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Effects of Filler Glass Fiber on the Tribological Properties of PTFE Composites

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ABSTRACT: The effects of filler on the friction and wear properties of 15% glass fibre and 25% glass fibre filled PTFE (Polytetrafluoroethylene) composites under dry friction conditions were studied. Meanwhile the influence of filler content, sliding duration, test speed and load were also investigated. Experimental results shows that wear rate of PTFE reduced by addition of glass fiber and tribological properties also improved. The friction and wear tests were conducted on pin-on-disc apparatus. For analysis here we used DOE (Design of Experiment) and MINITAB 16.

KEYWORDS: ANOVA, Design of Experiment, Glass fiber, MINITAB 16, PTFE, S/N ratio, Taguchi approach.

I. INTRODUCTION

PTFE is polytetrafluoroethylene based polymer compound with unparalleled bearing properties and white or grey in colour. It is an ideal bearing material for heavy and light load pressures with medium and low surface speeds. PTFE has all qualities of bearing alloy like compatibility, conformability embedability, load capacity, fatigue strength, corrosion resistance and hardness. It is a crystalline solid with good stability from -195°C to +260°C.

The addition of a lamellar solid lubricant to the glass fibres reduced both the wear and friction of PTFE. Because of the relative softness of PTFE, it is logical to expect that its load- carrying ability and its wear resistance might be improved by the addition of suitable fillers.

Glass fiber also called fiber glass. It is material made from extremely fine Fiberof glass. Fiber glass is a lightweight, extremely strong, and robust material. Although strength properties are somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using Molding processes.

Design of Experiments (DOE) techniques enables designers to determine simultaneously the individual and interactive effects of many factors that could affect the output results in any design. DOE also provides a full insight of interaction between design elements; therefore, it helps turn any standard design into a robust one. Simply put, DOE helps to pin point the sensitive parts and sensitive areas in designs that cause problems in yield. Designers are then able to fix these problems and produce robust and higher yield designs prior going into production. Here we use the “Taguchi orthogonal array” methods to perform the experiments.

An attempt has been made to study the influence of wear parameters like applied load, sliding speed, sliding distance and percentage of reinforcement on the dry sliding wear of the metal matrix composites. A plan of experiments, based on techniques of Taguchi, was performed to acquire data in controlled way. The objective is to establish a correlation between dry sliding wear of composites and wear parameters. These correlations were obtained by multiple regressions. Finally, confirmation tests were conducted to verify the experimental results foreseen from the mentioned correlations. The Taguchi method, which is effective to deal with responses, was influenced by multi-variables.

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II. LITERATURE SURVEY

Mohammed Yunus et al,[2]has explained in the paper entitled, "Optimization of process parameters of wear and hardness characterization of industrial ceramic coatings using Taguchi design approach" that taguchi method is important tool for the robust design in obtaining the process and product conditions which are least sensitive to noise to produce high quality products with low manufacturing costs. It involves various steps of planning, conducting and evaluating the results of specially designed tables called "orthogonal array" experiments to study entire parameter space with minimum number of trials to determine the optimum levels of control parameters. A quality loss function is then designed to evaluate the deviation between experimental value and desired value. Taguchi method is combine experiment design theory and quality loss function.

Supriyaroy and PrasantaSahoo,[3] has explained in the paper entitled, "Friction performance optimisation of chemically depositated Ni-P-W coating using taguchi method" that, taguchi method recommends the use of loss function which is then transformed into a S/N ratio to measure the performance characteristic deviating from the desired value and then S/N ratio for each level of process parameters is evaluated based on average S/N ratio response analysis and greater S/N ratio is corresponding to better quality characteristic irrespective of category and quality is evaluated based on average S/N ratio response analysis and greater S/N ratio is corresponding to better performance characteristic regardless of category and quality. To find which process parameters are statistically significant, Analysis of Variance (ANOVA) to be performed. Finally, to verify the optimal process parameters obtained from the parameter design, confirmation test to be conducted. To find the optimal combinations the following step by step procedure is followed for the DOE.

