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Optimization of Tribological Property of Carbon Fiber Reinforced Nano Filler Filled Polymer Composites Using Taguchi Method

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ABSTRACT

The field of nano-composites has become an interesting area of research and development. The tribological performance of epoxy based composites filled with woven carbon fabric with nano (Al_2O_3 + SiC) sized hybrid fillers in different proportions were investigated. The samples are prepared by varying the concentrations of fillers such as 1% and 2% nano fillers by weight manually followed by compression molding. Erosion tests were conducted at different parameters such as erodent size, impingement angle, impact velocity of sand and time. By the addition of nano particles, the tribological property has improved because of improved surface area. In the present work Taguchi (L_{27} orthogonal array) technique a statistical technique is applied to optimize the variables of process leading to least rate of erosion for the polymer composites. Significance of various factorslike impact velocity, abrasive particle size, time, filler % and impingement angle are found using Analysis of Variance (ANOVA).

Keywords: *Nano-composites, Carbon fiber, Taguchi's L_{27} Orthogonal Array, ANOVA*

INTRODUCTION

Composite are multiphase materials obtained by the combination of different materials in order to attain properties that the single components by themselves cannot achieve. These are heterogeneous in nature, created by the assembly of two or more components with fillers or reinforcing fibers and a compactable matrix. Composites filled with nano fillers enhance tribological, electrical, thermal and mechanical properties [1]. Because of its excellent tribological properties compared to traditional polymer composite, these can be used in applications where grease lubricants and fluid fails [2]. Mechanical degradation (wear) due to particle impinging on the surface is described by solid particle erosion. Damage caused by it has been reported in wide range of situation. Epoxy resin as a part of composite material exhibits some demanded properties and also to sustain good mechanical and tribological loads, which is generally reinforced with fillers. The filler particles favorably stiffen the material and also increase the strength under certain condition. On the other hand, it also has considerable effect on materials resistance against impact [3, 4]. The effect of impacting the solid particles facing the object leads to erosive wear. The surface material undergoes deformations and cutting actions by the impinging particles gradually which is a widely observed mechanism in firm. Slurries through pumping apparatus and piping are the best example in erosive wear.

The angle of impact and the velocity of eroding particles are the major contributor in erosion of coatings. Maximum wear rate observed at 90° for brittle materials and 15° to 30° for ductile materials. Lingaraju et al. [5] explored on mechanical and tribological properties of nano-composites which were affected by the nano filler addition in glass-

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epoxy composites. The lower slide wear rates found in dry slide wear testing of hybrid nano-composites, irrespective of the load and sliding speed related to pure composite. There is huge reduction (750%) in wear rate, 2.09% enhancement in tensile strength, 6.6% improvement in impact strength which can be observed by the addition of 1 wt.% of silica. The general performances of thermosetting and thermoplastic polymers are improved by new approach [6, 7]. The Spherical silica particles (0.5 – 4 wt.%) showed improvement in wear resistance of epoxy matrix and used to develop for various applications [8]. Amar Patnaik et al. [9] investigated the erosive response of hybrid composite using Taguchi experimental design and he observed significant increase in erosion resistance of glass-polyester composites by the inclusion of fillers such as SiC, Al_2O_3 and Flyash. Tribological properties of the directionally oriented wrap knitted glass fibers were used for the study including biaxial, tri-axial and quadra-axial thermosets namely polyester, vinyl ester and epoxy wereenhanced in wear resistance of the composite system [10]. The erosive wear of glass-epoxy polymer composite is higher than that of carbon-epoxy composite and also found that there is a significant influence of fiber orientation on erosive wear, peak erosion rate occurs at 60° impingement angle [11].

