

Research Article

# Experimental Investigation of PTFE & its Filler under Wet and Dry Condition

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## Abstract

During the past years, the investigations of the tribological behavior of PTFE are mainly in the field of dry friction, several researchers have also studied the friction and wear behavior of PTFE under dry condition. Unfortunately there are hardly any investigations on tribological behavior of PTFE in distilled water. In this paper tribological behaviors of PTFE+15% bronze, PTFE+ 25% glass and PTFE + 30% bronze composites against distilled water were comparatively investigated by using the Pin ON Disc arrangement. Test were carried out at sliding speed of 3.77, 5.03, 6.28 m/sec and under a nominal load 1, 2, 3 kg. Wear rate is obtained as a response of experimentation and then further analyzed in design expert software. The influence of fillers of the glass and bronze on PTFE composites under dry and wet condition has been compared. However, wear rate of specimen in distilled water and air exhibit significant differences. From study, 35 % Bronze filled PTFE are found excellent wear resistance and highest coefficient of friction.

**Keywords:** Composites, Design Expert, ANOVA, PTFE, Taguchi OA friction, wear

## 1. Introduction

Nowadays, there is very intensive growth in the large scale production of the fibre reinforced polymer composites since they possess certain advantage over the metals. The advantages include lower density, less need for maintenance and lower Cost [Hongxiang Teng *et al* 2012]. PTFE is a high performance plastic, which is used in a broad range of industries. This plastic is also known by trade names such as Teflon Dyneon or Fluon[W. Brostow *et al* 2010]. PTFE is based polymer compound with white or grey in color. PTFE has all qualities of bearing alloy like compatibility, conformability embed ability, load capacity, fatigue strength, corrosion resistance and hardness. It is a crystalline solid with good stability from -195°C to +260°C [Harshal P Deshmukh *et al*, 2015].

But PTFE exhibits poor wear and abrasion resistance, leading to early failure and leakage problem in the machine parts. To minimize this problem, various suitable fillers added to PTFE. Generally, reinforcements such as glass fibers, carbon fibers, bronze and solid lubricants are added internally or incorporated into the 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. The aim of

the present study was to investigate the tribological behaviour of Pure PTFE and its composite ON Pin ON Disc apparatus. The wear model for the tested materials was developed based on the applied load, Sliding speed and sliding distance. Water lubrication has advantages and disadvantages on its own explained from the involved mechanism and wear mode. Water lubrication in polymers-metal contacts can act as a cooling agent to reduce the frictional heating thus hindering the normal thermo-mechanical behavior like softening of polymers. Water absorption of polymers and plasticization are the two most common phenomenon occurring in a water lubrication. Absorption leads to changes in structure at the surface level by swelling and it also changes the elastic modulus and strength wherefore altering the friction and wear behavior. Positive effect of wet sliding of polymers has reduced in the induced shear stress. The positive or the negative effect of water lubrication is determined by the dominating mechanism involved in the sliding process [J. Sukumaran *et al* 2010]

## 2. Aim of the experiments

The industrial materials presently in white metal, vagues etc. are extensively used in sugar, chemical, cement, pharmaceutical and automobile industries as they exhibit excellent load carrying capacity and corrosion resistance. However this metal material suffers from following serious drawbacks

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- 1) Material is highly expensive.
- 2) The oil retaining capacity of the material; is very low due to absence of inherent porosity.
- 3) It exhibits a tendency to wear out rapidly.
- 4) It fails to function satisfactorily at higher loads and speeds.
- 5) Reliability of metal component is less under a lubricant like distilled water or sea water.

Against this background, the present research work is aimed at developing a new material for Industrial purpose also To investigate the tribological behavior of PTFE and its Composites under wet condition and compared wear rate of PTFE & its composites in air and lubricant.

### 3. Factors affecting PTFE and PTFE composite wear

- Normal Load:-In order for a PTFE composite to function as a solid lubricant it must be able to support the load, as well as the tangential stresses induced by sliding.
- Sliding Velocity:-The high sliding speeds can produce high temperatures due to friction heating. This may cause the polymer or the polymer composite additives to degrade.
- Sliding Distance:-sliding distance is one of most important parameters which influence wear rate Thus it is important to choose sliding distance for each particular polymer to ensure the optimum performance.
- Contact Area:- Contact area is important from two points of view. First the contact areas will determine the projected contact stresses. If the load cannot be reduced, one way of reducing stress is to increase the projected contact area; this lowers the stresses and promotes sliding in the mild regime of wear.
- Counter face Topography:- The material counter face that slides against a polymer composite is very important in determining the friction and wear characteristics of that composite. If the counter face is too rough it can abrade the composite and not allow a shear film or transfer film to form.
- Temperature and Molecular Relaxations:- At lower temperature the friction and wear properties of PTFE are not as exceptional as they are at or above ambient temperature. Temperature can affect the lubricating properties of the additives in polymer composite. Additives might desorb gases at certain temperature or even decompose. Temperature can also affect bonding between the additives and the polymer matrix.