III. MATERIALS AND METHODS, EXPERIMENTAL DETAILS

In pin-on-disc tribometer TR-20, a flat pin is loaded onto the test sample with a precisely known weight of 17.63 kg. The pin is mounted on a stiff lever, designed as a frictionless force transducer (fig. 1). The deflection of the highly stiff elastic arm, without parasitic friction, insures a nearly fixed contact point and thus a stable position in the friction track. The friction coefficient is determined during the test by measuring the deflection of the elastic arm..

The dry sliding wear tests were performed on pin on disc test setup (shown in fig.2) as per ASTM G99-05 standard.[1] In this experiment we used pin size 12mm diameter and 30mm length, rubbed against (EN32 grade) low carbon steel. EN32 is a carbon case hardening steel.

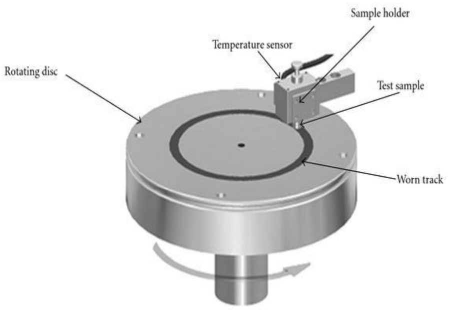

Fig.1 pin on disc

This steel is an unalloyed low carbon grade. It is a popular case hardening steel grade for general engineering, readily machineable and weldeable in its supply condition. Fig. 2 shows the schematic layout of the tester.

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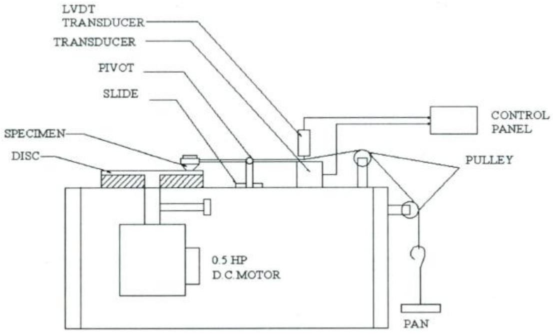

Fig. 2 Schematic diagram of the pin on disc friction and wear tester

EN32 is low tensile steel suited for lightly stressed components. EN32 is suitable for applications such as collets, cams, rollers, bushes, spindles, and gears. Table 3 shows process parameters with their values at three levels used for experiment. Properties of the materials are shown in the table 1 as follows:

Table 1: Properties of the Disk Materials

Content of EN32:	
Contents	**Quantity**
Carbon	0.10-0.18 %
Phosphorous	0.05 % max
Manganese	0.06-1.00 %
Sulphur	0.05 % max.
Silicon	0.05-0.35 %
Properties of EN32:	
Tensile strength	430-490 N/mm2
% Elongation	18

i. Orthogonal array:

A full factorial design will identify all possible combinations for a given set of factors. If an experiment consist of m number of factors & each factor at levels, then

Number of trails possible (Treatment Combination) =X^m

This method uses a special set of arrays called orthogonal arrays. Table 2 shows the plain orthogonal array. These standard arrays stipulate the way of conducting the minimal number of experiments, which could give the full information of all the factors that affect the performance parameter. There are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels.

Standard notation for Orthogonal Arrays is, $\mathbf{L_n (X^m)}$

Where, n=Number of experiments to be conducte X=Number of levels m= Number of factors
Common Orthogonal Arrays are listed below for quick reference
2- Levelarrays : L_4 (2^3), L_8 (2^7), L_{12} (2^{11}), L_{16} (2^{15}), L_{32} (2^{31}), L_{64} (2^{63}) etc.
3- Levelarrays : L_9 (3^4),L_{27} (3^{13}), L_{81} (3^{40}) etc.
4- Levelarrays : L_{16} (4^5), L_{32} (2^1*4^9) etc.

The experiments were conducted as per the standard orthogonal array. The selection of the +orthogonal array was based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those wear parameters. In the present investigation an *L*27 orthogonal array was chosen, which has 27 rows and 13 columns as shown in the table 2.

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Table 2:Orthogonal array L27 ($3^{\wedge 13}$) of taguchi :

$L_{27}(3^{\wedge 13})$	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
1	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	1	3	2	1	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	3	1	1	3	2
24	3	2	1	3	3	2	1	1	2	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	2	3

i. **Signal-to-noise (S/N) Ratio**:

Taguchi has created a transformation of the repetition data to another value which is measure of the variation present. The transformation is the S/N ratio. There are several S/N ratio available depending on the type of characteristics; lower is better (LB), nominal is best (NB), higher is better (HB). The process parameters are shown in the table 3.

