Tribological Analysis Of TiO_2 Filled Polymer Matrix Composites

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Abstract - *In the present work TiO_2 filled epoxy composite with filler having wt. % from 0 to 20 were prepared to improve the erosion wear and mechanical properties of epoxy. Tensile strength and impact strength of composite will be determined experimentally. Erosion wear test was conducted by using Air Jet Erosion Test Rig. Composites having 0, 10, 20, and 30 weight fraction of TiO_2 filled epoxy. Composite have been prepared by using a self-designed mould. All the experiments were conducted as per ASTM standard. The result was found that as the amount of TiO_2 increases in the composite from 0 to 20 wt. % the wear resistance as well as mechanical properties of the composite increases. The enhancement in these properties is related to strong bonding between the TiO_2 and epoxy which might have happened due to formation of an interphase between the TiO_2 and epoxy-matrix. Study of SEM (scanned electron microscope) also carried out to know about the fracture behavior of the composite.*

Key Words: **TiO_2, Erosion Wear, SEM**

1. INTRODUCTION

Composites material are made of two or more materials which are dissimilar to each other , which on joining produced a material having different properties from original constituents. Composites materials may be a single phase or polyphase materials. Now a day's Composite materials are used in several engineering areas, like in space craft implementation to industrial unit consumptions due to leading specific strength, leading modulus, low density and improved durability [1]. In aircraft industries or in space craft where strong, feather, no corrodible and non-breakable materials are required, composites play important role in these areas.

The composite material are less in weight, their expensiveness is also limited. Some filler material is used to improve the properties and to minimize the cost of components [2]. Compact granulated fillers like ceramic or metal bits are being used to upgrade wear resistive properties of polymers [3]. Addition of such particulates into polymers helps to minimizing the price and enhancement of stiffness [4]. Many scholars [5-8] have described that inclusions of fillers will upgrade the abrading resistance of polymers.

2. EXPERIMENT DETAILS

2.1 Material used

Epoxy (LY 556) is used as a matrix material and micro-sized titanium dioxide (TiO_2) is used as the filler material. Composites sample were prepared by hand layup techniques.

Table 1: List of particulate filled composites fabricated by hand-lay-up technique

Sample	Composition (TiO_2 as filler material)
1	Epoxy + 0wt% TiO_2
2	Epoxy + 10wt% TiO_2
3	Epoxy + 20 wt% TiO_2
4	Epoxy + 30wt% TiO_2

2.2 Physical Characterization

(a) Density and Void Fraction : Theoretical density of composite materials is find by using Agarwal and Broutman formula [9].

$$\rho_{ct} = \frac{1}{\left(W_f / \rho_f\right) + \left(W_m / \rho_m\right)}$$

Where, W and ρ represent the weight fraction and density respectively. The suffix f, m and ct, stand for the fiber, matrix and the composite sample respectively.

The actual density (ρ_{ce}) of the composite is find experimentally by simple water immersion technique. The volume fraction of voids (Vv) in the composites is calculated using the following equation:

$$V_v = \frac{\rho_{ct} - \rho_{ce}}{\rho_{ct}}$$

(b) Scanning Electron Microscopy: The surface morphology of the particulate reinforced composites material with the fillers in the matrix body has been studied using a scanning electron microscope JEOL JSM-6480LV.

2.3 Micro-hardness

Micro-hardness of the composite specimens is done by using a Leitz Micro-hardness Tester. In the present study, the load considered F = 0.493 N for a loading time of 20 seconds and Vickers hardness number is calculated using the following equation:

$$H_V = 0.1889\frac{F}{L^2}, \qquad L = \frac{X+Y}{2}$$

Here, L is the diagonal of square impression (mm), F is the applied load (N), X is the horizontal length (mm) and Y is the vertical length (mm).

2.4 Erosion Wear Behaviour

Erosion wear test were carried out as per ASTM G 76 using an air jet type erosion test rig. In the present study, dry silica sand particles of different sizes (i.e. 50, 100, 150 and 200 µm) are used as erodent. Erosion test is carried out on each sample for a period of 10 minutes with different impact velocities (32, 40, 48 and 56 m/s) at different angles of impingement (30^0 to 90^0). Velocity of impact is measured using the standard double disc method. After the test, samples are weighed again to determine the weight loss due to the impact of dry silica sand particles in order to find the erosion wear rate in every single test run. The erosion rate is defined as the weight loss of the specimen due to erosion divided by the weight of the erodent causing the loss.

