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Comparative Wear Studies of Three Polytetrafluroethylene (PTFE) Composites: A Taguchi Approach

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Abstract: In this paper, the effect of load, Velocity of sliding and sliding distance on wear of materials made of Polytetrafluroethylene. 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. Until very recently, most common type of 'bushing' and 'bearing' materials has either been bronze, copper and lead mixture and lead or tin based white metals. As such, bearing industries consume large quantity 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 literature survey Polytetrafluroethylene (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 will be reduced by adding suitable fillers. This paper presents the effects of varying load, sliding distance, sliding velocity and filler content in PTFE examine using a Pin –on –Disc Wear Test Machine. A comparative analysis of these composites ie. (PTFE + 30% Carbon, PTFE + 30% bronze and PTFE+30%Glass) showing how properties of PTFE can be improved by addition of filler content. The expected results taking into consideration the large number of factors, wear characteristics and optimum bearing construction can be achieved.

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

I. INTRODUCTION

There are more and more technical applications in which wear is critical issues. Polymer composites containing different fillers and or reinforcements are frequently used for these purposes. Nevertheless, new developments are still under way to explore other fields of application for these materials and to tailor their properties for more extreme loading and environmental temperature conditions and the demand for high wear resistance becomes increasingly important. Inorganic particles are well known to enhance the mechanical properties of polymers, which has been widely investigated in the past decades.

A. Scope

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

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 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. Following are the objectives of this paper

1) To study the effect of PTFE+30% Carbon, PTFE+30% Glass, PTFE+30% Bronze on rate of wear.
2) To study the effect of various parameters like load, velocity of sliding, sliding distance on wear rate.
3) To develop mathematical model for wear which includes load, velocity of sliding, sliding distance.

J.B. Singh et al. [1] have investigated in the paper entitled, 'Dry sliding of Cu–15 wt%Ni–8 wt.% Sn bronze: Wear behaviour and microstructures' , Dry sliding wear of Cu–15Ni–8Sn (in wt.%) bronze against a stainless steel 440C counter surface using a pin-on-disc tester in air and flowing Ar gas. The microstructure of the debris, the worn surface and the subsurface of the pin have been characterized using X-ray diffraction, scanning electron microscopy (SEM), transmission electron microscopy (TEM), energy dispersive spectroscopy (EDS) and X-ray photoelectron spectroscopy. The debris is found to comprise of particles of Fe_2O_3 and CuO phases, in addition to bronze particles. EDS analysis of the debris revealed that bronze picked up Fe and Cr elements from the stainless steel while the Fe_2O_3 particles picked up Cu, Ni and Sn elements from the pin, attesting the mechanical mixing of chemical species during the wear process. Cross-sectional TEM investigations of the capped layer revealed it to be a set of mechanically mixed layers (MML) comprising nano grains with varying grain size and composition. SEM micrographs also revealed the formation of subsurface cracks in the vicinity of the interface between the deformed subsurface layer and the capping layer. Wear processes are discussed in the light of these micro-structural observations, combined with wear rate and friction coefficient measurements. and friction coefficient measurements. W. Gregory Sawyer et al. [2] have explained in the paper entitled 'A study on the friction and wear behaviour of PTFE filled with alumina Nano particles', A solid lubricant composite material was made by compression moulding PTFE and 40 alumina particles. Prior to compression moulding the constituent powders were blended using a jet milling apparatus. Composites from 0 to 20 wt. % were prepared. These composites were tested against a polished stainless steel counter face on a reciprocating tribometer. The experimental conditions were a contact pressure of 6.4MPa, a stroke length of 50 mm, and a sliding speed of 50 mm/s. The friction coefficient of the composite increased over unfilled samples from roughly $\mu = 0.15$ to $\mu = 0.2$. At filler concentrations of 20 wt. %, the wear resistance improved 600. MeiginShi et al. [3] have explained in the paper entitled, 'The Friction and Wear Properties of PTFE Composite-Thermal Spray Metallic Binary Coatings', Cu-Al alloy and Mo coatings were deposited on a low carbon steel substrate using an atmospheric plasma spray machine. Pure PTFE and PTFE metal powder composites were deposited on the metallic coatings. Studied and compared are PTFE-metal coatings and PTFE composites metal coatings filled with different metal powders with the proportion of 10% (mass). Mass loss and coefficient of friction were measured under dry reciprocating sliding tests. The worn surfaces of samples were observed by microscopy. The influence of additives on the wear resistance was assessed. M. Conte n et al. [4]., have explained in the paper entitled 'Study of PTFE composites tribological behaviour', the analysis of seven PTFE composites is presented showing how properties of PTFE can be improved even if the most attractive characteristic of low friction is lost due to the presence of hard particles in the polymer matrix. How the use of both soft and hard phases in a polymer matrix enhances the self-lubricating and the load-carrying properties of the matrix improving the tribological properties of the PTFE is presented. S.Basavarajappay et al. [5] have explained in the paper entitled 'Wear Studies on Metal Matrix Composites: a Taguchi Approach', 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. The objective is to establish a correlation between dry sliding wear of composites and wear parameters. These correlations were obtained by multiple regressions. Finally, confirmation tests were conducted to verify the experimental results foreseen from the mentioned correlations.

