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Tribological Behavior of Polytetrafluoroethylene and Its Composites Using the Taguchi Method

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***Abstract* - The frictional and wear characteristics of polymer materials and their composites, particularly bearing materials, are studied in this paper. The study was achieved by inspecting a wide range of process parameters such as load, sliding distance, and sliding velocity. Optimization of experimentation was done using the Taguchi approach. The experimentation work was carried out on a Pin-on-disc machine. The ANOVA method was used to analyze the experimental results, which were then represented using tables and graphs. The wear analysis of the composite PTFE was studied with the help of Signal-to-Noise ratio and multiple regression analysis, which strongly indicates that the wear of a polymer material is greatly influenced by blending filler materials.**
***Keywords:* Polytetraethylene (PTFE), Analysis of Variance (ANOVA), Taguchi Method, Wear, Signal to Noise Ratio**

I. INTRODUCTION

A. PTFE as a Bearing Material

Polytetrafluoroethylene (PTFE) is grey or white color polymer based bearing material. Generally, PTFE is used for small and high load applications which functions at medium and low speeds, so it is used as a perfect material for bearing application. PTFE own its properties like embeddability, fatigue strength, compatibility, load capacity, corrosion resistance, conformability and hardness. The applications of Engineering such as, sugar industries, milk industries, pharmaceutical industries, where minute amount of wear or contamination is also not permitted. So, bearing used should be self-lubricated or lubrication is to be provided to material in running condition. Non-ferrous alloys are generally, used as a bearing material. In older days, widely used materials for bearings and bushing were, copper, bronze and lead or tin based white metals. Huge requirement of these materials lead to increase in the cost of material; and due to this heavy demand, availability of these materials is decreasing day by day, which leads to increase in the market of mining industries and this is affecting on the environment. These parameters force the various researchers to go for alternate bearing materials like polymer and its composites.

PTFE has better strength at a temperature ranging from -270℃ to +260℃. It is soft in nature and has bad conductivity of heat which limits its acceptability as a bearing material for the application having lower speed and low unit pressure. PTFE is an efficient and less expensive material than all other conventional bearing materials. Number of polymer bearing materials is used in the application where they are sliding against polymer, metals or other materials. Whenever there is contact between two materials, we face problem of friction and wear [1]. Due to the week bonding force between polymeric chains is get break; it results in the friction and wears [2]. Different kind of filler materials is blended in polymeric materials to improve its tribological properties. So, these filler materials plays very crucial role in minimizing the friction and wear of materials [4]. PTFE has poor wear resistance, which may causes early failure and problem of leakage [4]. To narrow down this issue, different kinds of filler materials are added in Pure PTFE like Graphite, Bronze, Carbon, Glass fiber etc. [4]. When reinforcement of Carbon fiber, MoS_2, PEEK particles are made with PTFE, shows major improvement is wear rate [11].

When PTFE is blended with different filler metal then it shows drastic improvement in wear resistance [4]. Maximum wear resistance shown by PTFE than other materials when it is blended with 18% Carbon and 7% Graphite. Also, in addition to this, wear resistance can be increased by addition of glass fiber in the PTFE. When PTFE is mixed with MoS_2 particles, it shows very small amount of improvement in wear resistance. But, when small percentage of PPDT (2.5%) is blend with PTFE, doesn't found any decent change in wear properties of PTFE [4]. Glass fiber and Bronze can also be used as a filler material in PTFE which also may lead to improvement in wear resistance [13]. Addition of glass fiber in PTFE under wet condition, also improves the wear performance of PTFE material under different varying condition like load, velocity and sliding distance [14].

B. Taguchi Approach

The main objective of Taguchi design is to minimize the number of experiments to the optimum level, also leads to minimization of experimental cost. Initially, it allows to select various control variables for the process and their levels as per the availability, these are called as a Factors. After finalization of factors and their levels, orthogonal array (OA) is to be selected from the availability of factors and their levels. Generally, L_9 or L_{27} OA are used to evaluate experiment. Then, as per orthogonal array, experiment are to be conducted. Once, experimentation is completed, the results are arranged in orthogonal array and analysis of variance (ANOVA) is carried out to study the effect of each parameter on response. We can plot, signal to noise ratio graph as per our requirement of output response such as smaller is the better or larger is the better approach.

II. PROCEDURE OF EXPERIMENT

A. Methodology

This paper includes the study of plain PTFE material and reinforcement material is carbon content. Wear behavior of three types of materials was studied in this paper. 25% carbon content with 75% plain PTFE was the first combination and 35% carbon content with 65% plain PTFE was the second combination. These two materials are compared with wear resistance of 100% plain PTFE. These Samples (cylindrical pin shape) standard samples are created (pin diameter 12mm and length 30mm).

