Wear Studies on Polytetrafluoroethylene (PTFE) Composites: Taguchi Approach

Sonam M. Gujrathi, Prof. L.S. Dhamande and Prof. P.M. Patare

Abstract--- *The present research work is aimed at developing a new material for industrial application. From literature review and surveying sugar factories from nearby area, it is found that conventional bearing material (Babbitt and bronze) leads to high wear rate as well as high coefficient of friction. Now a day's pure PTFE (polytetrafluoroethylene) is widely used as bearing material which is self lubricating and subjects to lower coefficient of friction, but problem with PTFE is that, it subjects to high wear rate, which can be reduced by adding suitable fillers. In this study, the effects of varying load, sliding distance, sliding velocity and filler content in PTFE are experimentally examined. A comparative analysis of three composites (PTFE, PTFE + 25% C and PTFE + 35% C) is presented showing how properties of PTFE can be improved by addition of filler content. A plan of experiment based on Taguchi technique, was performed to acquire data in controlled way. The results of experiments are presented in table which prove that the wear is strongly influenced by the composition of filler content. It was found that, by varying the different parameter like Load, Velocity and Sliding distance the PTFE containing 35% carbon percentage have the better wear performance.*

Keywords--- *Analysis of Variance (ANOVA), Orthogonal Array, PTFE Composite, Taguchi Technique*

I. INTRODUCTION

It is well known that polytetrafluoroethylene (PTFE) is one of the most commonly used self-lubricating material, which exhibits very low coefficient of friction. However, neat PTFE shows very poor wear resistance [1]. This deficiency has led to the use of fillers to improve the mechanical and wear properties of the PTFE matrix. PTFE has many advantageous properties, such as low friction, low out gassing, high temperature capability and high chemical inertness, which make it an ideal filler material for a wide variety of applications. 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.

A. Scope

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Bearing materials are special type of materials, which carry a moving or rotating component with least friction or wear. One of the principal difficulties in developing a good bearing material is that the two practically conflicting requirements are to be satisfied by a good bearing material. The material must be soft with extremely low shear strength as well as it must be strong enough to support heavy dynamic loads. Metallurgical structure inherently incorporating both hard and soft constituents. The soft, low melting constituents helping easy running of moving parts and the hard constituents bear the load, alternatively these might be strong metal coated with a very thin overlay of soft metal. These considerations lead the metallurgists to search for alternative bearing material with special attention to metal which are more easily available both at time of emergency and in normal times. From 1992, extensive research has been carried out in various countries for the development of composite polymer materials like PTFE and PTFE with carbon, glass fiber, carbon coke, graphite etc.

B. Objective

As bearings are used under widely different conditions, a bearing alloy that is well suited for one application may be unsuitable for another. The bearing materials presently in white metal, vagues etc. are extensively used in sugar, chemical, cement, pharmaceutical and automobile industries as they exhibit excellent load bearing capacity and corrosion resistance. However this material containing 88% Cu, 10% Sn and 2% Zn suffers from following serious drawbacks,

- 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 stick to the journal at high temperatures.
- 4) It fails to function satisfactorily at higher loads and speeds.

Against this background, the present research work is aimed at developing a new bearing material, which consists of pure PTFE and PTFE + carbon content which is cost effective and superior in properties to the conventional bearing materials. Fruitful research in this area could lead to development of superior and less expensive bearing materials. Also this newly investigated composite material will be highly wear resistance, which can withstand against high load as well as problem due to overheating.

Dinghan Xiang *et al.* [1] undertook an extensive review work on composite of PTFE and alloy steel and composite of PTFE and bronze. It was proposed by Arash Golchin *et al.* [2] that addition of filler materials (PTFE materials filled with

MoS₂, fiber glass, black glass, bronze and carbon) to PTFE can improve wear properties of base material. *David L. Burris* [3], this paper presents a PEEK filled PTFE composite that exhibits low friction and ultra-low wear. *L. Tomescu etl.* [4], this paper presents the influence of load and glass fibre concentration on profile parameters obtained after running composites with PTFE matrix against steel in water. *Yunxia Wang etl.* [5], have done the experimental work to study tribological behaviour of transfer films of PTFE/ bronze composites. *G. Theiler etl.* [6], have studied tribological behaviour of PTFE composites against steel at cryogenic temperature. Tribological performances of polymers depend significantly on the temperature at the friction contact. *J.R. Vail, B.A. krick etl.* [7], this work uses high tenacity expanded polytetrafluoroethylene (ePTFE) filaments as both a fiber reinforcement and a reservoir for solid lubricants. The wear rates obtained from the inclusion of expanded PTFE filaments were better than conventional powder filled PTFE-PEEK composites reaching values as low as $K=7 \times 10^{-8} \text{mm}^3/\text{Nm}$ and showed stable friction coefficients below = 0.125 for over 2 million cycles. *W.Wieleba* [8], has studied the effect of role of internal friction in the process of energy dissipation during PTFE composite sliding against steel.