David L. Burris et al. [6], this paper presents a PEEK filled PTFE composite that exhibits low friction and ultra-low wear Yunxia Wang etl. [7], have done the experimental work to study tribological behaviour of transfer films of PTFE/ bronze composites. J.R. Vail, B.A. krick et al. [8] this work uses high tenacity expanded Polytetrafluroethylene (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=7×10−8mm3/Nm and showed stable friction coefficients below = 0.125 for over 2 million cycles. *W.Wieleba* et al. [9] has studied the effect of role of internal friction in the process of energy dissipation during PTFE composite sliding against steel. L. Tomescu et al. [10] 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.

II. TAGUCHI APPROACH

Design of Experiments (DOE) is a powerful statistical technique introduced by R. A. Fisher in England in the 1920's to study the effect of multiple variables simultaneously. Dr. Taguchi's standardized version of DOE, popularly known as the Taguchi method or Taguchi approach, was introduced in the USA in the early 1980's. Today it is one of the most effective quality building tools used by engineers in all types of manufacturing activities. The DOE using Taguchi approach can economically satisfy the needs of problem solving and product/process design optimization projects. By learning and applying this technique, engineers, scientists, and researchers can significantly reduce the time required for experimental investigations. DOE using Taguchi approach attempts to improve quality which is defined as the consistency of performance. Consistency is achieved when variation is reduced. This can be done by moving the mean performance to the target as well as by reducing variations around the target. The prime motivation behind the Taguchi experiment design technique is to achieve reduced variation (also known as ROBUST DESIGN). This technique, therefore, is focused to attain the desired quality objectives in all steps. The classical DOE does not specifically address quality. "The primary problem addressed in classical statistical experiment design is to model the response of a product or process as a function of many factors called model factors. Factors, called nuisance factors, which are not included in the model, can also influence the response. The primary problem addressed in Robust Design is how to reduce the variance of a product's function in the customer's environment.

Sr. No	Steps
1	Problem Definition
2	Choice of Response Variable
3	Selection of Factors and Levels
4	Selection of Orthogonal Array
5	Enter Factor and Level Value In Selected Array Chart
6	Perform Experimentation As Per Chart Values
7	Analysis and Interpretation of Result

Table 1: Taguchi Approach An outline Procedure

III. APPROACH OF EXPERIMENT

- Materials

PTFE and addition of filler suitable filler materials are studied in this research work. Materials provided in the form of pins of 12mm diameter and 30mm height. The following are the require material for experiment:-

1) 30% Glass filled PTFE

2) 30% Carbon filled PTFE

3) 30% Carbon filled PTFE

- Experimental Set Up For Wear Test

In pin-on-disc tribometer TR-20, a flat pin is loaded onto the test sample with a precisely known weight of 17.63 kg. The pin is mounted on a stiff lever, designed as a frictionless force transducer. The deflection of the highly stiff elastic arm, without parasitic friction, insures a nearly fixed contact point and thus a stable position in the friction track. The friction coefficient is determined during the test by measuring the deflection of the elastic arm. Wear coefficients for the pin and disc material are calculated from the volume of material lost during the test. This simple method facilitates the study of friction and wears behavior of almost every solid-state material combination with or without lubricant. Furthermore, the control of the test parameters such as speed, contact pressure and varying time allow a close reproduction to the real life conditions of practical wear situations. It facilitates study of wear characteristics in sliding contacts under desired conditions. Sliding occurs between the stationary pin and a rotating disc. Normal load, rotational speed and It 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 1:- Experimental Set-up of Wear Test Machine

- *Experimental Plan*

As per the standard orthogonal array experiments were carried out. This present research work chosen the layout of L_9 (3^4) orthogonal array. Where,
9 = No. of experiments to be conducted
3 = No. of levels
4 = No. of factors.
In this present research work which is carried out for four factors i.e. a) sliding velocity b) load c) sliding distance d) material (PTFE + 30% Carbon, PTFE + 30% Glass, PTFE + 30% Bronze). Three levels i.e. 1, 2 & 3.

