Tribo Performance Analysis of Polyester Composite Filled with Blast Furnace Slag

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Abstract— In the present work Blast Furnace Slag (BSF) filled polyester composite with filler content from zero to thirty weight percentage have been arranged in order to improve the erosion wear and mechanical properties of polyester. Erosion wear test was led utilizing Air Jet Erosion Test. Composites having zero, ten, twenty, and thirty weight percentage of BFS reinforced polyester are prepared inside the research facility by utilizing a self-designed mould. Each one of the tests was led according to given standard. It was discovered that wear and mechanical properties are increasing comprehensively when filler content increases. Micro-Hardness increases about four times for filler content 30 weight% with the neat polyester. The enrichment in these properties is identified with vigorous holding between the BFS and Polyester which could have happened due to arrangement of an interphase between the BFS and polyester-grid. Artificial Neural Network (ANN) and predictive methods give the erosion rate not more than 15% with the experimental one.

Key words: BFS, ANN, Erosion Wear

I. INTRODUCTION

System is frequently set apart by the materials and innovation that demonstrate human potential and mind. Cyclic work on the material was begun in stone period that made progression in the Copper, Iron, Steel, component and Alloy ages, as modernization in technique, dissolving came to pass for and science made all these viable to continue towards exploring huge amounts of valuable materials potential.

Composites are the material made from two or more amounts of essential materials with remarkable divergent properties, that on alteration made a material having through and through totally unique properties from unique constituents. Antiquated materials have only a couple of limited properties with respect to combination of specific modulus, specific strength and low density and so forth. These materials are utilized in building territories extending from house create usage to mechanical unit utilizations owing to leading particular quality, leading modulus, less density and enhanced quality [1]. Use of economical, simply possible fillers is henceforth helpful to upgrade the properties and to decrease the estimation of segments [2]. Little coarse fillers and moreover ceramic or metal bits are getting used right presently to refresh properties of polymers [3]. A couple of scholars [4-6] have addressed that the wear resistance of polymers are upgraded by the use of fillers.

II. MATERIALS & METHODS

A. Matrix Material (Polyester)

Unsaturated is phthalic polyester provided by Reliance India Ltd. is taken as the matrix materials. Polyester is a class of polymer which contains the ester functional group in their fundamental chain. The term unsaturated polyester resin is for the most part refer to the unsaturated (implies containing chemical double bonds) resins formed by the reaction of dibasic organic acids and polyhydric alcohols. Polyester resin is also called as thermosetting plastic, which infers the plastic sets at high temperatures. Polyester resin (density 1.35 gm/cc, elastic modulus 3.25 GPa, thermal conductivity around 0.26 W/m-K) are the most economic and broadly utilized resins system, particularly in the marine business. Their advantages include low viscosity, ease and quick cure time. Likewise, polyester resins have for quite some time been viewed as minimum harmful.

B. Filler Material (Blast Furnace Slag)

A variety of natural or synthetic solid particulates, both organic and inorganic is already being commercially used as reinforcing fillers in polymeric composites. While ceramic powders such as Alumina (Al_2O_3), Silicon Carbide (SiC) , Silica (SiO_2), Titania (TiO_2) etc. are widely used as conventional fillers, the use of industrial wastes for such purpose is hardly found. In view of this, in the present work one industrial waste such as Blast Furnace Slag (BFS), a waste product from pig iron production route, is chosen as particulate filler to be used in the composites. Chemical analysis suggests the presence of Oxides of Calcium (36.36%wt), Silicon (37.63%wt), Magnesium (10.25%wt), Aluminium (12.54%wt), Iron (0.45%wt) and Titania (0.79%wt) in blast furnace slag. The blast furnace slag is collected from blast furnace 4 site of Rourkela Steel Plant, an integrated unit of Steel Authority of India Limited located in the eastern part of India. The slag particles are dried, granulated and sieved to the particle size of 100-110 micron for utilization in composite fabrication.

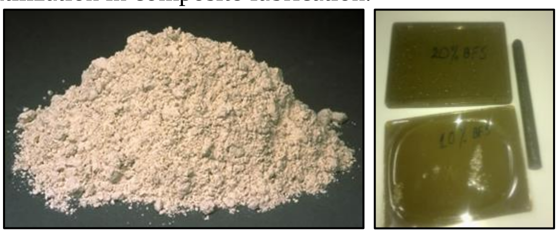

Fig. 2.1: Blast Furnace Slag & Composite Samples

C. Micro-Hardness

Micro-Hardness estimation of the composite material is made utilizing a Leitz Micro-Hardness Tester equipped with a screen and a microprocessor based controller. A diamond indenter, as an accurate pyramid with a square base is forced into the composite surface under a load F. The 2 diagonals X and Y of the indentation left on the surface of the material when load is removed are measured and their arithmetic mean L is observed within investigation, the load F = 0.493 N for a loading time of twenty seconds and Vickers hardness number is calculated utilizing the following equation:

$$H_V = 0.1889 \frac{F}{L^2} \quad (2.1)$$

Where, $L = (X + Y)/2$

Here, F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm). Around six to seven readings are taken for each example on various optically discernable focuses and the average value is accounted for as the mean hardness. It is then changed over and expressed as SI units (GPa).

