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Experimental Investigation of Slurry Erosion Wear Analysis of Epoxy Resin Reinforced with Aramid Woven Fabric with Taguchi Experimental Design

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Abstract: Fibre reinforced polymer composites as hybrid composites are commonly used for certain applications in which erosion wear and fracture are serious issues. These composites have engineering/structural applications in which they are subjected to sand slurries and dusty environment. Composites with different fibre loading are used to evaluate steady state erosion behavior for different operating conditions on slurry jet erosion testing machine. In this chapter Slurry jet erosion test rig is used for experimental investigation of steady state erosion rate of aramid composite samples as per ASTM standards. Steady state erosion test is conducted by defining certain control factors and fixed parameters. Test is conducted in two cases. In first case by varying impact angle and keeping impact velocity and discharge rate constant and in second case by varying impact velocity and keeping impact angle and discharge rate constant. Steady state erosion rate is calculated for both the cases. The Taguchi experimental design (orthogonal array) is used to optimize the design parameters and used to analyse the effect of control factors on output parameters, which reduces overall testing time and cost. To understand the effect of control factors and their iterations ANOVA (analysis of variance) is used. Results of steady state erosion rate and Taguchi experimental design are analysed to selection best suitable material for turbine blade application based on minimum erosion rate

Keywords: Aramid fibre, Polymer composite, Erosion wear, ANOVA, Taguchi, Steady State Erosion

I. INTRODUCTION

Solid particle erosion can be of two types one is constructive and second one is destructive. Constructive erosion is desired loss material whereas destructive erosion is undesired loss of material. Sand blasting, high-speed water-jet cutting, erosive drilling of hard materials are some recent applications of constructive erosion whereas erosion of machine parts, erosion of pipelines carrying slurries, surface degradation of steam turbine blades are some industrial applications of destructive type. Polymers and their composites are widely used in structural as well as some engineering applications have to come in contact with erosive environment [16] [17]. These composites havefurther applications such as in petroleum refining pipe line carrying sand slurries, pump impeller blades, high speed vehicles, aircraft operating in desert environment, helicopter rotorblades, aircraft engine blades, water turbines subjected to solid particle erosion [1] [2].Patnaik and Satapathy investigated the solid particle erosion of fly ash filled glass fibre reinforced polyester composites using Taguchi experimental design, in which factors like fly ash content, impingement angle, erodent size and impact velocity in order of priority are significant to minimize the erosion rate [3][10]. Filler loading, grit size and filler type are the most significant factors in controlling the specific wear rate of the carbon-epoxy composite asinvestigated by Ramesh and Suresh [4] [11]. Erosion wear rate of glass fibre reinforced vinylester composites increased (up to 6 times higher weight loss) as the erodent concentration of the slurry and total kinetic energy of the erodent particle is increased [5]. Inone of the recent paper M.J. Pawar and Patnaik have evaluated slurry jet erosion wear behaviour of unfilled and granite powder filled jute epoxy composite and have investigated that with the addition of granite powder (0 to 8 wt%) as filler, slurry erosion rate is reducesby 32%. But this reduction% is decreases to 20% as the filler content increases from 8 to 16 wt% and again increases to 25% reduction in erosion rate when filler content is in between 16 to 24 wt % [6] [12].

Against this background, the present research work has been undertaken to investigate the new class of synthetic organic (aramid) fibre reinforced polymer composite. The main emphasis has been on the fabrication of a number of aramid fibre reinforced epoxy composites, assessment of their erosion behavior using steady state erosion wear.

II. EXPERIMENTAL DETAILS

A. Slurry Jet Erosion Test of Composite

As per ASTM standard -73, slurry jet erosion test is conducted using slurry jet erosion tribometer as shown in Fig. 1. The test setup is consisting of a mixing chamber to make homogeneous mixture of water and sand particles, a nozzle valve of 3 mm inner diameter, a specimen holder plate to maintain different angles between samples and slurry jet direction. The velocity of jet changes from 10 m/s to 50 m/s. The test setup is having a 50 mm stand-offdistance (SOD) between sample and nozzle tip. The impingement angles are marked over the sample plate starting from 30° to 90° with an interval of 15°. Weights of the samplesprepared are taken using an analytical weighing machine with least count of 0.01 mg. For erosion test samples are prepared of dimensions 25 mm×25 mm from composite plate. The slurry jet erosion rate is obtained by calculating total mass loss of the sample. Total mass lossis the difference of weight taken before and after erosion test. In this study silica sand is takenas erodent of size 300 µm.

