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INVESTIGATION OF THE ABRASIVE WEAR BEHAVIOUR OF GRAPHITE FILLED CARBON FABRIC REINFORCED EPOXY COMPOSITE - A TAGUCHI APPROACH

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ABSTRACT

An experimental investigation was carried out to study the effect of the filler weight fraction, normal load and sliding distance on the abrasive wear behavior of Carbon/Epoxy composite. In this study, comparative abrasive wear performance of carbon fabric reinforced Epoxy composite filled with varying weight fraction of graphite fillers has been reported. Wear studies were carried out using rubber wheel abrasion test (RWAT) rig. Weight loss of the composites during abrasion has been examined as a function of sliding distance and normal load. Findings of the experiments indicate that abrasive wear of the composites depend on the applied load, as well as on the weight fraction of fillers. A plan of experiments, based on techniques of Taguchi, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were performed on the measured data and S/N (signal to noise) ratios to investigate the influence of the control parameters on the wear of these composites. Among the control parameters, normal load has the highest physical properties as well as statistical influence on the abrasive wear of the composites, followed by sliding distance and filler content. The interaction of sliding distance and normal load shows significant effect on the wear rate and the influence of other interactions are very less. Finally, confirmation tests were conducted to verify the experimental results foreseen from the mentioned correlations, it is found that there is a good agreement between the estimated value (21.2275) and the experimental value (21.6499) of S/N ratio with an error of 1.9%.

Keywords: Carbon fabric, epoxy, graphite, abrasive wear, orthogonal array.

1. INTRODUCTION

Polymer matrix composites are emerging as promising materials in many structural and tribological applications. Because of the high strength to weight and stiffness to weight ratios, easy processibility and chemical resistance, the composites are finding a wide variety of structural applications in aerospace, automotive, and chemical Industries. Polymer matrix composites are also used increasingly in applications where friction and wear are important parameters like gears, seals, bearings, breaks etc. The epoxy resin is a thermo set polymer, used as matrix material for producing composites in structural applications. Mechanical and tribological properties of the epoxy-based composites can be improved by incorporating the right kind of reinforcements and fillers. Among the various types of reinforcements like particulate, short, long, and bidirectional woven fabric, bidirectional woven fabric reinforcement is the most promising for fiber-reinforced composites. Modification of woven fabric reinforced composites by incorporation of fillers has been a popular research activity in the plastics industry since the properties of resultant materials may be significantly changed by the introduction of fillers and fabrics. Carbon fiber is one of the most useful reinforcement materials in composites, its major use being the manufacture of components in the aerospace, automotive, and leisure industries. The unique features of carbon fiber are low density, high strength, lightweight, high modulus and high stiffness leading to the development of new industrial applications.

A progressive loss of material from the surface of any component is called wear. It is a material response to the external stimulus and can be mechanical or chemical in nature. In abrasive wear, the hard asperities on one surface move across a softer surface under load, penetrate and remove material from the softer surface leaving grooves [1]. In the three-body abrasive wear, the particles are loose and may move relative to one another, and possibly rotate, during sliding across the wearing surface. Wear is always undesirable and the effect of wear on the reliability of industrial components is very important and recognized widely. Hence, a fundamental and comprehensive understanding of the three-body abrasive wear behavior of these composites is required.

Experimental investigations were carried out by Farag and Drai [2] to demonstrate the effect of graphite filler contents on the mechanical and tribological behavior of glass (30% volume fraction) -polyester composite system. They reported that the mechanical and tribological behavior was improved when the graphite filler content was increased up to 7.5% and then decreased thereafter. At 7.5% filler content, the modulus of elasticity, yield stress, ultimate tensile and compression strength and wear resistance increased as compared to unfilled composite, while the wear rate was decreased. Feng Hua Su et al. [3] studied the influence of nano Al_2O_3 and Si_3N_4 particulate filler in carbon fabric / phenolic resin composites on tribological properties, and concluded that, filled composites improved the friction and wear behavior of carbon fabric composites. Particulates increase the interfacial bonding strength, which increases mechanical strength. Nano particulates improve wear resistance of carbon fabric composites at elevated temperature. Wear rate of filled carbon fiber composite is less than the unfilled. Thomas Larsen et al. [4] studied the friction and wear properties of glass /epoxy and carbon aramid /epoxy composite and found that, coefficient of friction decreased by replacing carbon aramid with glass fiber, and wear rate of glass /epoxy composite is more than the carbon aramid /epoxy composites. Suresha et al. [5] investigated the friction and wear behavior of glass-epoxy composite with and without graphite filler. They concluded that the graphite filled glass epoxy composite showed higher resistance to sliding wear as

