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Friction and Wear Behaviour of Ptfe & its Composite in Dry Conditions

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Abstract- **In this work, the effects of velocity of sliding, load and sliding distance on friction and wear of polymer material made of PTFE composites with filler materials such as glass bronze and carbon are studied. The experimental work is performed on pin-on-disc apparatus and analysed with the help of Design-Expert software. Parameters are set for three different levels and in optimum possible combination by Taguchi experimentation design array. Wear rate is obtained as a response of experimentation and then further analysed in design expert software. Parametric relation is developed in the form of equation for each material composition. At the end all three materials are compared on the basis of wear rate and coefficient of friction. As graphical representation is the most user friendly way of interpretation of statistical data, three-dimensional graphs comparing wear rate of all three materials simultaneously under the influence of individual parameters namely load, sliding distance and sliding velocity are given in results. The results of experiments are presented in tables and graphs which shows that the addition of bronze and carbon filler to PTFE decreases wear rate significantly and there is marginal increase in coefficient of friction.**

Index Terms- Composites, Design Expert, PTFE, Taguchi OA friction, wear.

1. INTRODUCTION

The development of the fluoropolymer industry began with the discovery of the polytetrafluoroethylene (PTFE) by Dr. Roy J. Plunkett (1910-1994) at DuPont in 1938 and introduction as a commercial product in 1946 [10]. Polytetrafluoroethylene (PTFE) is a high performance engineering plastics which is widely used in industry due to its properties of self-lubrication, low friction coefficient, high temperature stability and chemically resistant. While PTFE exhibits poor wear and abrasion resistance, leading to early failure and leakage problem in the machine parts. To minimise this problem, various suitable fillers added to PTFE. Generally, reinforcements such as glass fibres, carbon fibres, bronze and solid lubricants are added internally or incorporated into the PTFE. Its relative softness and poor heat conductivity limit its suitability as a bearing material to applications involving low speeds and low unit pressure, the tribological behaviour of polymers is affected by environmental and operating conditions and by the type, size, amount, shape and orientation of the fibres. A relationship between the wear of the polymers and operating parameters is desirable to obtain the better understanding on the wear behaviour [4, 5]. The Pin on disc wear testing machine represents a substantial advance in terms of simplicity and convenience of operation, ease of specimen clamping and accuracy of measurements, both of Wear & Frictional force.

1.1 Parameters in Wear Testing:

- Load: Load is important factor when we consider friction & wear. As we know, friction & wear is proportional to the applied load.
- Sliding Velocity: When it’s deal with friction and wear testing machine, it is very necessary to consider the sliding velocity of the specimen.
- Sliding Distance: As we know, Sliding distance is directly proportional to wear rate.

1.2 Parameters to study:

- Coefficient Of Friction: The coefficient of friction is generally depends on the Load, sliding speed. Material should possess low coefficient of friction.
- Wear rate: Wear is the removal of material from either or both of the contacting surfaces. Material should have improved wear resistance under load and permanent deformation.

1.3 Purpose of Present Study:

- To find the effect of carbon filler & bronze filler in PTFE on wear rate in dry conditions.
- 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 in dry conditions.

2. LITERATURE SURVEY

Harshal Deshmukh, Navneet Patil [1] 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, and as the velocity of sliding increases wear rate slightly decrease.

Deepak Bagle [2] 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.

Sandip Chaudhari et al [3] 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 and there is marginal increase in coefficient of friction.

H. Unal et al [4] “Sliding friction and wear behaviour of polytetrafluoroethylene and its composites under dry conditions” in Materials and Design 25 (2004) 239–245 presented the influence of test speed and load values on the friction and wear behaviour of pure polytetrafluoroethylene (PTFE), glass fibre reinforced (GFR) and bronze and carbon (C) filled PTFE polymers under ambient conditions in a pin-on-disc arrangement concluded that The friction coefficient of pure PTFE and its composites decreases when applied load increases also pure PTFE is characterised by high wear because of its small mechanical properties. Therefore, the reinforcement PTFE with glass fibres improves the load carrying capability that lowers the wear rate of the PTFE.

Ayman A. Aly, et al [5] “Friction and Wear of Polymer Composites Filled by Nano-Particles: A Review”, World Journal of Nano Science and Engineering, 2012, 2, 32-39 has reviewed about friction & wear effects on nano particles filled composites. The survey showed that there is a significant improvement in mechanical properties of the composite due to the addition of the nano-particles. Many types of nanofilling martials, including SiC, Si3N4, SiO2, ZrO2, ZnO, CaCO3, Al2O3, TiO2, and nano-CuO, have been used to different types of polymers such as PEEK, PMMA, PTFE and epoxy. The mechanical properties which have been improved include fatigue resistance, fracture toughness, tensile strength, wear resistance, and friction coefficient.

