Parametric Evaluation of Erosion Response of Epoxy Resin Filled with Blast Furnace Slag Using Taguchi Technique

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Abstract

Blast furnace slag (BFS) is a major industrial waste generated in huge quantities during the extraction of iron from its ores in the blast furnace. Its potential as a filler material in polymeric matrices has not yet been reported and in view of this, the present work is undertaken to explore the possibility of making a class of erosion resistant polymer composites with the slag particles as the filler. Composites of four different compositions (with 0, 10, 20 and 30 wt% of BFS reinforced in epoxy resin) are prepared. Solid particle erosion wear trials are conducted following a well planned experimental schedule based on Taguchi's design of experiments (DOE). Significant control factors predominantly influencing the wear rate are identified. This work shows that blast furnace slag possesses good filler characteristics as it improves the erosion wear resistance of the polymeric resin. Factors like filler content, impact velocity and impingement angle are the significant factors affecting the erosion wear rate. It is further seen that the use of Taguchi model with the prescribed design strategy is quite effective for the parametric appraisal of the wear process within a well defined experimental domain.

Key words: Polymer composites, Epoxy; Blast Furnace Slag, Erosion, Taguchi Method

Introduction

It has been observed that by incorporating hard filler particles into polymer based composites, synergistic effects may be achieved in the form of higher modulus and reduced material cost [1–3]. The inclusion of such particulate fillers into polymers for commercial applications is primarily aimed at the cost reduction and stiffness improvement [4, 5]. Available references suggest a large number of materials being used as fillers in polymers [6–9]. Various kinds of polymers and polymer–matrix composites reinforced with metal particles have a wide range of industrial applications such as heaters, electrodes [10], composites with thermal durability at high temperature [11], etc. Ceramic filled polymer composites have also been the subject of extensive research in recent years and consequently, a number of reports are available on the use of ceramics such as Al_2O_3, SiC etc. as particulate fillers [12– 15]. But the potential of industrial wastes such as blast furnace slag (BFS) as a filler material in polymer matrix has not been reported so far. Against this backdrop, this work investigates and analyses the erosion wear response of epoxy composites filled with micro-sized blast furnace slag particles using Taguchi's experimental design strategy.

Experimentation

Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material for fabrication of composite. Its common name is Bisphenol-A-Diglycidyl-Ether. This 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. Epoxy resin has modulus of 3.42 GPa, and possess density of 1100 kg/m^3.The BFS loading (weight fraction of BFS in the composite) in the epoxy resin is varied from 0 to 30 wt% of samples. Erosion tests are carried out using an Air Jet Erosion test rig as per ASTM G 76. The erodent velocity is determined using standard double disc method. 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

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

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

The erosion 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 -34.6132 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, impact velocity is the most significant factor followed by the BFS content while others have 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_3, C_4, D_1 and E_4 gives the minimum wear rate shown in Fig. 1.

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

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	25.768	-28.2216
2	32	45	10	100	40	19.356	-25.7363
3	32	60	20	200	50	14.876	-23.4497
4	32	90	30	300	60	13.112	-22.3534
5	40	30	10	200	60	38.016	-31.5993
6	40	45	0	300	50	82.154	-38.2926
7	40	60	30	50	40	31.564	-29.9838
8	40	90	20	100	30	51.381	-34.2161
9	48	30	20	300	40	91.182	-39.1982
10	48	45	30	200	30	80.990	-38.1686
11	48	60	0	100	60	115.625	-41.2610
12	48	90	10	50	50	97.546	-39.7842
13	56	30	30	100	50	74.193	-37.4073
14	56	45	20	50	60	87.898	-38.8796
15	56	60	10	300	30	117.543	-41.4039
16	56	90	0	200	40	156.021	-43.8637

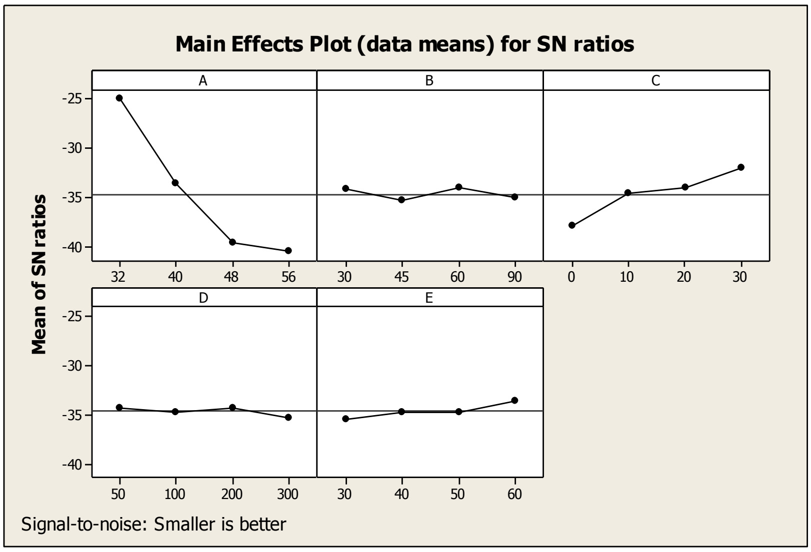

Figure 1 Main effects plot for S/N ratios

Table 3 Response table for minium erosion rate

Level	A	B	C	D	E
1	−24.94	-34.11	-37.91	-34.22	-35.50
2	-33.52	-35.27	-34.63	-34.66	-34.70
3	-39.60	-34.02	-33.94	-34.27	-34.73
4	-40.39	-35.05	-31.98	-35.31	-33.52
Delta	**15.45**	**1.24**	**5.93**	**1.09**	**1.98**
Rank	**1**	**4**	**2**	**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 erodent velocity is the most influencing factor followed by BFS content.

Conclusions

This analytical and experimental investigation leads to the conclusions that polymer composites suitable for engineering components to be used in highly erosive environments can be successfully prepared by 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. Factors like impact velocity, BFS content, 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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