SOLID PARTICLE EROSIVE WEAR OF POLYESTER HYBRID COMPOSITES USING TAGUCHI APPROACH

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Abstract

Solid particle erosion has been considered as a severe problem for many failures in engineering applications. This article presents the analysis of erosion reaction of a glass fiber reinforced polyester composites with modified weight proportions of natural filler materials like Arabic gum tree coal powder(A.C.P), Jambal tree coal powder(J.C.P) and Neem tree coal powders(N.C.P) which act as secondary reinforcement materials. Assessment of wear behaviour is carried out experimentally by an air jet type erosion test rig and Taguchi orthogonal arrays have been used. Taguchi method is well known technique that provides a universal and efficient methodology for design optimization and experiments were followed by using Taguchi experimental design (L27 orthogonal array). Use of orthogonal arrays significantly reduces the number of experimental configurations to be studied. Finally, the through experimentation has led to determination of significant process parameters and material variables that predominantly influence the wear rate of glass fiber reinforced polyester with modified weight proportions of natural particulate fillers of Arabic tree coal powder(A.C.P), Jambal tree coal powder(J.C.P) and Neem tree coal powders(N.C.P) respectively.

Key words: Solid particle Erosion, Polyester, Natural fillers (A.C.P/J.C.P/N.C.P), Taguchi Method

1 INTRODUCTION

The subject of erosion wear of polymer composite has drawn attention of researchers in the past decades. Increasing utilization of polymer based composites in aerospace, transportation and processing industries indicates that the importance of polymer based composite materials in the applications where they can be subjected to multiple solid or liquid particle impact. Examples of such applications are pipe lines carrying sand slurries in petroleum refining, helicopter rotor blades, pump impeller blades, high speed vehicles and aircraft operating in desert environments.

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In most erosion processes, target material removal typically occurs as a result of a large number of impacts of irregular angular particles, usually carried in pressurized fluid streams. Bitter J.G.A [1], studied and identified that the erosion is a material loss caused by the impingement of particles entrained in a fluid system impacting the surface at high speed. Hutchings [2] defines it as an abrasive wear process in which the repeated impact of small particles entrained in a moving fluid against a surface results in the removal of material from the surface. Erosion due to the impact of solid particles can either be constructive (material removal desirable) or destructive (material removal undesirable), and therefore, it can be desirable to either minimize or maximize erosion, depending on the application.

S.R.Chauhan et al. [3] studied the effect of fly ash content in the sliding wear behaviour glass reinforced composites. It was found that the coefficient of friction decreases with addition of 10wt%-20wt% of fly ash and wear resistance is increased for the addition of 10wt% -20wt% of fly ash. Pressure and velocity is the main factor that has the highest physical and statistical significance in influencing the coefficient of friction and specific wear rate. Design of experiments approach by Taguchi method enabled successfully to analyze the friction and wear behavior of the composites with (p v) factor (combined pressure velocity), sliding distance and filler content as test variable. Effect of variables factor and sliding distance is more pronounced on the coefficient of friction of the composites than the fly ash as filler content. Effect of variables (p v) factor and filler content is more pronounced on the sliding wear of the composites. The effect of sliding distance on sliding wear rate of composites is insignificant.

The design of experimental approach by Taguchi technique has been successfully used by researchers in study of sliding wear behavior of metal matrix composites. Taguchi technique is a powerful tool for the design of high quality systems [4-6]. The Taguchi approach to experimentation provides an orderly way to collect, analyze, and interpret data to satisfy the objectives of the study. In the design of experiments, one can obtain the maximum amount of information for the amount of experimentation.

Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation [7]. This is carried by the efficient use of experimental runs to the combinations of variables to be studied. This technique is a powerful tool for acquiring the data in a controlled way and to analyze the influence of process parameters over some specific parameters, which is unknown function of these process variables. The crucial stage in the plan of experiments is selection of factors which have effects on the process. Taguchi technique creates a standard orthogonal array to consider the effect of several factors on the target value and defines the plan of experiments. The experimental results are analyzed by using analysis of means and variance of the influence of factors [8-9]. Sandhya rani et. al [10] studied the solid particle erosive wear of epoxy composites. It was found that the influence of impingement angle on erosion rate of the composites filled with different weight percentage of red mud reveals their semi-ductile nature with respect to erosion wear. The peak erosion rate is found to be occurring at 60^0 impingement angle for all the composite samples under various experimental conditions. The erosion rate is also greatly affected by the erodent temperature.

2. Experimental Details

2.1 Fabrication of composite Specimens

Three types of composites are prepared with different natural fillers are prepared using hand layup technique. The weight percentage of polyester, E-glass fiber, hardener and natural fillers Arabic gum tree coal powder (A.C.P), Neem tree coal powder (N.C.P) and Jambal tree coal powder (J.C.P) are fixed.

2.2 Preparation of Test Specimens

The test specimens are prepared as per ASTM-G76 from the fabricated composite slabs of dimensions 30X30X3 mm. Adequate care has taken to keep the thickness constant for all specimens.

2.3 Erosion Test Apparatus

The erosion test rig apparatus used for the present investigation is designed as per ASTM-G76 standard as shown in Figure-1. It consists of an air compressor, a particle feeder, and an air particle mixing and accelerating chamber. The compressed dry air is mixed with the erodent particles, which are fed at a constant rate from a belt-type feeder conveyor into the mixing chamber and then accelerated by passing the mixture through a converging nozzle of 4 mm diameter. These accelerated particles impinge the ASTM-G76 standard specimen and the specimen is held at various angles with respect to the impinging particles using an adjustable sample holder. The test apparatus has also been fitted with a rotating double disc to measure the velocity of the erodent particle. The impact velocities of the erodent particles has been evaluated experimentally using rotating double disc method developed by Ives and Ruff [11]. A standard test procedure is employed for each erosion test. The samples are cleaned in acetone, dried and weighed to an accuracy of 1×10^{-3} gm using an electronic balance, prior and after each test.

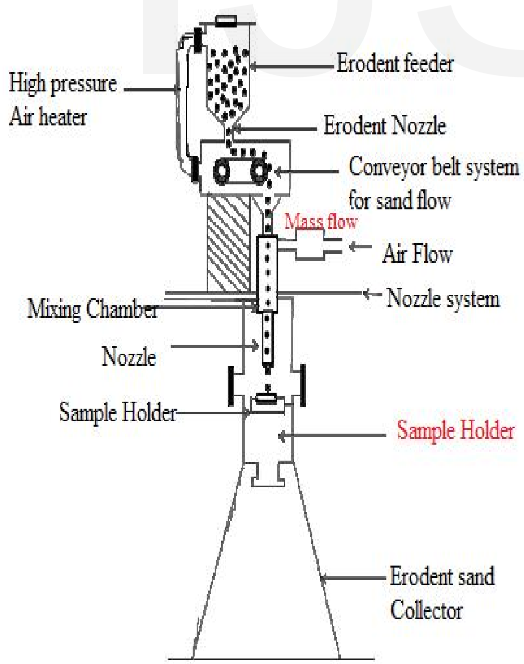

Figure-1: Erosion Test Apparatus

2.4 Experimentation

The prepared test samples after loading in the test rig were eroded for 1 minute at a given impingement angle and then weighed again to determine weight loss (Δw). The erosion rate (Er) is then calculated by using the following equation

$$Er = \Delta W / W_e$$

Where,

ΔW- is the mass loss of test sample in gm and

W_e - is the mass of eroding particle (i.e., testing time × particle feed rate)

3. TAGUCHI DESIGN OF EXPERIMENTS

Experimental research work are expensive and time consuming. To satisfy the design objectives with less number of experiments is an important constraint. In this context, Taguchi method provides the designer with a systematic and efficient approach for experimentation to determine near optimum settings of design parameters for performance and cost. Taguchi uses a special design of orthogonal array to study the entire process parameters with the help of minimum number of experiments. Taguchi method is desired for process optimization and identification of optimal combination of factors for a given response. The experimental observations are transformed in to S/N ratio. Three types of S/N ratios are used. They are lower the better (LB), Higher the better (HB) and Nominal the Best (NB).

