

Wear Analysis of Polytetrafluoroethylene (PTFE) and its Composites under Wet Conditions

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Abstract : In this paper, the effect of load, Velocity of sliding and sliding distance on friction and wear of materials made of Polytetrafluoroethylene (PTFE) and PTFE composites under wet condition with filler materials such as 25% bronze, 25% glass fiber and 25 % carbon have studied. The experimental work has performed on pin-on-disc friction and wear test rig and analyzed with the help of Design Expert software. The results of experiments are presented in tables and graphs which shows that the addition of bronze, glass and carbon filler to the virgin PTFE decreases wear rate significantly and there is marginal increase in coefficient of friction. The highest wear resistance was found for 25% carbon filled PTFE followed by 25% glass filled PTFE, 25% bronze filled PTFE and virgin PTFE. Through this study, we can develop the best bearing material for the various industrial applications which is available easily at the minimum cost.

Keywords: Design of Experiments, Friction, Pin-on-Disc, Polytetrafluoroethylene (PTFE), Wear

I. Introduction

Tribological behaviour may be evaluated by several qualitative and quantitative parameters. We select friction coefficient and wear as relevant for this study. PTFE based materials are notable for their characteristics such as very low friction coefficient and good resistance to heat and corrosion in different application environments. Unfortunately, pure PTFE is not performing satisfactory in wear resistance and needs to be modified. The use of fillers and additives in PTFE is the most common way to improve its tribological and mechanical properties. The influence of fillers on the tribological behaviour of the composites cannot be predicted and has to be tested experimentally [1].

1.1 Nature of Problem

Unfortunately PTFE has poor thermal conductivity, high coefficient of thermal expansion and relatively not strong. PTFE suffers from poor wear resistance too. Because of this PTFE is suitable only for light loads and at low speeds. 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. Accordingly, several fillers were tried by researchers in combination with this plastic, including graphite, molybdenum disulfide, fiber glass, carbon, bronze, dental silicate, silicon, titanium dioxide, silver, copper, tungsten and molybdenum [2].

1.2 Previous Work

Deepak Bagle [3] has studied the tribological behavior of polytetrafluoroethylene and its composites with filler materials as carbon and bronze under dry conditions. He found that addition of filler materials such as bronze and carbon to PTFE causes an increase in hardness and wear resistance, while the coefficient of friction is slightly increased. From the results the highest wear resistance was found for PTFE with carbon filler followed by PTFE with bronze filler and pure PTFE. Jaydeep Khedkar et al [4] studied the tribological behaviour of polytetrafluoroethylene (PTFE) and PTFE composites with filler materials such as carbon, graphite, glass fibers, MoS₂ and poly-*p*-phenyleneterephthalamide (PPDT) fibers. The present filler additions found to increase hardness and wear resistance in all composites studied. The highest wear resistance was found for composites containing (i) 18% carbon + 7% graphite, (ii) 20% glass fibers + 5% MoS₂ and (iii) 10% PPDT fibers.

It was proposed by Lancaster [5] that addition of high aspect ratio filler materials (carbon fibers, glass fibers) to PTFE can improve its wear resistance due to preferential load supporting action by these fibers. There have also been some reports on the use of particulate filler materials like MoS₂ and graphite to modify the tribological properties of PTFE. V.B. Raka [6], has study and analyze the effect of applied load, sliding velocity and sliding time on friction and wear behaviour of Polytetrafluoroethylene (PTFE) and its two composites viz. 25% carbon filled PTFE and 60% bronze filled PTFE, is experimentally examined and analytically analyzed. Taguchi's approach and L9 orthogonal array is used for design of experiment. Depending on pressure, sliding velocity and sliding time, material used in this study can be ranked as 60BFT>25CFT>PTFE for their friction

performance and 25CFT >60BFT >PTFE for their wear performance. Adding fillers to pure PTFE matrix reduces wear rate for both the composite used in the study.

D.S. Bajaj et al [7], have studied the tribological properties of PTFE can be improved by adding some filler materials such as glass fibers, carbon, bronze, graphite. Friction and wear are very important surface phenomenon. This paper describes the dependency of wear and friction on surface roughness, sliding velocity and contact pressure for PTFE and its composites using a Pin- On-Disc tribometer. The parameters studied include wear rate and coefficient friction under varying load and for different surface roughness.

1.3 Purpose of Present Study

The present study will be aimed at developing a new bearing material, which is known as super bush bearing material, which consists of carbon filled PTFE, glass fiber filled PTFE and bronze filled PTFE which is cost effective and superior in properties to the conventional bronze bearing materials. Fruitful research in this area could lead to development of superior and less expensive bearing materials. The new carbon filled PTFE, glass filled PTFE and bronze filled PTFE will be developed during the present investigation and the properties of these materials will be evaluated. Following are the main objectives of the study.

- a. To find the effect of carbon filler, bronze filler and glass fiber filler in PTFE on wear rate.
- b. To study the wear behaviour of the selected materials and the effect of various parameters like load, sliding velocity and sliding distance on wear rate.