Fig.1. Slurry jet erosion testing machine

The slurry erosion rate is influenced by the number of control factors like impact velocity, impingement angle, fibre loading, erodent size, slurry concentration, stand-off distance, flow rate respectively [7][13].

Table 1. Operating conditions for slurry erosion test

Control Factors	Symbols	Fixed Parameters
Fibre/Filler Content	Factor A	Erodent as silica sand
Impact Velocity	Factor B	Nozzle diameter as 3 mm
Impingement angle	Factor C	Length of nozzle as 80 mm
Erodent discharge rate	Factor D	Erodent size as 300 µm

Table 2. Control factors and levels

Control Factors	Level				Units
	I	II	III	IV	
A1: Fibre loadingA2: Filler content	20	30	40	50	wt%
	0	5	10	15	wt%
B: Impact velocity	27	32	37	42	m/s
C: Impingement angle	30	45	60	75	°C
D: Erodent discharge rate	160	300	440	580	gm/min

B. Experimental Design using Taguchi Method

The Taguchi experimental design (orthogonal array) is used to optimize the design parameters and used to analyse the effect of control factors on output parameters, which reduces overall testing time and cost. It is a simple, systematic and efficient technique for optimization of control factors. Taguchi defines two types of variables; one is controlled variables known as signal or control factors and variables that are not under control known as noise. The objective of this experiment is to determine highest possible value of signal to noise ratio (S/N), that implies that signal is higher than effect of noise factors.

The slurry erosion rate is influenced by the number of control factors like impact velocity, impingement angle, fibre loading, erodent size, slurry concentration, stand-off distance, flow rate respectively [8][14].

Table 2 shows the levels for various control factors for slurry erosion test. In this study the design of experiments is planned for 4 levels and 4 factors, so the orthogonal array selected isL_{16} (4^4). Table 3 shows the orthogonal array design as per L_{16} for unfilled and marble dust powder filled aramid epoxy composites respectively.

Table 3. Orthogonal array for l_{16} (4^4) taguchi design

S. No.	Fibre/Filler loading	Impact Velocity	Impingement Angle	Erodent Discharge Rate
(Unit)→	(wt%)	(m/sec)	(degree)	(gm/min)
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	1	4	4	4
5	2	1	2	3
6	2	2	1	4
7	2	3	4	1
8	2	4	3	2
9	3	1	3	4
10	3	2	4	3
11	3	3	1	2
12	3	4	2	1
13	4	1	4	2
14	4	2	3	1
15	4	3	2	4
16	4	4	1	3

The major tool for Taguchi experimental design is S/N ratio, and is termed as the ratio of mean to standard deviation or the ratio of signal to noise. For minimum erosion rate, the S/N ratio is determined as logarithmic transformation by considering ‘smaller-is-the-better’ characteristic.

1) Comparison of S/N ratios of unfilled aramid Reinforced Epoxy Composites

Experimental design of unfilled aramid reinforced epoxy composites using orthogonal array (L16) is shown in Table 4. The mean S/N ratio of erosion rate is calculated is 50.29db. S/N ratios are calculated by considering smaller-is-the-better characteristic for minimization of slurry erosion rate.

TABLE 4. COMPARISON OF S/N RATIOS OF UNFILLED ARAMID REINFORCED EPOXYCOMPOSITES

S. No.	Fibre Loading (wt%)	Impact Velocity (m/s)	Impingement Angle (degree)	Erodent Discharge Rate- (gm/min)	ErosionRate	S/N Ratio
1	20	27	30	160	0.00375	48.5194
2	20	32	45	195	0.00512	45.8146
3	20	37	60	230	0.04340	27.2502
4	20	42	75	265	0.00301	50.4287
5	30	27	45	230	0.00130	57.7211
6	30	32	30	265	0.07540	22.4526
7	30	37	75	160	0.00312	50.1169
8	30	42	60	195	0.00102	59.8280
9	40	27	60	265	0.00075	62.4988
10	40	32	75	230	0.00304	50.3425
11	40	37	30	195	0.00358	48.9223
12	40	42	45	160	0.00125	58.0618
13	50	27	75	195	0.00358	48.9223
14	50	32	60	160	0.00125	58.0618
15	50	37	45	265	0.00075	62.4988
16	50	42	30	230	0.00217	53.2708