### 4. Literature survey

Investigate tribological behaviour of PTFE composite using two standard tribological tests approach i.e., pin-on-disc and thrust washer measurements, have been compared with sliding tests performed on composite. The obtained results indicate the different testing

methods continuous rotation vs. reciprocating linear movement for the pin-on-disc/thrust washer and sliding tests, respectively, the different techniques provide highly comparable data within the adopted experimental conditions [Luigi Mazza *et al* 2015].

Fluoropolymers have come a long way in the past 70 years. No doubt many new fluoropolymer materials will be developed and new applications will be found for old fluoropolymers. The importance of the fluoropolymer industry will not be destabilized before the emergence of new substitute materials [Hongxiang Teng 2012].

Prasad M Patare studies the effects of filler on the friction and wear properties of 15% glass fibre and 30% glass filled PTFE composites under dry friction conditions were studied. 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.

S.M.Gujarathi [S.M.Gujarathi, 2013] the incorporation of carbon particles in the PTFE matrix as a secondary reinforcement increases the wear resistance of the material. The smearing of the carbon and formation of protecting layer between the pin and the counter face enables in reducing the wear volume loss.

Deepak Bagle [Deepak Bagle, 2013] has studied the tribological behavior of PTFE 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 wear resistance.

Sandip Chaudhari [Sandip Chaudhari, 2013] has done wear analysis of PTFE and its composites under wet conditions. The results of experiments shows that the addition of bronze, glass and carbon filler to the virgin PTFE decreases wear rate significantly

Harshal Deshmukh [Harshal Deshmukh, 2015], Navneet Patil has studied three different composites of semi-metallic brake pads for wear rate under dry conditions. Conclusions of the work are, as load and sliding distance increases wear rate also increase.

Jaydeep Khedkar *et al* [Jaydeep Khedkar *et al*, 2002] In this paper the tribological behavior of polytetrafluoroethylene (PTFE) and PTFE composites with filler materials such as carbon, graphite He concluded that, addition of filler materials such as carbon, graphite, glass fibers and PPDT to PTFE causes an increase in hardness and wear resistance, while the coefficient of friction is slightly affected and remains low.

J. Sukumaran [J. Sukumaran *et al*] On using water lubrication the co-efficient of friction decreases to a specific value and then tends to be constant but in case of dry sliding the tendency overturn by having a rapid increase in the beginning of sliding and reaches a specific point from where the coefficient of friction grows in a constant rate. On the whole more data are required to characterize the wear mechanism in water

lubrication of polymers few of the observed quantitative data and its mechanisms from various researchers.

JK Lancaster [JK Lancaster 1990]. In a study by Lancaster *et al* it was mentioned that water lubrication has enhanced the tribological property of both the engineering plastics and the high performance polymer.

## 5. Experimental procedure

### A. Specimen Preparation

Materials used for experiment to analyze comparative tribological behaviour, wear and coefficient of friction of 25% glass filled PTFE, 30% bronze filled PTFE and 15% bronze filled PTFE under load of 1 kg, 2 kg, 3 kg and sliding velocity 3.77 m/s, 5.03 m/s and 6.28 m/s under wet friction condition. The sample specimen has been prepared by performing necessary turning and facing operations on the respective rods. Then respective codes has been assigned to the specimen as follows.

**Table I:** Assigning codes specimens

Material Name	Chemical Composition in Wt.%
I	30%Bronze filled PTFE
II	15%Bronze filled PTFE
III	25% Glass filled PTFE

### B. 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.

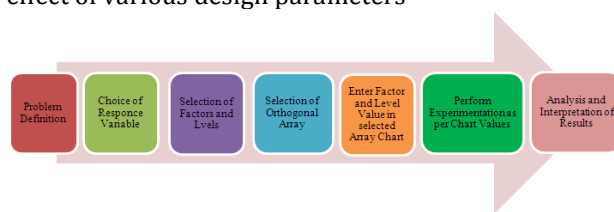
### C. Introduction to Design Expert

Design-Expert, version 9.05 software 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.

### D. Taguchi Approach

Taguchi approach is significant analysis tool for the influence of control variable on performance output. It

provides a simple, efficient and systematic approach to optimize design of performance, quality. The method is valuable when design parameters are qualitative and discrete. Taguchi Parameter design can optimize the performance to source of variation parameter. Taguchi approach is consist problem definition, choice of response, selection of factors and levels, selection of orthogonal array, enter factor and level value in selected array chart, perform experimentations per chart value, analysis and interpretation of result. The design of experiment process made up of three main phase: the planning phase, the conducting phase and analysis interpretation phase. The planning phase is the most important phase one of must give a maximum importance to this phase. The data collected from all the experiment in the set are analyzed to determine the effect of various design parameters



**Fig.1** An outline Procedure for Taguchi Approach

### E. 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. 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.

### F. 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. The ANOVA allows analyzing the influence of each variable on the total variance of the results.