S. Basavarajappa etl. [9] [10], in their study and discussion, 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 were examined in greater detail. The sliding

distance is the wear factor that has the highest physical properties as well as statistical influence on the dry sliding wear of the composites (49.12%), the load (22.69%), sliding speed (7.63%) and reinforcement (6.01%), and the interaction of sliding speed and sliding distance will contribute more (4.46%) and other interactions will influence very less.

II. TAGUCHI TECHNIQUE

Taguchi technique is a powerful tool for the design of high quality systems. It provides a simple efficient and systematic approach to optimize designs for performance, quality and cost. The methodology is valuable when design parameters are qualitative and discrete. Taguchi parameter design can optimize the performance characteristics through the setting of design parameters and reduce the sensitivity of the system performance to source of variation. This technique is multi-step process, which follow a certain sequence for the experiments to yield an improved understanding of product or process performance. An outline procedure for Taguchi Approach is shown very clearly with the help of flowchart as shown in Figure 1. This design of experiments process made up of three main phases: the planning phase, the conducting phase and analysis interpretation phase. The planning phase is the most important phase one must give a maximum importance to this phase. The data collected from all the experiments in the set are analyzed to determine the effect of various design parameters.

Figure 1: An outline Procedure for Taguchi Approach

This approach is to use a fractional factorial approach and this may be accomplished with the aid of orthogonal arrays. Analysis of variance is a mathematical technique, which is based on a least square approach. The treatment of the experimental results is based on the analysis of average and analysis of variance [9][10].

III. EXPERIMENTAL APPROACH

A. Materials

Pure PTFE and two PTFE based composite materials were studied in the present work. The materials were provided in the form of pins of 12mm diameter and 30mm height. The material selected are,

- 1) Plain PTFE (PTFE)
- 2) 25% Carbon filled PTFE (PTFE + 25% C)
- 3) 35% Carbon filled PTFE (PTFE + 35% C)

B. Wear Test Experimental Setup

The friction and wear tests were carried out using single pin type "Pin-on-disc friction and wear monitor "TR20", Magnum make, Bangalore. Figure 2 shows a diagram of pin holder of pin on disc machine which is to be used for this work. The machine consists of Steel disc, which is mounted on circular turn table. The turn table is mounted on a bearing housing which provides unidirectional motion to the turn table. The cylindrical pin is holed firmly in a holder, which is attached to a pivoted loading arm. The loading arm is supported in bearing arrangement to allow load to be applied to the specimen. Frictional force and wear is measure by digital display. This machine also facilitates study of friction and wear characteristics in sliding contacts under desired conditions. Sliding occurs between the stationary pin and a

rotating disc. Normal load, rotational speed and wear track diameter can be varied to suit the test conditions. Tangential frictional force and wear are monitored with electronic sensors

and recorded on PC. These parameters are available as functions of load and speed.

Figure 2: Tribological Test Configuration

Table 1: Layout of $L_{27} (3^{13})$ Orthogonal Array

L_{27} test	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	2	1	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

C. Plan of Experiment

The experiments were conducted as per the standard orthogonal array. In the present investigation, an L_{27} orthogonal array was chosen, which has 27 rows and 13 columns as shown in Table 1, where 1, 2 and 3 are levels. In L_{27} array one can study 13 factors at a time with 3 levels also one can edit these level and factor values with experimentally decided values. The wear parameters chosen for the experiment are (1) sliding velocity, (2) load (3) sliding distance and (4) material (PTFE, PTFE+ 25% C, PTFE + 35% C) Table 2, indicate the factors and their level. The experiment consists of 27 tests (each row in the L_{27} orthogonal array) and the columns were assigned with parameters. The first column was assigned to load (kg), second column was assigned to sliding velocity (m/s), fifth column was assigned to sliding distance (km), and ninth column was assigned to material and the remaining columns were assigned to their interactions. The response to be studied was the wear with the objective of smaller is the better. The experiments were conducted as per the orthogonal array with level of parameters given in each array row. The wear test results were subject to the analysis of variance.