2) ANOVA and the Effect of Factors

It is required to develop analysis of variance (ANOVA) to understand effect of controlfactors and their interactions. Table 5 shows the results of the ANOVA with the erosion rate. This analysis was undertaken for a level of confidence of significance of 95%. The last column of the table indicates that the main effects are highly significant (all have very small p-values).

Table 5. Anova table for erosion rate of unfilled aramid epoxycomposites

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	446.54	446.54	148.85	0.67	0.62
B	3	360.60	360.60	120.20	0.54	0.69
C	3	338.40	338.40	112.80	0.50	0.71
D	3	89.82	89.82	29.94	0.13	0.93
Error	3	671.35	671.35	223.78		
Total	15	1906.70				

DF: degree of freedom; Seq. SS: sequential sum of squares; Adj SS: extra sum of squares; Adj MS: extra mean squares; p: level of significance; F: variance ration.

III. RESULTS AND DISCUSSION

A. Effect of Impact Angle on Erosion Rate of Composites

The erosion wear behavior of composites loaded with different fibre loading (20wt% - 50wt%) are plotted with change in impingement angle and by keeping all other parameters constant (impact velocity = 37 m/s, stand-off distance = 50mm and erodent size = 300 µm). It can be noted form Fig. 2. that irrespective of fibre content (20wt% - 50wt %) of all the samples at an angle of 45° peaks of erosion rates are located. This type of behaviour of composite is called semi-ductile erosion behaviour. The erosion rate in increasing order can be written as EA20<EA30<EA40<EA50 respectively. The slurry jet erosion behaviour of composites is dependent upon the working condition. The erosion can be of ductile or brittle nature depending upon certain parameters such as change in impingement angle, fibre content, and properties of erodent material. Erosion rate decreases as the fibre content increases from (20wt% - 50wt %), this is due to the decrease in the void fraction from (20wt% - 40wt %). But due to again increase in void fraction for fibre loading of 50wt%, there is marginal decrease in the erosion rate for fibre loading of (40wt% - 50wt %). Therefore, it is clear that erosion resistance increases with increase in fibre loading.

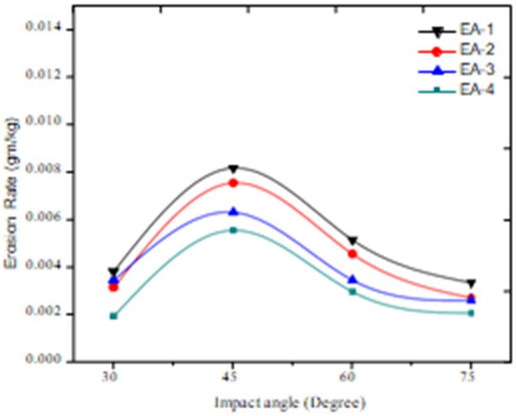

Fig. 2. Effect of impact angle on erosion rate

B. Effect of Impact Velocity on Erosion Rate of Composite

Erosion tests are conducted to study the influence of impact velocity on erosion rate by altering the impact velocity from 27 m/s to 42 m/s while other parameters like impingement angle (60°), stand-off distance (50 mm) and erodent size (300µm) were retained constant.

The change in erosion rate was recorded with change in impact velocity as shown in Fig. 3. With increase in impact velocity a systematic increase in the steady state erosion rate is observed. As the impact velocity of the sand particles increases, leads to increase in the kinetic energy, which further increases erosion wear [9][15].

