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Research Article

Research on Sliding Wear Behavior of TiO_2 Filled Glass Fiber Reinforced Polymer Composite

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Abstract: In this study, Titanium Oxide (TiO_2) particulate filled e-glass fiber reinforced composites in the unsaturated polyester resin matrix were prepared and its dry sliding wear behavior was optimized. Composites of varying fiber lengths of 1, 2 and 3 cm, respectively with different fiber content of 30, 40 and 50 wt. %, respectively were made. The particulate was varied with 2, 5 and 9 wt. %, respectively. The hybrid reinforced composites were prepared by hand layup method and the wear was measured adopting pin-on-disk system. Taguchi's experimental design approach was used to make a parametric analysis of the variable fiber length, fiber content and filler material content. The influencing parameter on the wear rate was determined using the Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA). The fiber content emerged as the most significant factor affecting the wear rate of the composites. The regression analysis was carried out to determine the nonlinear analysis for the prediction of the optimized model.

Keywords: Analysis of Variance (ANOVA), hybrid reinforced composites, regression analysis, Titanium Oxide (TiO_2)

INTRODUCTION

Composite materials are engineering materials made from two or more constituent materials that remain separate and distinct on a macroscopic level while forming a single component. Matrix and reinforcement are the two categories of constituent materials. The matrix transfers the stresses between the reinforcing fibres and prevents them from mechanical or environmental action. The material properties of particulate reinforced polymer composites can be varied through the control of filler content, matrix combinations and the selection of processing techniques (Yoshida *et al*., 2001). A judicious selection of matrix and the reinforcing solid particulate phase can lead to a composite with better material properties compared to the conventional metallic materials (Jang, 1994; Shao-Yun, 2008).

GFRP composite materials consist of high strength glass fiber embedded in a cementitious matrix. In this composite, the fiber-matrix interface shear strength was used as an indicator to improve the fiber-matrix adhesion, as well as to determine a suitable value of fiber length (Sapuan and Maleque, 2005). GFRP composite materials find its application in nonwoven structures for automotive component substrates (Ellison *et al*., 2000) and used as an alternative to inorganic/material based reinforcing fibers in commodity fiber-thermoplastic composite materials (Roger, 2006).

Hard particulate fillers consisting of ceramic or metal particles (Rusu *et al*., 2001) and fiber fillers made of glass are being used these days to dramatically improve the wear resistance of composites, even up to three orders of magnitude (Sawyer *et al*., 2003). Polymer reinforced composites with addition of particulate fillers shows considerable improvement in their properties (Reynaud *et al*., 2001; Katz and Milewski, 1978; Chen *et al*., 2006) and finds its application in have a wide range of industrial applications such as heaters, electrodes, composites with thermal durability at high temperature (Jung-Il *et al*., 2004) etc. These engineering composite properties can improve by addition of fiber in the metal matrix or polymer matrix (Zhu and Schmauder, 2003). Several analyses have been carried out in the field of polymer composite and its corresponding influence in the properties of the material (Basavarajappa, 2009; Sakip *et al*., 2012; Guo-Ming *et al*., 2012). The wear behaviour of hybrid composites was determined by factorial techniques (Ravindran *et al*., 2012). Taguchi's parameter design was adopted to study the effect of various parameters and their interactions (BalaMurugan

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et al., 2009; Dobrzanski, 2007; Basavarajappa *et al*., 2007).

In the present study, the TiO_2 filled; glass fiber reinforced in the unsaturated polyester resin matrix composites was prepared. The wear tests were carried out by pin-on-disc apparatus and its effects on dry sliding wear performance were studied. The wear resistance parameters like fiber length, fiber content and particulate material content was analyzed with Taguchi's experimental approach. Regression model was used to ensure the optimal parameters.

MATERIALS AND METHODS

The raw materials include E-glass fiber made of alumina-borosilicate glass with less than 1 wt. % alkali oxides, unsaturated polyester resin, titanium oxide particulate and accelerator. Ethyl methyl ketone was used as accelerator and Cobalt (II) naphthenateas the catalyst. E-glass fibres with density 2.5 g/cm^3, Elongation 2.5% and modulus 70 GPa were used as a reinforcing material in matrix. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on a composite structure. Unsaturated polyester was used as resin matrix due to its ease of handling, moulding characteristics and curing properties. Titanium dioxide, a fine white powder is used as the particulate material in the GRPF composite. The major composition of e-glass fiber was silicon dioxide and aluminum trioxide. Chemical composition for E-glass fiber is shown in Table 1.

