Wear Analysis of Polytetrafluoroethylene and it's Composites under Dry Conditions using Design-Expert

Deepak Bagale , Sanjay Shekhawat , Jitendra Chaudhari

Department of Mechanical Engineering
SSBT'S COET, Bambhori, Jalgaon, Maharashtra, India

Abstract- In this paper, the effects of load, velocity of sliding and sliding distance on sliding friction and sliding wear of polymer material made of polytetrafluoroethylene (PTFE) and PTFE composites with filler materials such as 40% bronze and 40% carbon are studied. The experimental work is performed on pin-on-disc apparatus and analyzed with the help of Design-Expert 7 software. The results of experiments are presented in tables and graphs which shows that the addition of bronze 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 40% carbon filled PTFE followed by 40% bronze filled PTFE and virgin PTFE. Through this study, we can design and develop a best bearing material for industrial application..

Index Terms- Design-Expert, Polymer, PTFE, Sliding wear

I. INTRODUCTION

Polytetrafluoroethylene (PTFE) is an important polymer based engineering material. When rubbed against a hard surface, PTFE exhibits a low coefficient of friction but a high rate of wear . It is white or gray in color. It is an ideal bearing material for heavy and light load pressures with medium and low surface speeds. PTFE has all qualities of bearing alloy like compatibility, conformability, embedability, load capacity, fatigue strength, corrosion resistance and hardness [1]. The low-friction characteristics of PTFE are largely responsible for the inception of this paper.

PTFE is a popular polymer solid lubricant because of its resistance to chemical attack in a wide variety of solvents and solutions, high melting point, low coefficient of friction, and biocompatibility. It is commonly used in bearing and seals applications. Unfortunately, PTFE suffers from poor wear resistance [2]. 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 are 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 [3].

There are different opinions in literature about the reducing wear of polymer by incorporating the different types of filler. H.Unal et al.[4] study and analyze the influence of test speed and load values on the friction and wear behavior of purepolytetrafluoroethylene (PTFE), glass fibre reinforced (GFR), bronze and carbon (C) filled PTFE polymers. Adding glass fiber, bronze and carbon fillers to PTFE were found effective in reducing the wear rate of the PTFE composite. Jaydeep Khedkar et al.[5] they study 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. The present filler additions found to increase hardness and wear resistance in all composites studied. U.Sen et al.[6] based on the experimental and regression analysis results of dry friction and wear tests are presented. The specific wear rate for 25% bronze filled PTFE composite increases with an increase in load and are in the order of 10^{-4}–10^{-5} mm^3/N m. S.Basavarajappay et al.[7] they study the influence of wear parameters like applied load, sliding speed, sliding distance and percentage of reinforcement on the dry sliding wear of the metal matrix composites. A plan of experiments, based on techniques of Taguchi, was performed to acquire data in controlled way. An orthogonal array and the analysis of variance were employed to investigate the influence of process parameters on the wear of composites. Talat Tevruz [8] has studied that the coefficient of friction and the wear are strongly influenced by the thickness and composition of these films depending on the adhesion between steel and composite surfaces, the cohesive properties of the polymer used, pressure and the sliding distance.

II. EXPERIMENTAL TOOLS AND TECHNIQUES

A. 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. 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.

B. TAGUCHI METHOD

As the number of factors considered at multi-levels increases, it becomes increasingly difficult to conduct the experiment with all treatment combinations. To reduce the number of experiments to 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 practical fractional experiment, but there are no general guidelines for fractional experiments that cover many applications. This method uses a special set of arrays called orthogonal arrays. 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. A full factorial design will identify all possible combinations for a given set of factors. If an experiment consist of m number of factors & each factor at levels X, then Number of trails possible is given by (Treatment Combination) = X^m.

C. A TYPICAL ORTHOGONAL ARRAY (OA)

While there are many standard orthogonal arrays available, each of the arrays is meant for a specific number of independent design variables and levels. Standard notation for orthogonal Arrays is, L_n (X^m) Where,

n=Number of experiments to be conducted
X=Number of levels
m= Number of factors

III.EXPERIMENTAL DESIGN PROCEDURE

1. Statement of experimental problem:

Analysis of plain PTFE and composite PTFE material consist 40% carbon filled and 40% bronze filled, using Pin-on-Disc wear and friction testing machine < Fig.1 > considering the following point.

●Study of friction behavior of PTFE material.
●Study of wear of PTFE material under different varying condition
●Comparison of wear of Plain PTFE with Bronze filled and Carbon filled PTFE by considering varying conditions.