Table 3:Process parameters with their values at three levels:

Level	**Load in Kg**	**Sliding distance in km**	**Velocity in m/sec**
1	1	2	1.09
2	2	4	2.199
3	3	6	3.29

The experimental observations are transformed into signal-to-noise ratio. There are several ratios available depending on the type of characteristic, which can be calculated as logarithmic transformation of the loss function.

For lower is the better performance characteristic ratio is calculated as per the number of observations and the observed data. "Lower is the better" (LB) characteristic, with the above ratio transformation, is suitable for minimization of wear rate. A statistical analysis of variance (ANOVA) is performed to identify the control parameters that are statistically significant. With the ratio and ANOVA analyses, the optimal combination of wear parameters is predicted to acceptable level of accuracy.Table 4 shows orthogonal array of Taguchi, in which we get values of S/N ratio from process parameter, wear and coefficient of friction.

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Types of S/N ratios:

The S/N ratio, which condenses the multiple data points within a trial, depends on the type of characteristics being evaluated. The equations for calculating S/N ratios for LB, NB or HB characteristics are:

1. Lower is better:

$S/N_{LB} = -10 \log (\frac{1}{r}\sum_{i=1}^{r} yi\text{^}2)$

Where, r = number of tests in trial

2. Nominal is best:

$S/N_{NB1} = -10 \log(V_e)$ (variance only)

$S/N_{NB2} = 10 \log(V_m - V_e / r*V_e)$ (mean and variance)

3. Higher is better:

$S/N_{HB} = -10\log (\frac{1}{r}\sum_{i=1}^{r} 1/yi\text{^}2)$

Table 4:Orthogonal array of Taguchi for wear and COF:

std	Load	SD	Velocity	Material	Wear	S/N Ratio	COF	S/N Ratio
1	1	2	2.199	Virgin PTFE	142.005	-43.0461	0.1591	15.9666
2	1	4	3.29	Virgin PTFE	146.0797	-43.2918	0.3496	9.126336
3	1	6	1.09	Virgin PTFE	32.309	-30.1865	0.29	10.75204
4	2	4	2.199	Virgin PTFE	236.0076	-47.4585	0.1976	14.08031
5	2	6	3.29	Virgin PTFE	322.278	-50.1646	0.25	12.0412
6	2	2	1.09	Virgin PTFE	133.8655	-42.5334	0.1808	14.85315
7	3	6	2.199	Virgin PTFE	446.3	-52.9925	0.1297	17.7412
8	3	2	3.29	Virgin PTFE	188.8362	-45.5217	0.2044	13.79038
9	3	4	1.09	Virgin PTFE	323.034	-50.185	0.159	15.97206
10	1	2	1.09	PTFE+15%GF	33.7851	-30.5745	0.415	7.639038
11	1	4	2.199	PTFE+15%GF	23.2363	-27.3233	0.238	12.46846
12	1	6	3.29	PTFE+15%GF	7.3251	-17.2963	0.5498	5.195905
13	2	4	1.09	PTFE+15%GF	4.5922	-13.2404	0.4129	7.683102
14	2	6	2.199	PTFE+15%GF	11.4054	-21.1422	0.4769	6.431454
15	2	2	3.29	PTFE+15%GF	12.3338	-21.8219	0.3084	10.21771
16	3	6	1.09	PTFE+15%GF	8.31526	-18.3975	0.3358	9.478386
17	3	2	2.199	PTFE+15%GF	38.9656	-31.8136	0.22	13.15155
18	3	4	3.29	PTFE+15%GF	15.6609	-23.8963	0.2167	13.28282
19	1	2	3.29	PTFE+25%GF	12.322	-21.8136	0.421	7.514358
20	1	4	1.09	PTFE+25%GF	17.323	-24.7725	0.4698	6.56174
21	1	6	2.199	PTFE+25%GF	17.0309	-24.6248	0.4884	6.224487
22	2	4	3.29	PTFE+25%GF	4.8859	-13.7789	0.1477	16.61239
23	2	6	1.09	PTFE+25%GF	7.9044	-17.9574	0.3873	8.238377
24	2	2	2.199	PTFE+25%GF	15.6955	-23.9155	0.3584	8.91264
25	3	6	3.29	PTFE+25%GF	5.2811	-14.4545	0.3335	9.538083
26	3	2	1.09	PTFE+25%GF	8.16844	-18.2428	0.1825	14.77474
27	3	4	2.199	PTFE+25%GF	9.2596	-19.3318	0.3039	10.34539

