STATISTICAL ANALYSIS FOR THE ABRASIVE WEAR BEHAVIOR OF BAGASSE FIBER REINFORCED POLYMER COMPOSITE

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Abstract— In the present study, a mathematical model has been developed to predict the abrasive wear behavior of bagasse fiber reinforced polymer composite. The experiments have been conducted using full factorial design in the design of experiments (DOE) on pin-on-disc type wear testing machine, against 400 grit size abrasive paper. A second order polynomial model has been developed for the prediction of wear loss. The model was developed by response surface method (RSM). Analysis of variance technique at 95% confidence level was applied to check the validity of the model. The effect of volume percentage of reinforcement, applied load and sliding velocity on abrasive wear behavior was analysed in detail. To judge the efficiency and ability of the model, comparison of predicted and experimental response values outside the design conditions was carried out. The result shows, good correspondence, implying that, empirical models derived from response surface approach can be used to describe the tribological behavior of the above composite.

Keywords- *Response surface methodology (RSM), Full factorial design, Wear loss, bagasse fiber.*

INTRODUCTION

In the recent years, natural fiber reinforced with polymer matrix have attracted the attention because of their low cost, lightweight, renewability, low density, high specific strength, non-abrasivity, combustibility, non-toxicity, low cost and biodegradability. The availability of natural fibres and ease of manufacturing have tempted researchers to try locally available inexpensive fibres and to study their feasibility of reinforcement purposes and to what extent they satisfy the required specifications of good reinforced polymer composite for tribological applications [1]. In tropical and equatorial countries, fibrous plants such as banana, oil palm, bamboo, sugarcane, etc. are available in abundance [2, 3] and fibres like sugarcane [4, 5 and 6] appear to have a considerable interest as reinforcement in polymer matrices for low-cost composites. They are widely used in the production of bearing components used in automobile industries such as gears, wheels, bushes, etc. [7-10] in which friction and wear are critical issues. The importance of tribological properties convinced many researchers to study the friction and wear behavior and to improve the wear resistance of polymeric composites.

Little information concerning the tribological performance of natural fibre reinforced composite material [11–14] has been reported. Basavarajappa et al. [15] studied the dry sliding wear behavior of graphite filled glass epoxy composites and concluded that Addition of Graphite in glass–epoxy composite exhibits lower weight loss, whose value drops as the percentage of Graphite increases in the composite. U.K.Dwivedi et al. [16] investigated on the influence of MA-g-PP on abrasive wear behavior of chopped sisal fiber reinforced polypropelene composites. They concluded that the addition of MA-g-PP coupling agent has significantly influenced the wear resistance of sisal fibre reinforced PP composites.

Besides experimental work on natural fiber based composite, researchers have worked on different mathematical models to predict the material properties. Most of these researchers have worked on Metal Matrix composite (MMCs). Sahin and Ozdin [17] investigated the abrasive wear behaviour of aluminium based composites using pin on disc type of machine and developed in terms of the applied load, sliding distance and particle size using factorial design. N.S.M. El-Tayeb et al.[18] Studied the cryogenic effect on frictional behaviour of titanium alloy sliding against tungsten carbide using response surface methodology (RSM) approach and expressed the interrelationship between the friction coefficient (response) and independent variables such as speed, load, and sliding distance. Farias et al. [19] studied the sliding wear of austenitic stainless steels. They adopted to obtain an empirical model of wear rate as a function of applied load and sliding velocity using RSM. From these discussions it is clear that though lot of work has been done on MMCs, as per the information of author no work has been done on the use of RSM technique to predict the tribological performance of natural fiber composite.

Therefore in the present work an attempt has been made to investigate the abrasive wear behaviour of bagasse fiber reinforced epoxy composite under various testing conditions. RSM was adopted to obtain an empirical model of wear loss (response) as a function of amount of reinforcement, applied load and sliding velocity (input factors).