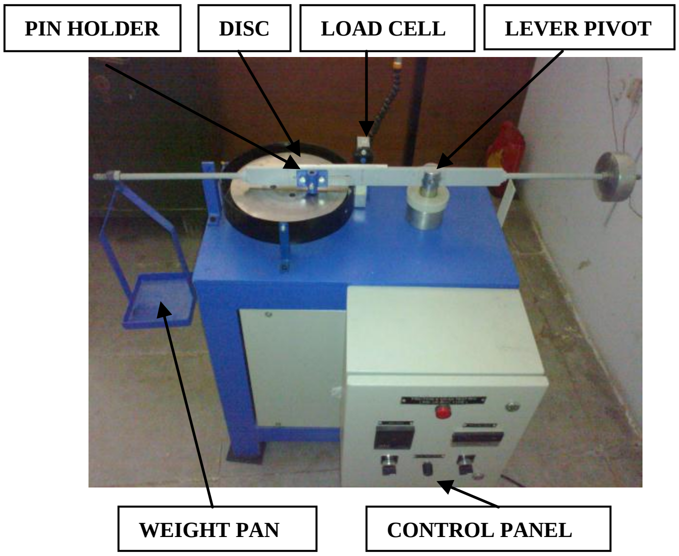

Figure 1: Experimental Setup of Friction and Wear test rig

2. Choice of response variable:

Wear is taken as the response variable in present investigation work.

3. Choice of factors levels and ranges:

In this investigation work, which is carried out for 3 factors (load, velocity of sliding and sliding distance), each factor at 3 levels, an L_9 (3^4) orthogonal array is chosen for conducting the experiments. The forth factor can be deleted. The assignments of levels to the different independent factors used in investigation and it's a coding and designation of materials are shown in < Table I-III >.

Table I: Assigning of Levels to the variable as Applicable to Pin on-Disc machine

Level→	**Low**	**Medium**	**High**
Load (Kg) A	1	2	3
Speed (RPM) B	500	700	900
Sliding distance (m) C	1500	3000	4500
Code	-1	0	+1

Table II: Designation for PTFE materials

Material	**Composition in Wt.%**
I	Plain PTFE
II	40% Bronze filled PTFE
III	40% Carbon filled PTFE

Table III: Assigning of Levels to the Variable as Applicable Practically

Level→	**Low**	**Medium**	**High**
Load (kg) (A)	1	2	3
Velocity of Sliding (m/s) (B)	2.62	3.66	4.71
Sliding distance (m) (C)	1500	3000	4500
Code	-1	0	+1

4. Selection of DOE:

Design of experiments (DOE) offers a systematic approach to study the effects of multiple variables or factors on products or process performance by providing a structural set of analysis in a design matrix which is shown in < Table IV >.

5. Performing the experiments:

Conducting the experiments as per the design matrix and recording the response parameters as shown in < Table V >.

6. Data analysis:

7. Analysis of results and conclusions:

8. Confirmation test:

To test the accuracy of the model the confirmation tests were performed. The comparison of wear results from the mathematical model equation developed in the present work <

Table VI > with the values obtained experimentally has shown in < Table VII >.

Table IV: Design matrix of L_9 (3^4) Orthogonal Array

Trial No.	**Factor A**	**Factor B**	**Factor C**	**Factor D**	**Response Y**
1	-1	-1	-1	-1	Y1
2	-1	0	0	0	Y2
3	-1	+1	+1	+1	Y3
4	0	-1	0	+1	Y4
5	0	0	+1	-1	Y5
6	0	+1	-1	0	Y6
7	+1	-1	+1	0	Y7
8	+1	0	-1	+1	Y8
9	+1	+1	0	-1	Y9

Table V : Layout of L_9 (3^4) Orthogonal Array for Experimentations

Trail No.	**Load (Kg)**	**Velocity (m/s)**	**SD (m)**
1	1	2.62	1500
2	1	3.66	3000
3	1	4.71	4500
4	2	2.62	3000
5	2	3.66	4500
6	2	4.71	1500
7	3	2.62	4500
8	3	3.66	1500
9	3	4.71	3000

Table VI: Mathematical model equation of all material

Material	**Wear equation**
I	Wear (gm/m) = -19.69174 + 13.55277×Load + 8.83728×Velocity of Sliding + 3.30416×SD - 4.74803×Load×Velocity of Sliding + 2.66856×Load×SD - 1.21962×Velocity of Sliding×SD
II	Wear (gm/m)= -19.23989 + 11.18184×Load + 8.98735×Velocity of Sliding - 1.83946×SD – 4.68456×Load×Velocity of Sliding + 3.27900×Load×SD - 0.52316×Velocity of Sliding×SD
III	Wear (gm/m) = -4.47723 + 3.34108×Load + 2.37343 × Velocity of Sliding - 0.85120×SD – 1.41006×Load×Velocity of Sliding + 1.02987×Load×SD - 0.082974×Velocity of Sliding×SD