PROPERTIES OF AN ORTHOGONAL ARRAY:

1. The orthogonal array has the following properties that reduce the number of experiments to be conducted. First row has all 1's.There is no row that has all 2's or all 3's.
2. The columns of the array are orthogonal or balanced. This means that the level settings appear an equal number of times. The columns are also balanced between any two. This means that level combination exist in equal numbers and is unique.
3. Effect of factor A can be separated from the effects of other factors B, C etc. and Vice-Versa.
4. Because of the balancing property, the total number of experiments shall be multiple of 2 and 3.

Table 2: - Layout of L_9 (3^4) Orthogonal Array

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

Table 3: - Level assigning to the variable as applicable on pin-on-disc machine

Level	Load (kg)	Speed (RPM)	SD (km)	Material & Code
Low	3	300	0.8	PTFE and 30% carbon (I)
Medium	4	300	1.13	PTFE and 30% bronze (II)
High	5	300	1.4	PTFE and 30% glass (III)

IV. RESULTS AND DISCUSSION

The experiments were conducted as per the standard orthogonal array. The selection of the orthogonal array was based on the condition that the degrees of freedom for the orthogonal array should be greater than or equal to sum of those wear parameters. In the present investigation an L_9 orthogonal array was chosen, which has 9 rows and 4 columns. The wear parameters chosen for the experiments were (S) speed, (L) load, (SD) sliding distance, (V) Velocity.

Table 4:-Wear Data of Material as per Taguchi's orthogonal Array

Sr.No	L (Kg)	S (RPM)	V (m/s)	SD (Km)	Time in (Min)	Wear rate (gm/m)X10-4
1	3	300	0.9424	0.8	14.14	**0.625**
2	3	300	1.2566	1.13	14.98	**1.6814**
3	3	300	1.5707	1.4	14.85	**2.84285**
4	4	300	1.2566	1.13	14.98	**3.1858**
5	4	300	1.5707	1.4	14.85	**4.6428**
6	4	300	0.9424	0.8	14.14	**0.0176641**
7	5	300	1.5707	1.4	14.85	**4.9371**
8	5	300	0.9424	0.8	14.14	**0.3**
9	5	300	1.2566	1.13	14.98	**4.21581**

Table 5:-Wear Data of Material II as per Taguchi's orthogonal Array

Sr. No	L (Kg)	S (RPM)	SD (Km)	V (m/s)	Time in (Min)	Wear rate (gm/m)X 10-4
1	3	300	0.8	0.9424	14.14	1.625
2	3	300	1.13	1.2566	14.98	3.5398
3	3	300	1.4	1.5707	14.85	4.5714
4	4	300	1.13	1.2566	14.98	5.9292
5	4	300	1.4	1.5707	14.85	7.5714
6	4	300	0.8	0.9424	14.14	3.124701
7	5	300	1.4	1.5707	14.85	7.57464
8	5	300	0.8	0.9424	14.14	4.5669
9	5	300	1.13	1.2566	14.98	6.57249

Table 6:-Wear Data of Material III as per Taguchi's orthogonal Array

Sr. No	L (kg)	S (RPM)	V (m/s)	SD (Km)	Time in (min)	Wear rate (gm/m) X10-4
1	3	300	0.9424	0.8	14.14	0.5
2	3	300	1.2566	1.13	14.98	1.5044
3	3	300	1.5707	1.4	14.85	2.1428
4	4	300	1.2566	1.13	14.98	3.0088
5	4	300	1.5707	1.4	14.85	4
6	4	300	0.9424	0.8	14.14	0.15432
7	5	300	1.5707	1.4	14.85	3.9871
8	5	300	0.9424	0.8	14.14	2.5491
9	5	300	1.2566	1.13	14.98	3.4579

A. Result

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.