IV. RESULTS AND DISCUSSIONS

A. **Analysis of variance (ANOVA)**:

i. ANOVA is a statistical technique which can provide some important conclusions based on analysis of experimental data. This method is very useful for revealing the level of significance of the influence of factor(s) or interaction of factors on a particular response.

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ii. It separates the total variability of the response into contributions of each of the factors and the error. Using Minitab ANOVA is performing to determine which parameter and interaction significantly affect the performance characteristics.

iii. Table 5 shows the ANOVA result for friction coefficient. ANOVA calculates the F ratio, which is the ratio between the regression mean square and the mean square error. The F ratio, also called the variance ratio, is the ratio of variance due to the effect of a factor and variance due to the error terms.

Table 5 Anova table for signal to noise ratio

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% contribution wear
Load	2	74.560	74.560	37.280	4.51	0.064	5.47
Sd	2	32.182	32.182	16.091	1.95	0.223	1.08
Vel	2	5.693	5.693	2.846	0.34	0.722	0.31
Mat	2	103.00	103.00	51.500	6.23	0.034	56.97
Load*sd	4	8.394	8.394	2.234	0.27	0.887	2.76
Load*vel	4	45.471	45.471	11.368	1.38	0.345	0.98
Load*mat	4	18.874	18.874	4.712	0.57	0.695	10.66
Res. Error	6	49.559	49.559	8.260			
Total	26	338.24					

B. Analysis of Signal-to-Noise Ratio

i. Taguchi method is used to optimise process parameter to achieve the high quality with low cost. Taguchi recommends the use of loss function to measure the quality characteristics. The value of the loss functions is further transform into a statistical measure called signal to noise ratio where signal means desirable value (mean) and the noise is undesirable value (S.D.).

ii. A larger S/N ratio represents better quality characteristics because of the minimisation of noise and corresponding process parameter are insensitive to the variation of environmental conditions and other noise factor. The variability can easily captured if S/N ratio is used to convert the experimental results into the value for the evaluation characteristics in the optimum parameter analysis, instead of the mean

iii. The idea is to maximise the S/N ratio thereby minimizing the effect of random noise factors, which have significant impact on the process performance. As the friction coefficient is to be minimised, so lower the better(LB) criterion of S/N ratio is used which is given by lower the better(LB):

iv.

$$\textbf{S/N ratio} = -10\log(1/n\sum yi^2)$$

Where y is the observed data and n is the number of observations.

The total mean S/N ratio for the 27 experiments is also calculated and listed in table 3. All the calculations are performed using MINITAB 16. The response table 6 and 7 shows the average of selected characteristics for each level of the factors.

Table 6:Wear rank:

Level	Load	SD	Velo	Material
1	-29.2144	-31.031	-27.3433	-45.0422
2	-28.0014	-29.2532	-32.4054	-22.834
3	-30.5373	-27.4685	-28.0044	-19.8769
Delta	2.535884	3.56252	5.06206	25.16537
rank	4	3	2	1

Table 7:Coefficient of friction rank:

Level	Load	SD	Velo	Material
1	9.049885	11.86891	10.6614	13.8137
2	11.00781	11.79251	11.70245	9.505381
3	13.1194	9.515681	10.81324	9.858023
Delta	4.069516	2.353226	1.041049	4.308316
rank	2	3	4	1

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The response table includes rank based on delta statics which compare the relative magnitude of effects. The delta statics is the highest average for each factor minus the lowest average for the same. Ranks are assigned based on delta values; rank 1 is assigned to highest delta values, rank 2 the second delta values, and so on. The corresponding main effects and interaction effects plots between the process parameter are also shown in figure 3 and 4. In the main effect plots, if the line for particular parameter is near horizontal, the parameter has no significant effect. On the other hand parameter for which line has the highest inclination will have most significant effect is shown in fig. 3 and fig. 4.

