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Two Body Abrasive Wear of Coconut Shell Particle Reinforced Epoxy Composites: A Taguchi Approach

G. H. Manjunatha Chary, K. Sabeel Ahmed

Department of Mechanical Engineering, Jawaharlal Nehru National College of Engineering, Shivamogga - 577 204, Karnataka, India.

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ABSTRACT

The multipass two-body abrasive wear behavior of coconut shell particle reinforced epoxy composites has been evaluated. The composite samples were rubbed against the water proof silicon carbide abrasive grit papers of 600,800 and 1000 grade affixed on rotating disc of pin-on-disc wear testing set up under dry sliding conditions. Taguchi L_9 orthogonal array was used for the analysis. The experimental values of wear loss were transformed to S/N ratio. The influence of each control factors was analyzed with S/N response table with the help of MINITAB 16 software. The effect of four independent variables, viz., abrasive grit, sliding velocity, normal load, and sliding distance is considered for this study. Results revealed that abrasive grit has the highest influence of 48.92% on wear behavior followed by the normal load (31.70%), sliding velocity (10.35%), and sliding distance (9.01%).

Key words: *Coconut shell particle, Abrasive grit, Taguchi L9 orthogonal array.*

1. INTRODUCTION

In the recent years, as a result of rising environmental awareness, natural fillers (bio-based) have been in huge demand as a reinforcing material in the fabrication of polymer composites especially for substitution to wood products. Many researches have been undergone to find the best use of natural fillers in the place of synthetic materials because of their advantages such as low density, low cost, biodegradability, and renewability. Furthermore, the composites made of natural fillers are less abrasive to processing equipment [1], hard, stiff, and easily machinable. The use of natural fillers as reinforcement material in the fabrication of polymer composites can compensate the scarcity of wood resources. Several researchers have made an attempt to investigate the abrasive wear property of composites [2-5]. Syed *et al*. [2] studied the three-body abrasive wear behavior of 5% and 10% w/w coleus spent (CS) filled and unfilled unsaturated polyester (USP)/ polymethyl methacrylate. The results revealed that the wear volume decreases with increase in CS content that contributes to the fact that the natural fillers are nonabrasive. Suresha *et al*. [3] investigated the three-body abrasive wear behavior of carbon fabric reinforced epoxy (C-E) and silane treated 5-10% graphite filled C-E composites. Their results showed that the specific wear rate decreased with the increase in abrading distance and load and also depends on % filler loading. Ravi Kumar *et al*. [4] carried out experimentation on two-body abrasive wear characteristic of nanoclay filled low density polyethylene (LDPE) composites with and without ethylene-co-glycidyl methacrylate as compatibilizer. They concluded that the wear rate increases with increasing abrasive grain size and nanoclay filled LDPE composite with compatibilizer exhibited better abrasion than unfilled one. Mahapatra *et al*. [5] performed two-body abrasive tests on developed chopped sugarcane fiber reinforced USP composites. From this study, the author has concluded that abrasive wear (weight loss) increases with increasing load. However, the size of chopped fiber also plays an important role on surface damage of composite by abrasive material loss. From the review of literature, it can be seen that the study on abrasive wear characterization of natural filler composites is scanty. Hence, an attempt has been made to investigate the two-body abrasive wear property of composite made from coconut shell particles as reinforcement.

2. EXPERIMENTAL

2.1. Material Details

The materials used for fabrication of composites consists of fully dried coconut shell particles of distinct sizes, *viz*., 0.25 mm, 0.5 mm, 1 mm, and 2 mm

*Corresponding Author:
E-mail: manju_gh2006@yahoo.co.in

as a reinforcement material. The epoxy resin LY556 and hardener HY951 in the ratio of 10:1 were used as matrix. 5% of melamine was also added into the matrix to have better surface finish of the developed composites. The resin, hardener, and melamine were procured from M/s insulation house, Bengaluru, India.

2.2. Selection of Optimum Filler Composition and Grain Size

Based on the dry sliding wear tests that were conducted on coconut shell/epoxy composite samples with filler volume fractions of 40%, 50% and 60% and particle sizes of 0.25 mm, 0.5 mm, 1 mm, and 2 mm, it was observed that, the wear loss was minimum for composite samples with coconut shell particles of 0.25 mm size and filler volume fraction of 40%. Hence, composites with this composition were selected for two-body abrasive wear test.