compared to plain glass-epoxy composites. S R Chauhan et al. [6] studied the tribological behavior of glass fiber reinforced vinylester composites filled with fly ash particulates using a pin on disc wear testing apparatus. Orthogonal array and analysis of variance (ANOVA) were used to investigate the influence of process parameters on the tribological properties. The results revealed that the inclusion of fly ash decreased the coefficient of friction and increased the wear resistance of the composites significantly. Also they concluded that the factorial design of experiment can be successfully employed to describe the frictional and wear behavior of composites and developed linear equations for predicting wear rate with selected experimental conditions. S Basavarajappa et al. [7] studied the tribological behavior of glass epoxy polymer composites with SiC and graphite particles using a pin on disc wear test rig under sliding conditions. The results showed that the inclusion of SiC and graphite particles will increase the wear resistance of the composite greatly. They also developed a mathematical model using Design of experiments approach by Taguchi method.

Wealth of information is available in the literature on the tribological behavior of various fiber reinforced polymer matrix composites. A number of studies have been reported on the effect of normal load, sliding distance, fiber fraction, orientation, etc., on the wear rate of polymer composites. The knowledge of the relations between material parameters and tribological performance is important in the determination of strength and wear rate of the composite. The design of experiment approach by Taguchi technique has been successfully used by researchers in the study of wear behavior of polymer composites. Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to the source of variation. Taguchi technique creates a standard orthogonal array to consider the effect of several factors on the target value and defines the plan of experiments. The experimental results were analyzed by using analysis of means and variance of the influence of factors.

The present work focuses on the study of three body abrasive wear characteristics of bi-directional woven carbon fiber reinforced epoxy composites filled with graphite particles. An inexpensive and easy to operate experimental strategy based on Taguchi experimental design technique is used to determine the relative significance of various control factors influencing the wear rate.

2. EXPERIMENTAL

2.1 Materials

In this investigation, composites were fabricated using bidirectional plain-woven carbon fabric (density 200 g/m^2), containing Polyacryl nitrile (PAN) based carbon fiber, supplied by CS Interglass AG, BenzstraBe, as reinforcement. The matrix system used is a medium viscosity epoxy resin (LAPOX -12), and a room temperature curing polyamine hardener (K5), both supplied by ATUL India Ltd, Gujarat, India.. The fillers that have been used are graphite particulates supplied by Luba Chemie, Bombay. Details of the fabrication method and the mechanical properties of the carbon epoxy composites are given in our previous work [8]. Three types of composite samples were prepared based on the weight fraction of graphite filler in the composite.

2.2 Experimental setup

The dry sand rubber wheel abrasion test setup as per ASTM G65 is used to conduct the wear studies. The abrasives are introduced between the test specimen and the rotating wheel with a chlorobutyl rubber tire. The test specimen is pressed against the rotating wheel

at a specified force by means of lever arm while a controlled flow of grits abrade the test surface. The rotation of wheel is such that its contact face moves in the direction of grit flow. The pivot axis of the lever arm lies within a plane, which is approximately tangential to the rubber wheel surface and normal to the horizontal diameter along which the load is applied. The tests were carried out for different loads and sliding distances.

2.3 Test procedure

The test samples were prepared by cutting the composite laminates into 25mm X 75mm X 3mm size pieces. The samples were cleaned, dried and its initial weight was determined in a high precision digital electronic balance (0.0001 gm accuracy) before it was mounted in the sample holder. The silica sand was used as abrasives in the present experiments. The abrasive was fed at the contacting face between the rotating rubber wheel and the test sample. The tests were conducted at a rotational speed of 200 rpm. The rate of feeding of the 400 µm silica sand abrasive was 250 gm/min. The experiments were carried out at a normal load of 11 N, 23N and 35N, and the abrading distances chosen were 300m, 600m and 900m. The wear was measured by the loss in weight.

