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Research Article

Performance Behaviour of Composite Polytetrafluroethylene (PTFE)-A Taguchi Approach

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Abstract

In this study, the effects of varying load, sliding distance and sliding velocity on friction and wear of bearing material made of Polytetrafluroethylene(PTFE) and its composite(25% and 35% carbon filled PTFE) are experimentally examined with the help of Pin-on-disc machine and analyzed with the help of Design Expert 7 software. The results of experiments are presented in tables and graphs which prove that the wear is strongly influenced by the composition of fillers depending on the adhesion between steel and composite surfaces.

Keywords: *Analysis of variance (ANOVA), PTFE, Orthogonal array, Taguchi method, Wear.*

1. Introduction

Polytetrafluroethylene (PTFE) is polymer based compound with 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. The low-friction characteristics of PTFE were largely responsible for the inception of this project. It is a crystalline solid with good stability from -454°F to +500° F (-270°C to +260°C). Its relative softness and poor heat conductivity limit its suitability as a bearing material to applications involving low speeds and low unit pressures. PTFE is technically superior and economically cheaper friction material as compared to conventional bearing materials.

Many polymers and polymer based composites are widely used for sliding couples against metals, polymers and other materials. However, where the contact is there, there is the problem of friction and wear [Talat Tevrüz, 1998]. Adhesion component is responsible for the friction of polymer and is a result of breaking of weak bonding forces between polymer chains in the bulk of the material [D.S.Bajaj *et al*., 2008]. Addition of some filler materials to the polymers, improve tribological behaviours & fillers play the most important role on the transferred film's structure, stability and adhesion to the opposite surface so they reduce the wear [Jaydeep Khedkar *et al*., 2002]. PTFE exhibits poor wear and abrasion resistance, leading to early failure and leakage problems [Jaydeep Khedkar *et al*., 2002]. To minimize or overcome this problem, various suitable fillers added to PTFE such as carbon, glass fiber, graphite, bronze etc.

Fig. 1 shows that the addition of filler materials can cause a dramatic improvement (up to one order of magnitude) in the wear resistance of PTFE. Composite B (PTFE + 18% carbon + 7% graphite) exhibited the highest wear resistance amongst all composites. This behavior can be attributed to the presence of hard carbon particles, which are embedded within the matrix and impart additional strength to the composite. Comparing the wear resistance of composites C and D (Fig. 1), it can be seen that increasing the percentage of the glass fibers in the PTFE, increases the wear resistance.

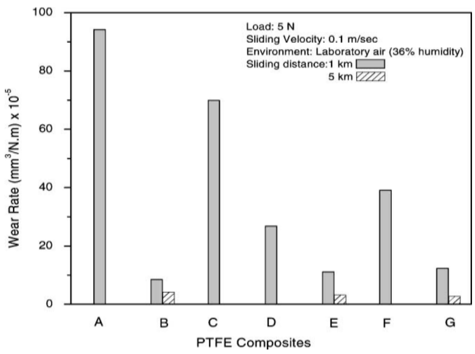

Fig. 1. Average wear rate of PTFE and PTFE composites (A: PTFE; B: 75% PTFE + 18% carbon + 7% graphite; C: 85% PTFE + 15% E glass fibers; D: 75% PTFE + 25% E glass fibers; E: 75% PTFE + 20% glass fibers + 5% MoS2; F: 97.5% PTFE + 2.5% PPDT fibers; G: 90%PTFE + 10% PPDT fibers).

The results for composite E also suggest that glass fibers with the presence of a small amount of MoS2 particulates

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(5%) in PTFE cause a significant improvement in the wear resistance. Although, the percentage of glass fiber in composite E (20% glass fiber) is lower than that of composite D (25% glass fiber), the addition of MoS2 particulates (composite E) enhances the wear resistance as seen in Fig. 1. This indicates that addition of MoS2 to glass fiber PTFE composite is more effective than increasing the percentage of glass fiber. Similarly, PPDT, a high strength and elastic modulus fiber, when incorporated in significant levels (10%) to PTFE (composite G) can cause a remarkable improvement in the wear properties of the composite. When present in low levels such as in composite F (PTFE + 2.5% PPDT), was not found to be as effective.

2. Scope of Present Investigation

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. This is generally achieved either by having a bearing material with a 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.

Practically in all cases a plain bearing material is a non-ferrous alloy or a mixture. With the development of engineering industries, the amount of bearing metal requirement is increasing at a very fast rate. As such, bearing industries consume large qty. of copper, lead, tin; indium, silver and antimony etc. apart from the cost factor of these materials, some of these materials are not available or not produced in India or produced negligibly in small quantity and consequently can be termed rare in relation to present day requirements of the industries. 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.