Table 1: Chemical composition for e-glass fiber (in weight percent)

Type	SiO_2	Al_2O_3	CaO	MgO	B_2O_3	Na_2O
E-glass	54.5	14.5	17	4.5	8.5	0.5

Table 2: Different compositions of fiber reinforced polymer composite

Fiber length (cm)	Fiber content (wt. %)	Filler content (wt. %)
1	30	2
1	40	5
1	50	9
2	30	2
2	40	5
2	50	9
3	30	2
3	40	5
3	50	9

Fig. 1: Hybrid polymer composite with 1 cm fiber length and three different particulate content

Fig. 2: Pin-on-disk

Fig. 3: Data acquisition

Specimen preparation: The mould was kept well cleaned and dried; the wax polish which is a release agent was laid up on the mould. E-glass fiber was then added to the fiber mould. The Unsaturated Polyester Resin was mixed with accelerator (1.5% wt) and catalyst (1.5% wt). The titanium oxide particulate was amassed with this mixture and agitated well. With the assistance of a special brush, Unsaturated Polyester Resin mixture was mixed evenly on to the mould.

The mould was kept closed and pressed uniformly for 24 h to cure. Once the composites were completely dried, the specimens were cut to the standard size. Different compositions of the hybrid composites are shown in Table 2. The prepared specimen's are shown in Fig. 1.

Wear test: Wear is the most unenviable property, which is, defined as erosion or sideway displacement of material from its derivative and original position on a solid surface. The Ducom tribometer machine was used for conducting the wear test. The quantum of wear was measured by the Ducom tribometer by adopting a pin-on-disk system. The unit includes an arm to which the pin was attached, a fixture which accommodates discs up to 165 mm in diameter and 8 mm thick, an electronic force sensor for measuring the friction force and computer software WINDUCOM was used for displaying the parameters for analysis. The turntable produced up to 2000 rpm, measuring the wear groove with a profilometer and measuring the amount of material removed quantified wear. The specification of the Ducom tribometer machine is shown in Table 3.

The friction coefficient signal was exhibited in real time on a computer based screen. Data was viewed as logged for the complete test duration, which might be recalled later for the analysis. The software provides for nine different logged test files for online mapping. Fig. 2 and 3 are shown the Ducom tribometer machine pin on disc apparatus and data acquisition system.

Table 3: Specification of wear testing machine

Parameter	Min.	Max.	Unit
Pin size	3	12	Mm
Disc size	165×8 mm thick		Mm
Sliding speed	0.05	10	m/s
Disc rotation	200	2000	Rpm
Normal load	0	200	N
Frictional force	0	200	N
Wear	0	2	Mm
Track radius	To be set manually		Mm

Min.: Minimum; Max.: Maximum

Table 4: Factors and level of the wear test

Code	Factor	Levels 1	2	3
A	Applied force in (N)	20	30	40
B	Fiber content in (wt. %)	30	40	50
C	Velocity in (m/s)	1	3	5

The specimen to be tested was mounted on the turn table fixture. The test variables like sliding velocity, normal load, distance and time duration were specified. The normal load was applied to the pin using a system of weights. The turn table was rotated while the normal load was still engaged. This forces the pin causing sliding wear and frictional force, which are to be sized. The value of the wear, frictional force and the co efficient of friction were transcript. For consistency of the reading, three trials of tests were carried out and the minimum wear rate specimen was considering for the analysis. The same procedure was carried on for the remaining specimens and their corresponding values of the wear, frictional force and the co efficient of friction were in scripted.

Taguchi's parameter design: Taguchi's parameter design is an important tool for robust design considering the fact that it offers a simple and systematic approach to optimize design for performance, quality and cost. Taguchi technique uses a special style of orthogonal arrays to check the whole parameter space with a minimum number of experiments. Then the experimental results are transformed into a Signal-to-Noise (S/N) ratio. The S/N ratio is used to measure the characteristics deviating from the desired values. The S/N ratio for each level of process parameters is computed based on the S/N analysis. The S/N ratio characteristics for this study is to minimize the wear rate and given by equation smaller the better characteristic:

$$S/N = -10 \log (1/n) (\sum y2) \quad (1)$$

where,

$\tilde{y}$: The average of observed experimental data
s2y : The variation of y
n : The quantity of observations
y : The observed experimental data

In the present study, the orthogonal array was assigned with three parameters that include applied force (A), fiber content (B) and velocity (C). The range of parameters was determined from the preliminary experiments. Each parameter was selected at three levels to study the non-linearity effect of the process parameters. The minimum number of trials in the array was given by Nmin = (l-1) k+1, where k is the number of the factors and l is the number of levels. According to the Taguchi quality loss function for present investigation, L_9 orthogonal array was selected. Each test parameter was assigned a column and nine process parameter combinations were available. Thus, only nine parameters were in need to study the entire process parameter space using L9 orthogonal array. The identified wear parameters affecting the process of composite specimen and their levels are shown in Table 4.