2.4 Taguchi technique

A plan of experiments, based on the Taguchi technique, was performed to acquire data in a controlled way. An orthogonal array and analysis of variance (ANOVA) were applied to investigate the influence of process parameters on the wear behavior of composites. The Taguchi design of experiment approach eliminates the need for repeated experiments and thus saves time, material and cost. Taguchi approach identifies not only the significant control factors but also their interactions influencing the wear rate predominantly. The most important stage in the design of experiment lies in the selection of the control factors. In the present work, the impacts of three such parameters are studied using L27 (3^{13}) orthogonal array. The operating conditions under which abrasive wear tests carried out are given in Table 1.

Table 1: Levels of variables used in the experiments

Control factors	Units	Level		
		I	II	III
Filler Content (A)	%	2	4	6
Normal Load (B)	N	11	23	35
Sliding distance (C)	m	300	600	900

Three parameters are percentage of filler, normal load and sliding distance and each at three levels are considered in this study. Three parameters each at three levels would require Taguchi's factorial experiment approach to 27 runs only, offering a great advantage. The experimental observations are transformed into a signal-to-noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristics. The S/N ratio for minimum wear rate coming under smaller is better characteristic, which can be calculated as logarithmic transformation of the loss function by the equation:

$$\frac{S}{N} = -10 \log \frac{1}{n} \sum y_n{}^2 \qquad (1)$$

Where 'n' is the repeated number of trial conditions and y_1, y_2....y_n are the response of the wear rate characteristics.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of Experimental Results

The analysis of the experimental data is carried out using the software MINITAB 16 specially used for design of experiment applications. In order to find out statistical significance of various factors like filler content (A), normal load (B) and sliding distance (C), and their interactions on wear rate, analysis of variance (ANOVA) is performed on experimental data. Before analyzing the experimental data using this method for predicting the measure of performance, the possible interactions between control factors are considered. Thus, factorial design incorporates a simple means of testing for the presence of the interaction effects. The mean response refers to the average values of the performance characteristics at different levels. The overall mean for the S/N ratio of the wear rate was found to be 10.11897 db.

Table 2 shows the result of the ANOVA with the wear rate. The last column of the table indicates p-value for the individual control factors and their possible interactions. It is known that smaller the p-value, greater the significance of the factor/interaction corresponding to it.

Table 2. ANOVA table for S/N ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	2	2.94	2.94	1.47	5.63	0.03
B	2	661.334	661.334	330.667	1266.04	0.000
C	2	156.529	156.529	78.264	299.66	0.000
A*B	4	1.884	1.884	0.471	1.8	0.221
A*C	4	1.959	1.959	0.49	1.87	0.208
B*C	4	12.426	12.426	3.106	11.89	0.002
Residual Error	8	2.089	2.089	0.261		
Total	26	839.162				

The ANOVA table for S/N ratio (Table 2) indicate that, the normal load (p=0.000), sliding distance (p= 0.000) and filler content (p=0.030) in this order, are significant control factors effecting the wear rate. It means, the normal load is the most significant factor and the filler content has less influence on the performance output. Between the three possible interactions, the interaction of normal load and sliding distance (p=0.002) shows remarkable contribution on the wear rate followed by the interaction of filler content and sliding distance (p=0.208) and the interaction of filler content and normal load (p=0.221).

Table 3. Response Table

Level	C1	C2	C3
1	10.47	16.974	13.275
2	10.21	7.915	9.647
3	9.677	5.468	7.435
Delta	0.793	11.506	5.841
Rank	3	1	2

The response table shows the average of each S/N ratios for each level of each factor. The table includes ranks based on Delta statistics, which compare the relative magnitude of effects. The Delta statistic is the highest minus the lowest average for each factor. Minitab assigns ranks based on Delta values; rank one to the highest Delta value, rank two to the second highest, and so on. From the response tables 3, it is clear that, first rank to the normal load, followed by the sliding distance and filler content. From both ANOVA and response tables it is clear that, the normal load is the most significant factor and the filler content has less influence on the performance output.