MATERIALS AND METHODS

Fabrication of composites

The type of epoxy resin used in the present investigation is LY 556 and hardener HY951 supplied by Ciba- Geigy of India Limited. Epoxy is mixed with hardener in the ratio 10:1 by weight. Different volume fraction of chopped bagasse fibers (10, 15 and 20%) were added separately in the above epoxy mix and stirred for 10 min by a glass rod to obtain uniform dispersion. The final resultant mix of chopped bagasse fiber and resin was poured into cylindrical mould [Fig.1] and fixed properly. During fixing some of the polymer mix squeezed out. Care was being taken for this in the experiment to make composite pins of length 35 mm and diameter of 10 mm. The samples were kept in the moulds for curing at room temperature (29 ^{0}C) for 24 hr. Cured samples were then removed from the moulds and used for different measurements.

Response surface methodology (RSM)

Response surface methodology (RSM) is practical, economical and relatively easy to use. RSM is a collection of mathematical and statistical techniques that are useful for the modeling and analysis of problems in which output or response is influenced by several input-variables and objective is to find the correlation between the response and the input-variables. It comparises: designing a set of experiments, determining a mathematical model and determining the optimal value of the response to better understanding of the overall system behaviour [20]. A polynomial model of second order type was proposed to represent the relationship between wear loss and tribo test independent variables. The performance of the model depends on a large number of factors that can act and interact in a complex manner. In the present work, the input variables are wt. % of reinforcement (R) or fiber concentration, Sliding velocity (V), and Normal applied load (L) and the output (response) is wear loss (w). A response surface model is usually expressed as:

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_i x_i^2 + \sum_{i=1}^{k}\sum_{j=1}^{k} \beta_{ij} x_i x_j + \varepsilon \quad \textbf{for } \mathbf{i<j} \qquad \mathbf{(1)}$$

where β_0, β_i (i = 1, 2, . . . , k) and β_{ij} (i = 1, 2, . . . , k, j = 1, 2, . . . , k) are the unknown as regression coefficients to be estimated by using the method of least squares. In this equations ε are experimentally random errors and x_1, x_2.......... x_k are the input variables that influence the response y, k is the number of input factors. The method of least square is used to estimate the coefficients of the second order model. The response surface analysis is then done in terms of the fitted surface. The degree of significance of the model was tested by analysis of variance (ANOVA) using the software MINITAB-14.

Design of experiments (DOE)

A full factorial design is used with three design factors of each of three levels to describe response of the wear loss and to estimate the parameters in the second-order model. Overall $3^3 = 27$ wear experiments are carried out.

Table 1. Important factors and their levels for abrasive wear.

Sl.No	Factor	Notation	Unit	Levels		
1	Reinforcement	R	Wt.%	10	15	20
2	Applied Load	L	N	5	7.5	10
3	Sliding Velocity	V	m/s	0.837	1.256	1.675

Pin-on-disc wear test

Wear tests were carried out by using a pin-on-disc wear tester supplied by Magnum, Bangalore. Abrasive paper of 400 grade (grit-23 µm) was pasted on a rotating disc (EN 31 Steel disc) of 120mm diameter using double-sided adhesive tape. The sample pin was fixed in a holder and was abraded under different applied loads (5N, 7.5N and 10N). Each set of test was carried out 6 times for a period of 15 mins run. After each 15 mins run the test pieces were removed from the machine and weighted accurately to determine the loss in weight.

RESULTS AND DISCUSSION

Development of wear model

By using the full factorial design, a total of 27 experiments are conducted and regression coefficients are calculated. The full models for abrasive wear loss (w) can be expressed in term of the coded values of the independent variables in equation (2).

$$\mathbf{w = 0.300370 - 0.113333*R + 0.076667*L + 0.151667*V + 0.025556*R^2 + 0.002222*L^2 + 0.020556*V^2 - 0.031667*R*L - 0.055833*R*V - 0.003333*L*V} \qquad \mathbf{(2)}$$

Analysis of variance (ANOVA)

Analysis of variance (ANOVA) and the F-ratio test have been performed to check the adequacy of the model as well as the significance of the individual model coefficients. The ANOVA was carried out on the model for a confidence level of 95%. The results of ANOVA tables for wear loss are listed in Table (2, 3). Table 2 presents the ANOVA table for the second order model propose for wear loss given in equation (2). It can be appreciated that the P-value is less than 0.05 which means that the model is significant at 95% confidence level. Furthermore, the significance of each coefficient in the full model was examined by the t-values and P-values and the results are listed in Table 3. The larger values of t-test and smaller values of ‘‘P” indicate that the corresponding coefficient is highly significant [21]. Hence, the results given in Table 3 suggest that the influence of Load (L^2), Reinforcement x Load (R x L) and Load × Velocity (L × V) and are non-significant and therefore can be removed from the full model to further improve the model. By doing so, the full model for the wear loss can be reduced as:

$$w = 0.30185 - 0.11333*R + 0.07667*L + 0.15167*V + 0.02556*R^2 + 0.02056*V^2 - 0.05583*R*V \quad (3)$$