III. RESULTS & DISCUSSION

This chapter reports the measured values of the physical properties and erosion wear characteristics of Polyester and Blast Furnace Slag (BFS) composites. Erosion wear characteristics have been explored following an arrangement of experiments based on the Taguchi procedure which is utilized to obtain the erosion test information. This section reports the wear rates got from these erosion preliminaries and presents a basic examination of the test outcomes. Further, erosion rate forecasts following an ANN approach for various test conditions are exhibited. A relationship among different control factors affecting the erosion rate has additionally been proposed for prescient reason. Conceivable wear mechanisms are recognized from the scanning electron microscopy of the eroded surfaces.

A. *Density & Void Fraction*

Density is a material property which is of prime significance in many weight delicate applications. Hence, in numerous such applications, polymer composites are found to replace ordinary metals and materials principally for their low densities. Higher void substance normally means less fatigue resistance. The data about the measure of void substance is for estimation of the nature of the composites. In the present research work, the measured and the theoretical densities of BFS filled polyester composites are accounted for alongside the relating volume portion of voids in Table 3.1. The distinction between the theoretical and measured density is a proportion of voids and pores present in the composites. It is seen that, by the expansion of BFS, the density of the composites progressively increments. It is evident that the density of BFS is higher than that of the polymers taken in this work. As the filler content in the composite increments from 0 to 30 wt %, the volume portion of voids is additionally found to increment proportionately. Comparable perceptions have been accounted for before by past specialists.

Filler Content (wt)	Theoretical Density (gm/cm)	Measured Density (gm/c^3)	Void Fraction (%)
0	1.35	1.35	-----
10	1.405	1.413	0.56
20	1.467	1.479	0.82
30	1.541	1.562	1.34

Table 3.1: Measured and Theoretical Densities along with the Void Fractions of the Composites

It is understandable that a good composite ought to have fewer voids. However, presence of void is unavoidable in composite making especially through hand lay-up route. The composites under the present examination possess very less voids (maximum ≈ 1.5%) and can thus be called as good composites.

B. *Micro-Hardness*

Micro-Hardness is taken into account as a standout amongst the foremost important variables that manage the wear and tear opposition of any material within the present work, micro hardness estimations of the polyester composites loaded up with BFS particles are calculated and also the check outcomes introduced in Figure 3.1. It is evident that with addition of BFS, micro hardness of the composites is increased.

The hardness is found to possess increased constantly for the composites with addition of BFS (0.287 GPa for 30 wt% and it is clear because the inherent hardness of BFS is above those of the resin materials. Micro hardness increases about 4 times for filler content 30 weight percentage.

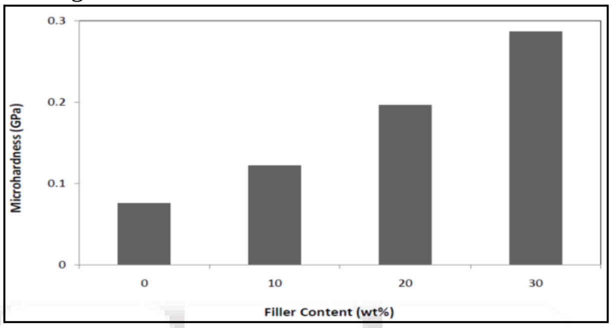

Fig. 3.1: Micro-Hardness of Blast Furnace Slag filled Composites

C. *Erosion Test Results & Taguchi Analysis*

Factor A denotes Impact Velocity (m/sec), Factor B denotes Impingement Angle (^{0}), Factor C denotes Erodent Size (μm), Factor D denotes Erodent Temperature (^{0}C), Factor E denotes BFS Content (wt%), ER denotes Erosion Rate (mg/kg), S/N Ratio denotes Signal to Noise Ratio (db)

The S/N ratio response analysis is presented in Table 3.2. This table shows the hierarchical order of the control factors as per their significance on the composite erosion rate. From fig. 3.2, it is clear that factor combination A1 (impact velocity), B3 (impingement angle), C3 (erodent size), D4 (erodent temperature) and E4 (BFS content) will give the minimum erosion rate.