2.3. Fabrication of Composite

The coconut shell particle reinforced epoxy (CSPE) composite board was fabricated with 0.25 mm particle size in 40% filler volume fraction using open mold process.

2.4. Taguchi Approach

The experimental plan was formulated considering four parameters (variables) and three levels based on the Taguchi technique. The four independent variables and their levels considered for this study are as given in Table 1.

Table 1: Control factors and their levels.

Control factors	Levels I	Levels II	Levels III	Units
Abrasive grit	600	800	1000	-
Sliding velocity	3	4	5	m/s
Normal load	5	10	15	N
Sliding distance	300	400	500	m

2.5. Plan of Experiment

In this work, a standard L9 orthogonal array was chosen for conducting the experiment. The wear parameters chosen are: (i) Abrasive paper grit size, (ii) sliding velocity, (iii) normal load, and (iv) sliding distance. The experiment consists of 9 tests and the columns were assigned with parameters. Experiments were conducted with a level of parameters given in each array row. The output is the wear loss of test samples which are repeated two times corresponding to 9 tests. The experimental results are further transformed into signal to noise ratio (S/N ratio). The response is the wear loss with the objective as smaller is the best, which was calculated as logarithmic transformation of loss function (Equation 1).

$$\frac{S}{N} = -10 \times \log \frac{1}{n} (\Sigma y_i^2) \tag{1}$$

Where "n" is the number of observations, y_i is the measured value of wear loss.

2.6. Wear Test Setup

Series of abrasive wear tests were conducted using a pin-on-disc machine (Model: Wear & Friction Monitor TR-20LE) supplied by DUCOM Instruments, Bengaluru, as per ASTM G99. The parameters considered for the tests are described in Table 2. The sample of size 6 mm × 6 mm × 50 mm) was held against the counterface of abrasive grit paper affixed to the rotating disc (EN32 steel disc) with a track radius of 80 mm. The pin was loaded against the disc through a dead weight loading system. The contact surface (6 mm × 6 mm) was cleaned with acetone after each test. The specimens were weighed to an accuracy of 0.0001 g using digital electronic balance before and after each test and the wear loss was calculated.

3. RESULTS AND DISCUSSION

Table 2 presents the results of wear tests along with the S/N ratios generated using statistical software

Table 2: Standard L9 orthogonal array.

Testrun	Abrasive paper	Sliding velocity (m/s)	Normal load (N)	Sliding distance (m)	Wear loss (g)	S/N ratio (dB)
1	600	3	5	300	0.05125	25.8061
2	600	4	10	400	0.13235	17.5655
3	600	5	15	500	0.24335	12.2754
4	800	3	10	500	0.04525	26.8876
5	800	4	15	300	0.07810	22.1470
6	800	5	5	400	0.02800	31.0568
7	1000	3	15	400	0.05413	25.3312
8	1000	4	5	500	0.0220	33.1515
9	1000	5	10	300	0.03685	28.6713

MINITAB 16. The influence of controlled process parameters on wear rate was analyzed, and rank was assigned based on the signal to noise response as given in Table 3. It is evident from the Table 3 that, among these parameters, abrasive grit is the most dominant influencing factor on the wear rate followed by the normal load, sliding velocity and sliding distance.

3.1. Analysis of Variance (ANOVA) for Wear Rate

ANOVA was carried out at a level of 5% significance, i.e., up to a confidence level of 95%. In Table 4, the last column indicates the percentage contribution of each factor on the total variation indicating their degree of influence on the result. One can observe from the ANOVA table that the abrasive grit (48.92%), normal load (31.70%), sliding velocity (10.35%), and sliding distance (9.01%) have great influence on the abrasive wear of coconut shell/epoxy composites.

Table 3: Response table for S/N ratios.