N.V. Klaas, et al [6] “The tribological behaviour of glass filled Polytetrafluroethylene”, Tribology International 38 (2005) 824-833 has tested glass filled PTFE by using reciprocating wear tester apparatus under and concluded that The wear rate of PTFE composites was an order of two magnitude higher in water than under dry sliding conditions.

W. Gregory Sawyer et al [7] “A study on the friction and wear behavior of PTFE filled with alumina nanoparticles”, Science Direct, Wear 254 (2003) 573–580. In this paper composites were tested against a polished stainless steel counterface on a reciprocating tribometer. The friction coefficient & wear rate of as received PTFE powder & jet milled composite PTFE powder were compared. After result, he concluded that composite has slightly increased friction over unfilled samples. Also the wear resistance increased monotonically with increasing filler concentration.

Jaydeep Khedkar et al [9] “Sliding wear behavior of PTFE composites”, wear 252 (2002) 361-369. In this paper the tribological behavior of polytetrafluroethylene (PTFE) and PTFE composites with filler materials such as carbon, graphite, E glass fibers, MoS2 and poly-*p* phenyleneterephthalamide (PPDT) fibers has studied. In this work, unidirectional sliding friction and wear tests were carried out in the laboratory using a computer controlled pin-on-disc type tribometer. 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. Filler materials in general are effective in impeding large-scale fragmentation of PTFE, thereby reducing the wear rate.

The following work in this paper concentrates more on the material composition and there wear rates. Pin on disc setup is used for performing experimental work to obtain wear rate, the result is analyzed using design expert 7 software, and the relation between various tests parameters are found in terms of a mathematical equation. The basic trend of effects of parameters like Normal load, Velocity of sliding and Sliding Distance on wear rate is interpreted in graphical form. Finally a comparison between three material compositions is made.

3. METHODOLOGY

3.1 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].

3.2 Introduction to Design Expert: Design-Expert, version 7 software (DX7) 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. DX7 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].

3.3 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 [3].

3.4 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.

3.5 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 is involved therefore, analysis of variance is carried out using the standard "Design Expert 7" statistical software.

4. LABORATORY WORK

4.1 Specimen Preparation:

PTFE composites material consist 20% carbon filled and 20% bronze filled & 35% bronze filled are easily available in market. 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 1: ASSIGNING CODES SPECIMENS

Specimen	Chemical Composition in Wt.%
I	20% Carbon filled PTFE
II	20% Bronze filled PTFE
III	35% Bronze filled PTFE

4.2 Experimental Setup:

Standard pin on disc test set up is used for the experiment on the specially made pins. The photo of test setup is shown on "Fig 1".

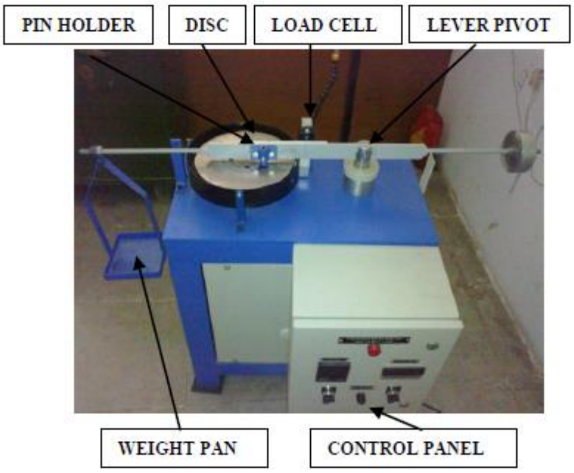

Figure 1: Experimental Setup of Friction and Wear test rig

4.3 Design of test runs:

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 2: FACTORS AND THEIR LEVELS

Level→	Low	Medium	High
Load (kg)	01	02	03
Disc Speed (RPM)	600	800	1000
Sliding distance(km)	02	03	04

If the parameter given in "Table 2" are put in Design expert software it will generate a following Run sheet of parameters for pin-on-disc setup shown in "Table 3" which can be further utilized as Observation table to note wear rate as response.

Table 3: LAYOUT OF L9 ORTHOGONAL ARRAY FOR EXPERIMENTATION

Run	Load (kg)	Disc 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 setup 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 4".