Level	A	B	C	D	E
1	-24.14	-33.81	-33.91	-35.24	-37.69
2	-33.23	-34.98	-34.34	-34.36	-34.31
3	-39.46	-33.63	-33.89	-34.38	-33.57
4	-40.26	-34.67	-34.94	-33.11	-31.52
Delta	16.12	1.34	1.05	2.13	6.17
Rank	1	4	5	3	2

Table 3.2: S/N Ratio Response Table for Erosion rate of Polyester-BFS Composites

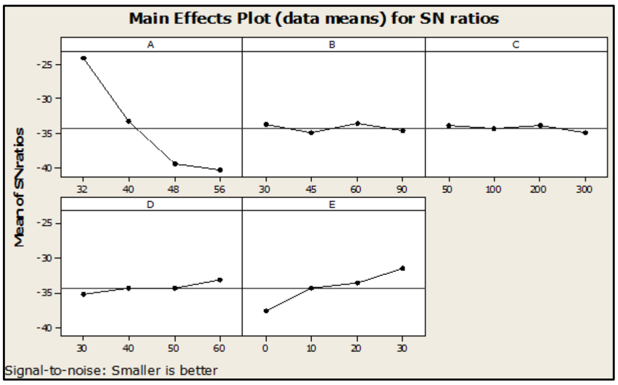

Fig. 3.2: Effect of Control Factors on Erosion Rate for Polyester-BFS Composites

D. Wear Rate Estimation using Predictive Equation

The solid particle erosion wear rate of the composite samples can also be determined using a nonlinear predictive equation showing the relationship between the erosion rate and combination of control factors. This correlation is developed statistically using standard software SYSTAT 7.In order to express the erosion rate in terms of a nonlinear regressive mathematical equation, the following form is suggested:

$$\text{Erosion Rate (ER)} = k_0 + k_1 \times A + k_2 \times B + k_3 \times C + k_4 \times D + k_5 \times E \quad (3.1)$$

Here, ER is the performance output term i.e. the Erosion Rate in mg/kg and ki (i = 0, 1, 2, 3, 4, 5) are the model constants.

A is the impact velocity (m/sec), B is the impingement angle (degree), C is the erodent size (micron), D is the erodent temperature (^{0}C) and E is the BFS content in the composite (wt%).

By using the software, the values of all of the constants are calculated and the final nonlinear regression expressions for the Polyester-BFS composite is obtained by the Equation 3.2.

$$\text{Erosion Rate (ER)} = - 105 + 3.97\,A + 0.346\,B + 0.0615\,C - 0.231\,D - 1.42\,E \quad (3.2)$$

The correctness of the calculated constants is confirmed because a very high correlation coefficients (r^2) of 0.949 and is obtained for Equation (3.2); therefore, the models are quite suitable for further analysis. A comparison between the wear rate obtained from experimental results and the predictive equation for composite combination are shown in Table 3.3, which indicates that the percentage errors associated with the predicted values with respect to the experimental ones vary in the range of 0 to 15 %.

Polyester-BFS		
ER Experimental	ER Predicted	% Error
24.268	25.565	5.34
17.856	20.32	13.80
13.376	14.15	5.79
11.612	12.17	4.81
36.516	38.42	5.21
80.654	76.27	5.44
30.064	27.795	7.55
49.881	55.76	11.79
89.682	76.75	14.42
79.49	69.9	12.06
114.13	98.61	13.59
96.046	94.025	2.10
72.693	79.7	9.64
86.398	93.705	8.46
116.04	125.4	8.06
154.52	151.52	1.94

Table 3.3: Comparison between Experimental and Predicted Values for Erosion Rate

E. ANN Based Prediction

Artificial neural network (ANN) is a technique that involves database preparing to predict input-output evolutions. In this attempt to simulate the erosion wear process and to predict the erosion rates of Polyester-BFS composites under different operating conditions, five input parameters (impact velocity, impingement angle, erodent size, erodent temperature and BFS content) are taken, each of which is characterized by one neuron in the input layer of the ANN structure. Different ANN structures with varying number of neurons in the hidden layer are tested at constant cycles, learning rate, error tolerance, momentum parameter, noise factor and slope parameter. Based on least error criterion, one structure, shown in Table 3.4 is selected for training of the input-output data for Polyester-BFS composite. The optimized three-layer neural network used in this simulation is shown in Figure 3.3. A software package NEURALNET for neural computing based on back propagation algorithm is used as the prediction tool for erosion wear rate of the composites under various test conditions.