The bi-directional glass reinforced epoxy composites at normal incidence showed better erosion wear resistance in comparison of erosive wear resistance of unfilled epoxy unidirectional glass and bi-directional carbon reinforced epoxy composite[12]. Design of quality system can be fetched by an orderly way of collecting and interpreting the data using Taguchi technique [13]. Optimization of performance characteristics through the parametric design of taguchi reduces the sensitivity of system performance. This can be achieved by the enough experimental runs to analyze the influence of process variables. Factor selection is an important aspect in planning of the experimentation in taguchi technique which forms an array to accommodate the impact of various factors on the target and influences of various factors are interpreted using ANOVA [14-15]. The erosive response of glass fiber reinforced with polyester composites filled with flyash is studied using Taguchi's design, which removes the necessity of repeated trials and hence saves material, price and consumption of time. Even the interactions influencing the rate of erosion can be found along with significant control factors [16].

MATERIALS AND METHODS

The composites were prepared by different combinations as mentioned in the Table 1.

TABLE 1. Composition of composite materials employed.

Sl. No	Reinforcement (Carbon Fiber)	Epoxy (% by Wt.)	SiC (% by Wt.)	Al_2O_3 (% by Wt.)
1	60	40	-	-
2	60	39	0.5	0.5
3	60	38	1	1

Fabrication Process

The fabrications of all polymer matrix composite laminates used in this work were manufactured by Hand/Wet layup technique which is one of the simplest methods and was first used to manufacture boat hulls in older days. It is a process in which laminates of resin and reinforcement are stacked manually into an open mould surface until the required thickness is obtained. In lay-up process there are five main steps: mould cleaning, releasing agent application, laying-up of reinforcements, curing and removal of part as shown in Figure 1 (a) and (b)

Basic Processing Steps

The preliminary steps involved in the Hand lay-up process consist of:

1. A Teflon sheet was attached to mould to get smooth surface finish.
2. For easy removal of the component, a releasing spray was applied to the Teflon sheet.
3. One coat of Epoxy resin mixed with filler and hardener was applied to Teflon sheet.
4. A layer of carbon fabrics which was cut to the required dimension was impregnated over resin.

5. Another coat of resin applied over the mat, it is uniformly distributed around the surface using a roller.
6. Process is repeated until 3mm thickness of the composite was obtained.
7. Whole assembly was kept in a hydraulic press of 25 kg/cm^2 and allowed to cure at room temperature for a day.
8. After a day of curing in room temperature composite was cured for 1 hour in furnace at 100 to 110°C.

(a)

(b)

FIGURE 1. Schematic representation of Hand Layup technique

Specimen preparation

By using hand-layup method, carbon-epoxy laminates were prepared followed by hydraulic compression which uses epoxy resin as a matrix and bidirectional carbon woven fibers as the reinforcement with nano SiC and Al_2O_3 as filler material. Finally the laminates were cooled uniformly to enhance the properties of the composites. Total numbers of specimens prepared are 27 as per ASTM standards and L_{27} orthogonal array, described in Table 2 and Figure 2 depicts specimen for the Testing.

TABLE 2. Erosion wear test specifications

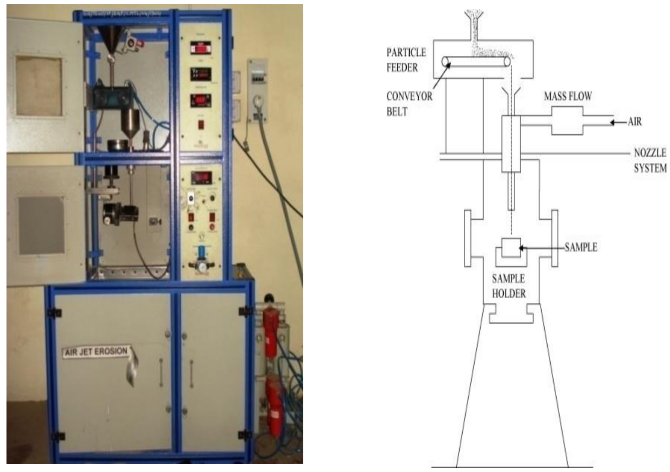
Sl. no	Erosion wear test (ASTM G-76)	Dimension in mm
1.	Size of Specimen	50 x 50 x 3mm
2.	Impingement angle	up to 90º
3.	Nozzle diameter	7.5mm
4.	Stand-off distance	up to 150mm