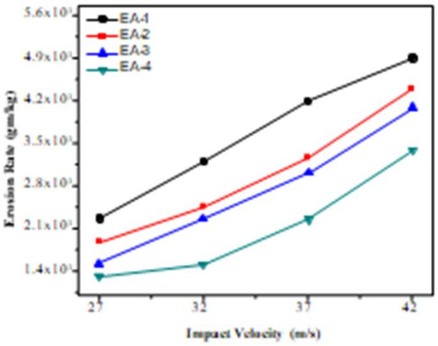

Fig. 3. Effect of Impact Velocity on Erosion Rate of Composites

C. Comparison of Taguchi experimental results of erosion rate of unfilled and marble dust filled aramid reinforced epoxy composites

The mean S/N ratio of erosion rate is 50.29 db. Fig. 4. is the graphical representation of the effect of four control factors on erosion rate of composites. MINITAB 16 based on design of experiment is used for analysis. Possible interactions between the control factors are determined. From this analysis it is concluded that to get minimum erosion rate A4, B4, C2 and D1 are significant factor levels. The average S/N ratios of the marble dust filled composites are recorded as 53.37 db.

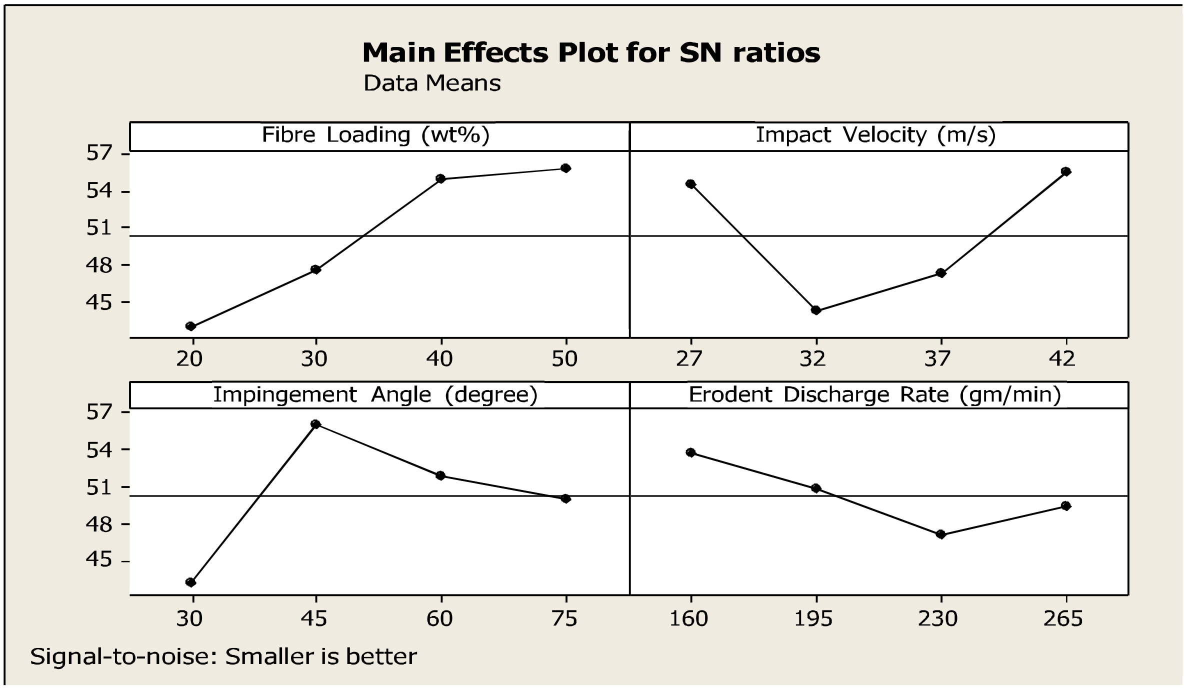

Fig. 4. Effect of Four Control Factors on Erosion Rate of Composites

IV. CONCLUSION

In this present analysis a series of aramid fibre reinforced epoxy matrix composites have been fabricated successfully. The experimental evolution erosive characteristics of composites of different fibre loading 20wt% - 50wt% is done. The study of impact velocity, impingement angle and erodent discharge rate on erosion rate of unfilled and marble dust filled composites shows semi-ductile behaviour of the material with respect to erosion wear. Irrespective of fibre content (20wt% - 50wt %) and filler content (5wt% - 15wt %) of all the samples the peak erosion rates are located at an angle of 45°. The erosion rate is also influenced by the impact velocity and erodent discharge rate. Result shows that fibre/filler content, impact velocity, slurry concentration, and impingement angle are the significant factors in decreasing order i.e., impingement angle is least significant factor.