Input Parameters for Training	Values
Error tolerance	0.001
Learning rate (β)	0.002
Momentum parameter (α)	0.002
Noise factor (NF)	0.001
Number of epochs	1,00,00,000
Slope parameter (£)	0.6
Number of hidden layer neurons (H)	11
Number of input layer neurons (I)	5
Number of output layer neurons (O)	1

Table 3.4: Input Parameters for Training

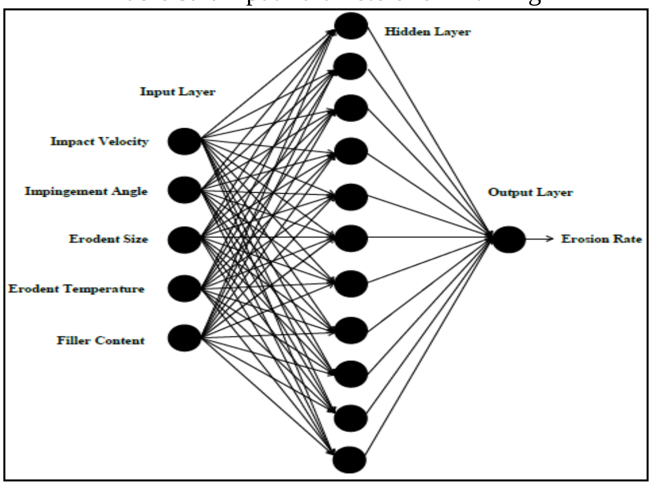

Fig. 3.3: Three Layer Neural Network

The ANN predictive results of erosion wear rate for all the 16 test conditions and for all the composite combinations are shown and compared with the experimental values along with the associated percentage errors in Table

3.5. It is observed that the errors lie in the range of 0-12%, which establishes the validity of the neural computation. The errors, however, can still be reduced and the quality of predictions can be further improved by enlarging the data sets and optimizing the construction of the neural network.

Polyester-BFS		
ER Experimental	ER Predicted	% Error
24.268	25.2804	4.17
17.856	18.74	4.95
13.376	14.9	11.39
11.612	10.523	9.38
36.516	34.2804	6.12
80.654	81.9863	1.65
30.064	29.4484	2.05
49.881	47.0475	5.68
89.682	80.0982	10.69
79.49	74.1969	6.66
114.13	102.1735	10.47
96.046	101.2564	5.42
72.693	75.8818	4.39
86.398	85.8715	0.61
116.04	127.8594	10.18
154.52	161.2646	4.36

Table 3.5: Percentage Error between Experimental Result and ANN Prediction

Figure 3.4 presents the comparison of the measured erosion rates with those obtained from the ANN prediction and from the proposed predictive equation for Polyester-BFS composite. While the errors associated with the ANN predictions lie in the range of 0-12%, the same for results obtained from the proposed correlation lie in the range of 0-15%. Thus it can be concluded that both ANN and the proposed correlation can be used for predictive purpose as far as the estimation of erosion wear rate of the composites under this investigation is concerned.

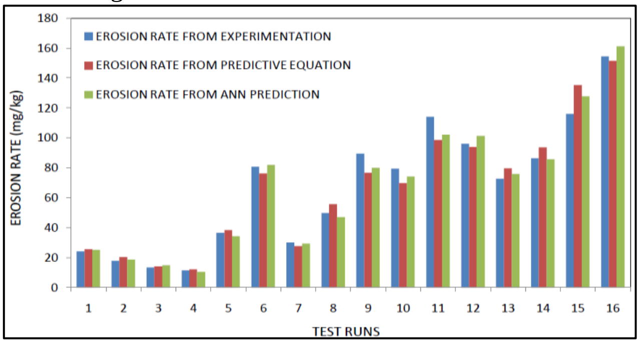

Fig. 3.4: Comparison of Erosion Rates Obtained from Different Methods

IV. CONCLUSIONS

This investigation on using BF Slag in wear resistant composites has led to the following specific conclusions:

1) Blast Furnace Slag (BFS) has adequate potential to be utilized as a practical filler in thermosetting polymers. It is proved that with addition of BFS, micro-hardness of the composites get improved.
2) The composites made using BFS possess very less voids (maximum ≈ 1.5%) and can be considered as good composites.
3) The hardness values found to have improved for the composites with addition of BFS (around 4 times).
4) Solid particle erosion wear characteristics of BFS filled polymer composites have been successfully analyzed using Taguchi technique. Significant factors affecting the erosion rate of these composites are identified through successful implementation of signal-to-noise response approach.
5) Two predictive models; one based on Artificial Neural Networks (ANN) approach and the other on Taguchi approach are proposed in this work. It is demonstrated that these models well reflect the effects of various factors on the wear loss and their predictive results are consistent with the experimental observations. Neural computation is successfully applied in this investigation to predict and simulate the wear response of these composites under various test conditions within and beyond the experimental domain.

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