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Studies on Wear Resistance of PTFE Filled With Glass and Bronze Particles Based on Taguchi Technique

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Abstract

An attempt has been made to study the influence of wear parameters like applied load, sliding speed, sliding distance on the dry sliding wear of PTFE, PTFE+25% Glass and PTFE+40% Bronze composites. 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 employed to investigate the influence of process parameters on the wear of composites. The experimental results shows that sliding distance and applied load were found to be the more significant factors among the other control factors on wear. The objective is to establish a correlation between dry sliding wear of composites and wear parameters. These correlations were obtained by multiple regressions. A good agreement between the predicted and actual wear resistance was seen.

Keywords: PTFE, Composites, Wear, Analysis of variance, Taguchi method.

1. Introduction

Polytetrafluroethylene (PTFE) is currently finding increasing utility in high performance mechanical seals due to its unique properties like high chemical resistivity, low coefficient of friction and high temperature stability [1, 2]. However, PTFE exhibits poor wear and abrasion resistance, leading to early failure and leakage problems in the seals. The wear resistance of PTFE can be significantly improved by addition of suitable filler materials [3]. Besides the type, the shape and size of the materials added also influence the tribological properties [4].

The desired testing parameters are either determined based on experience or by use of a handbook. It, however, does not provide optimal testing parameters for a particular situation. Therefore, several mathematical models based on statistical regression techniques have been constructed to select the proper testing or cutting conditions [5-7]. The Taguchi's design can be simplified by expending the application of the traditional experimental designs to the use of orthogonal array and linear graphs. It is an efficient and systematic approach to optimize designs for performance, quality and cost. The Taguchi method has led to limited numbers of applications in a world-wide range of industries in recent years [8-10]. The dry sliding wear of composites also depends on several factors such as size, shape, content of particle, environment and the test conditions, such as load, speed and temperature [11–12].

The aim of the present study was, therefore, to investigate the tribological behaviour of Pure PTFE and its composite under various testing conditions. The wear model for the tested materials was developed based on the applied load, Sliding speed and sliding distance. Furthermore, analysis of variance (ANOVA) is employed to investigate the testing characteristics of these materials.

2. Materials and Experimentation

2.1 Materials

The compression molded Pure PTFE and Two PTFE based composite materials were studied in the present work. The compositional details of each material are presented in Table 1. The materials are purchased in the form of rectangular sheets with dimensions 100 mm X 100 mm X 3 mm by Poly fluoro Ltd. (Bangalore, India). The size of the Pure PTFE, Glass particle and Bronze particle used for manufacture are 23.5 µm, 40 µm, 48 µm respectively.

2.2 Experimental Procedure

A pin-on-disc test apparatus was used to investigate the dry sliding wear characteristics of the Pure PTFE and their composites as per ASTM G 99-95 standards. The disc used is En-32 steel hardened to 62HRC, 120 mm track diameter and 8 mm thick, with surface roughness of 10 µm Ra. The tests were conducted by selecting test duration, load and velocity and performed in a track of 130 mm diameter. The test specimen 10 mm X 10 mm X 3 mm is affixed to a pin of

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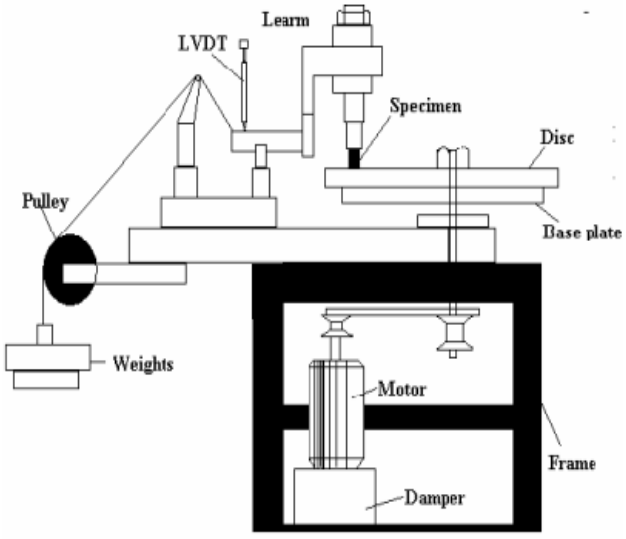
dimensions 3 mm diameter and 30 mm height with an adhesive of high bonding strength. The composites specimen makes contact to the counter surface. Prior to testing, the samples are rubbed over a 600 grade SiC paper to ensure proper contact with the counter surface. The surface of both the samples and disc are cleaned with a soft paper soaked in acetone before the test. The test set up used for the experimentation is as shown in the Figure. 1.