Table 4: 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	10.61
4	2	600	13.26
5	2	800	13.25
6	2	1000	5.30
7	3	600	17.68
8	3	800	6.63
9	3	1000	7.96

4.4 Testing:

Experiments are conducted as per the design matrix "Table 4" 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 5".

Table 5: FINAL TEST RUN DATA FOR SOFTWARE

Run	Load (kg)	Sliding 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

5.1 Analysis for Wear Rate:

Analysis of Variance (ANOVA) for Wear Rate is done for all three Material compositions. Result graphs are obtained after wear rate analysis in Design -Expert software.

5.1.1 Interaction Effect of Parameters on Wear of Material 'I':

Figure 2 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km. Figure 3 shows interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s. Figure 4 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

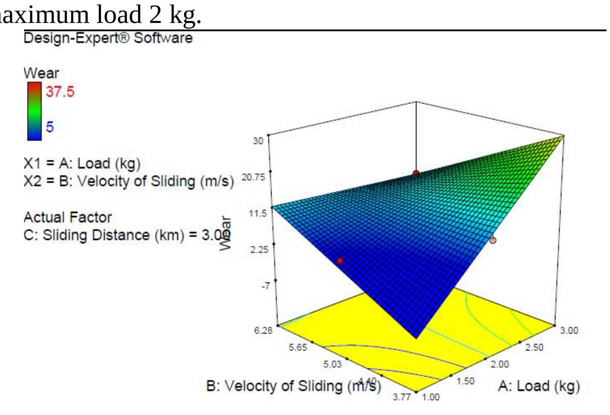

Figure 2: Interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km.

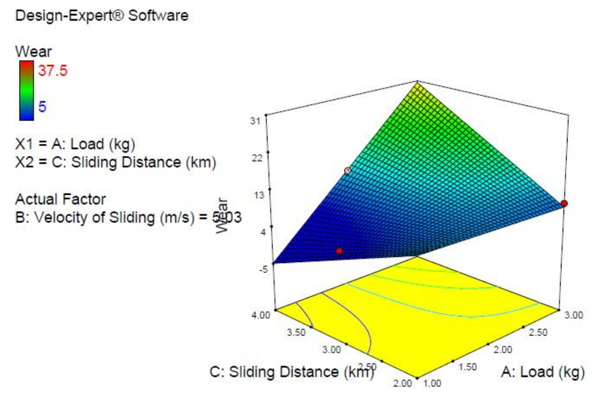

Figure 3: Interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s.

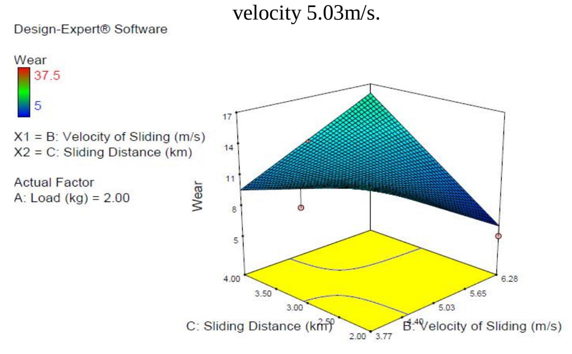

Figure 4: Interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

5.1.2 Interaction Effect of Parameters on Wear of Material 'II':

Figure 5 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km. Figure 6 shows interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s. Figure 7 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

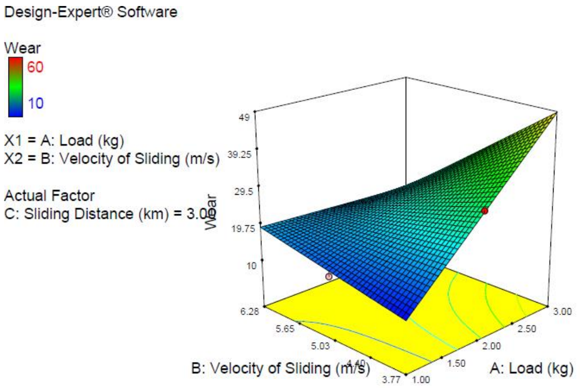

Figure 5: Interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km.

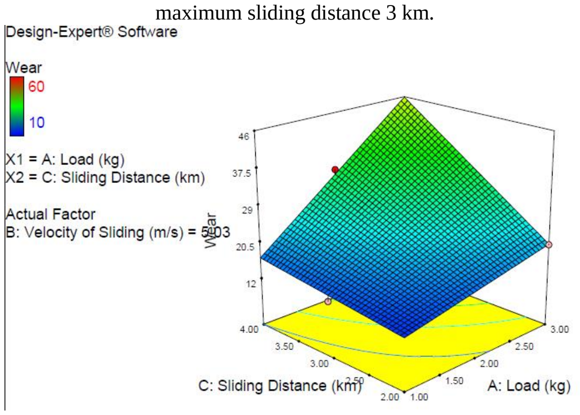

Figure 6: Interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s.