II. Experimental Tools, Techniques and Methodology

2.1 Design of Experiment

It is methodology based on statistics and other discipline for arriving at an efficient and effective planning of experiments with a view to obtain valid conclusion from the analysis of experimental data. Design of experiments determines the pattern of observations to be made with a minimum of experimental efforts. To be specific Design of experiments (DOE) offers a systematic approach to study the effects of multiple variables / factors on products / process performance by providing a structural set of analysis in a design matrix. More specifically, the use of orthogonal Arrays (OA) for DOE provides an efficient and effective method for determining the most significant factors and interactions in a given design problem [3].

2.2 Introduction to Design Expert

Design-Expert, version 8 software (DX8) is a powerful and easy-to-use program for design of experiments (DOE). With it you can quickly set-up an experiment, analyze your data, and graphically display the results. This intuitive software is a must for anyone wanting to improve a process or a product. Design-Expert software offers an impressive array of design options and provides the flexibility to handle categorical factors and combine them with mixture and/or process variables. After building your design, generate a run sheet with your experiments laid out for you in randomized run order. DX8 offers features for ease of use, functionality and power that you won't find in general statistical packages. Add, delete or duplicate runs in any design with the handy design editor. Rotatable 3-D colour plots make response visualization easy [3].

2.3 Taguchi Method

Taguchi has envisaged a new method of conducting the design of experiments which are based on well defined guidelines. This method uses a special set of arrays called 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. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment. The technique of laying out the conditions of experiments involving multiple factors was first proposed by the Englishman, Sir R. A. Fisher. The method is popularly known as the factorial design of experiments. A full factorial design will identify all possible combinations for a given set of factors. Since most industrial experiments usually involve a significant number of factors, a full factorial design results in a large number of experiments. To reduce the number of experiments to a practical level, only a small set from all the possibilities is selected. The method of selecting a limited number of experiments which produces the most information is known as a partial fraction experiment. Although this method is well known, there are no general guidelines for its application or the analysis of the results obtained by performing the experiments. Taguchi constructed a special set of general design guidelines for factorial experiments that cover many applications.

2.4 Statistical Regression Analysis

Statistical regression analysis is the study of the relationship between two or more variables, used to establish the empirical equation relating input-output parameters, by utilizing least square method. Moreover, it

is the most commonly used statistical modelling technique developed based on experimental data. The following steps are to be considered for carrying out statistical regression analysis of a process.

1. Identifying the important process control variables and finding their upper and lower limits.
2. Developing the design matrix (Statistical design of experiments).
3. Conducting the experiments as per the design matrix and recording the response parameters.
4. Developing the models and calculating the regression coefficients.
5. Checking the adequacy of the models.
6. Testing the significance of coefficients and arriving at the final models.
7. Presenting the direct and interaction effects of the process.
8. Analysis of Results.

2.5 Analysis of Variance (ANOVA)

The adequacy of the models is tested using the analysis of variance (ANOVA) technique. It is a statistical tool for testing null hypothesis for designed experimentation, where a number of different variables are being studied simultaneously. ANOVA is used to quickly analyze the variances present in the experiment with the help of Fisher test (F test). The results of F test indicate whether there are differences in the means due to varying the test conditions. If the estimates are similar, the changes of the subgroup averages being detectably different are small. If the estimates are significantly different, then the subgroup averages may be significantly different. If the F value calculated based on the data is greater than the F theoretical value based on F distribution, then the null hypothesis is rejected and the means are considered to be statistically significant. Usually analysis of variance computation would be done using a statistical software package. In the present work more number of variables are involved therefore, analysis of variance is carried out using the standard “Design Expert 8” statistical software.

2.6 Methodology

In this study the wear rate of each material i.e. plain PTFE, 25% carbon filled PTFE, 25% bronze filled PTFE and 25% glass filled PTFE have been calculated under the wet conditions (Lubricated condition). So, we need the Pin-on-Disc apparatus for the experimental work which must provide the lubrication facility. For the present work following methodology has been followed.

1. It starts with the specimen preparation according to the “Pin-on-Disc Friction and Wear Testing Machine” specifications. The sample specimens have been prepared by performing necessary turning and facing operations on the respective rods.
2. After specimen preparation perform the wear test on each of the specimen for varying conditions of load, sliding distance and sliding velocity.
3. Then calculating the wear rate of each material. For the present work we are using “Pin-on-Disc Friction and Wear Testing Machine” manufactured by Magnum Engineers which gives the direct values of wear, coefficient of friction and frictional force so, there is no need to calculate the wear and coefficient of friction manually.
4. Then experimental results are analyzed with the “Design Expert 8 Software”. Analysis involves the regression analysis of all four materials which can be done in “Design Expert 8 Software”. Analysis of experimental data using the design expert software generates the equation of wear for each material. This equation contains the variables as load, velocity of sliding and sliding distance. By putting the values of all variables in the given equation we can calculate the wear of all materials. Then we will compare the values of experimental wear with the values of wear which are obtained by solving the equation of wear.

Then perform the confirmation test. Confirmation tests are done to check the accuracy of the model by selecting the random values of all involved variables.