G. Design of test runs

The To ensure the optimum interaction of all the parameters L9 (3^4) Method of Taguchi Orthogonal array is used which have nine test runs, 3 levels of factors, and maximum 4 factors, we identified 3 factors

**Table II:** Test run parameter

	LEVELS		
	low	medium	high
Load(kg)	1	2	3
Disc Speed(rpm)	600	800	1000
Sliding Distance(km)	2	3	4

If the parameter given in “Table I” are put in Design expert software it will generate a following Run sheet of parameters for pin-on-disc setup shown in “Table II” which can be further utilized as Observation table to note wear rate as response.

**Table III:** layout of L9 orthogonal array for experimentation

Run	Load (kg)	Speed(rpm)	Sliding Distance (km)
1	1	600	2
2	1	800	3
3	1	1000	4
4	2	600	3
5	2	800	4
6	2	1000	2
7	3	600	4
8	3	800	2
9	3	1000	3

The arrangement to set sliding distance is not provided on test set up instead the time of run can be calculated and can be monitored using stopwatch. The final test run and parameter combination is shown in “Table IV”. 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) against distilled water.



**Fig.2** Pin on disc Test-Rig

**Table IV:** Final test run design

Run	Load(kg)	Disc Speed(rpm)	Time (min)
1	1	600	8.84
2	1	800	9.94
3	1	1000	10.62
4	2	600	13.26
5	2	800	13.25
6	2	1000	5.31
7	3	600	17.68
8	3	800	6.63
9	3	1000	7.96

H. Testing

Experiments are conducted as per the design matrix “Table IV” and response is recorded in terms of wear by weight loss method. Weight of pin before run and weight of pin after run is noted and calculated to obtain wear rate. Weighing scale with minimum capacity of 10 mg is used for the same. For the analysis and to find correlation all factors should be in same unit therefore while filing the data in software Disc speed and Run time is converted in Sliding Velocity (m/s) and Sliding Distance (Km) as shown in “Table V

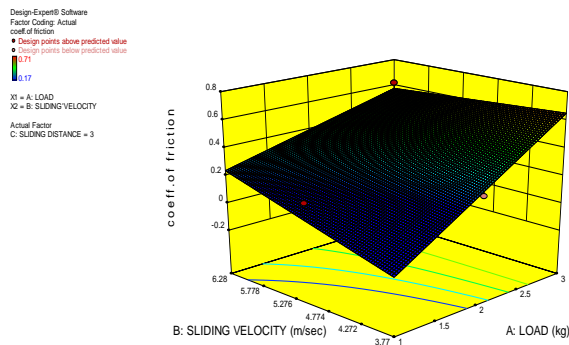
**Table V:** Conversion of Disc speed and Run time to Sliding Velocity (m/s) and Sliding Distance (Km)

Run	Load(kg)	Velocity(m/s)	Sliding Distance(m)
1	1	3.77	2000
2	1	5.03	3000
3	1	6.28	4000
4	2	3.77	3000
5	2	5.03	4000
6	2	6.28	2000
7	3	3.77	4000
8	3	5.03	2000
9	3	6.28	3000

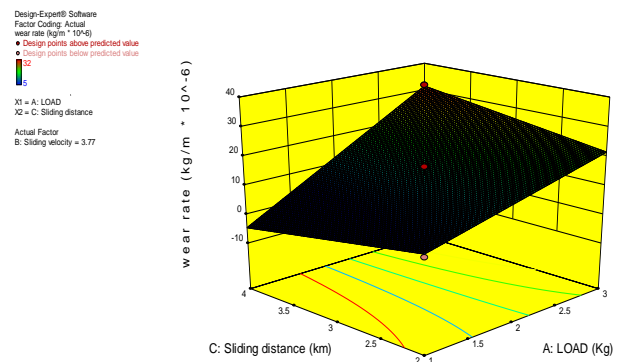
5. Results and discussion

Analysis of Variance (ANOVA) for Wear Rate is done for all three Material compositions, checked whether it is suggested for liner model or 2FI model and then if the model is significant and suggested or not. For all material liner model is significant and all the study parameter is also significant. But it gives model graph with 2FI also. When all models were significant the following effects are shown in fig.