3. Necessity of Developing Carbon Filled PTFE

Dry journal bearings are considered to be the best solution when lubricant supply is the major problem owing to lubricant contamination, improper facility to supply lubricant and such other factors. Dry bearings are less expensive and resist contamination better when compared with rolling element bearings. These bearings are used in a wide range of applications, right from toys, printers to rocket engines.

Polymer and their composites form a very important class of tribo-engineering materials and are invariably used in many mechanical components such as gears, cams, wheels, impellers, brakes, seals, bearings, bushes, bearing cages etc. Where adhesive wear performance in non-lubricated condition is a key parameter for the material selection. In most of these cases the materials are subjected to stringent conditions of loads, speeds, temperatures and hazardous environment. For tribological loaded components, the coefficient of friction, the mechanical load carrying capacity, and the wear rate of the materials determine their acceptability for industrial applications.

Polymer based composite materials are the ones employed in such tribological applications owing to their ever increasing demand in terms of stability at higher loads, temperatures, better lubrication and wear properties. To combat these situations composites should possess better mechanical and tribological properties.

4. 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.

4.1 Advancement of Taguchi's Robust Design

The first systematic approach to fractional experiments was provided by Finney (1945). Plackett and Burman (1946), also contributed to this field, and Dr. Ranjit K. Rao (1947) introduced further innovations with his orthogonal arrays. In the 1950's and1960's experimental design was liberated from its agricultural roots and a variety of design concepts were suggested. The response of surface methodology introduced by Box and Hunter (1957) led to more versatile modeling and statistical optimization. Box (1957) and Box Draper (1969) introduced, evolutionary operation for sequentially searching the design space for optimal conditions; In 1970's and 1980's it was noted that there are limitations when conventional experiment design techniques are applied to industrial experimentation. For instance, they are not adequate for handling noise factors, and for handling averages and dispersion simultaneously. Taguchi's robust design (1980) added a new dimension to conventional experimental design and most popular tools in this method is parameter design and S-N ratio.

4.2 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
Common Orthogonal Arrays are listed below for quick reference,

(2- Level arrays)--- L_4 (2^3), L_8 (2^7), L_{12} (2^{11}), L_{16} (2^{15}), L_{32} (2^{31}), L_{64} (2^{63}) etc.
(3- Level arrays)--- L_9 (3^4), L_{18} (2^1*3^7), L_{27} (3^{13}), L_{54} (2^1*3^{25}), L_{81} (3^{40}) etc.
(4-Level arrays)--- L_{16} (4^5), L_{32} (2^1*4^9) etc.

Table 1 Levels to the variable as Applicable to Pin-on-Disc machine

Level→	Low	Medium	High
Load,Kg (A)	1	2	3
Speed (RPM) (B)	300	600	900
Sliding distance (Km) (C)	2	4	6
Code	-1	0	+1

Table 2 Assigning Codes for Three PTFE materials

Material	Chemical Composition in Wt.%
I	Plain PTFE
II	25% Carbon filled PTFE
III	35% Carbon filled PTFE

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

Trail No.	A Load (Kg)	B Velocity (m/s)	C SD(Km)
1	1	1.57	2
2	1	3.14	4
3	1	4.71	6
4	2	1.57	4
5	2	3.14	6
6	2	4.71	2
7	3	1.57	6
8	3	3.14	2
9	3	4.71	4

Table 4 Cumulative Experimental Wear Data of all Material

Trail No.	L Kg[A]	V m/s[B]	SD Km[C]	Mat I(μ)	Mat II(μ)	Mat III(μ)
1	1	1.57	2	225	36	12.4
2	1	3.14	4	346	62	20.3
3	1	4.71	6	365	72	24
4	2	1.57	4	575	123	40
5	2	3.14	6	610	135	44
6	2	4.71	2	226	45	15.86
7	3	1.57	6	1126	273	91
8	3	3.14	2	291	60	19
9	3	4.71	4	313	64.5	21

5. Process Modeling

Table 5

	I-Material % Contribution	II-Material % Contribution	III-Material % Contribution
A-load	17.59	25.18	25.39
B-velo	21.29	15.32	12.69
C-sld dist	39.68	32.01	28.86
AB	11.79	15.63	18.40
AC	7.61	10.74	13.76
BC	1.81	1.05	0.80

The Table 5 shows the percentage contribution of each factor on the total variation indicating their degree of influence on the result for all three materials. One can observe from the above table that the sliding distance (39.68%, 32.01% and 28.26%) has great influence on the wear, followed by load for all three materials. However, interaction between the velocity and sliding distance has negligible influence on the wear for all three materials.