III. Laboratory Work

3.1 Experimental Set up

The Pin on Disc Friction & Wear Testing Machine designed and developed by MAGNUM ENGINEERS is primarily intended for determining the tribological characteristics of wide range of materials under conditions of various normal loads, sliding speeds & temperatures (optional). A stationary pin mounted on a pin holder is brought into contact against a rotating disc at a specified speed as the pin is sliding, resulting frictional force acting between the pin and disc are measured by arresting the deflecting pin holder against a load cell. Both normal load and speed can be set as desired. Results such as wear rate, frictional force and coefficient of friction etc. are displayed digitally on the computer screen.

3.2 Specifications of Friction & Wear Test Rig

1. Normal Load Range : 0 – 200 N
2. Frictional Force Range : 0 - 200N with a resolution of 1N with tare facility
3. Wear Measurement range : +/-2mm with tare facility RESULTS
4. Disc Speed : 100 to 3000 rpm
5. Preset Timer Range : up to 99:59:59
6. Wear Disc Track Diameter : 10 mm- 140 mm
7. Specimen Diameter : 3 mm to 12 mm
8. Specimen Length : 25mm -30 mm

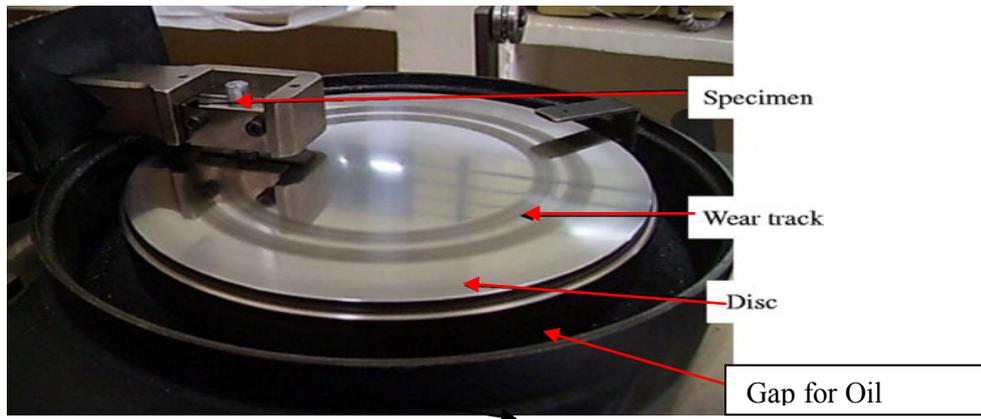


Figure 1: Experimental Set Up

3.3 Specimen Preparation

The standard rod of virgin PTFE and its composite with fillers such as 25% bronze, 25% glass fiber and 25% carbon are available in the market. The sample specimen has been prepared by performing necessary turning and facing operations on the respective rods.

Each specimen has the following dimension:

1. Diameter of Specimen : 8 mm
2. Length of Specimen : 25 mm



Figure 2: Test Specimens

3.4 Procedure

1. Insert the test specimen into the pin holder.
2. Put the desired load on load span.
3. Switch on the control panel and set the desired speed and time.
4. Switch on the computer which is connected to the control panel and open the program Wear & Friction monitor by double clicking the icon.
5. Then enter the desired parameters such as specimen diameter, speed, time, load etc. in the program.
6. Now click on “START TEST” icon of program and press the button “CYCLE START” simultaneously. So the test will start after pressing the button.
7. As we are taking the tests in wet condition so switch on lubricant motor if continuous lubrication is required otherwise drop lubrication can be done. Here we are using drop lubrication and dropping the two drops of lubricant on the disc after every one minute.
8. Test will automatically stopped once preset time is over and the results are directly saved in computer. There is no need to take the readings manually.

Above procedure can be used for various conditions of load, speed and time and for all test specimens.

Table 1: Assigning Codes for Four PTFE Materials

Material	Chemical Composition in Wt.%
I	Plain PTFE
II	25% Bronze filled PTFE
III	25% Glass fiber filled PTFE
IV	25% Carbon filled PTFE

3.5 Result Data

The Pin on Disc Friction & Wear Testing Machine designed and developed by MAGNUM ENGINEERS shows results digitally. So, wear rate (microns), frictional force (N), and coefficient of friction can be directly read and there is no need to calculate them manually which greatly saves the time.

Table 2: Result Data of Material ‘I’ & ‘II’

Sr. No.	Load in Weight Span (kg)	Disc Speed (N)in (rpm)	Sliding Distance (L) in (km)	Velocity of Sliding* (Vr) in (m/s)	Time* (T) in (min)	Wear Rate (I) of ‘Material I’ in (microns)	Coefficient of Friction of ‘Material I’ (μ)	Wear Rate (I) of ‘Material II’ in (microns)	Coefficient of Friction of ‘Material II’ (μ)
1	1	500	1.5	2.62	9.55	19.556	0.1701	14.222	0.1779
2	1	700	3.0	3.66	14.04	24.222	0.1724	17.222	0.1764
3	1	900	4.5	4.71	16.32	25.111	0.1715	18.444	0.1753
4	2	500	3.0	2.62	19.09	33.222	0.1690	23.00	0.1708
5	2	700	4.5	3.66	20.49	34.44	0.1679	25.33	0.1724
6	2	900	1.5	4.71	5.30	19.55	0.1624	15.55	0.1692
7	3	500	4.5	2.62	29.02	54.22	0.1561	41.77	0.1599
8	3	700	1.5	3.66	7.23	22.22	0.1544	16.00	0.1582
9	3	900	3.0	4.71	11.01	23.22	0.1554	18.00	0.1601