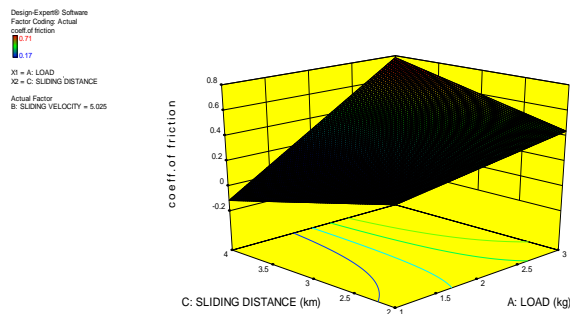




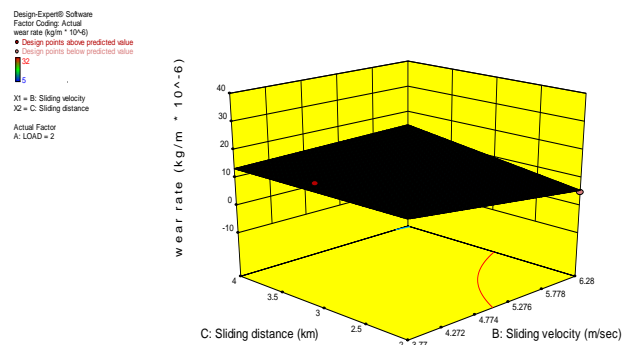
**Fig.11** 3D View of interaction effect of sliding velocity and load on coeff of friction at sliding distance 3m



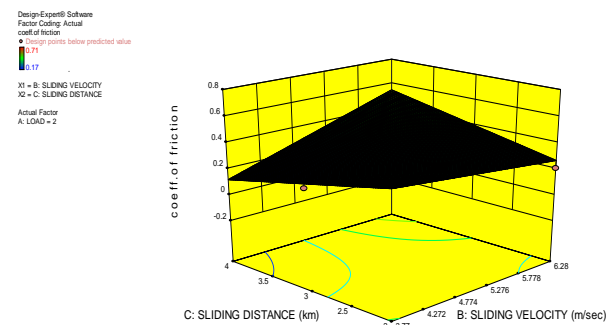
**Fig.15** 3D View of interaction effect of sliding distance and load on wear rate at sliding velocity 3.77m/sec



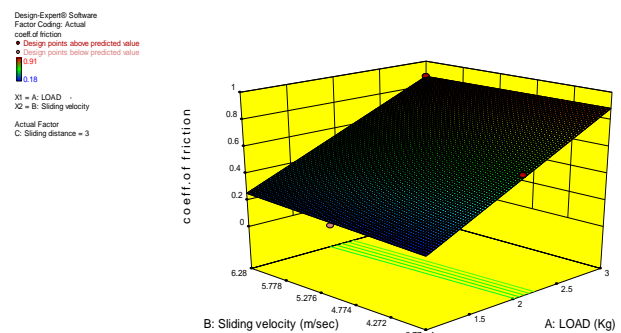
**Fig.12** 3D View of interaction effect of sliding distance and load on coeff of friction at sliding velocity 5.03m/sec



**Fig.16** 3D View of interaction effect of sliding distance and velocity on wear rate at load 2kg

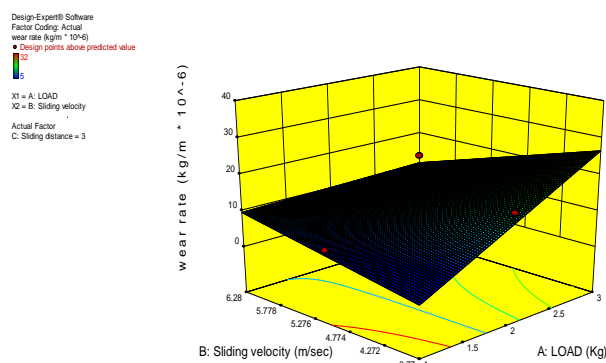


**Fig.13** 3D View of interaction effect of sliding distance and velocity on coeff of friction at load 2 kg

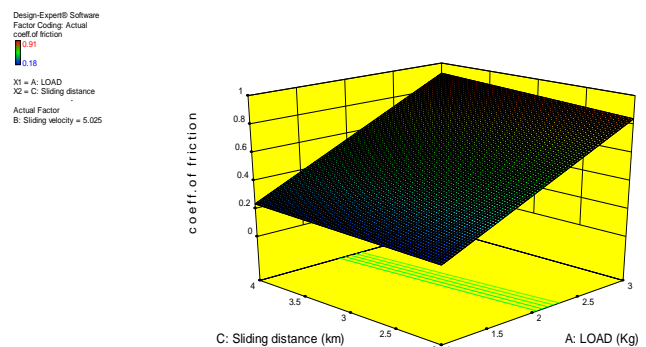


**Fig.17** 3D View of interaction effect of sliding velocity and load on Coeff of friction at sliding distance 3m

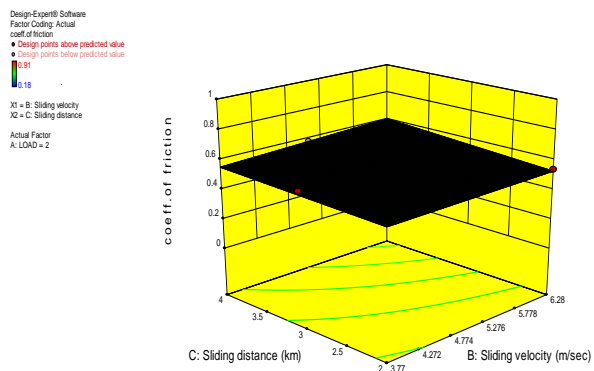
■ For material III (25% Glass+PTFE)