Figure 1 shows graphically the effect of the three control factors on wear rate of the composite specimens. A main effect is seen when different levels of a factor affect the response differently. A main effects plot graphs the response mean for each factor level connected by a line. When the line is horizontal, then there is no main effect present. Each level of the factor affects the response in the same way, and the response mean is the same across all factor levels. When the line is not horizontal, then there is a main effect present. Different levels of the factor affect the response differently. The steeper the slope of the line, the greater the magnitude of the main effect on the wear rate. For each control factors, a level with maximum value of mean of S/N ratio will give minimum wear rate. In this case, the analysis of results leads to the conclusion that factors combination A1, B1 and C1 gives minimum wear rate as shown in the figure 1. That is, 2% graphite filler, with 11 N load and 300 m sliding distance will lead to a minimum wear rate.

When the effect of one factor depends on the level of the other factor, interaction plot can be used to visualize possible interactions. Parallel lines in an interaction plot indicate no interaction. The greater the difference in slope between the lines, the higher the degree of interaction. From the interaction plot shown in the figure 2, it is observed that the interaction A x B, i.e., percent filler and normal load shows significant effect on the wear rate of the composite samples.
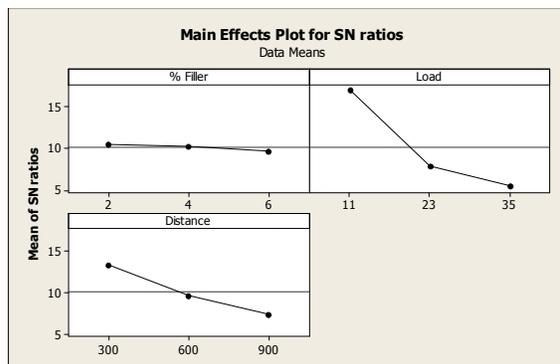

Figure 1. Effect of control factors on wear   Figure 2. Interaction Plot.
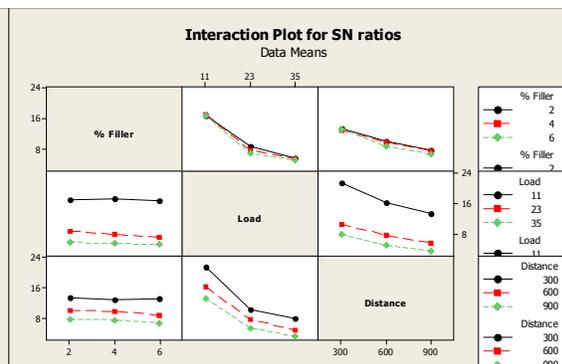
3.2 Confirmation test

The confirmation experiment is the final step in the design of experiments process. The confirmation experiment is conducted to validate the inference drawn during the analysis phase. The confirmation experiment is performed by considering the new set of factor setting A1 , B1 and C1 to predict the wear rate.

The predicted value of the S/N ratio at the optimum level η̂ is calculated as:

$$\hat{\eta} = \eta_m + \sum_{i=0}^{o}(\bar{\bar{\eta}}_1 - \eta_m) \qquad (2)$$

Where η_m is the total mean S/N ratio, $\bar{\bar{\eta}}_l$ is the mean S/N ratio at the optimal level, and o is the number of main design parameters that significantly affect the wear performance of the composites. A new combination of factor levels A1, B1 and C1 are used to predict the S/N ratio of wear predictive equation and is found to be 21.2275 with an error of 1.9%. Table 4 shows the comparison of the predicted S/N ratio with the actual (experimental) S/N ratio using the optimal parameters and there seems to be a quite good agreement between the two. This validates the statistical approach used for predicting the measures of performance based on knowledge of the input parameters.