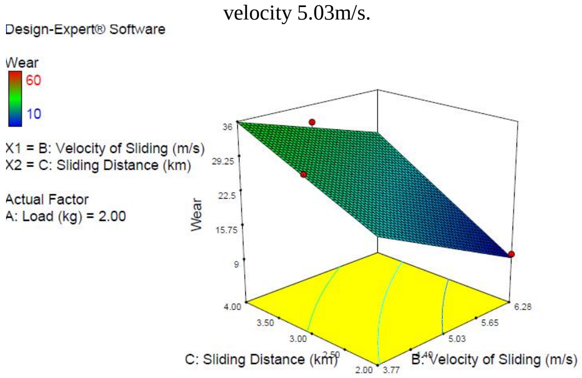

Figure 7: Interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

5.1.3 Interaction Effect of Parameters on Wear of Material 'III':

Figure 8 shows interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km. Figure 9 shows interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s. Figure 10 shows interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

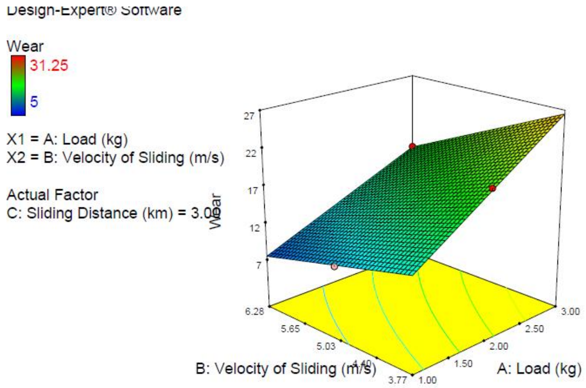

Figure 8: Interaction effect of load and velocity of sliding on wear at maximum sliding distance 3 km.

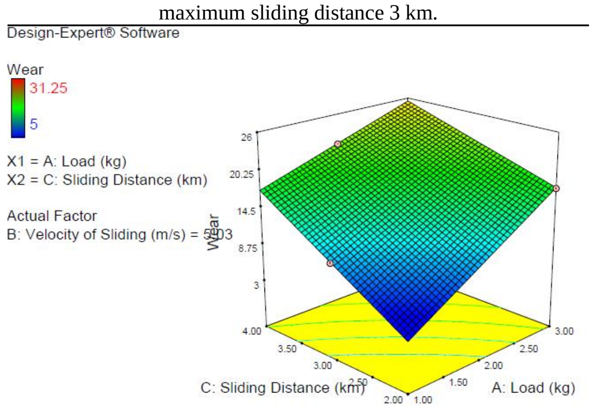

Figure 9: Interaction effect of load and sliding distance on wear at maximum velocity 5.03m/s.

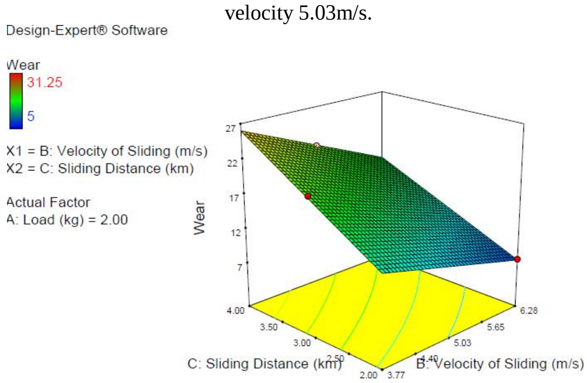

Figure 10: Interaction effect of velocity of sliding and sliding distance on wear at maximum load 2 kg.

5.1.4 Comparative Study of Materials:

We can observe from the Figure 11-13 that, as load increases, wear of all material goes on increasing (Fig 11), as velocity of sliding increases, wear of all material goes on decreasing (Fig 12), as sliding distance has great influence on the wear for of all the tested specimens. Wear rate increases with increasing sliding distance (Fig 13). It is observed that the wear of specimen "I" is less than specimen "II" & slightly less than specimen "III" i.e. specimen "II" has higher wear rate.