Table VII: Confirmation test

Material	**V_r**	**L**	**SD**	**Actual wear**	**Predicted wear**	**Variation**
	m/s	Kg	Km	(gm/m) X 10^{-5}	(gm/m) X 10^{-5}	%
I	1.5	2	2	19.3333	20.0491	- 3.70
	2.8	3.5	2.5	29.4444	29.0296	1.41
II	1.5	2	2	10.8889	10.4187	4.32
	2.8	3.5	2.5	20.5555	19.5829	4.73
III	1.5	2	2	3.4444	3.7030	-4.15
	2.8	3.5	2.5	6.1111	6.3461	-3.84

IV. RESULTS AND DISCUSSION

1) One can observe from < Fig. 2-4 >, that as laod and sliding distance increases wear of all material goes on increasing where as velocity of sliding increases wear of all material goes on decreasing.

2) It is observed from < Table VIII > that the wear of material III is less than material I and II and pure PTFE has higher wear rate and bronze filled PTFE has higher Wear rate than carbon filled PTFE.

3) < Table IX > 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 (46.95%) has great influence on the wear; followed by velocity of sliding for all materials. However, the interaction between the velocity of sliding and sliding distance (0.44%) has neglisible influence on the wear.

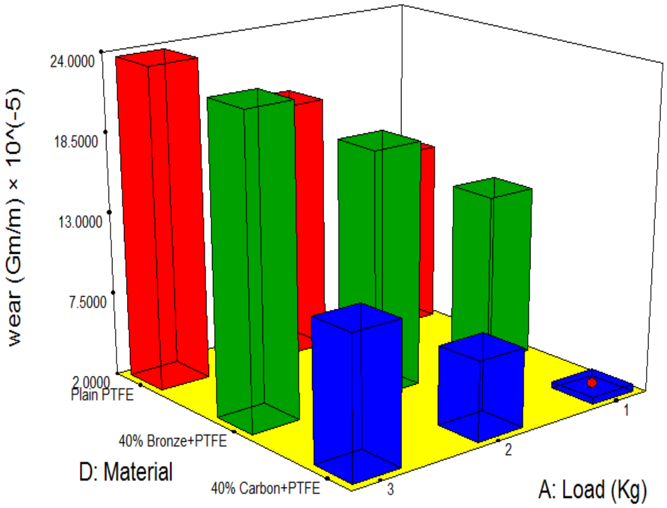

Figure 2: Wear v/s Load

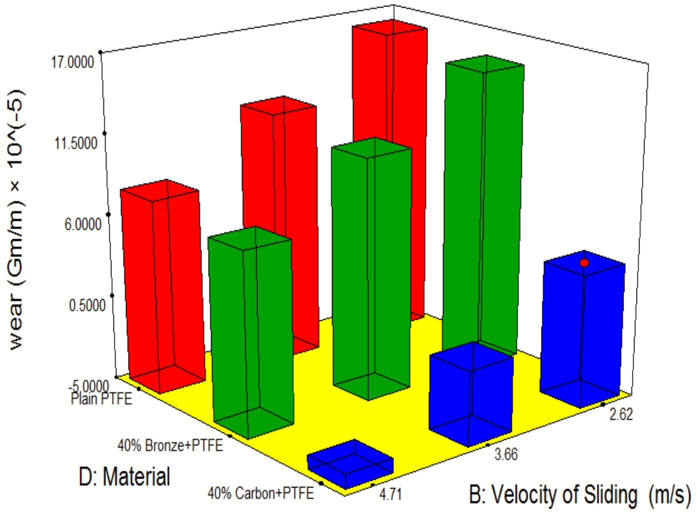

Figure 3: Wear v/s Velocity of sliding

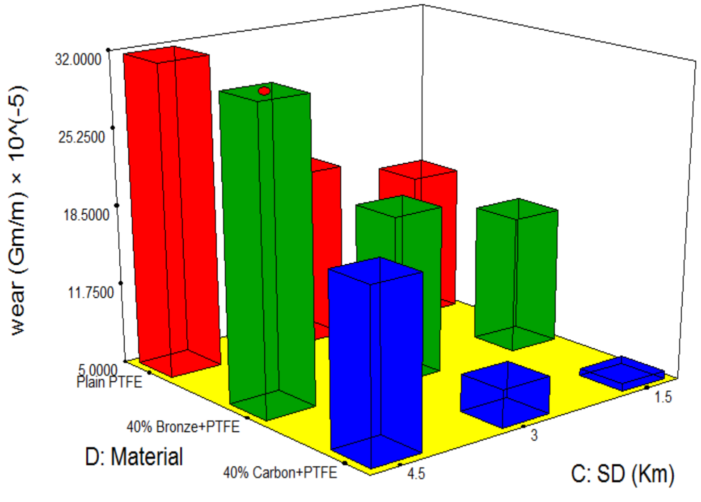

Figure 4: Wear v/s Sliding distance

Table VIII: Comparative wear data of all material

Material	**Total Wear rate (I) in (gm/m)**	**Average Coefficient of friction (μ)**
I	157.7776×10^{-5}	0.2047
II	91.2221×10^{-5}	0.2107
III	29.5555×10^{-5}	0.2217