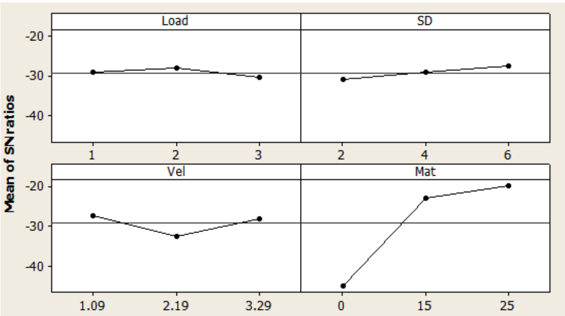

Fig 3. Main effects plot for S/N ratio for wear

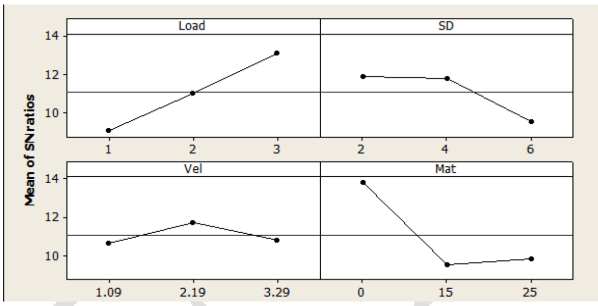

Fig 4. Main effects plot for S/N ratio for cof

C. Confirmation Test

The confirmation test is the final test in the design of experiment process. The purpose of the confirmation test is to validate the conclusions drawn during the analysis phase. This test is conducted to verify the improvement of results and to predict the optimum performance at the selected levels of significant parameters.

Table 8: Process parameter for confirmation test:

Load	SD	Vel	Mat
2	6	1.09	PTFE+ 25%GF
3	2	2.199	PTFE+ 15%GF

The confirmation test for wear, fig. 2 and fig. 3 shows the levels $A_2B_3C_1D_3$ and $A_3B_1C_2D_1$ respectively to predict error in wear rate and coefficient of friction. Table 8 shows process parameters and Table 9 shows comparison between actual and predicted of wear and COF tests.

Table 9:Comparison between actual and predicted of wear and COF tests:

	Optimum levels		
	Estimation	**Experimental**	**Difference**
Level	$A_2B_3C_1D_3$	$A_3B_1C_2D_1$	
Wear	7.9044	4.1017	3.8027
	38.9656	22.04449	16.92111
COF	0.38733	0.3267	0.06063
	0.22	0.2376	-0.0176

V. CONCLUSION

1. Glass fiber contributed significantly in reducing friction and exhibited better wear resistant properties.
2. Design of experiments approach by Taguchi method enabled us to analyse successfully the friction and wear behaviour of composites with filler, sliding velocity, load, sliding distance as the variables with fewer experiments that would otherwise be needed.
3. The confirmation tests indicated that it is possible to decrease wear rate significantly (43.42%) by using the proposed statistical technique. The experimental results confirmed the validity of Taguchi method for enhancing the wear performance and optimizing the wear parameters under dry sliding conditions .In future, this study can be extended to learn the wear behaviour of similar multiphase polymer composites.

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ANOVA results indicated that material is the factor which is having highest physical as well as statistical influence (56.97%) on the wear of the composites followed by load (5.47%), sliding distance (1.08%), and velocity (0.31%).However, interactions of these factors have less significant effect on wear rate.

4. ANOVA results indicated that normal load is the factor which is having highest physical as well as statistical influence (24.94%) on the coefficient of friction of the composites followed by material (23.33%), sliding distance (9.32%), and sliding velocity (0.04%). However, interactions of these factors have less significant effect on coefficient of friction.

5. Table 6. shows wear rank, in which material(25.16) affect the most on wear followed by velocity (5.06), sliding distance (3.56) and normal load (2.53).

6. Table 7. shows coefficient of friction rank, in which material(4.30) affect the most on wear followed by load(4.06), sliding distance (2.35) and velocity(1.04).

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