Table 2: Assigning of Levels to the Variable as Applicable to Pin-on-Disc Machine

Levels	Low	Medium	High
Load (kg)	1	2	3
Speed (rpm)	300	600	900
Sliding distance (km)	2	4	6
Material	PTFE	PTFE + 25% C	PTFE + 35% C

IV. RESULTS AND DISCUSSION

The experiments were conducted with an aim of relating the influence of sliding velocity (SV), load (L), sliding distance (SD) and material (M) on wear of all the composites under study. On conducting the experiments as per the orthogonal array, the dry sliding wear results for various combinations of parameters were obtained and shown in Table 3.

Table 3: Experimental Wear Data of Material as per Taguchi's Orthogonal Array

st d	run	L (kg)	SV (m/s)	SD (km)	M	wear rate (micrometer)
1	22	1	1.0995	2	PTFE	81.48
2	25	1	1.0995	4	PTFE+25% c	22.06
3	9	1	1.0995	6	PTFE+35% c	39.12
4	5	1	2.1991	2	PTFE+25% c	27.12
5	11	1	2.1991	4	PTFE+35% c	32.28
6	2	1	2.1991	6	PTFE	222.238
7	19	1	3.2986	2	PTFE+35% c	6.00
8	14	1	3.2986	4	PTFE	188.997
9	7	1	3.2986	6	PTFE +25% c	8.25
10	27	2	1.0995	2	PTFE +25% c	65.3469
11	6	2	1.0995	4	PTFE +35% c	40.00
12	12	2	1.0995	6	PTFE	431.25
13	26	2	2.1991	2	PTFE +35% c	45.5685
14	13	2	2.1991	4	PTFE	400.16
15	4	2	2.1991	6	PTFE +25% c	16.7266
16	8	2	3.2986	2	PTFE	278.665
17	15	2	3.2986	4	PTFE +25% c	17.3029
18	21	2	3.2986	6	PTFE +35% c	31.1455
19	20	3	1.0995	2	PTFE +35% c	57.3101
20	1	3	1.0995	4	PTFE	613.54
21	18	3	1.0995	6	PTFE +25% c	17.1907
22	23	3	2.1991	2	PTFE	497.276
23	24	3	2.1991	4	PTFE +25% c	13.7509
24	16	3	2.1991	6	PTFE +35% c	49.0513
25	10	3	3.2986	2	PTFE +25% c	18.5748
26	3	3	3.2986	4	PTFE +35% c	12.2924
27	17	3	3.2986	6	PTFE	1056.92

A. Results

1. 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. To establish the correlation between the wear parameters sliding velocity, load, time and sliding wear, multiple linear regression models is obtained using statistical software "DESIGN EXPERT 7". The terms that are statistically significant are included in the model. The regression coefficient of the model is 0.9998. The last column in Table 4 shows the percentage contribution of each factor on the total variation indicating their degree of influence on the result. One can observe from the table that the material (57.291%) has great influence on the wear; followed by load (10.163%). Similarly sliding distance and sliding velocity has percentage contribution of 2.198 and 0.219 respectively. However, the interaction between the sliding velocity and load (0.624%) has negligible influence on the wear.

Table 3: Analysis of Variance (ANOVA) for Wear Results

Source	sum of square	df	mean Square	F Value	% contribution
Model	1.59E+06	14	1.13E+05	166.04	
A-load	1.62E+05	1	1.62E+05	237.55	10.163
B-sliding velocity	3497.18	1	3497.18	5.12	0.213
C-sliding distance	35072.67	1	35072.67	51.38	2.198
D-material	9.14E+05	2	4.57E+05	669.33	57.191
AB	9963.18	1	9963.18	14.6	0.622
AC	18521.98	1	18521.98	27.14	1.161
AD	3.10E+05	2	1.55E+05	227.27	19.434
BC	26146.23	1	26146.23	38.3	1.639
BD	30333.92	2	15166.96	22.22	1.901
CD	87381.4	2	43690.7	64.01	5.478
Residual	8191	12	682.58		
Total	1.60E+06	26			100

This analysis is carried out for a level of significance of 5%. i.e the level of confidence 95%. The Model F-value of 5436.10 implies the model is significant. There is only a 0.020% 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, D, AB, BC, AC, AD, BD, CD are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

Table 3: Model Statistics for Suggested Model

Std. Dev.	26.13	R-Squared	0.9949
Mean	158.87	Adj R-Squared	0.9889
C.V. %	16.44	Pred R-Squared	0.8455
PRESS	2.46E+05	Adeq Precision	53.878