Fig. 1 Pin on disc machine

Fig. 2 Friction and wear Monitor

TABLE I CONFIGURATION OF MATERIALS

Sl. No.	Samples	Base Material	Filler Material
1	Sample 1	100% PTFE	--
2	Sample 2	75% PTFE	25% Carbon
3	Sample 3	65% PTFE	35% carbon

B. Wear Test

Experimental tests were carried out on pin-on-disc machine of TR20 model under the dry sliding condition. In these wear tests, flat surface of samples having cylindrical shape (diameter 12mm and length 30mm) was in contact with rotating cylindrical disc of 160mm diameter and 8mm thick made with En-32 steel with 150mm wear track diameter. The experiments wear conducted under varying loads: 1, 2, 3 Kg, sliding distance of 2, 4, 6 km and speed of 1.57, 3.14, 4.71 m/s. A wear and frictional force were measured by pin on a disc machine digital display. Study of frictional behaviour under varying load and sliding speed condition can also be studied by using pin-on-disc machine. Wear of test material occurs due to sliding between rotating disc and fixed pin. This wear of material and tangential force were measured with the help of electronic sensors of machine and these are recorded on display of computer. The co-efficient of friction is quantify by frictional force and normal load.

TABLE II L9 ORTHOGONAL ARRAY FOR EXPERIMENTATION

Expt No.	Load (Kg)	Velocity (m/s)	SD (Km)	Sample 1 Wear µm	S/N for Wear	Sample 2 Wear µm	S/N for Wear	Sample 3 Wear µm	S/N for Wear
1	1	1.57	2	225	-47.04	36	-31.12	12.4	-21.87
2	1	3.14	4	346	-50.78	62	-35.84	20.3	-26.15
3	1	4.71	6	365	-51.25	72	-37.15	24	-27.62
4	2	1.57	4	575	-55.19	123	-41.80	40	-32.04
5	2	3.14	6	610	55.70	135	-42.60	44	-32.87
6	2	4.71	2	226	-47.08	45	-33.06	15.86	-24.01
7	3	1.57	6	1126	-61.03	273	-48.72	91	-39.18
8	3	3.14	2	291	-49.28	60	-35.56	19	-25.58
9	3	4.71	4	313	-49.91	64.5	-36.19	21	-26.44

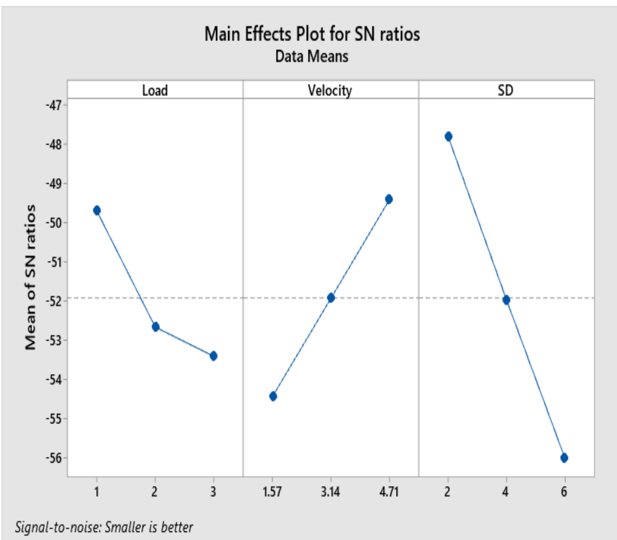
TABLE III OUTPUT TABLE OF SIGNAL-TO-NOISE RATIO

	Sample 1			Sample 2			Sample 3		
Level	**Load**	**Velocity**	**SD**	**Load**	**Velocity**	**SD**	**Load**	**Velocity**	**SD**
1	-49.69	-54.42	-47.80	-34.71	-40.55	-33.25	-25.21	-31.03	-23.82
2	-52.66	-51.92	-51.96	-39.16	-38.01	-37.95	-29.64	-28.20	-28.21
3	-53.41	-49.41	-55.99	-40.16	-35.47	-42.83	-30.40	-26.02	-33.22
Delta	3.72	5.01	8.19	5.45	5.08	9.57	5.19	5.01	9.40
Rank	3	2	1	2	3	1	2	3	1