FIGURE 2. Erosion wear test specimen

Testing Procedure

Before starting the experiment, the test rig shown by Figure 3 (a) and (b) was cleaned and checked whether all switches, knobs and valves are in off position. The compressor and main supply of the air jet erosion test rig was switched on and conveyor motor speed was adjusted for the required conveyor speed which maintains the sand flow rate constant. The initial specimen weight were noted down and required cycle time was set by using the press buttons and pressure was maintained constant with the help of pressure regulator valve and standoff distance was adjusted to 10mm over the specimen. Impingement angle of air jet on the specimen was set as per the requirement with the help of indexing table. All the doors of the test rig were closed considering safety.

The test rig was allowed to complete the test cycle for the set elapsed time and the compressor valve was closed simultaneously with the cycle stop. After the completion of test the door was opened and the specimen was taken out, cleaned thoroughly and weighed. The same process is repeated for different conditions, which is given by Taguchi's L_{27} orthogonal array as per Table 4. Finally the difference in weight loss was calculated using Equation 1 and erosion rates were calculated using Equation 3.



(a) (b)

FIGURE 3. (a) Pictorial and (b) Schematic drawing of Erosion test rig.

TABLE 3. Specifications of Erosion wear Setup

Parameters	Specifications
Nozzle size	3 mm dia
Particle velocity	20 m/s to 100 m/s
Test gas	Dry air
System pressure	140 kPa
Flow rate	9.29 g/min
Test temperature	Room temperature
Particle feed rate	2.0 g/min
Nozzle length	50 mm
Stand-off distance	10 mm

Calculations

$$\text{Weight loss} = \text{Intial weight} - \text{Final weight} \quad (1)$$

$$\text{Erosion wear volume} = (\text{weight loss})/\text{density} \quad (2)$$

$$\text{Erosion rate} = (\text{weight loss})/(\text{flow rate x erosion time}) \quad (3)$$

RESULTS AND DISCUSSION

Erosion Test

The solid particle erosion rate of any material relay on various control factors. In the present work, optimization of parameters is done using taguchi technique which leads to least rate of erosion in polymer composites. Erosion activity of composites is mainly relay on certain factors such as size of erodent, angle of impingement, time and velocity of sand. Out of these impingement angle affects more on erosion rate. Ductile behavior of the material is distinguished by utmost erosion rate which generally results at 15°–30°. Brittle behavior is distinguished by utmost erosion rate at 90° and at 45°-60° Semi-ductile behavior is observed by the utmost rate of erosion. Figure 4 shows the peak erosion for brittle/ductile materials with respect to impingement angle. In our case maximum erosion occurred at around 90° for the filled composites. When we compare the column VII and VIII of Table 4, experimental and analytical values are almost same for all the readings.

TABLE 4. Taguchi's L_{27} orthogonal array combinations for nano filler filled composites