Table 7:- (ANOVA) for Wear Results of Material I

Source	DF	Seq SS	Adj SS	Adj MS	F	P
L (kg)	2	133.125	133.125	66.563	13.65	0.068
V(m/s)	2	11.604	11.604	5.802	1.19	0.457
S.D(km)	2	109.504	109.504	54.752	11.2	0.082
Residual Error	2	9.756	9.756	4.878		
Total	8	263.988				

R-Sq = 93.3%   R-Sq (Adj) = 89.3%

Regression Equation of Material I

To establish the correlation between the wear parameters velocity of sliding, load and sliding distance, multiple linear regression models is obtained using 'Mini Tab R14' software. The equation in terms of coded factors:

Wear rate (gm/m) = - 0.000457 + 0.000097 Load (kg) - 0.000019 Velocity (m/s) + 0.000309 S.D (km) ………….Eq 1

Table 8:- (ANOVA) for Wear Results of Material II

Source	DF	Seq SS	Adj SS	Adj MS	F	P
L (kg)	2	137.415	137.415	68.708	25.07	0.038
V (m/s)	2	9.992	9.992	4.996	1.82	0.354
S.D(km)	2	104.462	104.462	52.231	19.06	0.05
Residual Error	2	5.481	5.481	2.741		
Total	8	257.35				

R-Sq = 96.3%   R-Sq (Adj) = 95.0%

Regression Equation of Material II

Wear rate (gm/m = - 0.000586 + 0.000124 Load (kg) - 0.000018 Velocity (m/s) +0.000368 S.D (km) ………….Eq 2

Table 9:- (ANOVA) for Wear Results of Material III

Source	DF	Seq SS	Adj SS	Adj MS	F	P
L (kg)	2	64.461	64.461	32.23	22.97	0.042
V (m/s)	2	3.363	3.363	1.681	1.2	0.455
S.D (km)	2	79.414	79.414	39.707	28.29	0.034
Residual Error	2	2.807	2.807	1.403		
Total	8	150.044				

R-Sq = 98.1%   R-Sq (Adj) = 92.5%

Regression Equation of Material III

Wear rate (gm/m) = - 0.000686 + 0.000150 Load (kg) - 0.000046 Velocity (m/s) + 0.000582 S.D (km) ………….Eq 3

V.CONCLUSION AND SCOPE FOR FUTURE WORK

CONCLUSION:-

1. Filler materials such as carbon, bronze and glass to PTFE material causes an increase in hardness and wears resistance.
2. 30% carbon filled PTFE in properties is much better than 30% bronze filled PTFE is greater than 30% glass filled PTFE for their wear performance.
3. The addition of carbon filler to plain PTFE improves wear resistance significantly as compared to bronze and glass filler.

SCOPE FOR FUTURE WORK:-

The Experimental work can be performing under wet working condition.

1) The Experimentation can be performing at different conditions of Load, Velocity of Sliding and sliding distance.
2) The Experimentation can be done for different combination of fillers.

REFERENCE

[1]. Jaydeep Khedkar, Ioan Negulescu, Efstathios I. Meletis, -Sliding wear behaviour of PTFE composites, Wear 252 (2002) 361-369.
[2]. H. Unal, U. Sen, A. Mimaroglu, -An approach to friction and wear properties of Polytetrafluroethylene composite, Materials and Design 27 (2006) 694-699.
[3]. N.V. Klaasa, K. Marcusa, C. Kellock, -The tribological behaviour of glass filled Polytetrafluroethylene, Tribology International 38 (2005) 824-833.
[4]. David L. Burris, W. Gregory Sawyer, ―A low friction and ultra-low wear rate PEEK/PTFE composite, Wear 261 (2006) 410-418 .
[5]. S.Basavarajappay and G.Chandramohan,-Wear Studies on Metal Matrix Composites: A Taguchi Approach, J. Mater. Sci. Technol. 21 (2005) 845-850.
[6]. Talat Tevruz, -Tribological behaviours of carbon filled Polytetrafluroethylene (PTFE) dry journal bearings, Wear 221 (1998) 61-68.
[7]. Koji Kato, -Wear in relation to friction - a review, Wear 241 (2000) 151–157.
[8]. M. Conte n and A. Igartua, "Study of PTFE composite tribological behaviour." Wear 296, Pp., 568-574, 2012.