Table 6 Summary of Analysis of All Material for All Condition

Material	R-Squared	Adjusted R-Squared	Pred R-Squared
I	0.9999	0.9998	0.9962
II	0.9998	0.9994	0.9902
III	0.9998	0.9991	0.9866

The Pred R-Squared of (0.99) for all material is in reasonable agreement with the Adj R-Squared of (0.999) of all material.

Table 7 Mathematical Model for all material

Material	Wear equation
I	-5.80429+158.42667*load+157.78010*velocity+ 26.46929 * sliding dist. -83.57052*load*velocity+52.71070*load* sliding dist. -16.38126*velocity*sliding dist.
II	-58.70800+46.14193*load+45.96708*velocity-3.61035* sliding dist.-24.73402*load*velocity+16.10714*load* sliding dist.-3.20542 * velocity * sliding dist.
III	-16.94090+14.68731 * load+16.55846 * velocity-3.3256 * sliding dist.-8.88060*load*velocity+6.03286*load*sliding dist.-0.92844*velocity*sliding dist.

Table 8 Confirmation test of material I, II and III

Material	V m/s	L Kg	SD Km	Pred wear Micron	Test wear micron	Variation %
I	1.047	2.5	2.5	539.44	519	-3.85
	1.832	4	3	776.455	787	1.33
II	1.047	2.5	2.5	123.86	131	5.45
	1.832	4	3	193.65	198	2.19
III	1.047	2.5	2.5	40.83	38	-7.44
	1.832	4	3	64.38	60	-7.3

From the analysis of table VIII, we can observe that the calculated error varies from 1% to 7.5% for wear. Therefore the multiple regression equation derived above correlate the evaluation of wear in the Polymer with the degree of approximation.

6. Results and Discussion

One can observe from the Fig 2-4 that load has great influence on the wear for of all the tested materials. For all the test material as sliding velocity increases wear of all material goes on decreasing. It is observed that the wear of material III is less than material I and material II and pure PTFE has higher wear rate and as percentage of carbon in PTFE increases wear rate goes on decreasing

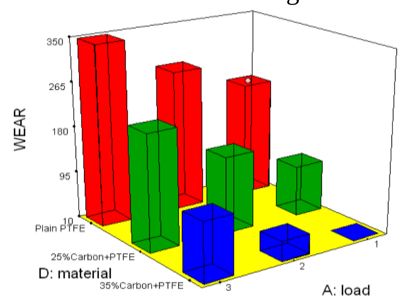

Fig 2: Wear v/s Load

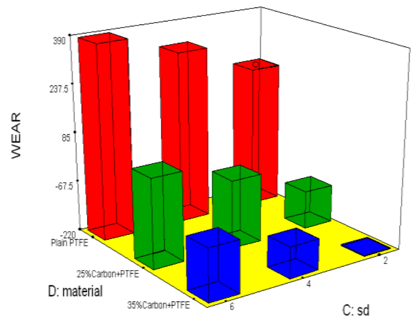

Fig 3: Wear v/s Sliding distance

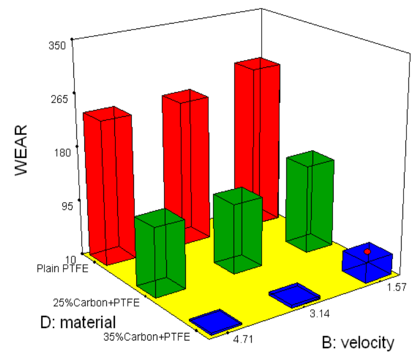

Fig 4: Wear v/s Velocity

Conclusions

It is observed that the wear of PTFE decreases as carbon percentage increases. Wear of 35% Carbon filled PTFE is observed to be less than 25% Carbon filled PTFE and Pure PTFE.

Wear of Pure PTFE is decreased about 75% by adding 25% carbon and 93% by adding 35% carbon. It is observed that the effect of velocity is decreased by 6% by adding 25% carbon and 8% by adding 35% carbon.

From Confirmation test it is observed that the percentage of Variation is for wear is between 1 to 7.5% which tells that the mathematical model developed for all three materials is significant.

From table VIII, it is observed that the percentage of deviation between test and predicted value of wear is 0 to 7.5% for all three materials, so developed model for all three materials is significant statistically.

Depending upon Load, Velocity and Sliding distance material used in this study can be ranked as 35% carbon filled PTFE > 25% carbon filled PTFE > Pure PTFE for their wear Performance.

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