The "Pred R-Squared" of 0.8455 is in reasonable agreement with the "Adj R-Squared" of 0.9889. "Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. This ratio of 53.878 indicates an adequate signal. This model can be used to navigate the design space. Final Equation in Terms of Actual Factors:

Material – PTFE

$$\begin{aligned} \text{Wear} = & -182.37928 + 173.95068 \times \text{load} + 23.91764 \\ & \times \text{sliding velocity} + 144.31190 \\ & \times \text{sliding distance} - 25.47056 \times \text{load} \\ & \times \text{sliding velocity} + 0.13945 \times \text{load} \\ & \times \text{sliding distance} - 14.87467 \\ & \times \text{sliding velocity} \\ & \times \text{sliding distance} \end{aligned}$$

Material – PTFE + 25% C

$$\begin{aligned} \text{Wear} = & -297.24602 + 86.68023 \times \text{load} + 88.24009 \\ & \times \text{sliding velocity} + 71.53823 \\ & \times \text{sliding distance} - 25.47056 \times \text{load} \\ & \times \text{sliding velocity} + 0.13945 \times \text{load} \\ & \times \text{sliding distance} - 14.87467 \\ & \times \text{sliding velocity} \times \text{sliding distance} \end{aligned}$$

Material – PTFE + 35% C

$$\begin{aligned} \text{Wear} = & -450.23352 + 115.01577 \times \text{load} + 109.18040 \\ & \times \text{sliding velocity} + 65.29768 \\ & \times \text{sliding distance} - 25.47056 \times \text{load} \\ & \times \text{sliding velocity} + 0.13945 \times \text{load} \\ & \times \text{sliding distance} - 14.87467 \\ & \times \text{sliding velocity} \times \text{sliding distance} \end{aligned}$$

Substituting values of the variables for the above equation, the sliding wear of all the three materials 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 decreases with the increase in associated variables.

V. CONCLUSION AND FUTURE ENHANCEMENT

- Based on literature survey PTFE is seemed to be a very good polymer material which can be effectively used for many applications.

- PTFE has very low coefficient of friction but it subject to more wear which can be reduced by adding suitable filler combination.
- Material has highest influence on wear of composites (57.291%) which is followed by load (10.163%), sliding distance (2.198), sliding velocity (0.219) and the interaction of load and material (19.435) and other interactions will influence very less.
- 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.

The present work is carried out for dry operating condition as PTFE is itself a self lubricant but due to addition of filler self lubricating property of PTFE gets affect up to some extent. So one can perform same experimentation at lubricated condition. Also experimentation can be done with different percentage of carbon.

REFERENCES

- [1] Dingham Xiang and Kunlun Shan, "Friction and wear behavior of self lubricating and heavily loaded metal- PTFE composites", Wear 260, Pp.1112-1118, 2006.
- [2] Arash Golchin, Gregory Simmons and S.B. Glavatskith, "Break away friction of PTFE materials in lubricated condition", Tribological International 48, Pp. 54-62, 2012.
- [3] Jaydeep Khedkar a, Ioan Negulescu b and Efstathios I.n Meletis a, "Sliding wear behavior of PTFE composites", Wear 252, Pp. 361–369, 2002.
- [4] M. Conte n and A. Igartua, "Study of PTFE composites tribological behavior", Wear 296, Pp. 568–574, 2012.
- [5] Yunxia Wang and F. Yan, "A study on Tribological behavior of transfer films of PTFE/bronze composites", Wear 262, Pp. 876-882, 2007.
- [6] G. Theiler, W. Hubner, T. Gradt, P. Klein and K. Friedrich, "Friction and wear of PTFE composites at cryogenic temperatures", Tribology International 35, Pp 449-458, 2002.
- [7] J.R. Vail, B.A. Krick, K.R. Marchman and W. Gregory Sawyer, "Polytetrafluoroethylene (PTFE) fiber reinforced polyetheretherketone (PEEK) composites", Wear 270, Pp. 737–741, 2011.
- [8] W. Wieleba, "The role of internal friction in the process of energy dissipation during PTFE composite sliding against steel ", Wear 258, Pp. 870-876, 2005.
- [9] S. Basawarajappa, G. Chandramohan and J. Paulo Davim, "Application of Taguchi techniques to study dry sliding wear behaviour of metal matrix composites", materials and design 28, Pp 1393-1398, 2007.
- [10] S. Basawarajappa and G. Chandramohan, "Wear Studies on Metal Matrix Composites: a Taguchi Approach", Journal of material science and technology 21, Pp. 845-850, 2005.
- [11] Jiju Antony, Design of experiments for engineers and scientists. Elsevier Science & Technology Books publishing; 2003.

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