Table 3: Result Data of Material ‘III’ & ‘IV’

Sr. No.	Load in Weight Span (kg)	Disc Speed (N)in (rpm)	Sliding Distance (L) in (km)	Velocity of Sliding* (Vr) in (m/s)	Time* (T) in (min)	Wear Rate (I) of ‘Material III’ in (microns)	Coefficient of Friction of ‘Material III’ (μ)	Wear Rate (I) of ‘Material IV’ in (microns)	Coefficient of Friction of ‘Material IV’ (μ)
1	1	500	1.5	2.62	9.55	13.556	0.1830	12.222	0.1894
2	1	700	3.0	3.66	14.04	16.555	0.1841	13.00	0.1897
3	1	900	4.5	4.71	16.32	17.555	0.1802	13.333	0.1860
4	2	500	3.0	2.62	19.09	22.22	0.1754	15.00	0.1797
5	2	700	4.5	3.66	20.49	23.33	0.1790	15.55	0.1798
6	2	900	1.5	4.71	5.30	15.00	0.1706	12.22	0.1766
7	3	500	4.5	2.62	29.02	36.11	0.1670	20.66	0.1692
8	3	700	1.5	3.66	7.23	16.33	0.1637	12.55	0.1687
9	3	900	3.0	4.71	11.01	16.55	0.1639	13.22	0.1696

*Velocity of sliding & Time is find out from sample calculation and early included in table 2& table 3.

3.6 Sample Calculations

For material no. 1 & reading no. (1),
 We have, N=500 rpm, L=1.5 Km, d=100 mm

Velocity of sliding $V_r = \frac{\pi \times d \times N}{60}$ m/s

$\therefore V_r = \frac{\pi \times 100 \times 10^{-3} \times 500}{60}$ m/s

$\therefore V_r = 2.6179$ m/s

$\therefore V_r = 2.62$ m/s

Sliding distance $L = V_r \times T$ m

\therefore Time $T = \frac{L}{V_r}$ Sec

$\therefore T = \frac{1500}{2.62}$

$\therefore T = 572.5190$ Sec

$\therefore T = 9.55$ min

In this way we can find out velocity of sliding and time for all materials and for all readings which are summarized in table 2 & table 3.

Table 4: Cumulative Wear Data of All Materials

Sr. No	Material	Total Wear Rate (I) in (Microns)	Average Coefficient of Friction
1	Plain PTFE	255.761	0.1644
2	PTFE + 25% Bronze	189.538	0.1689
3	PTFE + 25% Glass Fiber	177.206	0.1741
4	PTFE + 25% Carbon	127.755	0.1787

IV. Data Analysis & Interpretation

4.1 Regression Analysis of Material 'I'

Linear regression analyses have been carried out based on the data collected as per design of experiments, which are discussed below

Table 5: Model Fit Summary of Material 'I'

Source	Sum of Squares	Df	Mean Square	F-value	P-value Prob >F	
Mean vs Total	7888.23	1	7888.23			
Linear vs Mean	881.08	3	293.68	16.76	0.0025	
2FI vs Linear	<u>104.94</u>	<u>3</u>	<u>34.98</u>	<u>600.69</u>	<u>0.0001</u>	Suggested
Quadratic vs 2FI	0.17	2	0.087		<0.0001	Aliased
Cubic vs Quadratic	0.000	0	0.000			Aliased
Residual	0.000	1	0.000			
Total	8874.42	10	887.44			

Select the highest order polynomial where the additional terms are significant and the model is not aliased.

Table 6: Model Summary Statistics of Material 'I'

Source	Std. Dev.	R-squared	Adjusted R-squared	Predicted R-Squared	PRESS	
Linear	4.19	0.8934	0.8401	0.5731	421.03	
<u>2FI</u>	<u>0.24</u>	<u>0.9998</u>	<u>0.9995</u>	<u>0.9936</u>	<u>6.28</u>	Suggested
Quadratic	0.000	1.0000	1.0000		+	Aliased
Cubic					+	Aliased

Focus on the model maximizing the "Adjusted R-Squared" and the "Predicted R-Squared".

From table 5 & 6 it is clear that for predicting the wear behaviour of material, the **2FI** approach is better compared to the Quadratic, Cubic approach hence 2FI approach is used for regression analysis of the model as approach 1.

4.2 Linear Regression Analysis using 2FI Model

To establish the correlation between the wear parameters velocity of sliding, load and sliding distance, multiple linear regression models is obtained using statistical software “**DESIGN EXPERT 8**”. The terms that are statistically significant are included in the model. The regression coefficient of the model is 0.9991.