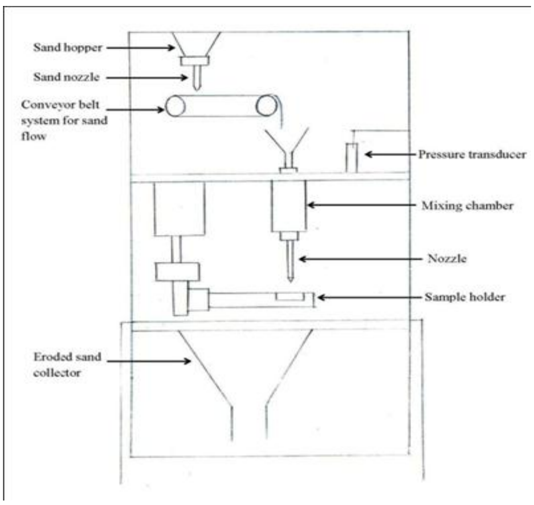


Fig. 1(a) : Schematic diagram of erosion test rig

Fig. 1(b): Solid particle erosion test set-up

2.5 We used Taguchi Method to determine the erosion rate of Composite material. In the present work, L_{16} orthogonal arrays are taken for the erosion wear experiments of composite samples.

2.6 Artificial Neural Network (ANN) is used for identifying several non-linear systems and control problems. This analysis combines Taguchi's design approach with the ANN for parametric analysis and prediction of wear performance of the composites.

3. RESULTS & DISCUSSIONS

3.1 Physical Characterization of the Composites

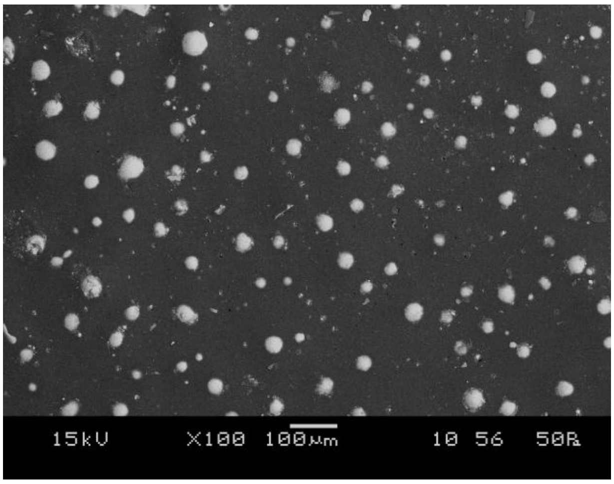
(a) Density and Void Fraction : The difference between the theoretical and measured density is a measure of voids and pores present in the composites. It is observed that, by the addition of TiO_2, density of the composites and volume fraction of voids increases.

Table 2: Measured and theoretical densities along with the void fractions of composites.

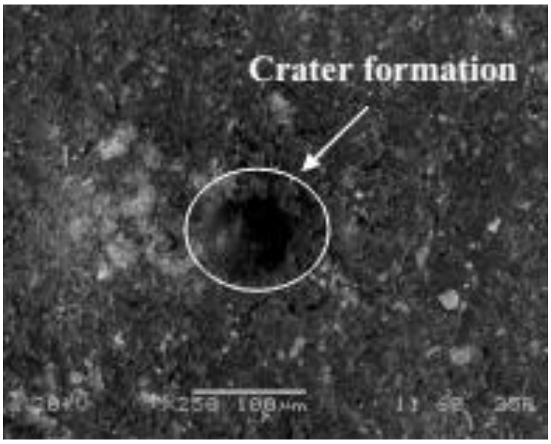
S. No.	Composition	Theoretical Density (gm/cm³)	Measured Density (gm/cm³)	Void Fraction (%)
1	EP + 0 wt% TiO_2	1.100	1.100	----
2	EP + 10 wt% TiO_2	1.161	1.155	0.51
3	EP + 20 wt% TiO_2	1.228	1.217	0.89
4	EP + 30 wt% TiO_2	1.310	1.291	1.45

3.2 Morphology of Composite Surfaces

Microstructures of the composites matrix were observed under scanning electron microscope. The surface of the composite before being subjected to solid particle erosion, shown in Figure 2(a), appears to be smooth with no wear grooves. Figures 2(b) is the SEM image of the eroded composite surface, which shows small craters and cracks due to impact of sand particles.



