STUDY ON EROSION WEAR PERFORMANCE OF JUTE-EPOXY COMPOSITES FILLED WITH INDUSTRIAL WASTES USING TAGUCHI METHODOLOGY

[1]ARUN KUMAR ROUT, [2]SUCHARITA SANGHAMITRA SAHOO

[1]School of Mechanical Engineering, KIIT University, Bhubaneswar, India-751024
E-mail: arun.rout.6314@gmail.com, sahoo.sucharita56@gmail.com

Abstract- Erosion wear process is considered as a complex non-linear problem due to its operating variables. The wear process depends on various parameters such as impact velocity, impingement angle, material, erodent size, etc. In order to obtain minimum erosion rate, experiments are to be conducted on the material with the combination of these parameters. In the present work, waste granite powder is used as filler in the jute fiber reinforced epoxy composite. Four different weight proportions of granite (0, 5, 10 and 15wt %) are used to fabricate four different composites. It is observed that granite filled samples have shown better erosion resistance than unfilled ones.

Keywords- Epoxy, Erosion wear, Jute, Taguchi method

I. INTRODUCTION

In recent times, natural fiber reinforced polymer composites has grown considerably in popularity due to their abundance, light weight, low cost, renewability, high specific modulus and biodegradability. It is postulated that composites formed by reinforcing natural fibers in polymer matrices can be tailored to produce lightweight, low cost, non hazardous and resilient materials. For example, due to the excellent mechanical properties of jute, it is a promising material for producing a strong and cost-effective composite.

In spite of several advantages, natural fibers have some limitations like high moisture absorption, high resin consumption and high shrinkage and swelling stress, which leads to surface cracking and debonding between resin and fiber. Since the interfacial bond between the fiber and resin matrix is an important element to improve mechanical and tribological properties of the composite, several chemical treatment methods such as acetylation, bleaching and alkali treatment has been implemented by various researchers.

Karmakar have used maleic anhydride grafted polypropylene (MAPP) as a coupling agent to improve the interfacial adhesion of jute fiber with polypropylene matrix. Ray et al. treated jute fiber with NaOH solution for 2h, 4h, 6h and 8h and found that 4h treated jute fiber reinforced vinyl ester composites have shown maximum flexural and impact strength as compare to others.

These chemical treatments are the process of removing surface impurities and OH-groups (as shown in Eq.1) so as to improve the interfacial adhesion and hydrophobic characteristics of the fiber.

$$OH + NaOH \rightarrow O^{-}Na^{+} + H_2O + impurities$$

As far as wear in natural fiber is concern, very limited work has been reported. In spite of several advantages over synthetic fibers, tribological aspects of natural fibers are still as a less researched area. The sliding wear properties of the natural fiber reinforced composites have been studied by some investigators. Different trends of specific wear rate and coefficient of friction have been analyzed under various experimental conditions. In some cases such as polyester, cotton/polyester and oil palm/polyester, specific wear rate has initially increased and then attains a steady state. At the same time, friction coefficients do not have a similar trend with specific wear rate. Coir/polyester, sisal/polyester, betel nut/polyester and bamboo/epoxy composites has shown a decreasing trend of specific wear rate to achieve steady state, whereas friction coefficient have not shown any trend in case of betel nut/polyester composites, and an increasing trend is observed for coir/polyester, sisal/polyester and bamboo/epoxy composites. Like sliding wear, very limited numbers of reports are available on erosion wear process of natural fiber reinforced composites. It is due to the complexity and non linear correlation between input parameters such as impact velocity, erodent size, standoff distance, impingement angle, etc. to the output i.e. erosion rate. Though some amount of work have been studied on erosion wear of natural fiber reinforced composites, but, there is no such report available on erosion wear study of granite powder filled treated jute fiber reinforced epoxy composites.