3.1 Taguchi experimentation of Epoxy Hybrid composites

In the present investigation L_{27} Taguchi orthogonal array was selected, where 27 experiments are considered for the selected parameters and their levels. The wear parameters (factors) and their levels are given in

Table-1. As wear is to be minimized, lower the better S/N ratio is selected and is calculated by the logarithmic transformation of the loss function shown below.

$$\frac{S}{N} = -10 \log \left[\frac{1}{n}\left(y_1^2 + y_2^2 + \cdots y_n^2\right)\right]$$

Where,

n----indicates the repeated number of trial conditions,

$y1, y2...y_n$ indicates the response of the erosive wear characteristics respectively

Table -1 shows the Control factors and Levels for Erosion test

Control factor	Levels			Notations
	I	II	III	
Type of Filler material	1	2	3	1- ACP 2- JCP 3- NCP
JetVelocity (m/sec)	1	2	3	1- 32 m/sec 2- 45 m/sec 3- 58 m/sec
Temperature (^oC)	1	2	3	1- 40 ^oC 2- 50 ^oC 3- 60 ^oC
Impingement Angle(Degree)	1	2	3	1- 30^0 2- 60^0 3- 90^0

To find the effect of the parameters like type of material, jet velocity impingement angle and temperature on the wear rate, analysis of variance is made using the well-known software specifically used for design of experiment applications known as MINITAB -14.

Table-2 shows the experimental results of polyester based natural filled glass fiber reinforced hybrid composites. Analysis of results leads to concluded that the experiment no-25 exhibited minimum erosion rate based on the orthogonal array i.e. smaller is better. Therefore the factor combinations Neem coal powder material (N.C.P) - jet velocity (32 m/sec)-temperature (60)-impingement angle (60^0 C) gives minimum erosion rate as shown in figure-2

Table-2: Experimental design using L_{27} array for Polyester based hybrid composites.

EXP. No	Type of filler material	Jet velocity m/sec	Tem ^0C	Impingement Angle	Er gm/kg	S/N Ratio
1	A	32	40	30	476.19	-53.5556
2	A	45	50	60	577.78	-55.2353
3	A	58	60	90	539.68	-54.6427
4	A	45	40	90	563.49	-55.0177
5	A	58	50	30	423.02	-52.5272
6	A	32	60	60	539.68	-54.6427
7	A	58	40	60	587.3	-55.3772
8	A	32	50	90	404.76	-52.144
9	A	45	60	30	473.81	-53.5121
10	J	32	40	30	444.44	-52.9563
11	J	45	50	60	706.35	-56.9804
12	J	58	60	90	396.83	-51.9721
13	J	45	40	90	384.13	-51.6896
14	J	58	50	30	515.87	-54.2508
15	J	32	60	60	579.37	-55.2591
16	J	58	40	60	706.35	-56.9804
17	J	32	50	90	444.44	-52.9563
18	J	45	60	30	607.14	-55.6658
19	N	32	40	30	460.32	-53.2612
20	N	45	50	60	710.32	-57.0291
21	N	58	60	90	603.17	-55.6088

22	N	45	40	90	535.71	-54.5786
23	N	58	50	30	543.65	-54.7064
24	N	32	60	60	626.98	-55.9451
25	N	58	40	60	711.11	-57.0387
26	N	32	50	90	527.78	-54.4491
27	N	45	60	30	702.38	-56.9314