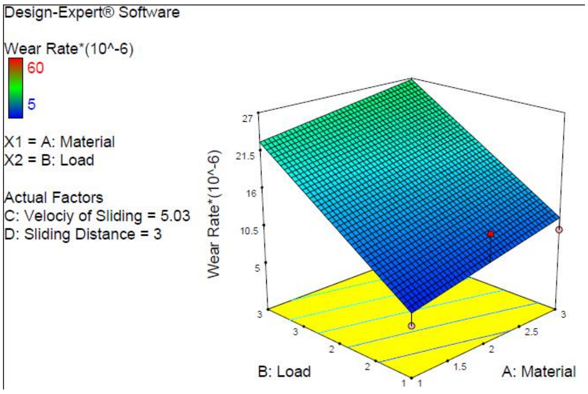

Figure 11: Wear Rate v/s Load

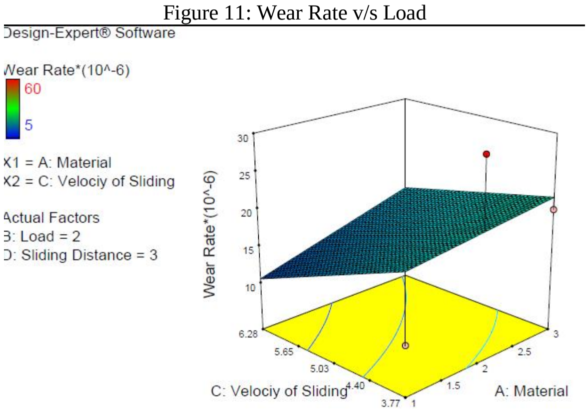

Figure 12: Wear Rate Vs Velocity of Sliding

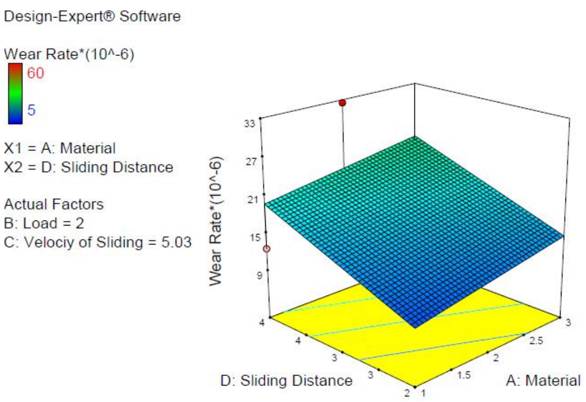

Figure 13: Wear Rate Vs Sliding Distance

5.1.5 Correlations:

Following correlations are obtained for three Specimens.

- For Specimen 1:
  Wear Rate = 13.02282931765 + 19.205084424208 × Load (kg) + 6.5452475811042 × Velocity of Sliding (m/s) - 31.442800227661 × Sliding Distance (km) - 7.6835515082527 × Load (kg) × Velocity of Sliding (m/s) + 9.2857142857143 × Load (kg) × Sliding Distance (km) + 2.8457598178714 × Velocity of Sliding (m/s) × Sliding Distance (km).

- For Specimen 2:
  Wear Rate = -25.852040725985 + 33.093173970784 × Load (kg) + 8.1859229747676 × Velocity of Sliding (m/s) - 8.4680819578827 × Sliding Distance (km) - 7.9681274900398 × Load (kg) × Velocity of Sliding (m/s) + 5.3585714285714 × Load (kg) × Sliding Distance (km) + 1.0449630051224 × Velocity of Sliding (m/s) × Sliding Distance (km).

- For Specimen 3:
  Wear Rate = -24.943333333333 + 14.856666666667 × Load (kg) + 0.465 × Velocity of Sliding (m/s) + 11.902380952381 × Sliding Distance (km) - 0.565 × Load (kg) × Velocity of Sliding (m/s) - 1.5471428571429 × Load (kg) × Sliding Distance (km) - 0.41642857142857 × Velocity of Sliding (m/s) × Sliding Distance (km).

5.2 Analysis for Friction:

Analysis of Variance (ANOVA) for Friction is done for all three Material compositions. Result graphs are obtained after Friction analysis in Design -Expert software.