Against this background the present work is undertaken to study the influence of granite filled jute fiber reinforced epoxy composites on the erosion wear and to establish neural computation as an effective tool to predict the wear response of such composites. Experiments have been conducted as per the design of experiment approach to establish the optimum parameter settings for minimum erosion rate.

II. EXPERIMENTAL DETAILS

Materials and methods

The low temperature curing epoxy resin (LY 556) and the corresponding hardener (HY 951) was mixed in a ratio of 10:1 by weight as recommended. Granite powder was collected from granite stone crushers. Jute fibers in the form of Hessian cloths were collected from Eastern Jute Industries, Kolkata, India. The granite powder was treated with 5% (w/w) NaOH solution for 24h and washed with distilled water for removal of excess alkali. It was then filtered and the treated granite obtained was dried in hot air oven for 2h at the temperature of 110^0C before using as filler in the composite. Similarly, the jute fiber (Hessian clothes) mats were treated with 5% (w/w) NaOH for 4h and then washed with distilled water for removal of excess alkali. The washed jute fibers were then dried in hot air oven for removal of moisture before composite fabrication.

Fabrication of composite

Four different composites were prepared with the treated jute fibers by varying the filler content (0, 5, 10 and 15wt %) as C1, C2, C3 and C4 respectively as shown in Table 1. All the composites are prepared by using simple hand-lay-up technique followed by light compression molding. At the beginning of fabrication, gelcoat with 2% (w/w) is uniformly brushed into the male and female parts of the mold. After curing of the gelcoat each layer of jute fiber mat was pre-impregnated with resin matrix and placed one over another as a sandwich making system. Then the mould was subjected to hot press (5 tons) for 1h at a temperature of 110^0C. The cast was then post cured in ambient air for another 24h. Specimens of suitable dimensions were cut in a diamond cutter for erosion wear test.

Table1.Detailed designation and composition of composite samples

Designation	Composition
C1	Epoxy (70 wt %) + Jute (30 wt %) + Granite powder (0 wt %)
C2	Epoxy (65 wt %) + Jute (30 wt %) + Granite powder (5 wt %)
C3	Epoxy (60 wt %) + Jute (30 wt %) + Granite powder (10 wt %)
C4	Epoxy (55 wt %) + Jute (30 wt %) + Granite powder (15 wt %)

Erosion wear test

Erosion wear tests were conducted as per ASTM G76 standard using an air jet erosion test rig as shown in Fig.1. It consists of five basic units such as filter-regulator unit, erodent hopper, air-erodent mixing chamber, testing chamber and erodent collector unit. Initially the air from compressor flow through the filter-regulator unit. At the same time, erodent (alumina powder) is filled in the hopper. After moving through the mixing chamber, the air-erodent mixture passes through a converging nozzle so as to get the required velocity. Then high velocity erodent particles strike on to the specimen placed in a specimen holder. Specimens can be placed in angular positions (0^0, 15^0, 30^0, 60^0, 75^0 and 90^0) before the nozzle by means of a specimen holder. After impact, erodent is collected in the collection chamber and weighed for calculation of erosion rate of the samples. In the present work, four different sizes of erodent were used such as 50μm, 90 μm, 100μm and 120μm. The samples were cleaned with acetone, dried and weighed to an accuracy of ±0. 1mg before and after the erosion test. The weight loss was recorded for subsequent calculation of erosion rate. The total process was repeated at least three times for attaining a steady state erosion rate.

