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# Tribological Behaviour of PTFE and its Composites

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***Abstract – In this study, the effect of applied load, Sliding time and sliding velocity on wear and friction behaviour of polytetrafluoroethylene (PTFE) or Teflon, and its three composites viz., 55% Bronze filled PTFE, 60% bronze filled PTFE & 40% Bronze filled PTFE, is experimentally examined & analytically analysed. Experiments were performed using a standard single pin type Pin-on-Disc arrangement, sliding uni-directionally against counter face material EN-31 steel. Experiments were carried out at dry condition and at ambient temperature, assuming other parameters to be constant. Experiments were performed using DOE (Design of Experiment) based on Taguchi's approach and $L_9$ orthogonal array. ANOVA is performed for critical analysis of the contribution of the individual input parameters on the optimality of the desired conditions. It is observed that, for the range of applied load and sliding velocity explored in this study, the applied load is the significant parameter than sliding velocity, with the exception of 60% Bronze filled PTFE, in which both the parameters are equally significant.***

***Keywords — PTFE, Wear, Friction, DOE, ANOVA.***

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## INTRODUCTION

New plastic materials are today available for engineering purposes owing to rapid development of polymers with better tribological and mechanical properties. The important tribological characteristics of commonly used polymeric material like PTFE or Teflon and its composites are frictional behaviour, load bearing capacity and wear. Because of variety of operating condition and use of material as new application , there is continuous need to investigate into these characteristic behaviours of pure PTFE and PTFE based composites available in Indian market in order to generate performance data [1,2].

To fulfil the requirements of NC and high precision machine tools there are different slide way system possible such as rolling anti-friction slide ways, hydrostatic slide ways, and low friction PTFE or resin composites. Of these, the low friction PTFE have the advantages such as corrosion resistance, excellent wear, high capacity for damping vibration, , high chemical stability, light weight, self lubricating properties and low cost. Thus, the slide way composites have gain importance and number of such material have been developed in the recent past. Numerous types of these materials are now available commercially and designer is uncertain in making the right choice [3,4]. Other applications of these materials are found as journal bearing material, high performance, mechanical seals, small size gears, etc [3].

However Polymers suffers from many disadvantages such as low thermal conductivity, less strength and modulus of elasticity than that of metals. The load carrying capacity of polymer bearings is also lower than same size of metal part. Addition of the fillers can compensate many disadvantages outline here [4,5]. Many polymers and its composites are widely used for sliding couples against metals, polymers and other materials.

## OBJECTIVES OF STUDY

The wear mechanism is dependent on following various factors such as

1. The load on the contacting area.

2. The sliding velocity.

3. The duration of the sliding.
4. The working conditions namely, dry or lubricated.
5. Metallurgical structure such as grain structure, hardness.

From the factors mentioned above only the first three parameters are varied for different experiments to examine the effect of different fillers on wear and friction characteristics of pure PTFE (Teflon) and its two composites, namely 60% Bronze filled Teflon and 25% carbon filled Teflon. Dry working conditions at ambient temperature have been used and other parameters have been considered constant. The objective will be to generate new performance data, which will be useful for design engineer.

## LITERATURE SURVEY

Tanaka K. And kawakami S.[7] Carried out work on wear and friction behaviour of various filler base PTFE under a constant applied load and varying velocity of sliding when composites pin was rubbed against a steel disc. It was found that friction of Teflon based composites was independent on filler type. Authors also discussed the effect of size and shape of filler on wear.

Bahadur S. and Tabor D.[8] studied effects of fillers on wear behaviour of Teflon sliding against glass and mild steel. Different fillers were used to find out their effect on Teflon wear rate. Graphite as a filler reduced the rate of wear of PTFE by a factor 100 whereas coefficient of friction was increased by 30%. While CuS filler showed equally much more reduction in wear rate but did not increase the friction coefficient.

Briscoe B.J. and Steward M.D. [9]. studied the effect of carbon aspect ratio on wear and friction of PTFE. Experiments were conducted differing particle shapes. The wear tests were conducted at constant load of 4 Kgf and at constant sliding velocity of 300 m/min, the counter face being mild steel. It is observed that the graphite filler reduces the wear rate of composite, the nuclear and polar forms being more beneficial at the same weight percentage levels than the Oleophilic form of graphite.