5.2.1 Interaction Effect of Parameters on Friction of Material 'I':

Figure 14 shows interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km. Figure 15 shows interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s. Figure 16 shows interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

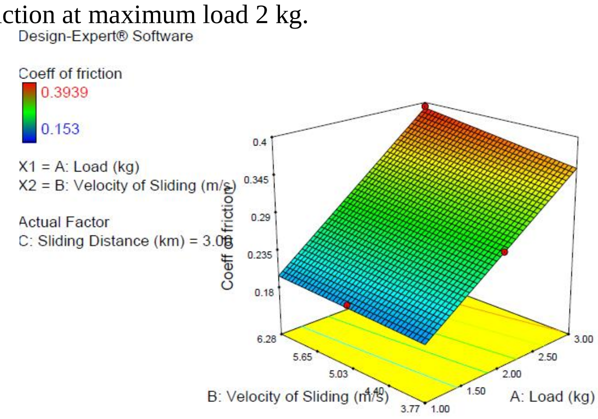

Figure 14: Interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km.

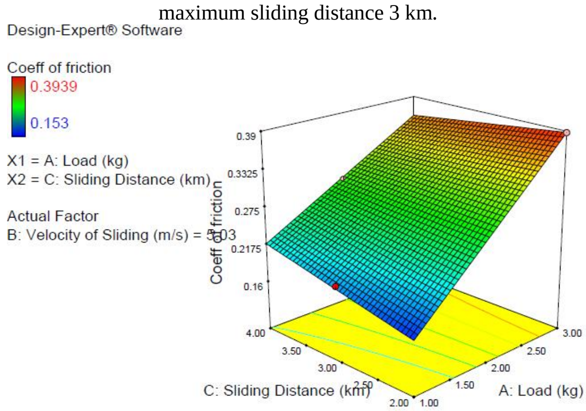

Figure 15: Interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s.

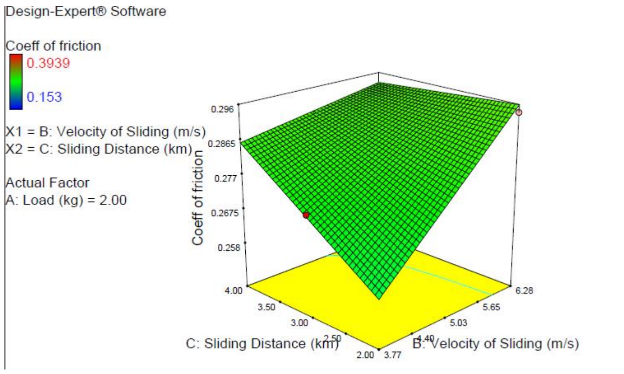

Figure 16: Interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

5.2.2 Interaction Effect of Parameters on Friction of Material 'II':

Figure 17 shows interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km. Figure 18 shows interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s. Figure 19 shows interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

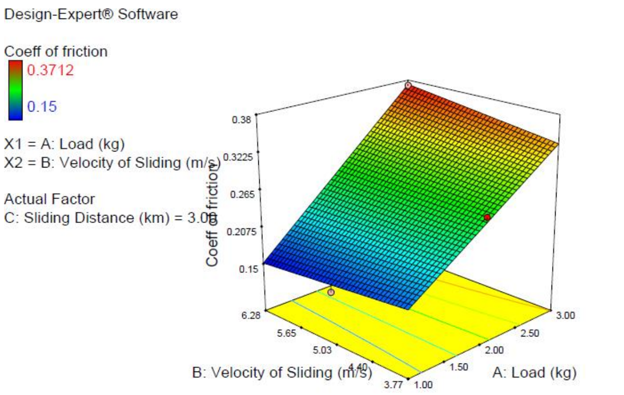

Figure 17: Interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km.

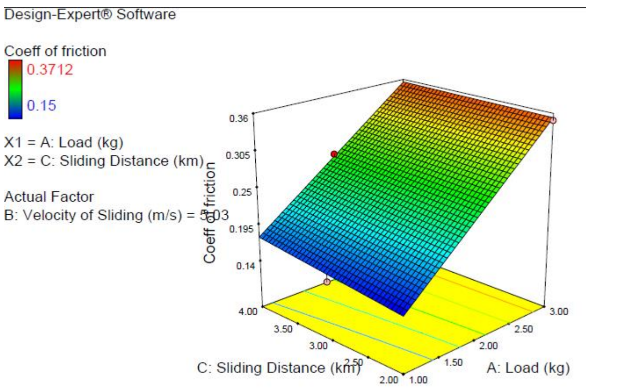

Figure 18: Interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s.