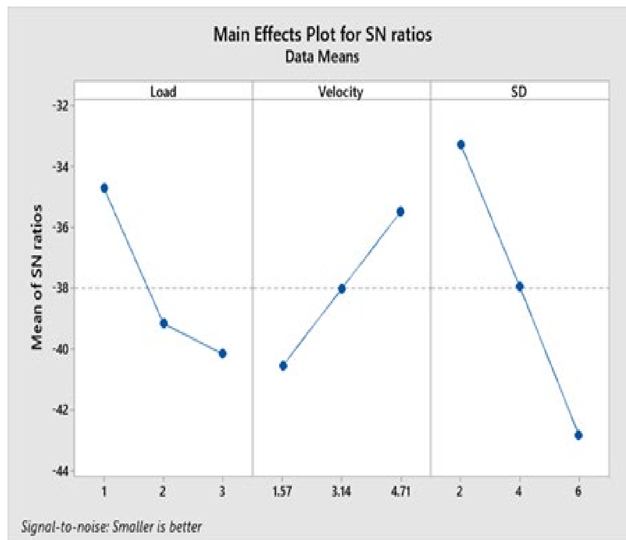
III. DESIGN OF EXPERIMENT (DOE)

In traditional method, it is needed to carry number of experimentation to reach at some acceptable results or conclusion and it is very time consuming process. In order to develop some strategic way to carryout experimentation Design of Experiment technique is used.

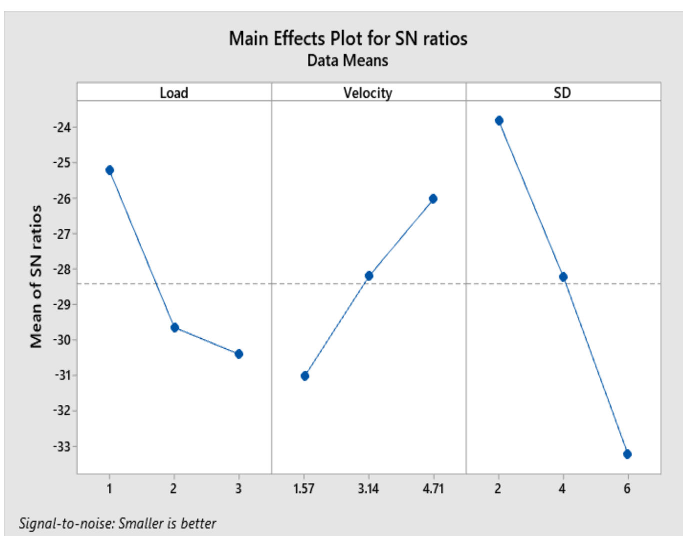
For optimization of experimental work to come up at acceptable conclusion, the design of experiment technique is used. It minimizes the experiment numbers to be carried out and concentrate on optimum test runs. The Orthogonal Arrays (OA) of Design of Experiment gives optimum test runs to be carried out. L_9 orthogonal array is used for this study.



Sample 1



Sample 2



Sample 3

Fig. 3 Mean of signal to noise ratio

IV. RESULTS AND DISCUSSION

Results derived from the experimentation on said samples for the wear properties of Pure PTFE, 25% carbon filled PTFE and 35% carbon filled PTFE are shown in Table II. The wear rate is the main target of consideration and discussion.

Best fitted parameters for the process were found with help of signal to noise ratio of Taguchi approach [6]. The know the effect of process parameters on the response output i.e. wear rate; the wear test were performed on pin-on-disc. L_9 OA was selected to carry out optimum experiments. Experimental data is used to calculate signal-to-noise, S/N ratio of output parameter. The quantitative effect on output features was studied using obtained response graphs. Admissible factors and its effect on wear rate were identified by using analysis of variance, S/N ratio analysis etc. The mean of all responses (S/N ratio) for all three samples at each level are shown in Table III. The wear rate is increases considerably along with increase in sliding velocity, as shown in Fig. 3. It also signifies that, load and sliding distance are inversely proportional to the wear rate of PTFE. When PTFE is used with composition of carbon then, the sliding distance at level first, load at level second and sliding velocity at level third can give best possible response results. whereas, for plain PTFE, sliding distance at level first, sliding velocity at level second and load at level third was found as a best possible response results.

V. CONCLUSION

The wear resistance of PTFE can be significantly enhanced by incorporating carbon content into it. Optimal process parameters for minimizing wear rate include a sliding distance of 1000 m, a load of 20 N, and a sliding speed of 4.71 m/s. Confirmation tests have demonstrated that these parameters can indeed achieve the desired reduction in wear rate. Moreover, the addition of 25% carbon to PTFE results in a decrease in wear rate by 70-75%, while a 35% carbon content can further reduce the wear rate by 85-90%. However, it is important to note that exceeding a carbon percentage of 35-40% may lead to increased brittleness in the composite material. Therefore, it is not advisable to surpass the 35% carbon content threshold.

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