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Multiple response analysis of tribological property of epoxy composites by Taguchi method

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ABSTRACT

In this study, 60 wt. % carbon filled-epoxy composites containing 0 wt. %Al_2O_3, 2.5 wt. %Al_2O_3 and 5 wt. %Al_2O_3 nano particles were fabricated by mixing method associated with compression molding method. The tribological property of the composites was investigated in a conventional wear machine using Taguchi method (TM). The influences of different parameters like nano addition, load, sliding speed and grit size on the wear resistance of the tested samples were investigated under SiC abrasives. The results exhibited that grit size was an effective on the wear resistance, load and speed was followed it, respectively. Optimized processing condition of the tribological resistance of the composites was first level of load, speed, grit size and third level of material's type. Multi-linear regression equation was developed to predict the tribological resistance of the composites with the average error of 4.2%.

Keywords: Epoxy; SiC; Al_2O_3; nano; Carbon filled composite; load; speed; wear; Taguchi method

1 Introduction

Fiber-reinforced polymer composites have been used for a wide range of structural applications such as aircraft, automotive, marine, package and construction industries due to their high specific strength and high stiffness [1]. Polymers based composite forms a very important class of tribological engineering materials in many elements of mechanical system such as gears, cams, bearings, bushes, bearing cages, etc. where the tribological property without lubricated condition is a dominant factor [2]. In addition to these advantages, other benefits are to have lower coefficient of friction and higher resistance to corrosion and insulating property, associated with easy manufacturing and machining. Among the fiber/particle's reinforcements; glass, Kevlar, Al_2O_3, SiC and boron have been used considerably for making the polymer and metal matrix composites. However, carbon fabric is the best selection for such an application in comparison to short fibers or particles due to tightness properties in the polymer matrix composites, but carbon fiber is brittle and highly cost effective. In order to improve the carrying capacity of load, carbon in the form of fabrics were selected due to having the aligned structure [3].

Wear involves a progressive loss of material because of relative motion between sliding hard and soft surfaces. Abrasive wear is the most common type of wear in industry since its contribution is about 63% of total financial cost [4]. It occurs as the hard particles or hard protuberances force against and moving along the solid surface. Over the last two decades, the investigation on the tribological and frictional characteristics of many types of polymer composites were reported, such as glass fibre reinforced epoxy polymer composite including some SiC, Al2O3, graphite [5,6,7,8], glass-filled and carbon-filled PTFE composite [9], PEEK/PI composite [10-15]. Mathematical models were developed for predicting the tribological behavior of fiber-reinforced composites [16, 17, 18, and 19].

The literature survey has indicated that some studies conducted on the tribological properties of epoxy based

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composites at abrasive conditions [6-14]. But, restricted numbers of investigations are carried out on the fabric-reinforced composites using some statistical methods [16-18, 19]. The purpose of this work, thus, is to study the effects of load, speed, grit size and nano addition on the tribological behaviors of the composite through the TM.

2 EXPERIMENTAL

2.1. Manufacturing the composites

Carbon filled epoxy composites including 60wt. % carbon were produced with molding method. Filler materials were carbon in the form of fabrics supplied by MC technic Ltd. The carbon type was a plain weave fabric having a 7-10 µm diameter and 200 g/m^2 specific weight. Thermosetting bisphenol-A epoxy (SR 8500) and amine-system harder (SD 860x) was applied as a matrix system in a ratio of 100: 28. These are supplied by MC technic Ltd., Netherland.

For manufacturing of nano composites, the fillers material used were Al_2O_3-Alpha, 99.5% pure (grit size is about 40-60 nm) was provided from MKnano, Canada. The specific gravity was about 3.3 g/cm^3. Nano particles were evenly distributed in epoxy with mechanical stirring at a period over 45 min. The epoxy resin was mixed thoroughly with weight fractions of nano Al_2O_3 powders (0wt.%, 2.5 wt.%, 5wt.%). The mixtures of resin were spatulated on composite panel of 150 x 150mm^2 in size. The thickness of the mould plate was about 4.0 mm. The percentage of carbon fabrics in the composites was about 60±3 by weight (60 wt.% CF). The whole assembly was pressed between mould plates under a load of 0.5 MPa for 24 hours. Finally, post-curing was done at 45 ^{o}C for 24 hours. Composite laminates without nano particles were also prepared in the same manner for a comparison purpose. Three different types of specimens produced and used for wear tesing. These are called as fabric-reinforced epoxy composite (CFRC) containing 60wt.%BF, CF60+2.5wt.% Al_2O_3 reinforced nano epoxy composites and CFRC+5wt.%Al_2O_3 reinforced nano epoxy composites were manufactured, respectively.