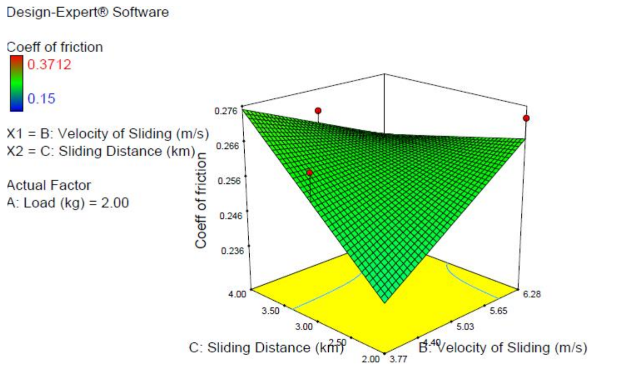

Figure 19: Interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

5.2.3 Interaction Effect of Parameters on Friction of Material 'III':

Figure 20 shows interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km. Figure 21 shows interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s. Figure 22 shows interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

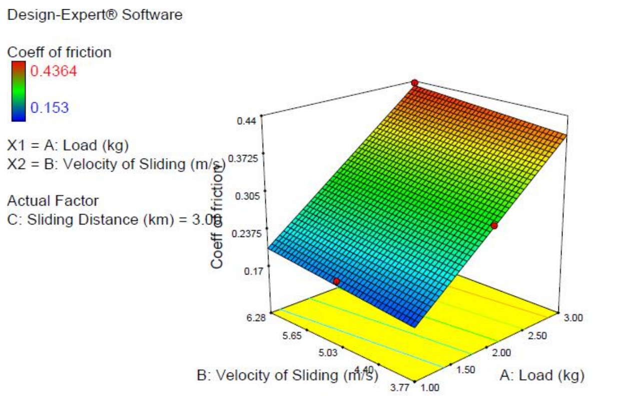

Figure 20: Interaction effect of load and velocity of sliding on friction at maximum sliding distance 3 km.

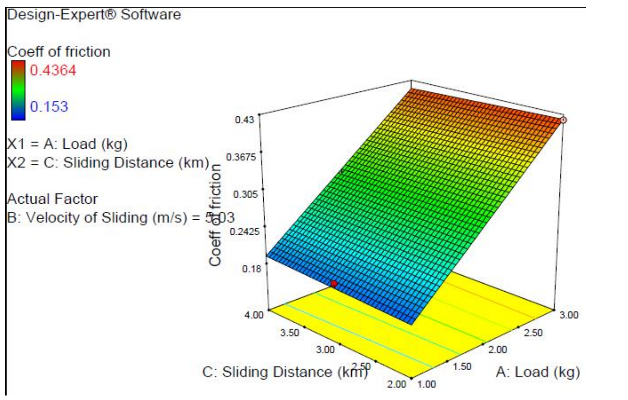

Figure 21: Interaction effect of load and sliding distance on friction at maximum velocity 5.03m/s.

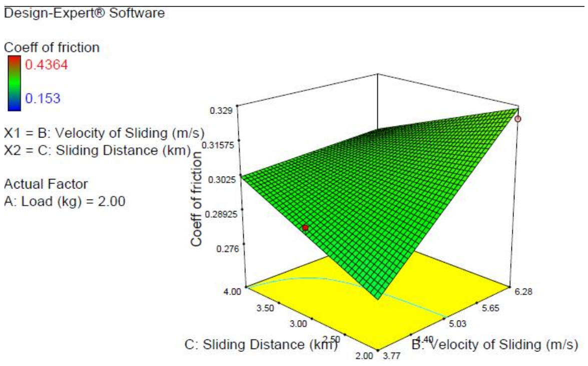

Figure 22: Interaction effect of velocity of sliding and sliding distance on friction at maximum load 2 kg.

5.2.4 Comparative Study of Materials:

We can observe from the Figure 23-25 that, as load increases, coefficient of friction of all material goes on increasing (Fig 23), as velocity of sliding increases, coefficient of friction of all material goes on increasing (Fig 24), as sliding distance has great influence on the wear for of all the tested materials. Coefficient of friction increases with increasing sliding distance (Fig 25). It is observed that the coefficient of friction of specimen "II" is less than specimen "I" & the coefficient of friction of specimen "I" is less than specimen "III" i.e. specimen "III" has higher coefficient of friction.