Table-2. ANOVA for wear loss (Full model)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression (Significant)	9	0.807108	0.807108	0.089679	31.11	0.000
Linear	3	0.751050	0.751050	0.250350	86.84	0.000
Square	3	0.006483	0.006483	0.002161	0.75	0.537
Interaction	3	0.049575	0.049575	0.016525	5.73	0.007
Residual Error	17	0.049010	0.049010	0.002883		
Total	26	0.856119				

Table-3. Estimated regression coefficients for wear loss of composite. (Full model)

Term	Coef	SE Coef	T	P
Constant	0.300373	0.02734	10.987	0.000
R	-0.113333	0.01266	-8.955	0.000
L	0.076667	0.01266	6.058	0.000
V	0.151667	0.01266	11.984	0.000
R*R	0.025556	0.02192	1.166	0.260
L*L	0.002222	0.02192	0.101	0.920 (Non- Significant)
V*V	0.020556	0.02192	0.938	0.362
R*L	-0.031667	0.01550	-2.043	0.057 (Non- Significant)
R*V	-0.055833	0.01550	-3.602	0.002
L*V	-0.003333	0.01550	-0.215	0.832 (Non- Significant)

Table-4. ANOVA for wear loss (Reduced model)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	6	0.794912	0.794912	0.132485	43.29	0.000 (Significant)
Linear	3	0.751050	0.751050	0.250350	81.81	0.000
Square	2	0.006454	0.006454	0.003227	1.05	0.367
Interaction	1	0.037408	0.037408	0.037408	12.22	0.002
Residual Error	20	0.061206	0.061206	0.003060		
Total	26	0.856119				

Table-5. Estimated regression coefficients for wear loss of composite. (Reduced model)

Term	Coef	SE Coef	T	P
Constant	0.30185	0.02381	12.680	0.000
R	-0.11333	0.01304	-8.692	0.000
L	0.07667	0.01304	5.880	0.000
V	0.15167	0.01304	11.632	0.000
R*R	0.02556	0.02258	1.132	0.271
V*V	0.02056	0.02258	0.910	0.374
R*V	-0.05583	0.01597	-3.496	0.002

ANOVA was performed on the reduced model and the results are presented in Table (4, 5) and found that the model is highly significant. Thus, Eq. (3) represents the coded form of final empirical model for wear loss of composite. It should be noted that the above equations are valid over the range of conditions 10% < Reinforcement < 20%; 0.837m/s; < Sliding velocity< 1.675 m/s and 5N < Normal applied load < 10N for abrasive wear of above composite against 400 grit size.

Residual Plots for wear loss

The regression model is used for determining the residuals of each individual experimental run. The difference between the measured values and predicted values are called residuals. The residuals are calculated and ranked in ascending order. The normal probabilities of residuals are shown in Fig. 1. The normal probability plot is used to vary the normality assumption. As shown in Fig. 1, the data are spread roughly along the straight line. Hence it can be concluded that the data are normally distributed [22].

Figure 2 is used to show the correlation between the residuals and from this, it is emphasized that a tendency to have runs of positive and negative residuals indicates the existence of a certain correlation. Also the plot shows that the residuals are distributed evenly in both positive and negative along the run. Hence the data can be said to be independent.

Figure 3 indicates the residuals versus fitted values, which shows only the maximum variation of-0.5 to 0.5 mm in wear loss between the measured and the fitted values. This plot does not reveal any obvious pattern and hence the fitted model is ample.