Table 7: Effect List of Parameters of Material ‘I’

Term Intercept	Effect	Sum of Squares	% Contribution
A-load	4.17	159.82	16.84
B-velocity	-4.53	264.48	27.86
C-sliding distance	6.26	469.03	49.42
AB	-4.97	32.31	3.41
AC	3.97	18.63	1.96
BC	-1.91	4.75	0.51
ABC		Aliased	
Lack Of Fit		0.17	0.087

The last column in table 7 shows the percentage contribution of each factor on the total variation indicating their degree of influence on the result. One can observe from the above table that the sliding distance (49.42%) has great influence on the wear; followed by velocity of sliding (27.86%). However, the interaction between the velocity of sliding and sliding distance (0.51%) has negligible influence on the wear.

Table 8: ANOVA for Selected Factorial Model of Material ‘I’

Source	Sum of Squares	Df	Mean Square	F-value	P-value Prob > F
Model	986.02	6	164.34	2822.03	<0.0001
A-load	45.82	1	45.82	786.83	<0.0001
B-speed	58.19	1	58.19	999.2	<0.0001
C-sliding	103.3	1	103.30	1773.88	<0.0001
AB	32.31	1	32.31	554.76	0.0002
AC	18.63	1	18.63	319.95	0.0004
BC	4.75	1	4.75	81.62	0.0029
Residual	0.17	3	0.058		
Cor Total	986.19	9			

This analysis was carried out for a level of significance of 5% i.e the level of confidence 95%. The Model F-value of 2822.03 implies the **model is significant**. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case **A, B, C, AB, BC, AC** are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. Final equation in terms of actual factors is

$$\text{Wear (Microns)} = -8.89488 + 13.64941 \times \text{Load} + 8.82208 \times \text{Velocity of Sliding} + 3.33472 \times \text{SD} - 4.75357 \times \text{Load} \times \text{Velocity of Sliding} + 2.64801 \times \text{Load} \times \text{SD} - 1.21555 \times \text{Velocity of Sliding} \times \text{SD} \dots\dots\dots (1)$$

Substituting values of the variables for the above equation, the sliding wear of the material “I” can be calculated. The positive value of the coefficient suggests that the sliding wear of material increases with their associated variables. Whereas the negative value of the coefficient suggest that the sliding wear of the material will decrease with the increase in associated variables.

Same procedure can be used for the regression analysis of material ‘II’, material ‘III’ & material ‘IV’. Therefore, for material ‘II’, material ‘III’ & material ‘IV’ final equation in terms of actual factors are

$$\text{Wear (Microns)} = -8.23498 + 11.23300 \times \text{Load} + 8.84215 \times \text{Velocity of Sliding} - 1.73256 \times \text{SD} - 4.63657 \times \text{Load} \times \text{Velocity of Sliding} + 3.22306 \times \text{Load} \times \text{SD} - 0.52162 \times \text{Velocity of Sliding} \times \text{SD} \dots\dots\dots (2)$$

$$\text{Wear (Microns)} = -7.63966 + 10.17766 \times \text{Load} + 6.87640 \times \text{Velocity of Sliding} + 1.54834 \times \text{SD} - 3.45471 \times \text{Load} \times \text{Velocity of Sliding} + 1.81235 \times \text{Load} \times \text{SD} - 0.76617 \times \text{Velocity of Sliding} \times \text{SD} \dots\dots\dots (3)$$

$$\text{Wear (Microns)} = +5.56007 + 3.27859 \times \text{Load} + 2.50113 \times \text{Velocity of Sliding} - 0.10254 \times \text{SD} - 1.34578 \times \text{Load} \times \text{Velocity of Sliding} + 0.90871 \times \text{Load} \times \text{SD} - 0.21560 \times \text{Velocity of Sliding} \times \text{SD} \dots\dots\dots (4)$$

4.3 Confirmation Test

To test the accuracy of the model the confirmation tests were performed by selecting the set of parameters as shown in table 9. The wear value for materials calculated from the mathematical model developed by **2FI Approach** were compared with values obtained experimentally as shown in table 10.

Table 9: Parameters used in the Confirmation Test

Material	Test	Velocity of Sliding (Vr) in (m/s)	Load in (kg)	Sliding Distance (L) in (km)
I	1	1.5	2	2
	2	2.8	3.5	2.5
II	3	1.5	2	2
	4	2.8	3.5	2.5
III	5	1.5	2	2
	6	2.8	3.5	2.5
IV	7	1.5	2	2
	8	2.8	3.5	2.5

Table 10: Confirmation Test of all Selected Materials

Material	Velocity of Sliding (Vr) in (m/s)	Load in (Kg)	Sliding Distance in (Km)	Actual Wear (Microns)	Predicted Wear (Microns)	Deviation %
I	1.5	2	2	30.111	30.991	-2.923
	2.8	3.5	2.5	40.886	39.995	2.184
II	1.5	2	2	21.666	21.446	1.011
	2.8	3.5	2.5	30.956	30.619	1.088
III	1.5	2	2	17.85	17.258	3.310
	2.8	3.5	2.5	31.985	31.373	1.913
IV	1.5	2	2	14.321	14.614	-2.049
	2.8	3.5	2.5	16.756	17.035	-1.666

From the analysis of above table 10, we can observe that the calculated error varies from 1% to 3.31 %. Therefore the multiple regression equation derived above correlate the evaluation of wear in the polymer with the degree of approximation.