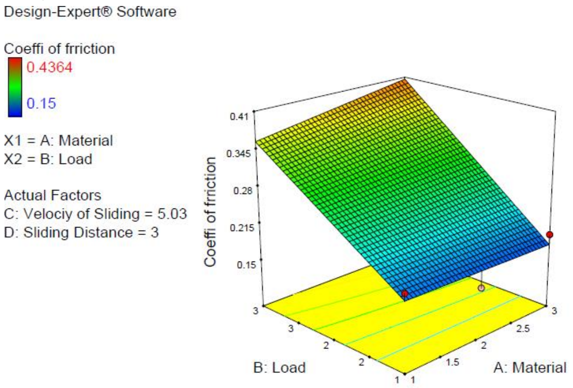

Figure 23: Coefficient of friction v/s Load

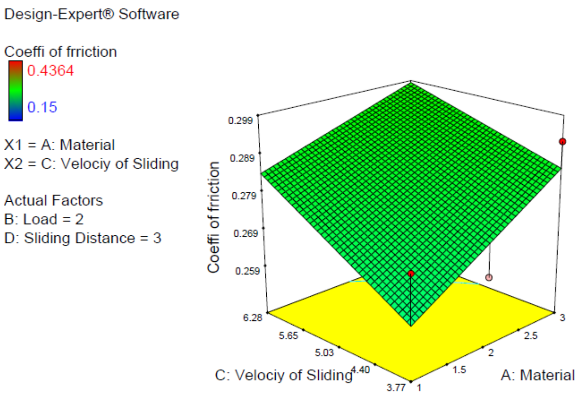

Figure 24: Coefficient of friction v/s Sliding Velocity

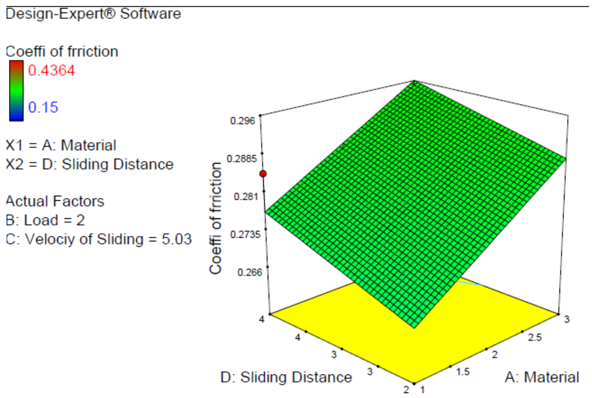

Figure 25: Coefficient of friction v/s Sliding distance

5.2.5 Correlations:

Following correlations are obtained for three Specimens.

- For Specimen 1:
  Coefficient of friction = -0.12139282236135 + 0.12540675393663 × Load (kg) + 0.016342250047429 × Velocity of Sliding (m/s) + 0.077520584329349 × Sliding Distance (km) + 0.0053158793397837 × Load (kg) × Velocity of Sliding (m/s) - 0.020571428571429 × Load (kg) × Sliding Distance (km) - 0.0060216277746158 × Velocity of Sliding (m/s) × Sliding Distance (km).
- For Specimen 2:
  Coefficient of friction = -0.03093836084234 + 0.05510724720167 × Load (kg) + 0.0076721684689811 × Velocity of Sliding (m/s) + 0.068243445266552 × Sliding Distance (km) + 0.011883892999431 × Load (kg) × Velocity of Sliding (m/s) - 0.0062857142857142 × Load (kg) × Sliding Distance (km) - 0.0096414342629481 × Velocity of Sliding (m/s) × Sliding Distance (km).
- For Specimen 3:
  Coefficient of friction = -0.16521807373680 + 0.13437201669512 × Load (kg) + 0.041392525137545 × Velocity of Sliding (m/s) + 0.057309144374881 × Sliding Distance (km) - 0.0010700056915196 × Load (kg) × Velocity of Sliding (m/s) - 0.0044857142857143 × Load (kg) × Sliding Distance (km) - 0.0094479225953329 × Velocity of Sliding (m/s) × Sliding Distance (km).

CONCLUSION

1. Friction & wear rates of all specimen increases with increase in load.
2. Wear Rate of specimen decreases with increasing sliding velocity where coefficient of friction of specimen increases with increasing sliding velocity.
3. Sliding distance has great influence on friction & wear for all the tested materials. Both coefficient of friction as well as wear rates increases with increasing sliding distance.
4. It is observed that the wear resistance of PTFE + 20% Carbon composite is much better than PTFE + 20% Bronze composite & wear resistance of PTFE + 35% Bronze composite has slightly less than wear resistance of PTFE +

20% Carbon composite. PTFE + 20% Carbon have higher wear resistance.

5. It is observed that the coefficient of friction of PTFE + 20% Bronze composite is less than PTFE + 20% Carbon composite & coefficient of friction of PTFE + 20% Carbon composite is less than coefficient of friction of PTFE + 35% Bronze composite. PTFE + 35% Bronze have higher coefficient of friction.

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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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