Table 4. Results of the confirmation experiments

	Optimal control parameters	
	Prediction	Experimental
Level	A1,B1,C1	A1,B1,C1
S/N Ratio	21.2275	21.6499
% Error	1.9%	

4. CONCLUSION

In this study, the effect of graphite filler on tribologiical properties of carbon reinforced epoxy composites has been examined. According to obtained results, it can be concluded that:
1. Design of experiments approach by Taguchi method enabled us to analyze successfully the wear behavior of the composites with filler material, load and sliding distance as test variables.
2. Among the control factors, normal load has the highest physical properties as well as statistical influence on the abrasive wear of the composites (p=0.000), followed by sliding distance (p= 0.000) and filler content (p=0.03). The interaction of sliding distance and normal load shows significant effect on the wear rate and other interactions will influence very less.
3. According to main effects plot, factors combination of A1, B1 and C1 gives minimum wear rate. That is, 2% graphite filler, with 11 N load and 300m sliding distance will lead to a minimum wear rate.
4. Based on the interaction plot, it is observed that the interaction A x B, i.e., percent filler and normal load shows significant effect on the wear rate.
5. During the confirmation test, it is found that there is a good agreement between the estimated value (21.2275) and the experimental value (21.6499) of S/N ratio with an error of 1.9%. Therefore, the factors combination of A1, B1 and C1 was treated as the optimal.

REFERENCES

[1]   D. Gates (1998), "Two-body and three-body abrasion: a critical discussion", Wear 214, pp 139-146.

[2]   Farag M. Mohammed and Drai A. Smait (2012), "Mechanical and Tribological Behavior of Glass-Polyester Composite System Under Graphite Filler Content", Eng. &Tech. Journal Vol. 30, No. 4, pp 672-683.

[3]   Feng-hua Su, Zhao-zhu Zhang and Wei-min Liu (2006), "Mechanical and tribological property of Carbon Fabric composites filled with several nano particulates", Wear 260, pp 861-868.

[4]   Thomas Larsen, Tom L Andersen, Bent Thorning, Andy Horsewell and Martn E Vigild (2007), "Comparison of friction and wear for an epoxy reinforced by a glass or carbon / aramid hybrid weave", Wear 262, pp 1013-1020.

[5]   B.Suresha,   G.Chandramohan,   P.Sampathkumaran   and   S.Sethuramu   (2007), "Investigation of the friction and wear behavior of glass-epoxy composite with and without graphite filler", Journal of Reinforced Plastics and Composites Vol. 26, pp 81-93.

[6]   S R Chauhan, Anoop Kumar, I Singh and Prashant Kumar (2010), "Effect of Fly Ash Content on Friction and Dry Sliding Wear Behavior of Glass Fiber Reinforced Polymer Composites – a Taguchi Approach", Journal of Minerals & Materials Characterization & Engineering, Vol.9, No.4, pp 365-387.

[7]   S Basavarajappa, K V Arun and J Paulo Davim (2009), "Effect of filler materials on dry sliding wear behavior of Polymer Matrix Composites-A Taguchi Approach", Journal of Minerals & Materials Characterization & Engineering, Vol.8, No.5, pp 379-391.

[8]   K Sudarshan Rao, Y S Varadarajan and N Rajendra (2011), "Mechanical behavior of Graphite filled and unfilled Carbon Epoxy Composite", CiiT International Journal of Automation and Autonomous Systems, Vol. 3, No. 8, pp 368 – 375.

[9]   S.S. Mahapatra and Vedansh Chaturvedi (2009), "Modelling and analysis of abrasive wear performance of composites using Taguchi approach", International Journal of Engineering, Science and Technology, Vol. 1, No. 1, pp. 123-135.

[10] J Paulo Davim and Rosaria Cardoso (2009), "Effect of reinforcement (carbon & glass) on friction & wear behavior of the PEEK against steel surface at long dry sliding", Wear 266, pp 795-799.

[11] P. Kurmi, S. Rathod and P. Jain, "Abrasive Wear Behavior Of 2014al-Tic In Situ Composite" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 3, 2012, pp. 229 - 240, Published by IAEME

[12] D.Lingaraju, K.Srinivas and B.A.Ranganath, "Failure Analysis Of Pin Loaded Glass Epoxy/Polystyrene Composite Plates" International Journal Of Advanced Research In Engineering & Technology (IJARET), Volume 3, Issue 2, 2012, pp. 137 - 144, Published by IAEME

[13] Hargude N.V and Ghatage k.D, "An Overview Of Genetic Algorithm Based Optimum Design Of An Automotive Composite (E-Glass / Epoxy And Hm-Carbon / Epoxy) Drive Shaft" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 1, 2012, pp. 110 - 119, Published by IAEME