Experimental design

Design of experiment methodology is a simple, efficient and systematic approach to optimize performance, quality and cost. In the present work, effects of four factors such as impact velocity, filler content, impingement angle and erodent size with each at four levels are studied on the erosion rate are described in Table 2. In order to identify the significant factors, 4^4=256 number of experiments is required to study in a conventional full factorial design where as in Taguchi design of experiment only 16 numbers of experiments are required. Thus offering a greater advantage with respect to cost and time of experiment. The experimental observations (erosion rate) are transformed into signal-to-noise (S/N) ratios for better analysis of the problem. The S/N ratio for the minimum erosion rate is coming under "Lower is better" (LB) characteristics and the logarithmic transformation of loss function is shown below as:

$$\frac{S}{N} = -10\log_{10}\left[\frac{1}{n}\left(\Sigma y^2\right)\right] \qquad (2)$$

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

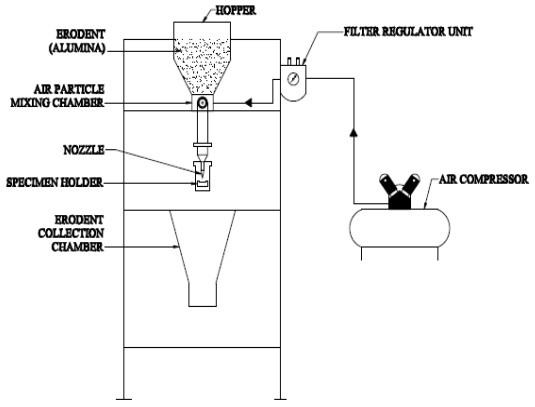


Fig. 1. Schematic diagram of erosion test rig

The tests were carried out as per experimental design shown in Table 3, in which each column represents a test parameter, and a row stands for a test condition (combination of parameter levels). The plan of experiment was: the second column was assigned to impact velocity (A), the third column to filler content (B), the fourth column to impingement angle (C), the fifth column to erodent size (D) to estimate the erosion wear rate (E_r).

Table 2. Levels of the control factors (variables) used in the experiment

Control Factor	Level				
	I	II	III	IV	Units
A:Velocity of impact	40	50	60	70	m/sec
B: Filler content	0	5	10	15	wt%
C:Impingement angle	30	45	60	90	degree
D: Erodent size	50	90	100	120	Mm

Table 3. Experimental design (L_{16} orthogonal array) with output and S/N ratio

Test run	A:Impact velocity	B:Filler content	C:Impingement angle	D:Erodent size	E_r:Erosion wear rate	S/N Ratio
	(m/s)	(wt)	(degree)	(μm)	(mg/kg)	(dB)
1	40	0	30	50	303.84	-49.65
2	40	5	45	90	223.35	-46.97
3	40	10	60	100	223.95	-47.00
4	40	15	90	120	214.53	-46.62
5	50	0	45	100	343.63	-50.72
6	50	5	30	120	265.25	-48.47
7	50	10	90	50	314.32	-49.94
8	50	15	60	90	316.11	-49.99
9	60	0	60	120	466.52	-53.37
10	60	5	90	100	421.74	-52.50
11	60	10	30	90	311.87	-49.87
12	60	15	45	50	391.13	-51.84
13	70	0	90	90	532.53	-54.52
14	70	5	60	50	525.85	-54.41
15	70	10	45	120	368.94	-51.33
16	70	15	30	100	416.73	-52.39

III. RESULTS AND DISCUSSION

Wear analysis using experimental design

The erosion rate obtained for all 16 test runs along with the corresponding S/N ratio are presented in Table 3. The overall mean for the S/N ratio of the wear rate is found to be -50.6056 dB. The analysis is carried out with the help of software MINITAB 16. The S/N ratio response analysis is presented in Table 4 which shows that among all the factors, impact velocity is the most significant factor, followed by filler content in the composite and then the erodent size. Impingement angle has least effect on erosion rate of granite filled jute-epoxy composites.

The effect of individual control factor is shown in Fig. 2. The analysis of the results leads to the conclusion that factor combinations of A_1 (impact velocity: 40m/s), B_3 (filler content: 10wt %), D_4 (erodent size: 120μm) and C_1 (impingement angle: 30^0) gives a minimum erosion rate. Table 5. represents the experimental values of erosion wear rate with the percentage error.