2.2. Taguchi method

In order to study the effect of main process parameters on the tribological behavior of epoxy composites, the technique of Taguchi being an empirical modelling was adopted to determine the relationship between the various testing factors and responses. This is defined as a collection of the statistical and mathematical technique and is used for optimization of various engineering problems. This design allows us for efficient estimation of the first- and second-order coefficients.

For L9 (3^4) design, this experiment indicated three main wear test conditions such as nano content (M), load (L), speed (S) and grit size (G) for these composites. Control parameters, their codes and levels were shown in Table 1, which exhibited the three levels of experimental plan. In order to acquire a more accurate results, at least each experimental run was repeated three times in these testing processes. In this approach, the results of experimental data were transformed into SNR using coded values.

TABLE 1. CONTROL PARAMETERS AND THEIR CODED AND UNCODED LEVELS

Symbol	Main control parameters	Unit	Level 1	Level 2	Level 3
	Coded values				
M	Material type/nano addition	Wt.%	-1	0	+1
L	Load	N	-1	0	+1
S	Speed	m/s	-1	0	+1
G	Grit size	Mesh	-1	0	+1
	Uncoded values				
M	Material type /nano addition	wt.%	0	2.5	5
L	Load	N	2	6	12
S	Speed	m/s	0.32	0.64	0.96
G	Grit size	Mesh	800≈15 µm	360≈38 µm)	180≈84 µm

2.3.Wear tests

The wear tests were conducted on the epoxy composites in a pin-on-disc set up. A steel holder was used in the wear machine to mount the pin specimens. Epoxy based composite was rubbed in a rotational motion under cold rolled steel of AISI 5190 (Ø120 x 14 mm). Specimens were machined from the laminated composites. For this aim, a water jet machining was preferred to cut the square shape of 5 mm with 4 mm thickness. For wear testing at abrasive sliding, different meshes of SiC abrasive emery papers were used. The nano added specimens were experimented under different loads and speeds. Maximum sliding distance reached was about 125 m. After completing wear tests, they were weighed on a microbalance. The weight loss was calculated from the mass loss method.

3. RESULTS AND DISCUSSION

3.1. Weight loss

The experimental data was analyzed using the software MINITAB 17. The experimental plan and results of the abrasive wear data of epoxy composites under different sliding conditions were shown in Table 2. The results also covered the SNR for the tested samples. Thus, the mean response referred to the average values of the wear perfor-

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mance under various levels. Among the control factors, the grit size indicated the highest influence on the wear resistance (Fig.1c) because of increasing the penetration ability of SiC abrasives for composite [9], but the factor L and the factor S were followed, respectively (Fig.1b,c). Furthermore, linear increases were evidenced with increasing the grit size, load and speed because increasing load and sliding speed increased the temperature at the interface. The frictional heat produced at the interface led to thermal softening of the matrix. The results were found to be in a good agreement with those obtained by the previous works [9,19,21,22].

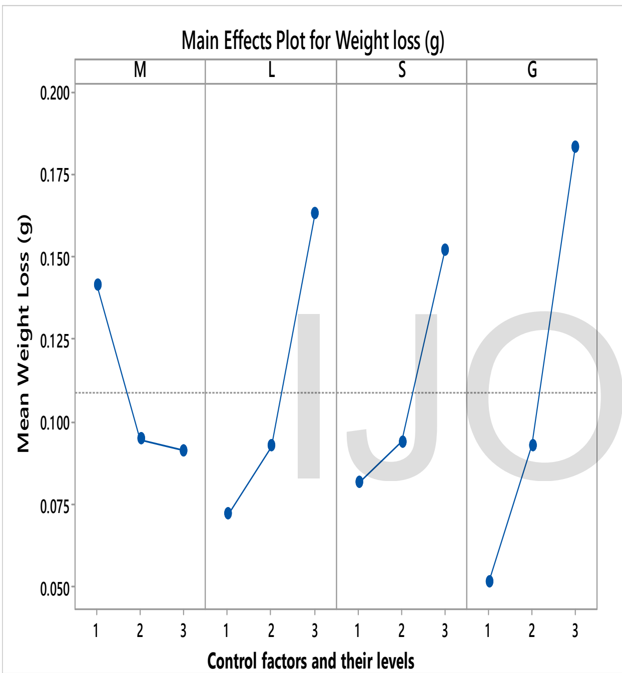

Fig.1. Mean weight loss of carbon-reinforced-nano composites when tested against SiC abrasive.