V. Results & Discussions

5.1 Interaction Effect of Parameters on Wear of Material 'I'

Figure 3 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 4500 m. Figure 4 shows interaction effect of load and sliding distance on wear at maximum velocity 4.71m/s. Figure 5 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 3 kg.

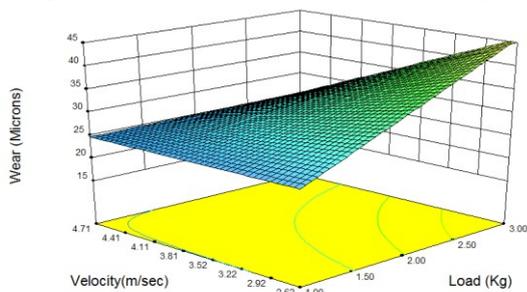


Figure 3: Graph of Interaction of Load and Velocity of Sliding with Wear at SD=4500 m

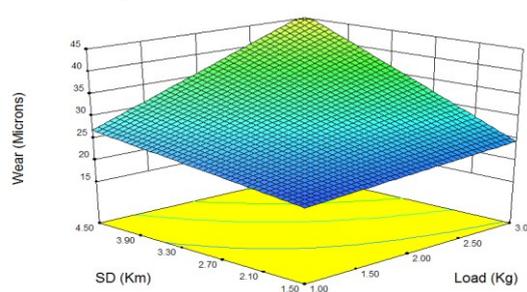


Figure 4: Graph of Interaction of Load and Sliding Distance with Wear at Vr =4.71 m/s

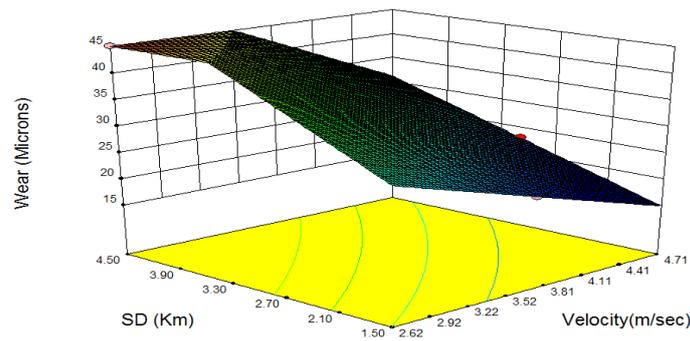


Figure 5: Graph of Interaction of Velocity of Sliding and SD with Wear at Load=3 Kg

5.2 Interaction Effect of Parameters on Wear of Material ‘II’

Figure 6 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 4500 m. Figure 7 shows interaction effect of load and sliding distance on wear at maximum velocity 4.71m/s. Figure 8 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 3 kg.

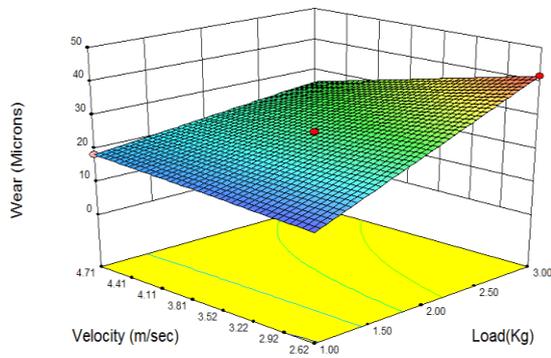


Figure 6: Graph of Interaction of Load and Velocity of Sliding with wear at SD=4500 m

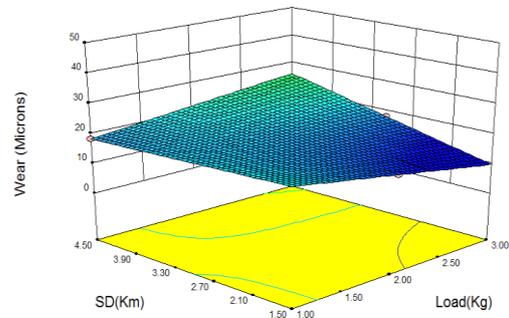


Figure 7: Graph of Interaction of Load and Sliding distance with Wear at Vr =4.71 m/s

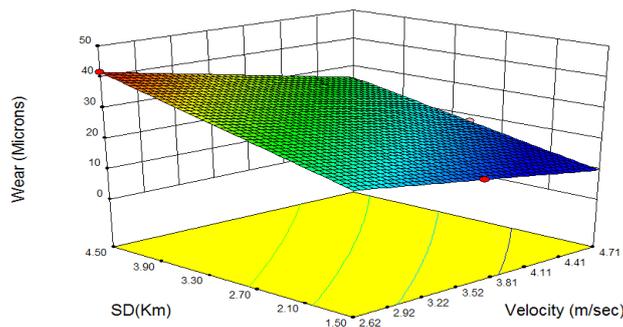


Figure 8: Graph of Interaction of Velocity and SD. with Wear at Load=3 Kg

5.3 Interaction Effect of Parameters on Wear of Material ‘III’

Figure 9 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 4500 m. Figure 10 shows interaction effect of load and sliding distance on wear at maximum velocity 4.71m/s. Figure 11 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 3 kg.