Levels	Abrasive paper	Sliding velocity	Normal load	Sliding distance
1	18.55	26.01	30.00	25.54
2	26.70	24.29	24.37	24.65
3	29.05	24.00	19.92	24.10
Delta	10.50	2.01	10.09	1.44
Rank	1	3	2	4

3.2. Multiple Linear Regression Model

The multiple linear regression models for wear loss developed by the software MINTAB 16 is given in Equation (2).

$$\text{Wear loss} = -0.0066 - 0.000262\ AG + 0.0263\ SV + 0.00915\ NL + 0.000241\ SD \quad (2)$$

Where AG is abrasive grit, SV - Sliding velocity, NL - Normal load and SD - Sliding distance.

3.3. Confirmation Experiment

An abrasive wear test was conducted using a specific combination of parameters and levels to validate the statistical analysis. The confirmation test was performed on composites by selecting the set of parameters shown in Table 5. The correlation of results between the confirmation experiment tests and regression model are also presented in Table 5.

From Table 5, it can be observed that the experimental results are in good agreement with those obtained from the regression model.

Table 4: ANOVA of S/N ratios.

Source	DOF	Sequential SS	Adjusted SS	Adjusted MS	% Contribution
Abrasive grit	2	0.019556	0.019556	0.009778	48.92
Sliding velocity	2	0.004140	0.004140	0.002070	10.35
Normal load	2	0.012670	0.012670	0.006335	31.70
Sliding distance	2	0.003602	0.003602	0.001801	9.01
Total	8	0.039969			100

ANOVA=Analysis of variance, SS=Sums of squares, MS=Mean squares

Table 5: Parameters used in the confirmation test and correlation of results.

Test run	Abrasive grit	Sliding velocity m/s	Normal load N	Sliding distance m	Experimental wear loss g	Regression model (equation)	Error (%)
1	600	3	15	400	0.14225	0.14875	4.36
2	800	4	10	300	0.05385	0.05180	3.80
3	1000	5	5	500	0.02635	0.02915	9.60

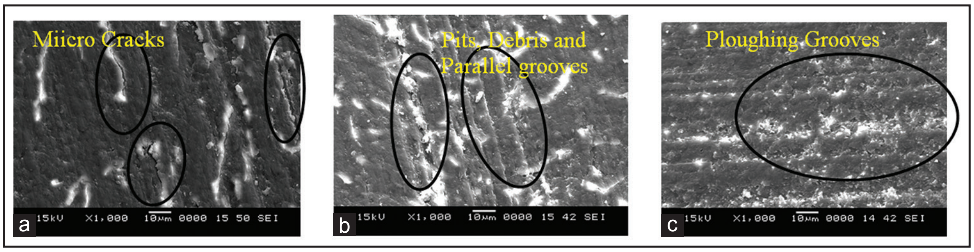

Figure 1: (a-c) Scanning electron microscopy features of composite samples.

3.4. Scanning Electron Microscopy (SEM)

The SEM micrographs of 40% filler volume fraction and 0.25 mm particle size composite samples tested for different abrasive grits, sliding velocities and sliding distances are shown in Figure 1a-c, respectively. The micrographs showed the formation of pits, debris, micro cracks and parallel grooves on the wear surface of the composite indicating the abrasion phenomenon. Heat generation by friction softens the resin [6] and also due to lower specific wear value of the composite [7] leads to ploughing grooves at the worn out surface of the sample.

4. CONCLUSIONS

Two-body abrasive wear characterization of CSPE composite with 40% filler volume fraction and 0.25 mm size coconut shell particles was conducted. The design of experiment was carried out using Taguchi L_9 orthogonal array to study the abrasive wear behavior of the composite. The ANOVA showed that the abrasive grit paper (48.92%) and normal load (31.70%) have a significant influence on the abrasive wear behavior. The confirmation tests showed that error associated with wear of CSPE composite is in the acceptable range.

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***Bibliographical Sketch**

Author 1 is currently working as Assistant Professor in the Department of Mechanical Engineering, Shimoga, Karnataka. He has 11 years of teaching experience and pursuing Ph.D. in the natural filler reinforced polymer composites. He has presented and published a paper in a National Conference.

Author 2 is currently working as Professor in the Department of Mechanical Engineering, Shimoga, Karnataka. He has 30 years of teaching experience and published more than 15 Journal and 10 Conference papers of International repute. Presently he is guiding three research scholars in the area of polymer composites.