As a result of this, the bonding between fiber and matrix degraded the weakness. On the one hand, the asperities of SiC over the steel counter face disc can remove the laminated composite by cutting action. The increases in the weight loss with grit sizes changed linearly. This might be because the sizes of SiC abrasives decreased from 800 meshes to 360 & 180 meshes, which are corresponded to about 15 μm, 38 μm and 84 μm, respectively. As a result of these, cutting abilities of SiC abrasives increased significantly, hence leading a higher weight loss. Therefore, under a higher load/speed/grit size condition, contact area between the sliding surfaces increased. However, it decreased slightly with increasing nano-addition to the epoxy composite, but no significant variations occurred. It is worth to note that the nano's sensitivity was lower than that of the speed and load, The filler contents and grit sizes exhibited the most significant factor on the tribological properties of the polymer composites at abrasive condition [23, 24,and 25].

Table 2. Average weight loss of carbon-reinforced epoxy composites when tested against sic abrasive
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Nano addition (wt.%),M	Load (N), L	Speed (m/s),S	Grit size (mesh),G	Weight loss (g)	SNRA (dB)	Theor. WL (g)	Error, %
1	1	1	1	0.0184	34.703	0.017	7.953
1	2	2	2	0.0931	20.621	0.103	10.43
1	3	3	3	0.312	10.116	0.310	0.436
2	1	2	3	0.116	18.710	0.110	4.900
2	2	3	1	0.063	24.013	0.057	9.417
2	3	1	2	0.104	19.659	0.098	5.500
3	1	3	2	0.0804	21.894	0.083	3.262
3	2	1	3	0.121	18.344	0.124	2.191
3	3	2	1	0.072	22.853	0.075	3.620

3.2. Regression analysis

The correlations between the control parameters like load, speed, weight fraction of nano, grit size and weight loss of the samples were found by multiple regressions. The correlations were as follows.

$$\text{Weight loss, } WL\,(g) = 0.0530 - 0.0031\,M + 0.0212\,L - 0.1860\,S + 0.0679\,G - 0.0374\,M{*}L + 0.0414\,M{*}S + 0.0599\,L{*}S \quad (1)$$

Where *WL* means is the average weight loss Eq. (1) indicated that the weight loss was increased with the load and grit size, but the weight loss decreased with the nano addition and speed in testing the composites. The model had an adjusted R^2 value of 96.6%.

The estimated weight loss of C60 fabric-reinforced epoxy composites was calculated using Eq.(1) with the substituting the recorded values of the variables. The predicted dry weight loss was found to be very close to the actual values in generalizing system characteristics by the predicting values. In the predicting of the weight loss, average error was found to be about 5.30%. Thus, the developed model can be effectively used to estimate the wear rate of CFRC and CFRC-n epoxy composites.

3.3. Confirmation test

At final step, the quality characteristic was verified through the optimal level of design parameters (M_3 L_1 S_1 G_1). The weight loss was calculated as Eq. (1) in terms of coded values. The measured value was about 0.0682 g while theoretical value of SNR was about 23.35 dB (Table 3). It is indicated that a comparison was made between the predicted

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weight loss and the actual weight loss when taking into account the optimal factors. It is observed that the difference between the verification and calculation was within a reasonable value (1.62%). The predicted testing condition yielding the lowest weight loss were 3 N load, 0.32 m/s speed, 800 grit (≈15 μm) when running with 5wt.%Al_2O_3 nano composite under the dry wear condition. The predicted WL of samples was calculated about 0.0682 g while measured values were about 0.071 g. The difference in the WL was about 4.25%, which is lower than 5%.

Table 3. Confirmation experiment.

Output	Optimal process parameters		Difference
Level	$M_3 L_1 S_1$ G1 (Experi.)	M_3 L_1 S_1 G_1 (Theor.)	(%)
SNR of weight loss (dB)	23.35	22.97	1.62
Weight loss (g)	0.0682	0.071	4.25

4.0 CONCLUSIONS

Taguchi method was applied on the tribological property of the fabric reinforced epoxy composites including 5wt. %Al_2O_3 nano-particles against the SiC abrasive and the results were presented at different conditions.

1. The grit size was found to be an important parameter on the wear resistance, followed by load, speed, and lastly the nano addition.
2. The predicted wear condition giving the lowest weight loss of the composites was 3 N load, 0.32 m/s speed and 800 grit size when running on the composite covering 5wt. %Al_2O_3 nano.
3. The linear regression equations were developed to predict the wear resistance for the tested materials. The difference between verification and calculation was about 4.25%, which is reasonable.

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