Analysis of Variance (ANOVA): The principle objective of the Analysis of Variance (ANOVA) is to investigate the design parameters which significantly affect the characteristic of process. Fisher test is used to spot out the design parameters having a significant effect on the quality characteristic. This accomplished by separating the total variability of the S/N ratios, which can be measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by every design parameters.

Regression modelling: The statistical tool, regression analysis helps to estimate the value of one variable from the known value of another. In regression analysis, there are two types of variables. One is the dependent variable whose value is to be predicted and the variable which influences the values used for prediction is called independent variable. There are two types of regression Linear and Non linear regression. In linear regression analysis, the specification of model is completed if the dependent variable is a linear combination of the parameters. If the model function is non linear combination of the parameters, then sum of squares must be minimized by an iterative procedure. In the present study, a nonlinear regression model was developed for the prediction of wear resistance of GFRP composites.

RESULTS AND DISCUSSION

S/N results for wear test: The measured values of wear as a function of the parameters were shown and the corresponding S/N ratio was shown in the Table 5 and 6. The Table 6 shows the result of Taguchi analysis for using smaller the better characteristics, from the Table 6, it can be seen by rank the factor fibre content (weight %) is the most significant parameter and the velocity is the next significant factor for the wear.

Taguchi analysis was done and the mean response for wear using smaller the better characteristics is shown in Table 6.

Table 5: S/N ratio response for wear using smaller the better

Applied force	Fiber content	Velocity	Wear rate	S/N ratio
20	30	1	0.005190	45.697
20	40	3	0.017450	35.164
20	50	5	0.003638	48.784
30	30	3	0.004299	47.333
30	40	5	0.003768	48.478
30	50	1	0.005574	45.077
40	30	5	0.007970	41.971
40	40	1	0.029550	30.589
40	50	3	0.004256	47.210

Table 6: Mean S/N response for wear using smaller the better

	Mean S/N ratio				
Parameter	Level 1	Level 2	Level 3	Delta	Rank
Applied force	43.112	46.960	39.920	7.040	2
Fibre content (wt. %)	45.000	38.077	47.024	8.947	1
Velocity	40.454	43.236	46.411	5.957	3

Table 7: ANOVA for wear

Symbol	Cutting parameter	DOF	S.S.	M.S.	F	Contribution
1	AF	2	72.981	36.491	1.064	22.218
2	FC	2	133.618	66.809	1.947	40.678
3	V	2	53.260	26.630	0.776	16.214
Error		2	68.622	34.311		20.891
Total		8	328.482	164.241		100.000

S.S.: Sum of square; M.S.: Mean of square

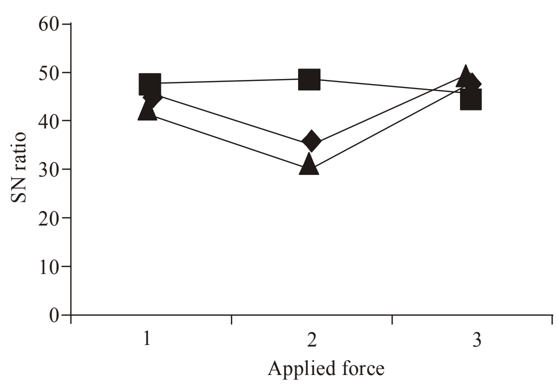

Fig. 4: S/N ratio vs. force

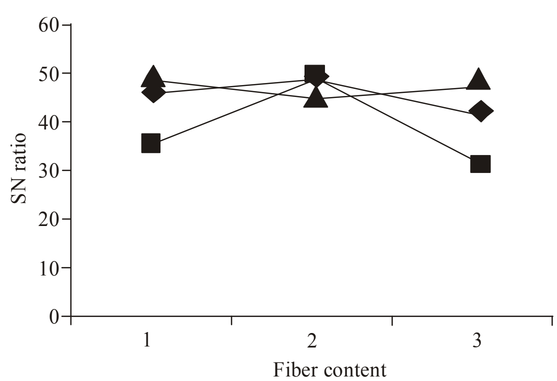

Fig. 5: S/N ratio vs. fiber content

By Table 6 the optimal condition for wear strength was realized, the minimum mean S/N ratio for each