2(a)



2(b)

Fig. 2 : SEM micrographs of uneroded and eroded surfaces of the epoxy composites

3.3 Micro-hardness

It is seen from the experiment that with addition of TiO_2, micro-hardness of the composites is improved. The maximum hardness value is for EP reinforced with 30 wt% TiO_2 (0.441 GPa) and this value is about 5 times the hardness of neat EP.

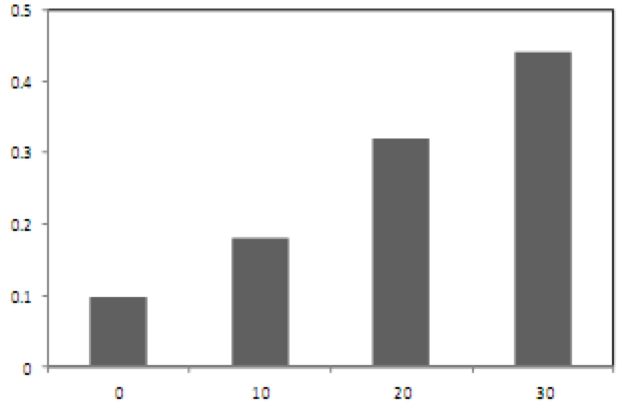


Fig. 3 : Micro-hardness of TiO_2 filled composites

3.4 Erosion Test Results and Taguchi Analysis

The erosion wear rates of TiO_2 filled epoxy composite obtained for all the 16 test runs along with the corresponding signal-to-noise ratio is presented in Table 3.

Table 3: Experimental design using L_{16} orthogonal array and wear test results for epoxy composite

Test run	A	B	C	D	E	EP- TiO_2	
						ER	S/N Ra
1	32	30	50	30	0	1.488	-3.452
2	32	45	100	60	10	1.493	-3.481
3	32	60	150	90	20	1.187	-1.489
4	32	90	200	120	30	1.003	-0.026
5	40	30	100	90	30	1.527	-3.676
6	40	45	50	120	20	1.554	-3.829
7	40	60	200	30	10	1.57	-3.917
8	40	90	150	60	0	1.622	-4.201
9	48	30	150	120	10	1.568	-3.906
10	48	45	200	90	0	1.615	-4.163
11	48	60	50	60	30	1.481	-3.411
12	48	90	100	30	20	1.524	-3.6591
13	56	30	200	60	20	1.631	-4.249
14	56	45	150	30	30	1.556	-3.840
15	56	60	100	120	0	1.647	-4.333
16	56	90	50	90	10	1.615	-4.163

Note : A denotes Impact Velocity (m/sec), B denotes Impingement Angle (^{0}), C denotes Erodent Size (μm), D denotes Erodent Temperature (^{0}C), E denotes TiO_2 Content

(wt%), ER denotes Erosion Rate (mg/kg), S/N Ratio denotes Signal to Noise Ratio (db).
From this table, the overall mean for the S/N ratio of the wear rate for epoxy composite is found to be -3.4755 db. This is done using the software MINITAB-1.

Table 4: S/N ratio response table for erosion rate of EP-TiO_2 composites

Level	A	B	C	D	E
1	-2.112	-3.821	-3.714	-3.717	-4.038
2	-3.906	-3.828	-3.788	-3.836	-3.867
3	-3.785	-3.288	-3.359	-3.373	-3.307
4	-4.147	-3.013	-3.089	-3.024	-2.739
Delta	2.035	0.816	0.699	0.812	1.299
Rank	1	3	5	4	2

The S/N ratio response analysis is presented in Table 4. This table shows the hierarchical order of the control factors as per their significance on the composite erosion rate.