**Fig.14** 3D View of interaction effect of sliding velocity and load on wear rate at sliding distance 3m



**Fig.18** 3D View of interaction effect of sliding distance and load on Coeff of friction at sliding velocity 5.03 m/sec



**Fig.19** 3D View of interaction effect of sliding distance and velocity on Coeff of friction at load 2kg

It is clearly seen from above results that, when the specimens are tested on “PIN ON DISC” set up against the distilled water, load and sliding distance increases wear rate of all three PTFE Composite also increases, whereas velocity of sliding increases wear of PTFE Composite materials decreases. We can observe from fig no. (6,7,8) , (12,12,14) and (18,19,20) that, as load increases, coefficient of friction of all material goes on increasing.

**6. Comparative wear data of all material**

S.No	Material name	Wear rate	Coefficient of friction
1	PTFE + 30% BRONZE	$1.02 \times 10^{-5}$	0.24
2	PTFE + 15%BRONZE	$1.37 \times 10^{-5}$	0.13
3	PTFE + 25% GLASS	$1.19 \times 10^{-5}$	0.20

**Correlation**

Following correlations are obtained for wear rate analysis of three Specimens under wet condition.

▪ For Material I

$$\begin{aligned} \text{Wear rate } 10^{-6} \text{ gm/m} &= \\ -2.57347 & \\ +3.47222 & \quad * \text{ Load (kg)} \\ -2.32476 & \quad * \text{ Sliding Velocity (m/s)} \\ +5.83333E-003 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [1] \end{aligned}$$

▪ For Material II

$$\begin{aligned} \text{Wear rate } 10^{-6} \text{ gm/m} &= \\ +15.12058 & \\ +3.33332 & \quad * \text{ Load (kg)} \\ -4.42643 & \quad * \text{ Sliding Velocity (m/s)} \\ +7.50000E-003 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [2] \end{aligned}$$

▪ For Material III

$$\begin{aligned} \text{Wear rate } 10^{-6} \text{ gm/m} &= \\ +1.89613 & \\ +5.27777 & \quad * \text{ Load (kg)} \\ -3.10341 & \quad * \text{ Sliding Velocity (m/s)} \\ +5.00000E-003 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [3] \end{aligned}$$

Following correlations are obtained for coefficient of friction analysis of three Specimens under wet condition:-

▪ For Material I

$$\begin{aligned} \text{Co. of Friction} &= \\ +1.44327E-003 & \\ +0.14313 & \quad * \text{ Load (kg)} \\ -0.037034 & \quad * \text{ Sliding Velocity (m/s)} \\ +4.61616E-005 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [1] \end{aligned}$$

▪ For Material II

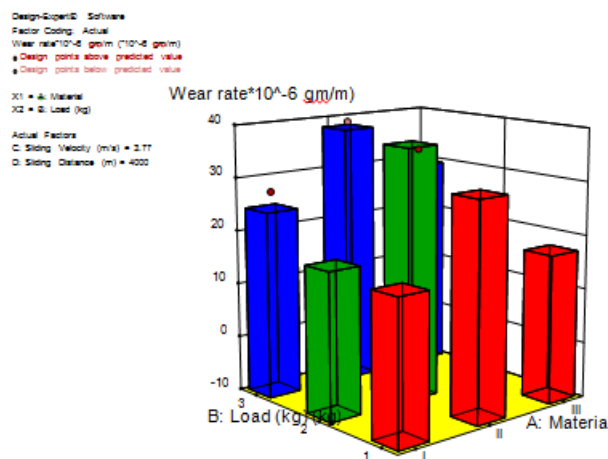
$$\begin{aligned} \text{Co. of Friction} &= \\ -0.066981 & \\ +0.078788 & \quad * \text{ Load (kg)} \\ -7.47299E-003 & \quad * \text{ Sliding Velocity (m/s)} \\ +2.47475E-005 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [2] \end{aligned}$$

▪ For Material III

$$\begin{aligned} \text{Co. of Friction} &= \\ -0.085319 & \\ +0.11793 & \quad * \text{ Load (kg)} \\ +2.00252E-003 & \quad * \text{ Sliding Velocity (m/s)} \\ +1.36364E-005 & \quad * \text{ Sliding Distance (m)} \dots\dots\dots [3] \end{aligned}$$

