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Influence of Parameters on Dry Sliding of Chopped Bamboo Reinforced Epoxy Composites Based on the Taguchi Method

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Chopped bamboo-reinforced epoxy composites were fabricated and tested to investigate their tribological properties. Three different weight fractions of 6%, 8% and 10% were used as reinforcement in the composites. Wear behaviour of composites was investigated by pin on disc wear testing device. To analyse the results the design of experiments (DOE) approach by using the Taguchi method was employed. Three different parameters (load, sliding speed, weight fractions) with three levels were chosen in design of experiments. Signal to noise ratio and analysis of variance (ANOVA) were used to investigate the influence of parameters on the wear rate and the coefficient of friction. According to the results, load was the most effective parameter for both wear rate and coefficient of friction.

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1. Introduction

Natural fibre composites have become a popular new material because of their high strength and stiffness, natural availability and environmental “friendliness”. Additionally, they are also recyclable, renewable and have a very low raw material cost. Natural fibres may play an important role in developing biodegradable composites to resolve the current ecological and environmental problems. There are various types of natural fibres today, and the variety continues to increase [1].

Experimental study of tribological properties requires a lot of time and is hard. Taguchi method is useful to avoid this and many researchers have used this method [2–9]. Design of experiment (DOE) is one of the important and powerful statistical techniques to study the effect of multiple variables simultaneously. It involves a series of steps which must follow a certain sequence for the experiment to yield an improved understanding of process performance [3]. Taguchi is one of the techniques which reduce the number of experiments and helps to predict results. The plan of experiments is generated in Taguchi method by the use of standard orthogonal arrays. The experimental results are then analysed by using analysis of mean and analysis of variance (ANOVA) of the influencing factors [10].

The purpose of this work is to investigate tribological properties of bamboo-reinforced epoxy composites. It is aimed to plan wear experiments by Taguchi method and analyse results using the ANOVA.

2. Experimental work

In this study the materials used for preparation of composites were chopped bamboo as the reinforcement and epoxy as the matrix material. A mould was manufactured for sample preparation. Epoxy resin (MGS L285) was mixed with hardener (HGS L285) in mass ratio of 100/40 as it is recommended by the supplier and then chopped bamboo was added to the matrix in the amount of 6 wt.%, 8 wt.%, 10 wt.%.

For wearing test samples, the fibre and epoxy mixture was poured into the mould and heated to 60 °C for one hour in an oven and than it was cured at room temperature for 24 hours. In the mould the wearing pin samples had the diameter of 10 mm. After curing they were machined to 6 mm for the tests. A pin on disc wear testing machine was used to investigate the dry sliding wear characteristics of composites. The wear specimen (pin) had a diameter of 6 mm and height of 30 mm. The initial weight of the specimen was measured using an electronic balance with accuracy of ±0.0001 g. During the test pin was pressed against the counterpart rotating against EN19 steel disc with hardness of 60 HRC, by applying the load. After running through a fixed sliding distance of 1000 m, the specimens were removed, cleaned with acetone, dried and weighted to determine the weight loss due to wear. The difference in the weight measured before and after test gave the sliding wear of the composite specimen. The density of the specimens was measured and then the wear rate of the composite was calculated according to Eq. (1) where Δm is the mass difference, ρ is density and d is the sliding distance.

$$\text{Wear rate} = \frac{\Delta m}{\rho d}. \quad (1)$$

Dry sliding wear tests were performed with three parameters: applied load (20 N, 30 N and 40 N), sliding speed (0.6 m/s, 0.8 m/s, 1 m/s) and percentage of weight fraction of fibre (6 wt.%, 8 wt.% and 10 wt.%). According to the rule that degree of freedom for an orthogonal array should be greater than or equal to sum of those wear parameters, a L9 orthogonal array which has 9 rows and 3 columns was selected. The response variables to be studied were wear rate and the coefficient of friction.

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The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. The analysis of the experimental data was carried out using MINITAB 15 software, which is specially used for DOE applications. The experimental results were transformed into signal to noise (S/N) ratios. S/N ratio is defined as the ratio of the mean of the signal to the standard deviation of the noise. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors [11]. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance [12]. The S/N ratio for wear rate and coefficient of friction using "smaller the better" characteristic, which can be calculated as logarithmic transformation of the loss function, is given as:

$$S/N = -10\log\left[\frac{1}{n\left(\sum y^2\right)}\right], \tag{2}$$

where y is the observed data (wear rate or coefficient of friction) and n is the number of observations.

2.1. Experimental results

It can be observed from Table I that the optimal conditions for wear rate were met in the 2nd experiment and for the coefficient of friction, in the 3rd experiment.

TABLE I

Results of L9 orthogonal array for bamboo reinforced epoxy composites.

Experiment number	Load [N]	Sliding speed [m/s]	Wt. pct. [%]	Wear rate [mm^3/m]	Coefficient of friction	S/N ratio of wear rate [dB]	S/N ratio of coefficient of friction [dB]
1	20	0.6	6	0.003108	0.870364	501.498	120.598
2	20	0.8	8	0.001422	0.824852	569.412	167.248
3	20	1	10	0.002111	0.791369	535.116	203.241
4	30	0.6	8	0.094733	0.970903	204.700	0.25649
5	30	0.8	10	0.107786	0.980170	193.487	0.17397
6	30	1	6	0.168165	0.923824	154.853	0.68822
7	40	0.6	10	0.069747	1.061.386	231.295	–0.51746
8	40	0.8	6	0.195905	1.102.588	141.591	–0.84826
9	40	1	8	0.163836	1.140.232	157.118	–113.986

The control parameter with the strongest influence was determined by the difference between the maximum and minimum value of the mean of S/N ratios. Higher the difference between the mean of S/N ratios, the more influential was the control parameter. From Tables II and III it can be observed that load is the dominant parameter on the wear rate and coefficient of friction. Weight percentage of bamboo is the second parameter that influences the wear rate and coefficient of friction, followed by the sliding speed.