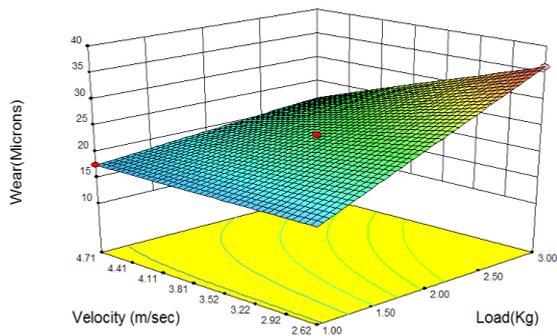


Figure 9: Graph of Interaction of Load and Velocity of Sliding with Wear at SD=4500 m

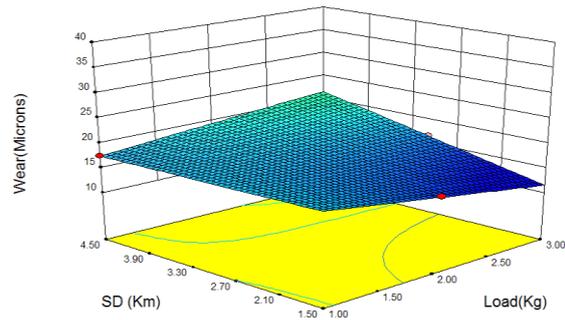


Figure 10: Graph of Interaction of Load and Sliding distance with Wear at Vr =4.71 m/s

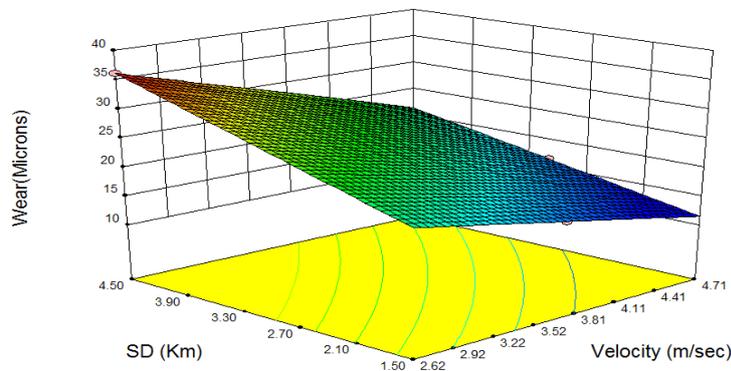


Figure 11: Graph of Interaction of Velocity and SD with Wear at Load=3 Kg

5.4 Interaction Effect of Parameters on Wear of Material ‘IV’

Figure 12 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 4500 m. Figure 13 shows interaction effect of load and sliding distance on wear at maximum velocity 4.71m/s. Figure 14 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 3 kg.

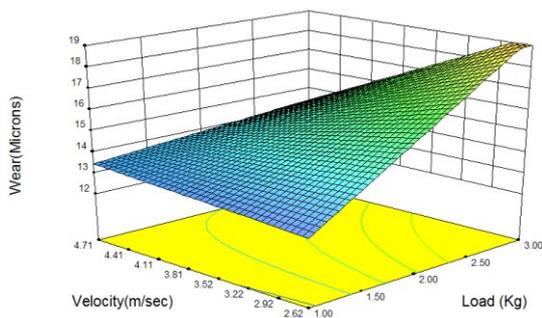


Figure 12: Graph of Interaction of Load and Velocity of Sliding with Wear at SD=4500 m

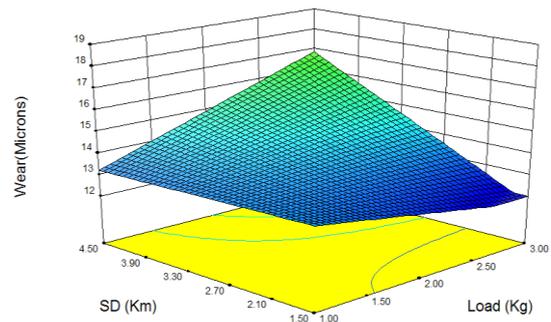


Figure 13: Graph of Interaction of Load and Sliding distance with Wear at Vr =4.71 m/s

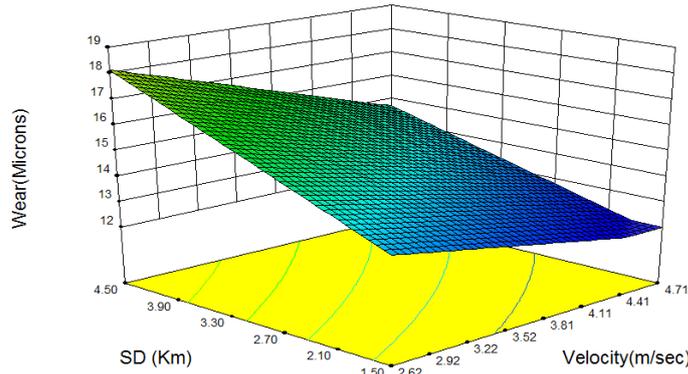


Figure 14: Graph of Interaction of Velocity and SD with Wear at Load=3 Kg

5.5 Comparative Study of Materials

One can observe from the Figure 15-17 that as load increases wear of all material goes on increasing and sliding distance has great influence on the wear for of all the tested materials. For all the test materials as velocity of sliding increases wear of all material goes on decreasing. It is observed that the wear of material “IV” is less than material “III”, material “II” and pure PTFE i.e. material “I” has higher wear rate.