**Comparison of materials in wet condition and dry condition**

▪ For wet condition



**Fig.20** 3D View of effect of load on wear rate against Distilled water for I, II, III material

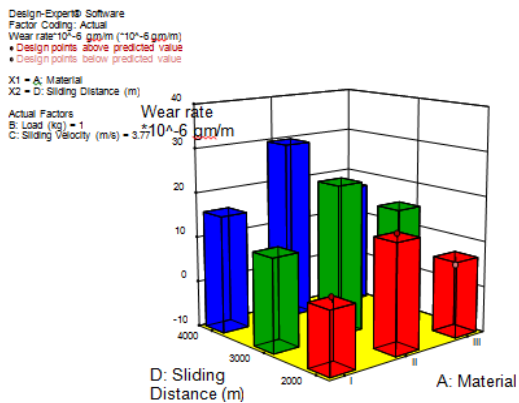


Fig.21 3D View of effect of sliding distance on wear rate against Distilled water for I, II, III material

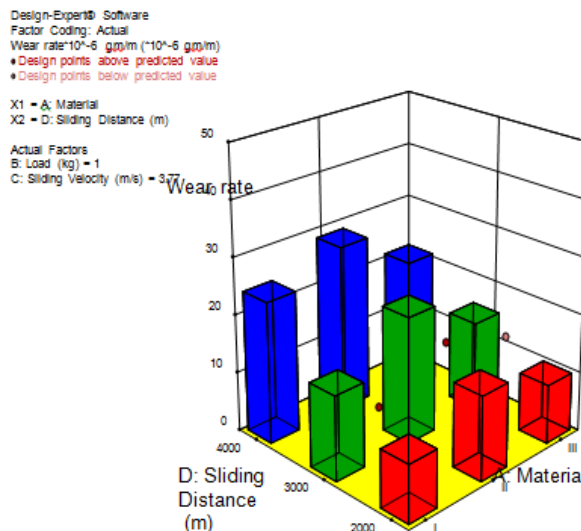


Fig.24 3D View of effect of sliding distance on wear rate against air for I, II, III material

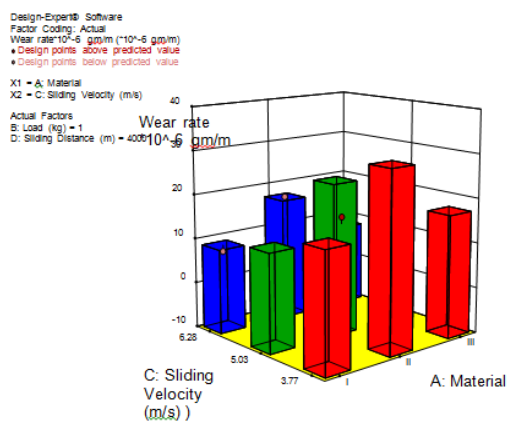


Fig.22 3D View of effect of sliding velocity on wear rate against Distilled water for I, II, III material

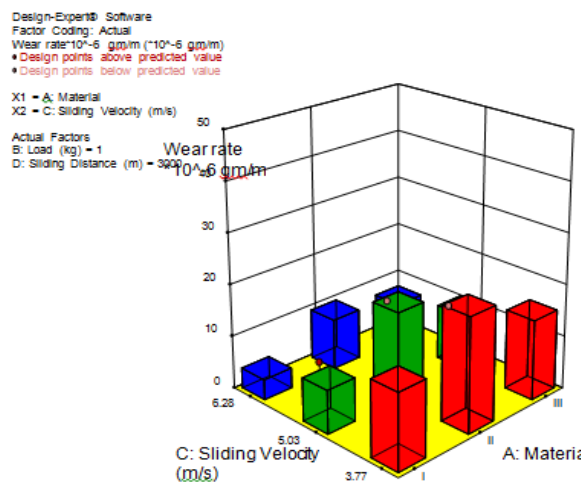


Fig.25 3D View of effect of sliding velocity on wear rate against air for I, II, III material

Factors	% Contribution		
	Material I	Material ii	Material iii
A:Load	22.08264187	11.312847	40.94843
B:Sliding Velocity	15.59128975	31.41873	22.299986
C: Sliding distance	62.32606837	57.268423	36.751584
	100	100	100