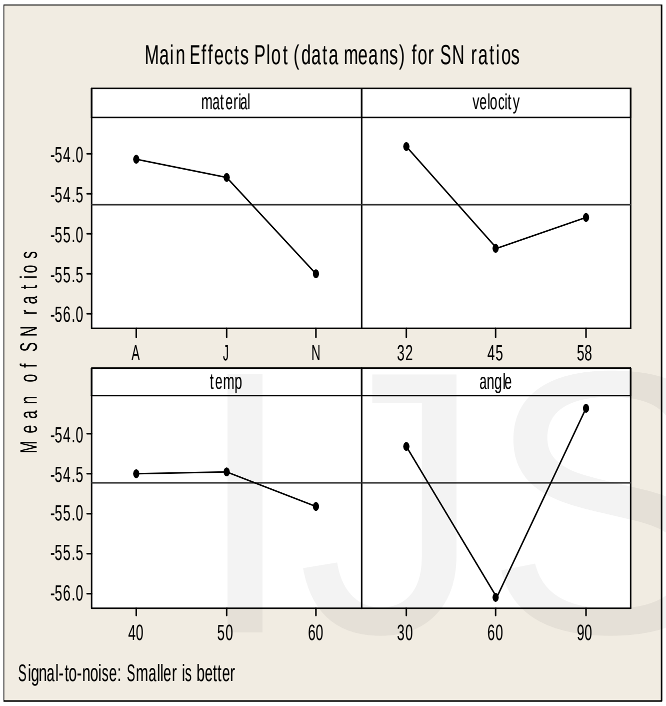

Figure-2 Effect of control factors on Erosion Rate(E_r) of Polyester hybrid composites

Table-3 Response Table for Signal to Noise Ratios Smaller is better

Level	Typeof filler material	Jet Velocity	Tempera-ture	Impinge-ment Angle
1	-54.07	-53.91	-54.50	-54.15
2	-54.30	-55.18	-54.48	-56.05
3	-55.51	-54.79	-54.91	-53.67
Delta	1.43	1.27	0.43	2.38
Rank	2	3	4	1

From response Table-3, impingement angle which is ranked first states that it influence the erosion rate to a greater extent when compare to type of filler material which is ranked second followed by jet velocity and temperature which is the least effecting parameter for erosion rate.

3.2 Effect of factors on Erosion Rate of Polyester Hybrid Composites by ANOVA

Statistical significance of various factors like type of filler material, jet velocity, impingement angle and temperature on Erosion rate (Er) are found out using analysis of variance (ANOVA) on experimental data.

Table-4 Analysis of Variance for Er (Polyester) gm/kg, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Type of filler material	2	42342	42342	21171	4.89	0.020*
Jet velocity	2	33394	33394	16697	3.86	0.040
Temperature	2	3203	3203	1602	0.37	0.696
Impingement Angle	2	113968	113968	56984	13.18	0.000**
Error	18	77853	77853	4325		
Total	26	270760				

DF-Degree of Freedom Seq SS-Sequential Sum of Squares Adj SS-Extra Sum of Squares Adj MS-Sequential mean sum F-F –test P-Percent Contribution

Table - 4 show the results of the ANOVA for the erosion rate of Polyester based hybrid composites. P- indicates percentage contribution of the control factors and their interactions on the performance output i.e. erosion rate. From table-6.8, it can be observed the type of filler material, jet velocity, impingement angle and temperature have 0.020, 0.040, 0.000 and 0.696 respectively. Finally, it can be concluded that the impingement angle is the major contributing factor for erosion followed by type of filler material, jet velocity and temperature.

4. CONCLUSIONS

Wear characteristics of polyester hybrid glass reinforced with modified natural filler composites are studied to find the wear behaviour of the composites under similar test conditions. The experimental results of erosion trials carried out on these hybrid composites. The critical analysis of the test results using Taguchi method and analysis of variance (ANOVA) are explained. The results indicate that ware rate is more at an impingement angle of 30^0 compared with 60^0 and 90^0 impingement angles. Higher wear resistance was observed when Neem coal powder was utilized as filler material compared to other fillers materials.

For all the three filler materials the wear rate is less with an impingement angle of 60^0 with different velocities and temperatures for glass polyester hybrid composites.

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