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Taguchi Approach to Tribological Behaviour of Chopped Carbon Fiber-Reinforced Epoxy Composite Materials

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Chopped carbon fiber-reinforced epoxy composites were fabricated and tested for tribological behaviour. Wear behaviour of composites was studied using pin-on-disc wear tester device. The design of experiment, using Taguchi method, was employed to analyse the results. Signal to noise ratio and analysis of variance (ANOVA) were used to determine the influence of parameters on the wear rate and coefficient of friction.

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1. Introduction

A composite material is made by combining two or more materials that have very different properties. The two materials work together to give the composite unique properties. Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement [1]. Many researchers have done studies of composites [2–4].

Wear is an undesired phenomenon in many mechanisms [5]. In the situations where the wear performance in nonlubricated conditions is a key parameter for material selection, polymer composites are used in mechanical components and these components are used in various types of wear situations [6]. Carbon, glass, aramid and graphite fibers are the most common fibers used for reinforcement in polymer matrix composites [7].

In the present work it is aimed to investigate tribological properties of carbon fiber-reinforced epoxy (CFRE) composites. Also it is aimed to plan wear experiments by Taguchi method and to analyse the results with ANOVA.

2. Tribological experiments

In this study the materials used for composite preparation were the chopped carbon fibers, added as reinforcement, and epoxy, added as the matrix material. A special mould was manufactured for samples used in tribological studies.

Epoxy resin (MGS L285) was mixed with hardener (HGS L285) in mass ratio of 100/40, as recommended by the supplier and then chopped carbon fiber was added to the matrix at a ratio of 6, 8 and 10 wt.%. The fiber and epoxy mixture was poured into the mould and heat treated at 60 °C for one hour in an oven, and after that cured at room temperature for 24 hours, to prepare the wear test samples. In the mould the wear pin samples had a diameter of 10 mm. After curing they were machined to 6 mm for tests.

A pin-on-disc wear testing machine was used to investigate the dry sliding wear characteristics of composites, according to ASTM G99-95 standards [8]. The wear specimen (pin) was 6 mm in diameter and 30 mm high. The initial weight of the specimen was measured using an electronic balance machine with accuracy of 0.0001 g.

During the test pin was pressed against the counter part, the 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 sliding wear of the composite was calculated according to Eq. (1), where Δm is difference in mass, ρ is density and d is the sliding distance.

$$\text{Wear rate} = \frac{\Delta m}{\rho d}. \tag{1}$$

2.1. Plan of experiments

Dry sliding wear tests were performed with three varied parameters: applied load (20, 30 and 40 N), sliding speed (0.6, 0.8 and 1 m/s) and fraction of fiber (6, 8 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, the L9 orthogonal array, which has 9 rows and 3 columns, was selected. The response variables, to be studied, were wear rate and coefficient of friction.

The experiments were conducted based on the run order generated by Taguchi model and the results were obtained. The analyses of experimental data were carried out using MINITAB 15 software, which is specially used for design of experiment 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

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of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. The S/N ratio for wear rate and coefficient of friction using "smaller the better" characteristics, which can be calculated as logarithmic transformation of the loss function, is given as:

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

where y is the observed data (wear rate or coefficient of friction) and n is the number of observations [9].

2.2. Experimental results

Results of L9 orthogonal array for chopped carbon fiber-reinforced epoxy composites are given in Table I.

TABLE I

Results of L9 orthogonal array for chopped carbon fiber-reinforced epoxy composites.

Exp. no.	Load [N]	Sliding speed [m/s]	Wt. ratio [%]	Wear rate [mm^3/m]	Coef. of friction	S/N ratio of wear rate [dB]	S/N ratio of coef. of friction [dB]
1	20	0.6	6	0.00342	0.54164	49,318	5.325
2	20	0.8	8	0.00284	0.63912	50.908	3.888
3	20	1	10	0.00374	0.63213	48.534	3.983
4	30	0.6	8	0.00539	0.64702	45.368	3.781
5	30	0.8	10	0.00559	0.62312	45.045	4.108
6	30	1	6	0.00464	0.67618	46.666	3.398
7	40	0.6	10	0.00719	0.69917	42.862	3.108
8	40	0.8	6	0.00801	0.75365	41.923	2.456
9	40	1	8	0.00850	0.77592	41.410	2.203

It can be observed from Table I, that optimum conditions for wear rate are in the 2nd experiment and for the coefficient of friction optimum conditions are in the 1st experiment. In these experiments the biggest S/N ratios were found.

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 of the wear rate and coefficient of friction. Weight ratio of chopped carbon fiber is the second parameter that influences the wear rate. Sliding speed is the second effective parameter of coefficient of friction.