Sl. No	Erodent size (µm)	Velocity (m/s)	Time (min)	Nano Filler (Wt.%)	Imp angle (degree)	Experimental Loss (mg)	Analytical Wt. loss (mg)	Erosion Rate (gm/gm)	S/N Ratio (dB)
1	106	30	1.5	0	60	0.034	0.039	0.0025	52.2083
2	106	30	3	1	75	0.057	0.067	0.0021	53.7361
3	106	30	4.5	2	90	0.081	0.076	0.0019	54.2684
4	106	35	1.5	1	75	0.035	0.052	0.0025	51.8834
5	106	35	3	2	90	0.069	0.071	0.0025	52.1196
6	106	35	4.5	0	60	0.103	0.096	0.0025	52.1154
7	106	40	1.5	2	90	0.044	0.048	0.0031	50.0538
8	106	40	3	0	60	0.081	0.081	0.0029	50.7143
9	106	40	4.5	1	75	0.126	0.099	0.0030	50.4053
10	212	30	1.5	1	90	0.028	0.026	0.0020	54.0768
11	212	30	3	2	60	0.050	0.049	0.0018	54.9919
12	212	30	4.5	0	75	0.068	0.078	0.0016	55.7302
13	212	35	1.5	2	60	0.029	0.035	0.0021	53.5558
14	212	35	3	0	75	0.095	0.073	0.0034	49.3296
15	212	35	4.5	1	90	0.087	0.082	0.0021	53.6055
16	212	40	1.5	0	75	0.034	0.049	0.0025	52.1829
17	212	40	3	1	90	0.063	0.068	0.0023	52.8422
18	212	40	4.5	2	60	0.087	0.082	0.0021	53.5955
19	425	30	1.5	2	75	0.009	-0.015	0.0006	64.2750
20	425	30	3	0	90	0.019	0.014	0.0007	63.3090
21	425	30	4.5	1	60	0.018	0.028	0.0004	67.1095
22	425	35	1.5	0	90	0.009	0.000	0.0007	63.6826
23	425	35	3	1	60	0.019	0.023	0.0007	63.3548
24	425	35	4.5	2	75	0.026	0.041	0.0006	64.1735
25	425	40	1.5	1	60	0.011	-0.001	0.0008	62.0356
26	425	40	3	2	75	0.021	0.027	0.0008	62.3573
27	425	40	4.5	0	90	0.033	0.047	0.0008	62.0356

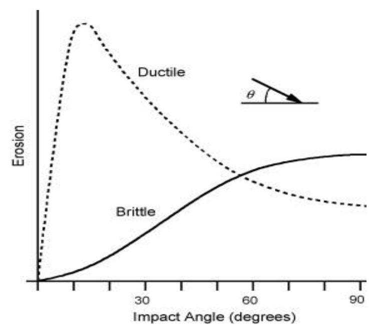


FIGURE 4. Effect of impingement angle on erosion rate

Taguchi Experimental Analysis

It was found that erosive wear rates of nano filler filled carbon fiber –reinforced epoxy composites shows better result than that of unfilled carbon-epoxy composites. This concludes that the presence of fillers enhance the erosion wear resistance of carbon fiber reinforced epoxy composites because of increased surface area.

