinforced polymer composites.

Production of iron from its ores in blast furnaces is associated with the generation of blast furnace slag (BFS) as the major waste material in iron industries worldwide. In this work, glass fibre-reinforced epoxy composites filled with micro-sized BFS in four different proportions (0, 10,20 and 30 wt%) are fabricated and their solid particle erosion wear characteristics are studied by conducting a well planned experimental schedule based on Taguchi design. Such an approach has been successfully applied earlier for parametric appraisal in the wire electrical discharge machining (WEDM) process, erosion behaviour of composites and many other engineering processes [3-6].

Experimentation

E-glass fibers (360 roving taken from Saint Gobian Ltd.) are reinforced in BFS filled Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol-A-Diglycidyl-Ether. The low temperature curing epoxy resin (LY 556) and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. The epoxy resin and the hardener are supplied by Ciba Geigy India Ltd. BFS collected from Rourkela Steel Plant is sieved to obtain particle size in the range 100 –110 micron. E-glass fiber and epoxy resin have modulus of 72.5 GPa and 3.42 GPa, respectively and possess density of 2590 kg/m3 and 1100 kg/m^3, respectively. The fiber loading (weight fraction of glass fiber in the composite) is kept at 40% for all the samples. Erosion tests are carried out in an Air Jet Erosion test rig as per ASTM G 76. The erodent velocity is determined using standard double disc method [2]. In the present study, dry alumina particles of four different size (50,100,200 and 300 micron) are used as erodent.

Taguchi Experimental Model

Taguchi's experimental design is a powerful analysis tool for modeling and analyzing the influence of control factors on performance output. The erosion wear tests on the composites are carried out under different operating conditions considering five parameters, viz., impact velocity, erodent size, erodent temperature, impingement angle and filler content each at four levels as listed in Table 1 in accordance with Taguchi's L_{16} (4^5) orthogonal array. The impacts of these five parameters are studied using this L_{16} array and the tests are conducted as per the experimental design. The experimental observations are further transformed into signal-to-noise (S/N) ratios. The S/N ratio for minimum wear rate can be expressed as ''smaller is better" characteristic and is calculated as follows

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

Where 'n' the number of observations, and y the observed data.

In conventional full factorial experimental design, it would require 4^5 = 1024 runs to study five factors each at four levels whereas, Taguchi's factorial design approach reduces it to only 16 runs offering a great advantage in terms of experimental time, cost.

Experimental Results and Discussion

Mechanical Characterization

In this study, the hardness values of the composites with different BFS content are found to be improving. The hardness values of the glass-epoxy composites improves from 54.37 Hv to

91.45 Hv with BFS content increasing from 0 wt% to 30 wt%. Marginal change in tensile and flexural strength of the composites with the addition of BFS is noticed.

Table 1 Control factors and their selected levels

Control Factor	**Level**				
	1	**2**	**3**	**4**	**units**
A: Impact Velocity	32	40	48	56	m/sec
B: Impingement Angle	30	45	60	90	degree
C: BFS content	0	10	20	30	wt %
D: Erodent Size	50	100	200	300	micron
E: Erodent temperature	30	40	50	60	^{0}C

Erosion Test Results

The specific wear rates obtained for all the 16 test runs along with the corresponding S/N ratio are presented in Table 2. From this table, the overall mean for the S/N ratio of the wear rate is found to be -48.1494 dB. This is done using the software MINITAB 14 specifically used for design of experiment applications. The S/N ratio response analysis shows that among all the factors, blast furnace slag content is the most significant factor followed by the impact velocity while others has relatively less significance on wear rate of the particulate filled composites under this investigation. The effects of individual control factor are assessed by calculating the response and the results of response analysis lead to the conclusion that factor combination of A_1, B_2, C_4, D_3 and E_3 gives the minimum wear rate shown in Fig. 1.

Table 2 Experimental design (L16) with output and signal-to-noise ratio

Test Run	Impact Velocity (A) m/sec	Impingement angle (B) degree	BFS content (C) wt %	Erodent Size (D) micron	Erodent temperature (E) ^{0}C	Erosion rate (Er) mg/kg	Signal-to-noise Ratio (db)
1	32	30	0	50	30	363.123	-51.2011
2	32	45	10	100	40	211.935	-46.5241
3	32	60	20	200	50	139.669	-42.9020
4	32	90	30	300	60	160.504	-44.1097
5	40	30	10	200	60	310.000	-49.8272
6	40	45	0	300	50	411.230	-52.2817
7	40	60	30	50	40	319.354	-50.0854
8	40	90	20	100	30	306.450	-49.7272
9	48	30	20	300	40	230.000	-47.2346
10	48	45	30	200	30	163.330	-44.2613
11	48	60	0	100	60	423.345	-52.5339
12	48	90	10	50	50	283.343	-49.0462
13	56	30	30	100	50	180.667	-45.1376
14	56	45	20	50	60	193.394	-45.7289
15	56	60	10	300	30	223.272	-46.9767
16	56	90	0	200	40	437.178	-52.8132

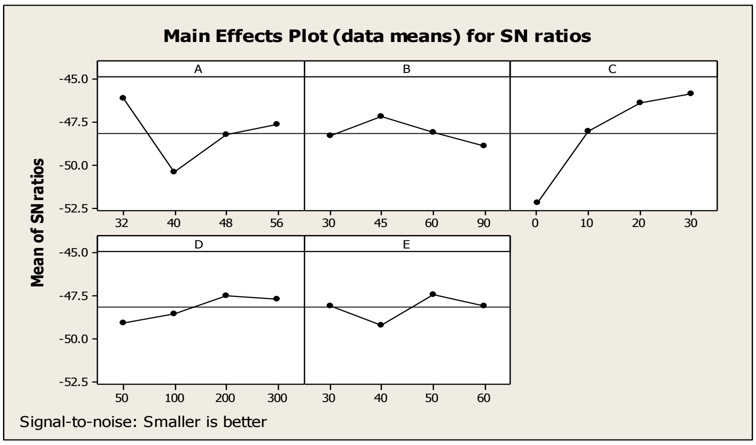

Figure 1 Main effects plot for S/N ratios

Table 2 Response table for minium erosion rate

Level	A	B	C	D	E
1	-46.18	-48.35	-52.21	-49.02	-48.04
2	-50.48	-47.20	-48.09	-48.48	-49.16
3	-48.27	-48.12	-46.40	-47.45	-47.34
4	-47.66	-48.92	-45.90	-47.65	-48.05
Delta	**4.30**	**1.73**	**6.31**	**1.56**	**1.82**
Rank	**2**	**4**	**1**	**5**	**3**

The response table for signal to noise ratio with smaller-is-better characteristic is given in Table 3. This table shows the delta value of the factors and according to that the factors are ranked. This also shows that the BFS content is the most influencing factor followed by impact velocity.

Conclusions

This analytical and experimental investigation leads to the conclusions that hybrid composites suitable for applications in highly erosive environments can be prepared by reinforcement of glass fibers and filling of micro-sized blast furnace slag particles in epoxy resin. The erosion wear performance of these composites improves quite significantly by addition of BFS. Erosion characteristics of these composites can be successfully analyzed using Taguchi experimental design scheme. Taguchi method provides a simple, systematic and efficient methodology for the optimization of the control factors. Factors like BFS content, impact velocity, erodent temperature, impingement angle in declining sequence are significant to minimize the erosion rate. The size of the erodent is identified as the least significant control factor affecting the erosion rate of such polymer composites.

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