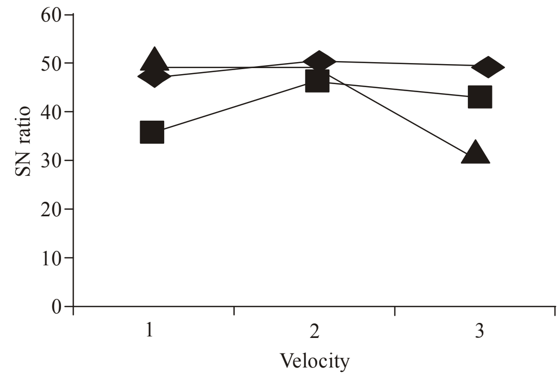

Fig. 6: S/N ratio vs. velocity

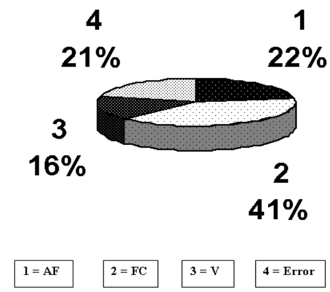

Fig. 7: Factors influencing the wear

parameter and the parameters were the applied force 20 N, fiber content 50 wt. % and velocity 5 m/s.

ANOVA results for wear: Analysis of Variance for wear was carried out for the wear test and the main effects of the plots for wear with the parameters of applied force, fibre content and velocity were shown in the Fig. 4 to 6.

Experiments were conducted with an application of Taguchi method and ANOVA to investigate the effect of the parameters on wear of the hybrid composite material. It shows that the wear resistance increases with increase in fibre content. When the load was applied to the GFRP composites, it is transferred to the fibers by a shearing mechanism between the fiber reinforcement and the matrix. Since the bond was perfect, the shearing mechanism creates the stress distribution across the fiber/matrix interface.

Hence, the more fiber content made to resist the applied load. Figure 7 shows various influencing factors of wear. From the analysis of variance table, fiber content subject to more contribution of the wear resistance (Table 7).

Regression model results: The wear resistance model is obtained by the regression analysis. The Non-linear summary statistics for wear resistance is shown in Fig. 8. Thus the regression model for wear resistance is:

$$\text{Wear Rate} = 8.30330 \times 10^{-13} \times AF^{-2.046056436} \times FC^{7.744994220} \times V^{1.513272257}$$

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Nonlinear Regression Summary Statistics     Dependent Variable WR

  Source                 DF  Sum of Squares  Mean Square

 Regression              4         .09187         .02297
Residual                 5   1.532781E-03   3.065562E-04
Uncorrected Total        9         .09340
(Corrected Total)        8         .07230

  R squared = 1 - Residual SS / Corrected SS = 0.97880

                                           Asymptotic 95 %

                          Asymptotic     Confidence Interval

  Parameter   Estimate     Std. Error     Lower         Upper

K           8.30330E-13   9.41564E-12  -2.33733E-11  2.50340E-11
X          -2.046056436   .938599113  -4.458802268   .366689396
Y           7.744994220   2.452698704   1.440131484 14.049856957
Z           1.513272257   .866626694  -.714462582  3.741007096
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Fig. 8: Result of regression model

For any optimal non-linear regression model the value of the term R squared should be more than 0.85. If not the model generated is not said to be optimal. From the Fig. 8, it is seen that the value of R squared is 0.97880; the generated non-linear regression model for wear resistance is optimal.

CONCLUSION

TiO_2 filled glass fiber reinforced polymer composites was fabricated successfully using hand layup technique with varying fibre length, fiber content and filler content. Dry sliding wear tests were conducted using a standard pin on disc test setup. By using Taguchi's orthogonal array, the main influencing factors like fiber length, fiber content and filler material content were chosen and optimization was done. The influences of independent parameters such as applied force, fiber content and velocity on wear performance were determined using Signal-to-Noise (S/N) ratio and Analysis of Variance (ANOVA). The results of the experiments revealed that the fibre content is the main parameter that has greater influence on wear. The wear resistance increases with the increase of fiber content. Other factors like velocity and applied force have been found to play significant role in determining wear magnitude. The regression model ensured that the generated model was optimal for the used parameters.

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