Therefore, it is clear that erosion resistance increases with increase in fibre loading. With increase in impact velocity a systematic increase in the steady state erosion rateis observed.

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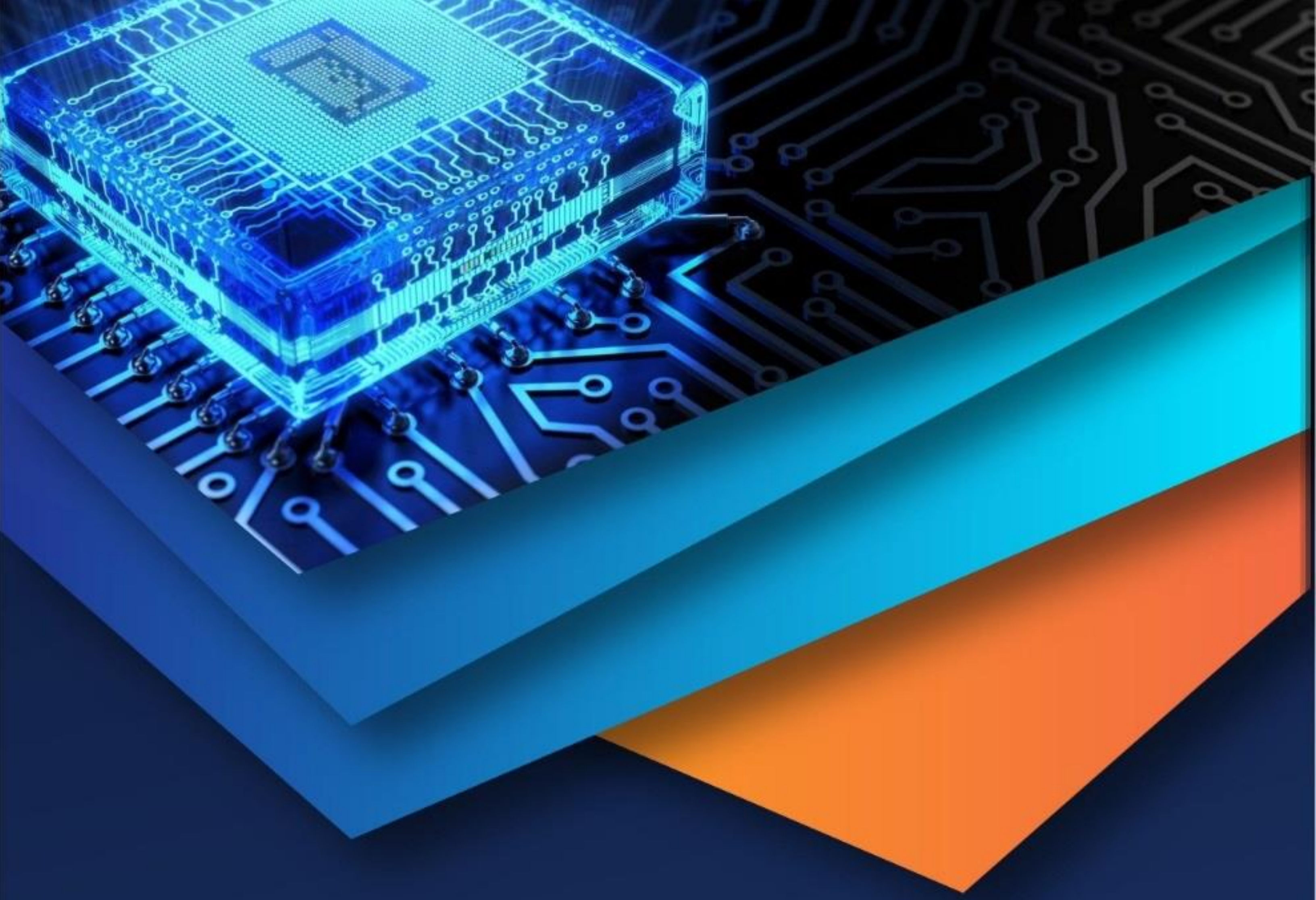

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