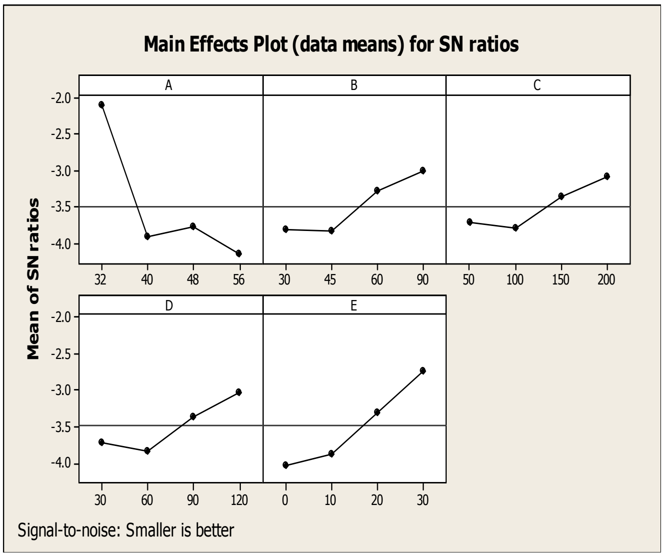


Fig. 4: Effect of control factors on erosion rate for EP- TiO_2 composites

Figure 6 illustrates the effect of control factors on erosion rate for EP- TiO_2 composite. Analysis of the results leads to the conclusion that factor combination of A1 (Impact velocity), B4 (Impingement angle), C4 (Erodent size), D4 (Erodent temperature) and E4 (TiO_2 content) gives minimum erosion rate (Figure 4.3) for EP- TiO_2 composites.

3.5 Wear Rate Estimation using Predictive Equation

Wear rate estimation is done by predictive equation which is developed by using standard software SYSTAT 7. Wear rate from experimental results and the predictive equation for composite combination indicates that the percentage errors vary in the range of 0 to 11 %.

Table 5: Comparison between experimental and predicted values for erosion rate

EP- TiO_2		
ER Experimental	ER Predicted	% Error
1.488	1.417	4.772
1.493	1.337	10.449
1.187	1.057	10.952
1.003	1.1	9.671
1.527	1.419	7.073
1.554	1.453	6.499
1.57	1.433	8.726
1.622	1.563	3.637
1.568	1.449	7.589
1.615	1.569	2.848
1.481	1.314	11.276
1.524	1.499	1.640
1.631	1.585	2.820
1.556	1.465	5.848
1.647	1.505	8.622
1.615	1.455	9.907

3.6 ANN Based Prediction

Table 6 is selected for training of the input-output data for EP-TiO_2 composite. A software package NEURALNET is used as the prediction tool for erosion wear rate of the composites under various test conditions.

Table 6 : Input parameters for training

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

It is observed (table 7) that the errors lie in the range of 0-10%. 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.

Table 7: Percentage error between experimental result and ANN prediction

EP- TiO_2		
ER Experimental	**ER Predicted**	**% Error**
1.488	1.351	9.207
1.493	1.365	8.573
1.187	1.164	1.938
1.003	0.97	3.290
1.527	1.462	4.257
1.554	1.472	5.277
1.57	1.49	5.096
1.622	1.524	6.042
1.568	1.41	10.077
1.615	1.597	1.115
1.481	1.41	4.794
1.524	1.49	2.231
1.631	1.528	6.315
1.556	1.485	4.563
1.647	1.494	9.290
1.615	1.536	4.892

ANN method is used for the analysis of erosion wear and wear rate of composites. The errors associated with the ANN predictions lie in the range of 0-10%, the same for results obtained from the proposed correlation lie in the range of 0-11%. Thus it can be concluded that both ANN and the proposed correlation can be used for predictive purpose.

4. CONCLUSIONS

This investigation on using glass micro-spheres in wear resistant composites has shows following specific conclusions:

1. TiO_2 possesses ample reinforcing potential to be used as functional filler in thermoset polymers. Successful fabrication of epoxy composites reinforced with TiO_2 is possible by simple hand-lay-up technique.
2. These TiO_2 filled composites possess very low amount of porosity (maximum ≈ 2%) and improved micro-hardness with improved hardness, these composites have the potential to be used in wear related applications.
3. In the present work, it can be concluded that for all types of epoxy based composites, among all the factors, impact velocity is the most significant factor as far as the erosion wear rate is concerned.
4. Two predictive models; Artificial neural networks (ANN) and the other is Taguchi approach are used in this work. These models show effects of various factors on the wear loss and their predictive results.

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