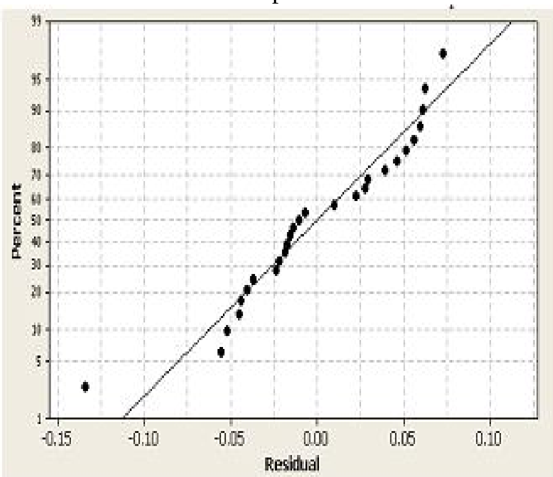

Fig. 1: Normal probability plot of the residuals (Response is w)

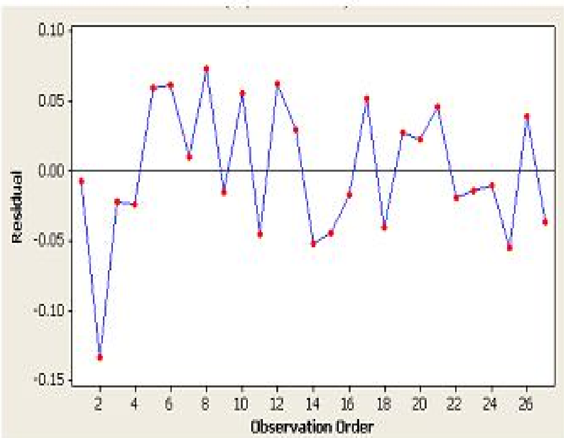

Fig. 2: Residual versus order of the data (Response is w)

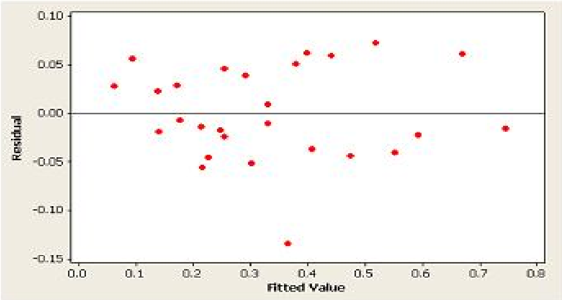

Fig. 3: Residuals versus the fitted values (Response is w)

Checking Adequacy of Mathematical Models

The goodness of fit of the mathematical models was also tested by coefficient of determination (R^2) and adjusted coefficient of determination (R^2_{adj}). The R^2 is the proportion of the variation in the dependent variable explained by the regression model. On the other hand, R^2_{adj} is the coefficient of determination adjusted for the number of independent variables in the regression model. Unlike R^2, the R^2_{adj} may decrease if the variables are entered in the model that does not add significantly to the model fit. The R^2 and R^2_{adj} values of mathematical models are found 0.929 and 0.907 respectively which clearly indicate the excellent correlation between the experimental and the predicted values of the responses.

Validity of the Models

The performance of the developed model was tested using five experimental data which were never used in the modeling process. The results predicted by the developed model were compared with the measured values and also average percentage deviation (φ_p) was calculated and presented in the Table 6. The results indicate that the model predicted wear loss has good validity with acceptable percentage deviation.

Table 6: Comparison of the predicted and measured results as a

Parameters			Wear loss		
R	L	V	Measured	Predicted	Deviation (%)
30	10	0.353	0.175	0.156	10.27
25	12.5	0.206	0.149	0.142	4.63
40	17.5	0.431	0.210	0.193	8.09
35	21.5	0.274	0.097	0.059	9.98
25	20.0	0.470	0.211	0.201	4.74

Avg. deviation: 7.542%

CONCLUSION

In this study, full factorial design of experiments has been employed to develop a second-order polynomial equation for describing abrasive wear behaviour of bagasse fiber reinforced Epoxy composites. The relationship of abrasive wear loss with fiber concentration, applied load and sliding velocity has been successfully obtained by using RSM at 95% confidence level. This model is valid within the ranges of selected experimental parameters of fiber concentration, applied load and sliding velocity. The accuracy of the RS model was verified with three sets of experimental data which were never used in modeling and average percentage deviation calculated as 7.542%.

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