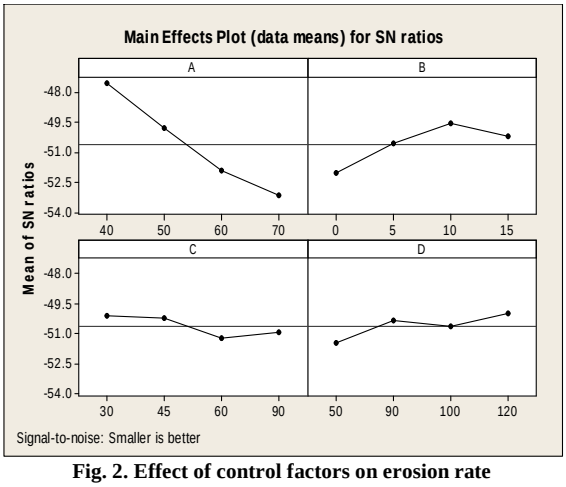


Fig. 2. Effect of control factors on erosion rate

Table 4. Signal to noise ratio response table for erosion rate

Level	A	B	C	D
1	-47.57	-52.07	-50.10	-51.47
2	-49.78	-50.59	-50.22	-50.35
3	-51.90	-49.54	-51.20	-50.66

4	-53.17	-50.22	-50.90	-49.95
Delta	5.60	2.53	1.10	1.51
Rank	1	2	4	3

Confirmation experiment

The confirmation experiment is the final test in the design of experiment process. The objective of the confirmation experiment is to validate the conclusions drawn during the analysis phase.

The confirmation experiment was performed by conducting a new set of factor settings $A_2B_3C_2D_3$ to predict the erosion wear rate. A prediction equation can be formulated using Taguchi's approach to estimate S/N ratio for erosion rate as.

$$\bar{\eta}_1 = \bar{T} + (\bar{A}_2 - \bar{T}) + (\bar{B}_3 - \bar{T}) + (\bar{C}_2 - \bar{T}) + (\bar{D}_3 - \bar{T}) \quad (3)$$

Where $\bar{\eta}_1$ is predicted average; $\bar{T}$ is overall experimental average; and $\bar{A}_3, \bar{B}_2, \bar{C}_3$ *and* $\bar{D}_3$ are the mean responses for factors at designated levels. By combining like terms, the equation reduces to:

$$\bar{\eta}_1 = \bar{A}_2 + \bar{B}_3 + \bar{C}_2 + \bar{D}_3 - 3\bar{T} \quad (4)$$

The new arbitrary combination of factor levels A_3, B_2, C_3 and D_3 is used to predict the wear rate through prediction equation (Eq. 4) and the $\bar{\eta}_1$ is found to be -48.403 dB.

An experiment was conducted under factor combination of A_3, B_2, C_3 and D_3 and the result has been compared with the value obtained from predictive equation as shown in Table 5.

The resulting model seems to be capable of predicting erosion wear rate to a reasonable accuracy. An error of 2.15 % for S/N ratio of erosion wear rate is observed. This validates the development of the mathematical model for predicting the measures of performance based on knowledge of the input parameters.

Table 5 Results of the confirmation experiments for erosion wear rate

	Optimal control parameters		Error (%)
	Prediction	Experimental	
Level	$A_2B_3C_2D_3$	$A_2B_3C_2D_3$	2.15
Erosion wear rate (mg/kg)	-48.403	-49.471	

CONCLUSION

Based on the present work, following conclusions are drawn:

(1) An industrial waste like granite powder can be utilized to produce low cost natural fiber composites.

(2) Chemical treatment of both filler and jute fiber has enhanced the erosion resistance of the composite samples.

.(3) Erosion wear characteristics of the composites can be successfully analyzed using Taguchi design of experiment. The study reveals that impact velocity, filler content and impingement angle are found to be the significant control factors affecting erosion rate.

(4) Erosion resistance of the developed composites is increasing with filler content and C_4 (15 wt% granite powder) composite has shown least erosion rate than others.

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