7. Comparative % contribution summary of all material under wet test

- For dry condition

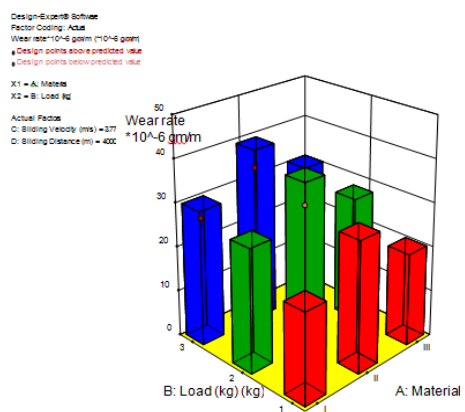
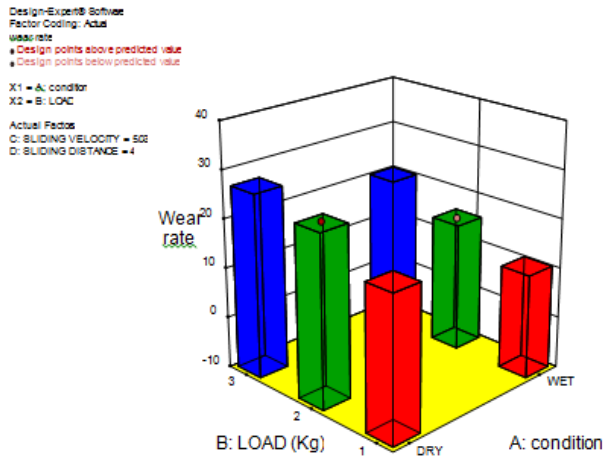


Fig.23 3D View of effect of load on wear rate against air for I, II, III material

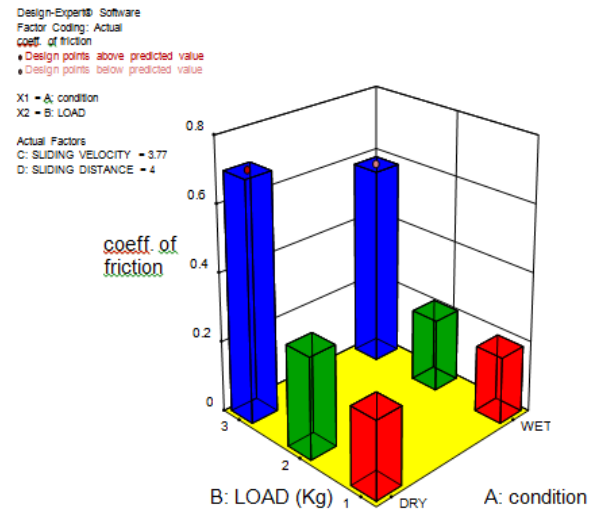
Factors	% Contribution		
	Material i	Material ii	Material iii
A:Load	21.243436	45.739145	39.428463
B:Sliding Velocity	21.259872	18.120833	18.640396
C: Sliding distance	57.496691	36.140023	41.931141
	100	100	100

8. Comparative % contribution summary of all material under dry test

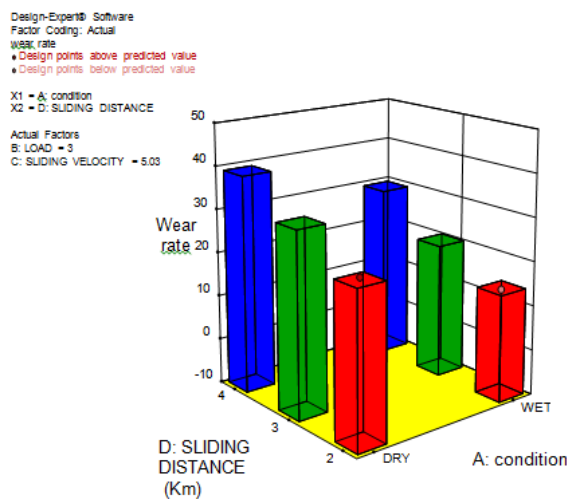
- Comparison of dry and wet condition



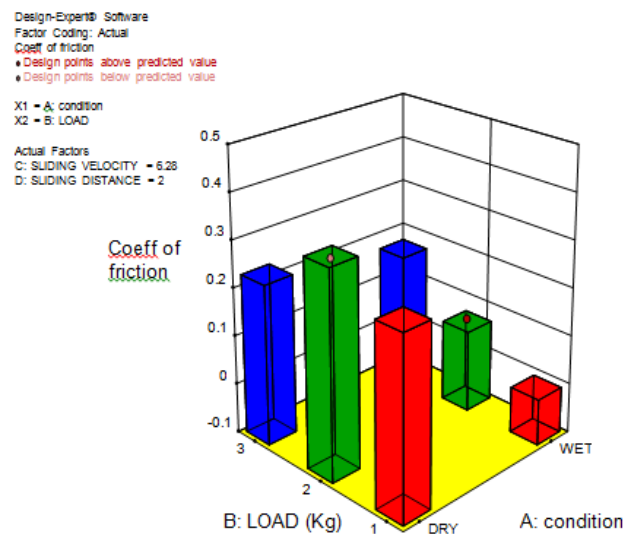
**Fig.26** Wear rate comparison for material I in wet & dry condition