TABLE II

Response table for S/N ratio for wear rate.

Level	Load	Sliding speed	Wt. pct.
1	53.53	31.25	26.60
2	18.43	30.15	31.04
3	17.67	28.24	32.00
Delta	35.87	3.01	5.4
Rank	1	3	2

2.2. Analysis of variance and the effects of parameters

Analysis of variance (ANOVA) is used to analyse the influence of wear parameters like sliding speed, applied load and weight percentage of fibres on the tribological performance characteristics: wear and coefficient of friction. These analyses were carried out for the level of significance of 10% with a 90% confidential level. Tables IV and V show the results of ANOVA analysis for wear rate and coefficient of friction. The value of the total sum of squares is used to measure the relative influence of the factors. The large the value of sum of squares, the more influential the factor is for controlling the responses. These values are used to determine the percentage contribution of factors. From Table IV, it is found that load (74.98%) is the most significant factor on wear rate, second factor is weight percentage of bamboo (12.65%) and third factor is sliding speed (11.31%).

On the other hand according to the analysis of variance for coefficient of friction from Table V, the applied load (93.24%) is the most significant factor followed by weight percentage of bamboo and sliding speed. The influences of sliding speed and weight percentage can be negligible.

2.3. Confirmation tests

The last step for Taguchi analysis is the confirmation test. According to Taguchi analysis optimum levels

TABLE III

Response table for S/N ratio for coefficient of friction.

Level	Load	Sliding speed	Wt. pct.
1	16.370	0.3150	0.3486
2	0.3729	0.3327	0.2630
3	-0.8352	0.5269	0.5630
Delta	24.722	0.2119	0.2999
Rank	1	3	2

TABLE IV

ANOVA for wear rate. DOF: Degree of freedom; Seq SS: Sequential sum of squares; Adj SS: Adjusted sum of squares; Adj MS: Adjusted mean squares.

Factors	DOF	Seq SS	Adj SS	Adj MS	F-test	% contrib.
Load	2	0.0349761	0.0349761	0.0174881	71.05	74.98
Sliding speed	2	0.0052761	0.0052761	0.0026380	10.72	11.31
Wt. pct.	2	0.0059016	0.0059016	0.0029508	11.99	12.65
Error	2	0.0004923	0.0004923	0.0002461		1.06
Total	8	0.0466460				100

of parameters were determined according to Tables II and III. The confirmation experiments were performed by taking an arbitrary set of factor combination $A_1B_1C_3$ for wear rate and $A_1B_3C_3$ for coefficient of friction. The estimated S/N ratio can be calculated according to Eq. (3) for wear rate and Eq. (4) for coefficient of friction.

$$\hat{\eta} = \bar{T} + \left(\bar{A}_1 - \bar{T}\right) + \left(\bar{B}_1 - \bar{T}\right) + \left(\bar{C}_3 - \bar{T}\right), \quad (3)$$

$$\hat{\eta} = \bar{T} + \left(\bar{A}_1 - \bar{T}\right) + \left(\bar{B}_3 - \bar{T}\right) + \left(\bar{C}_3 - \bar{T}\right). \quad (4)$$

Table VI shows the comparison of the predicted wear rate and frictional force with the actual response under study. The error is calculated between actual and predicted values of S/N ratio. The predicted error for wear rate is 2.788% and for coefficient of friction is 4.362%. This verifies that the predicted values are reliable.

3. Conclusions

- Dry sliding wear and coefficient of friction of the composite materials under different loads and sliding speeds were successfully analysed using Taguchi design of experiment.
- Applied load (74.98%) had the highest influence on the wear rate of bamboo reinforced epoxy composites. Also according to the analysis of variance for coefficient of friction, again the applied load (93.24%) is the most significant factor.
- The estimated S/N ratio using the optimal testing parameters for wear rate and coefficient of friction could be calculated and a good agreement between the predicted and actual wear rates and coefficient of frictions were observed.

TABLE V

ANOVA for coefficient of friction. DOF: Degree of freedom; Seq SS: Sequential sum of squares; Adj SS: Adjusted sum of squares; Adj MS: Adjusted mean squares.

Factors	DOF	Seq SS	Adj SS	Adj MS	F-test	% contrib.
Load	2	0.111510	0.111510	0.055755	19.48	93.24
Sliding speed	2	0.000553	0.000553	0.000277	0.10	0.46
Wt. pct.	2	0.001804	0.001804	0.000902	0.32	1.5
Error	2	0.005723	0.005723	0.002862		4.8
Total	8	0.119591				100

TABLE VI

Confirmation of tests results.

Wear rate		
Levels of parameters	20 N, 0.6 m/s, 10%	
	Actual	Predicted
S/N ratio for wear rate	58.659	57.234
Prediction error of S/N ratio [%]	2.788	
Coefficient of friction		
Levels of parameters	20 N, 1 m/s, 10%	
	Actual	Predicted
S/N ratio for coef. of frict.	2.032	1.943
Prediction error of S/N ratio [%]	4.362	

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