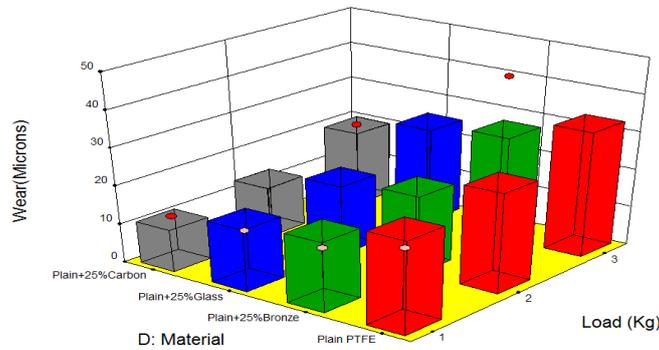


Figure 15: Wear v/s Load

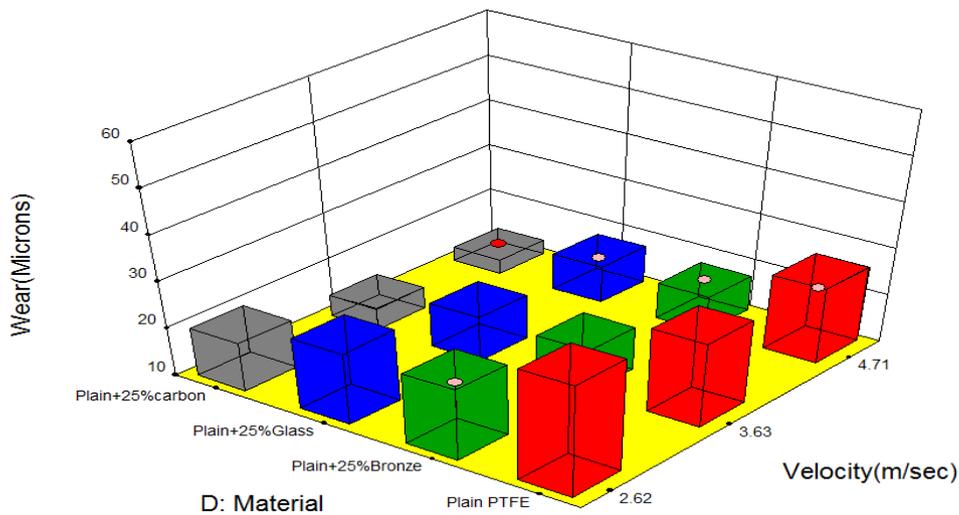


Figure 16: Wear v/s Velocity of Sliding

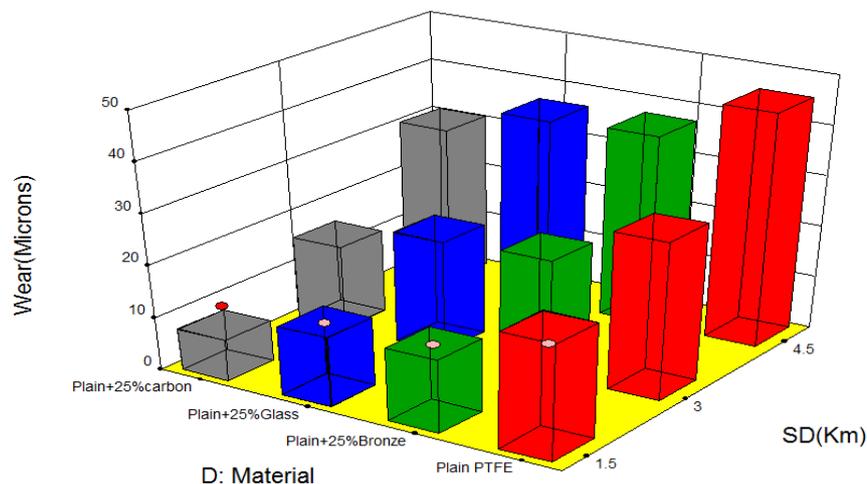


Figure 17: Wear v/s Sliding Distance

VI. Conclusions

The following conclusions can be drawn from the study:

- Addition of filler materials such as bronze, glass and carbon to PTFE causes an increase in hardness and wear resistance, while the coefficient of friction is slightly increased.
- Wear of pure PTFE is decreased about 26% by adding 25% bronze, 31% by adding 25% glass and 50% by adding 25% carbon.
- It is observed that the addition of carbon filler to plain PTFE improves wear resistance significantly as compared to glass and bronze filler.
- Depending upon load, velocity of sliding and sliding distance, material used in this study can be ranked as 25% carbon filled PTFE > 25% glass filled PTFE > 25% bronze filled PTFE > pure PTFE for their wear performance.

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