Table 1. Composition of PTFE composites

Sample code	Volume Fraction, %		
	PTFE	Fillers	
		Glass Particle	Bronze Particle
M1	100	-----	-----
M2	75	25	-----
M3	60	-----	40

Fig. 1. Schematic Diagram of Pin-o



n-Disc Apparatus

The initial weight of specimen was measured in a single pan electronic weighing machine with least count of 0.0001gm.fter running through a fixed sliding distance, the specimen were removed, cleaned with acetone, dried and weighed to determine the weight loss due to wear. The difference in the weight measured before and after test gives the sliding wear of composites specimen .The sliding wear of the composites studied as a function of the volume applied load, sliding speed and sliding distance.

2.3 Taguchi Design of Experiments

The experiments were conducted as per the standard L_{27} orthogonal array [13]. The plan of experiments, Taguchi method with their values at three levels was used. The wear parameters selected and their levels are presented in Table 2.

Table 2. Process parameters with their values at three levels

Levels	Applied Load in N	Sliding Speed in ms^{-1}	Sliding distance in m
1	20	2	200
2	40	4	400
3	60	6	600

3. Results and Discussion

The experiments were conducted with an aim of relating the influence of applied load (L), sliding speed (S) and sliding distance (D) on dry sliding wear of Pure PTFE, 25% Glass Particle+ PTFE, 40% Bronze Particle+ PTFE composites under study.

3.1 Anova and Effect of Factors

The ANOVA allows analyzing the influence of each variable on the total variance of the results. Table 3 shows the results of ANOVA of dry sliding wear of Pure PTFE test samples. This analysis was performed with a level of significance of 1% i.e. for a level of confidence of 99% [13, 14]. The last column of the Table shows the contribution % (P) of each variable in the total variation indicating the influence degree on the wear of contact pair. If the "Test F" value is greater than the F (1%) column value, then the assigned variable is statistically significant.

Table 3. ANOVA for Pure PTFE

Sources of variance	SS	Dof	Variances	Test F	F	P %
D	982.81	2	491.4	135.00	5.27^a	57.91
L	473.33	2	236.66	65.02	5.27^a	27.67
S	24.81	2	12.40	3.41	3.27^b	1.04
LXD	35.02	4	8.7550	2.41	2.12^c	1.21
LXS	23.38	4	5.8450	1.61	----	0.52
SXD	17.60	4	4.4000	1.21	----	0.18
Error/ Other	127.53	35	3.64			11.47
Total	1684.48	53	763.1			**100**

ss = sum of variance, Dof = Degree of freedom, P = Percentage of contribution, a = 99% confidence, b = 95% confidence, c = 90% confidence

One can observe from the ANOVA Table 3 that the sliding distance (p = 57.91%), applied load (p = 27.67%) and sliding speed (p = 1.04%) has great influence on the wear.

However the interactions between applied load/ Sliding distance (1.21%), applied load/ sliding speed (0.52%), sliding speed / Sliding distance (0.18%) also as an influence on the wear. The error associated in the ANOVA Table is about 11.47%.

Table 4. ANOVA for 25% Glass particle + PTFE composites.

Sources of variance	SS	Dof	Variances	Test F	F	P %
D	696.12	2	348.06	83.87	5.27[a]	41.22
L	660.39	2	330.20	79.57	5.27[a]	39.08
S	40.78	2	20.39	4.91	3.27 [b]	1.95
LXD	101.75	4	25.44	6.13	------	5.10
LXS	17.71	4	4.43	1.07	3.91 [a]	0.07
SXD	6.77	4	1.69	0.41	------	------
Error/ Other	145.31	35	3.54			12.58
Total	1668.83	53	733.75			**100**

ss = sum of variance, Dof = Degree of freedom, P = Percentage of contribution, a = 99% confidence, b = 95% confidence, c = 90% confidence

The ANOVA for 25% Glass particle+ PTFE composites is shown in Table 4. It can be observed that the sliding distance (p = 41.22%) is the major factor followed by applied load (p = 39.08%), sliding speed (p = 1.95%) and the interactions between applied load/ Sliding distance (5.10%), applied load / Sliding speed (0.07%) exerts a significant influence, but Sliding speed/ Sliding distance does not have significant effect on the dry sliding wear. The error is 12.58%.

The ANOVA for 40% Bronze particle+ PTFE composites is as shown in Table 5. It can be observed that the Sliding distance (p = 61.23%) is the major factor followed by applied load (p = 10.62%), sliding speed (p = 0.74%) and the interactions between applied load / sliding speed (6.42%), Sliding Speed / Sliding distance (3.95%), applied load / sliding distance (1.48%) exerts a significant influence on the wear. The error associated in the ANOVA Table is about 15.56%.