Table IX: Effect List

Term	% Contribution		
	I	II	III
A-load	16.17	18.73	18.37
B-velocity	26.06	20.67	23.18
C-sliding distance	46.95	45.01	45.24
AB	4.34	4.73	3.54
AC	6.01	10.72	9.64
BC	0.44	0.14	0.035

V. CONCLUSIONS

- Addition of filler materials such as bronze and carbon to PTFE causes an increase in wear resistance, while the coefficient of friction is slightly affected.
- Wear of 40% carbon filled PTFE is less than 40% bronze filled PTFE and Pure PTFE.
- Wear of Pure PTFE is decreased about 42% by adding 40% bronze and 81% by adding 40% carbon.
- It is observed that the addition of carbon filler to plain PTFE improves wear resistance significantly as compared to bronze filler.
- From Confirmation test it is observed that the percentage of Variation is for wear is between 1 to 4.73% which tells that the mathematical model developed for all three materials is significant.
- Depending upon load, velocity of sliding and sliding distance, material used in this study can be ranked as 40% carbon filled PTFE > 40% bronze filled PTFE > Pure PTFE for their wear Performance and as Pure PTFE > 40% bronze filled PTFE > 40% carbon filled PTFE for their friction Performance.

ACKNOWLEDGMENT

I would like to express my sincere thanks and appreciation to Mechanical Department of S.V.P.S.'s B.S.Deore College of Engineering, Dhule for valuable support and kind co-operation during experimentation work .

NOMENCLATURE

PTFE	Polytetrafluoroethylene
SD	Sliding Distance
DOE	Design of Experiment
OA	Orthogonal Array
Vr	Velocity of Sliding (m/s)
I	Wear Rate (gm/m)
μ	Coefficient of Friction
L	Load (Kg)

REFERENCES

[1] S. K. Biswas and Kalyani Vijayan, “Friction and wear of PTFE - a review”, Wear, vol. 158, 1992, pp. 193-211.

[2] W. Gregory Sawyer, Kevin D. Freudenberg, Praveen Bhimaraj, Linda S. Schadler, “A study on the friction and wear behavior of PTFE filled with alumina nanoparticles”, Wear, vol. 254, 2003, pp. 573-580.

[3] M. Xanthos, Functional Fillers for Plastics, in: Polymers and Polymer Composite, WILEY-VCH, 2005, pp.1-16.

[4] H. Unal, A. Mimaroglu, U. Kadıoglu, H. Ekiz, “Sliding friction and wear behaviour of Polytetrafluroethylene and its composites under dry conditions”, Materials and Design, vol. 25, 2004, pp. 239-245.

[5] Jaydeep Khedkar, Ioan Negulescu, Efstathios I. Meletis, “Sliding wear behavior of PTFE composites”, Wear, vol. 252, 2002, pp. 361-369.

[6] H. Unal, U. Sen, A. Mimaroglu, “An approach to friction and wear properties of Polytetrafluroethylene composite”, Materials and Design, vol. 27, 2006, pp. 694-699.

[7] S.Basavarajappay and G.Chandramohan, “Wear Studies on Metal Matrix Composites:A Taguchi Approach”, J. Mater. Sci. Technol., vol. 21, 2005, pp.845-850.

[8] Talat Tevrüz, “Tribological behaviors of carbon filled Polytetrafluoroethylene (PTFE) dry journal bearings”, Wear , vol. 221, 1998, pp. 61-68.

.

AUTHORS

First Author – Deepak Bagale
B.E. , M.E. pursuing
Department of Mechanical Engineering
SSBT’S COET, Bambhori, Jalgaon,
Maharashtra, India.
E-Mail: deepak_bagale@rediffmail.com

Second Author –Sanjay Shekhawat
B.E. , M.E. Ph.D pursuing
Department of Mechanical Engineering
SSBT’S COET, Bambhori, Jalgaon,
Maharashtra, India.
E-Mail: spshekhawat@rediffmail.com

Third Author – Jitendra Chaudhari
B.E. , M.E. Ph.D pursuing
Department of Mechanical Engineering
SSBT’S COET, Bambhori, Jalgaon,
Maharashtra, India.
E-Mail: jrchaudhari@yahoo.com

Correspondence Author – Deepak Bagale
E-Mail:deepak_bagale@rediffmail.com
Tel.: +918237508213