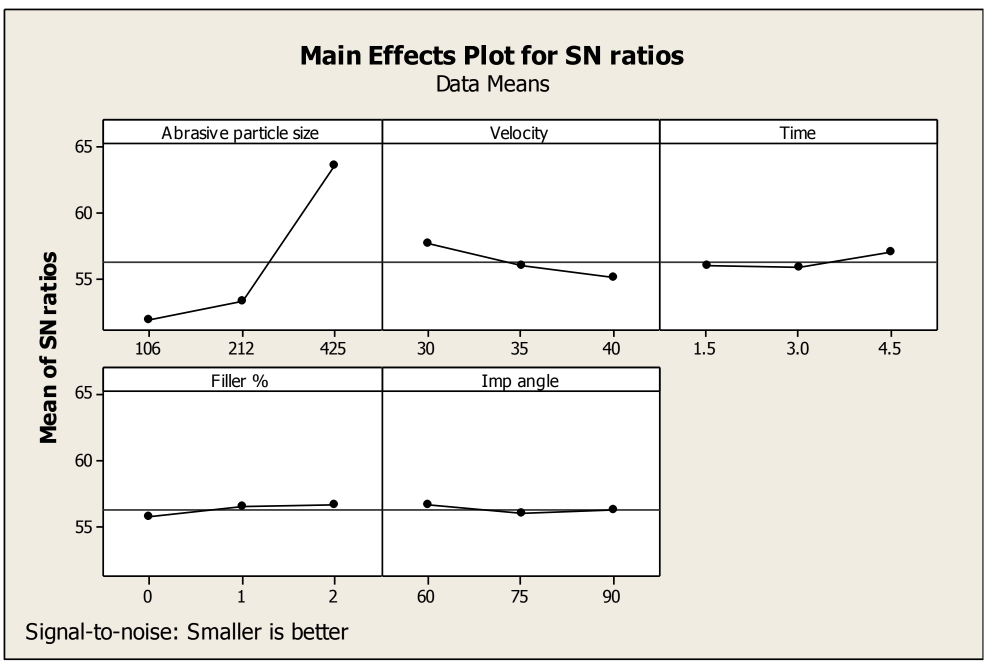


FIGURE 5. Abrasive wear rate performance by various control factors

Analysis of the result from Figure 5 concludes that the loading of nano filler reduces the specific wear rate with 1 wt.% of filler and further addition of filler to 2 wt.% further reduces the specific wear rate. The factor combination of A_3, B_1, C_3, D_3 and E_1 gives minimum erosion rate. It can be concluded from the analysis that factor combination of A_3 (Abrasive particle size = 425μm), B_1 (Velocity = 30 m/s), C_3 (Time = 4.5 min), D_3 (2 wt.% of filler) and (Impinging angle = 60º) gives least rate of erosion. So the factors A_3, B_1, C_3, D_3 and E_1 have significant effect on rate of erosion as shown in Figure 5.

TABLE 5. Response Table for S/N Ratio

Level	Abrasive particle size (A)	Velocity (B)	Time (C)	Filler % (D)	Impingement angle (E)
1	51.94	57.75	55.99	55.70	56.63
2	53.32	55.98	55.86	56.56	56.01
3	63.59	55.14	57.00	56.60	56.22
Delta	11.65	2.61	1.14	0.90	0.62
Rank	1	2	3	4	5

By analyzing Table 5, it is observed that among the various factors, abrasive particle size is most significant while impingement angle has least significance compared to the other remaining factors. The material loss rate of carbon epoxy composite decreases significantly by the addition of hard fillers into the epoxy matrix, this enhancement in the wear resistance depend upon two factors such as filler type and substance. Compared to composites filled with SiC and flyash, alumina filler filled shows good erosion resistance. The reduction in loss of material in these particle filler filled composites can be imputed to two main causes. One is enhancement in the bulk hardness with the addition of hard ceramic particles. Other, during the process of erosion, a good part of kinetic energy associated with the erodent is absorbed.

TABLE 6.ANOVA table of Taguchi method

Source	DF	Seq SS	Adj SS	F	P	% P
Abrasive particle Size	2	0.0000181	0.0000181	87.70	0.000	83.4
Velocity	2	0.0000013	0.0000013	6.35	0.009	6.0
Time	2	0.0000002	0.0000002	1.18	0.332	0.92
Filler %	2	0.0000002	0.0000002	1.18	0.333	0.92
Impingement angle	2	0.0000001	0.0000001	0.58	0.570	0.46
Error	16	0.0000017	0.0000017			
Total	26	0.0000217				

ANOVA and the Impact of Factors

To know the importance of various factors such as abrasive particle size (A), impact velocity (B), time (C), filler % (D) and Impingement angle (E), analysis of variance (ANOVA) is executed on experimental information. A Table 6 depicts the result of the ANOVA. Level of confidence of 5% is used to carry out the analysis. The last column of ANOVA table represents percentage contribution for the respective control factors. Larger is the percentage contribution, greater will be the significance of the factor correlated to it and which coincides with the response table with their ranking. It can be observed that, abrasive particle size is the most influential factor followed by velocity, filler%, time of erosion and angle of impingement.

CONCLUSIONS

There is significant reduction in wear volume and specific wear rate on filler addition. The addition of 2 wt.% filler filled composite showed lesser specific wear rate in comparison with neat and 1 wt.% filler filled composites. Analysis of the result showed that factor combination of A3 (Abrasive particle size = 425μm), B1 (Velocity = 30 m/s), C3 (Time = 4.5 min), D3 (2 wt.% of filler) and (Impinging angle = 60º) gives minimum erosion rate for nanocomposite.

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