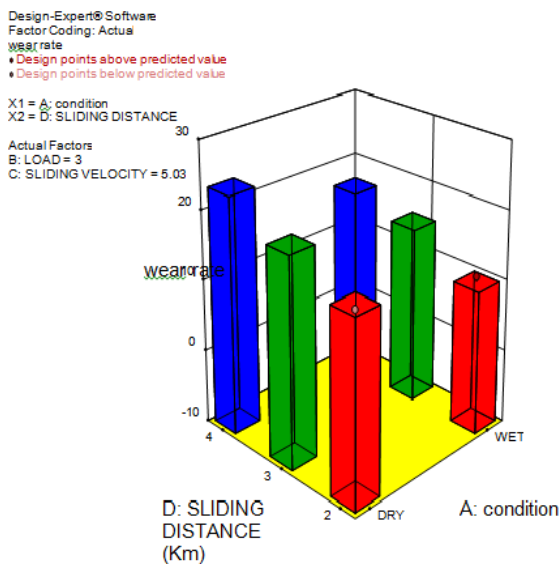
**Fig.29** Coeff. Of friction comparison for material I in wet & dry condition



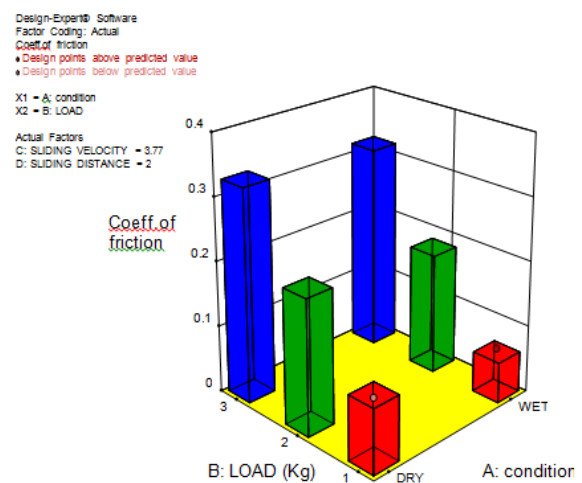
**Fig.27** Wear rate comparison for material II in wet & dry condition



**Fig.30** Coeff. of friction comparison for material II in wet & dry condition



**Fig.28** Wear rate comparison for material III in wet & dry condition



**Fig.31** Coeff. of friction comparison for material III in wet & dry condition

As per the software suggestion some model are not suggested for 2FI system still its provide the significant value and relative graphs of corresponding responses equation are generated for both 2FI and linear system but as per the study linear equations are more efficient for the analysis of specimen wear rate and coefficient

of friction. After the confirmation test and % deviation study it is clear that linear system equations are more accurate and give the efficient analysis. It give the proper response without complication in analysis equation.so in whole work the correlation of specimen is obtain from linear equation.

### 9. Comparative study of wear rate and coeff.of friction under dry and wet condition

Comparison		For dry condition	For wet condition
Sr.No	Material Name	wear rate (kg/m)	wear rate (kg/m)
1	PTFE +BRONZE 30 %	1.58333E-05	1.01852E-05
2	PTFE + BRONZE 15 %	2.48148E-05	1.37963E-05
3	PTFE + GLASS 25 %	1.60185E-05	1.18519E-05
Sr.No	Material Name	Coefficient .of friction	Coefficient. Of friction
1	PTFE +BRONZE 30 %	0.28	0.24
2	PTFE + BRONZE 15 %	0.27	0.12
3	PTFE + GLASS 25 %	0.217	0.2

### Conclusion

1. From the analysis on the results of dry and wet sliding wear of the PTFE Filled with Bronze and glass, the following conclusions can be drawn from the study.

- Wear rate of PTFE Composites increase with the increase in normal load.
- Wear rate of PTFE decreases with increase in sliding velocity.
- Wear rate of PTFE increases with increase in the sliding distance.

2. Both wear rate and coefficient of friction of all specimens drastically reduced against distilled water as compared to air.

3 Sliding distance is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear as well as wet sliding wear.

4. Depending upon load, velocity of sliding and sliding distance, material used in this study can be ranked as 30 % bronze filled PTFE > 25 % glass filled PTFE > 15 % bronze for their wear resistance Performance.

5. It is found that there is no direct correlation between coefficient of friction and wear rate.it increases with increase in load only.

6. While sliding against distilled water it is found that the material having lowest wear rate getting highest coeff. of friction.

### Acknowledgment

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### Nomenclature

PTFE	Polytetrafluoroethylene
SD	Sliding Distance
DOE	Design of Experiment
OA	Orthogonal Array
Vr	Velocity of Sliding (m/s)
M	Coefficient of Friction

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