Table 5. ANOVA for 40% Bronze particle +PTFE composites.

Sources of variance	SS	Dof	Variances	Test F	F	P %
D	0.50	2	0.250	125.00	5.27[a]	61.23
L	0.09	2	0.045	22.50	5.27[a]	10.62
S	0.02	2	0.005	2.50	2.47[c]	0.74
LXS	0.06	4	0.015	7.50	3.91[a]	6.42
SXD	0.04	4	0.010	5.00	2.12[c]	3.95
L×D	0.02	4	0.005	2.50	3.91[a]	1.48
Error/ Other	0.08	35	0.002			15.56
Total	0.81	53	0.332			**100**

ss = sum of variance, Dof = Degree of freedom, P = Percentage of contribution, a = 99% confidence, b = 95% confidence, c = 90% confidence

3.2 Regression Analysis

Based on the experimental results the correlation between the wear parameters are obtained by using linear regression technique and are as follows:

Regression Equation for Pure PTFE composites is

$$Y1 = -1.0 - 0.064\,L - 0.0084\,S + 0.0067\,D + 0.000285\,LXS + 0.000702\,LXD + 0.000024\,SXD - 0.00\,LXSXD \quad (1)$$

Regression Equation for 25% Glass Particle + PTFE composites is

$$Y2 = 4.59 + 0.024\,L - 1.83\,S - 0.0106\,D + 0.0128\,LXS + 0.000877\,LXD + 0.00715\,SXD - 0.000113\,LXSXD \quad (2)$$

Regression Equation for 40% Bronze Particle + PTFE composites is

$$Y3 = -0.463 + 0.0111\,L + 0.00108\,S + 0.00194\,D - 0.000023\,LXS - 0.000023\,LXD - 0.000002\,SXD + 0.000000\,LXSXD \quad (3)$$

In these equations, Y1, Y2 and Y3 are the dry sliding wear weight loss for Pure PTFE, 25% Glass particle+ PTFE composites, 40% Glass particle+ PTFE composites respectively. The coefficient of determination (R2) for Pure PTFE, 25% Glass particle+ PTFE composites, 40% Glass particle + PTFE composites are 90.1%, 92.6% and 77.6% respectively.

3.3 Confirmation Test

Table 6 shows the experimental conditions selected for the confirmation tests. Table 7 shows the results obtained from the tests, and a comparison is made between the computed values from the regression model developed in the present work (Eq 1, 2, 3) and the values obtained experimentally.

Table 6. Parameter used in the confirmation abrasive wear test.

Test	Applied load (N)	Sliding speed (m/s)	Sliding distance (m)
1	25	2.5	250
2	45	4.5	450
3	55	5.55	550

From analyzing the data in the tables, the error associated with the relationship between the experimental values and the calculated values from the regression model for Pure PTFE is between 1.04 and 22.15%. For 25% Glass particle + PTFE composites it is between 8.64 and 24.25%, while for 40% Bronze + PTFE composites it is between 2.44 and 23.33%. Hence, the model demonstrates a feasible and effective way to evaluate dry sliding wear behaviour of Pure PTFE and their composites.

Table 7. Confirmation test results and their comparison with regression model.

Test	Pure PTFE			25% Glass Particle+PTFE Composite			40% Glass Particle+PTFE Composite		
	Experimental	**Model (Eq 1)**	**Error %**	**Experimental**	**Model (Eq 2)**	**Error %**	**Experimental**	**Model (Eq 3)**	**Error %**
1	4.2	3.89	7.38	7.6	6.94	8.64	0.30	0.23	23.33
2	19.0	15.85	16.58	22.0	17.19	21.86	0.40	0.41	2.44
3	29.4	23.53	19.97	32.0	24.24	24.25	0.45	0.42	6.67

4. Conclusions

Based on the experimental analysis presented, the following conclusions are drawn from the dry sliding wear behavior of Pure PTFE and their composites.

- Addition of Glass and Bronze particles as fillers increases the wear resistance of the material. However, significant improvement in wear resistance is observed by the incorporation of Bronze particles.
- The error associated to the ANOVA Table (maximum 15.56% and minimum of 11.47%) for the factors and the coefficients of regression obtained with the multiple regression (maximum 0.926% and minimum 0.776%) shows that the satisfactory correlation was obtained.
- The confirmation tests showed that the error associated to Pure PTFE (maximum value 19.97% and minimum 7.38%), for 25% Glass particle + PTFE composites (maximum value 24.25% and minimum 8.64%), for 40% Bronze particle + PTFE composites (maximum value 23.33% and minimum 2.44%), which are excellent.

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