2.2.1. Analysis of variance

Analysis of variance (ANOVA) is used to analyse the influence of wear parameters, like sliding speed, applied load and weight percentage of fibers on the tribological performance characteristics: wear and coefficient of friction. These analyses were carried out for the level of significance of 10%, with 90% confidential level. Tables IV and V show the results of ANOVA analysis for wear rate and coefficient of friction. The value of total sum of squares is used to measure the relative influence of the factors. The larger 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 factors. From Table IV, it is found that load (94%) is the most significant factor of wear rate. Sliding speed and weight percentage of carbon fiber have very low influence on wear rate.

TABLE II

Response table for S/N ratio for wear rate.

Level	Load	Sliding speed [m/s]	Wt. ratio [%]
1	49.59	45.85	45.97
2	45.69	45.96	45.90
3	42.07	45.54	45.48
Delta	7.52	0.42	0.49
Rank	1	3	2

TABLE III

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

Level	Load	Sliding speed [m/s]	Wt. ratio [%]
1	4.399	4.072	3.727
2	3.763	3.485	3.291
3	2.590	3.195	3.734
Delta	1.810	0.876	0.442
Rank	1	2	3

TABLE IV

ANOVA for wear rate.

Source	DOF	Seq. SS	Adj. SS	Adj. MS	F	% contrib.
Load	2	0.0000316	0.0000316	0.0000158	19.98	94
Sliding speed	2	0.0000001	0.0000001	0.0000001	0.08	0.29
Wt. ratio [%]	2	0.0000001	0.0000001	0.0000000	0.05	0.29
Error	2	0.0000016	0.0000016	0.0000008		5.42
Total	8	0.0000334				

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

On the other hand, according to the analysis of variance for coefficient of friction from Table V, the applied load (74.21%) is the most significant factor, followed by sliding speed (16.36%) and weight percentage of carbon fiber (7.42%).

2.2.2. Confirmation tests

The last step of Taguchi analysis is the confirmation test. According to Taguchi analyses, the optimum levels of parameters were determined using Tables II and III.

TABLE V

ANOVA for coefficient of friction.

Source	DOF	Seq. SS	Adj. SS	Adj. MS	F	% contrib.
Load	2	0.0300559	0.0300559	0.0150279	18.96	74.21
Sliding speed	2	0.0066266	0.0066266	0.0033133	4.18	16.36
Wt. ratio [%]	2	0.0022314	0.0022314	0.0011157	1.41	7.42
Error	2	0.0015853	0.0015853	0.0007926		2
Total	8	0.0404991				

The confirmation experiments were performed by taking an arbitrary combination of factors, $A_1B_2C_1$ for wear rate and $A_1B_1C_3$ for coefficient of friction. The estimated S/N ratio can be calculated according to the Eq. (3) for wear rate and Eq. (4) for the coefficient of friction.

$$\hat{\eta} = \bar{T} + \left(\bar{A}_1 - \bar{T}\right) + \left(\bar{B}_2 - \bar{T}\right) + \left(\bar{C}_1 - \bar{T}\right), \quad (3)$$

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

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 3.33% and for coefficient of friction it is 3.41%. This verifies that the predicted values are reliable.

TABLE VI

Confirmation tests results.

S/N ratio of wear rate [dB]			S/N ratio of coefficient of friction [dB]		
Level: $A_1B_2C_1$			Level: $A_1B_1C_3$		
Predicted	Exp.	% Error	Predicted	Exp.	% Error
49.9518	51.675	3.334	5.03692	5.215	3.414

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 (94%) had the highest influence on the wear rate of carbon fiber-reinforced epoxy composites. According to the analysis of variance for coefficient of friction, the applied load (74.21%) is, again, the most significant factor.

The S/N ratio, estimated 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 coefficients of friction were observed.

References

[1] www.rsc.org/education/teachers/resources/inspirational/resources/4.3.1.pdf.

[2] S. Eksi, K. Genel, *Acta Phys. Pol. A* **128**, B-59 (2015).

[3] N. Ozsoy, M. Ozsoy, A. Mimaroglu, *Acta Phys. Pol. A* **130**, 297 (2016).

[4] I.K. Yilmazcoban, S. Doner, *Acta Phys. Pol. A* **130**, 342 (2016).

[5] A. Gunen, *Acta Phys. Pol. A* **130**, 217 (2016).

[6] B. Suresha, G. Chandramohan, P. Sampathkumaran, S. Seetharamu, S. Vynatheya, *J. Reinf. Plast. Comp.* **25**, 771 (2006).

[7] C. Soutis, *Mater. Sci. Engin. A* **412**, 171 (2005).

[8] ASTM G99-95, *Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus.*

[9] N. Ozsoy, M. Ozsoy, A. Mimaroglu, *Acta Phys. Pol. A* **128**, B-55 (2015).