Shah N.C.F. et al [10] has studied the tribo characteristics of unfilled and filler plastics. They found by experimentally the variation of the friction coefficient with variation in the sliding velocity and different conditions of surface preparations. PV curves for selection of the regime of working have been plotted for various combination of rubbing pairs including filled and unfilled plastics.

Satynarayan K. R. et al [11] have studied the tribological behaviour of some non ferrous, ferrous and polymeric materials, used for different applications in machine tools in solid lubricants and dry conditions using. They also developed an empirical relationship of friction and wear dependent on influencing parameters. Some ‘‘Iso-wear’’ curves have also been plotted for obtaining the values of parameters and their treatment combination for a specific wear rate.

Talat T. [12,13] In his two different, experimentally Studied the effect of bearing pressure, sliding distance, and the medium and low speed on wear and friction in journal bearing made up of 35% carbon filled Teflon composite and in other paper with 60% carbon filled PTFE. He observed that friction coefficient and wear are mostly influenced by the composition and thickness of transfer film's, depending on adhesion between composite surfaces and steel, the polymer's cohesive properties used, sliding distance and pressure.

Unal H. et al. [5] found that the effect of load and test speed values on wear and friction behaviour of pure PTFE, 17% glass fibre reinforced (GFR), 25% Bronze, and 35% carbon filled polymers. They observed that, for pure PTFE and its composites used in investigation, the coefficient of friction increases with the increase in load. Addition of bronze, glass fiber, and carbon fillers to PTFE were observed effective reduction in the wear rate of composite of PTFE. In addition, the wear rate showed large sensitivity for applied load and very little sensitivity to test speed at high load values.

Yijin Shi et al. [14] has investigated that, there is strong interfacial adhesion between PTFE and carbon filled after surface treatment, and the load support capacity of carbon filled is increased. The rubbing off of PTFE and large scale transfer, and then reduces the wear of composites.

## TAGUCHI DESIGN METHOD

Taguchi method of design was developed by Dr. Genichi Taguchi during the Second World War. During Second World War due to the scarcity of the resources the need for optimization was at peak. Taguchi method believes that every problem has easy solutions and that every problem can have linear solutions. The taguchi method provides set of experiments arranged in arrays such as L9, L18 etc that provides same solution that would have got using all the permutations and combinations in the levels and input parameters of the experiment. The three levels of parameters were taken as shown in the table 2. The actual vales calculated for the parameters are shown in the table 3.

The taguchi method is applied in following 4 steps,

1. Search for the quality characteristics and design input parameters

2. Design and conduct the experiment

3. Define the output parameters and calculate the same

4. For confirmation of the optimal solution check using the confirmation test.

The levels of the parameters are as shown in the table 1 and the actual values are as shown in the table 2.

***A. Signal-to-Noise Ratio*:**

Following are three Signal-to-Noise ratios of common interest for optimization as follows:

(I) Smaller-The-Better: n = -10 Log10

[Mean of sum of squares of measured data]

(II) Larger-The-Better: n = -10 Log10

[Mean of sum squares of reciprocal of measured data]

(III) Nominal-The-Best: n = 10 Log10 (square of mean) / Variance.

***B. Work Material and Equipment:***

For the Experimentation the test material was turned in the form of Pin with Diameter of 12 mm and Length 25 mm. Test Parameters used with test Rig are shown in following

**Fig 1. Pin on Disc apparatus**

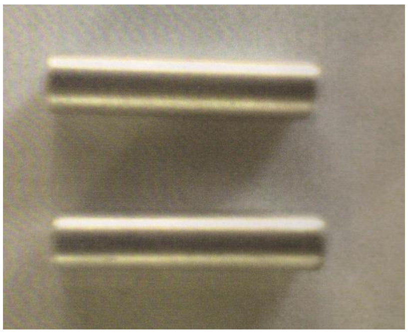

**Fig 2. Pin used in experiment**

**TABLE 1 ASSIGNING OF LEVELS TO THE VARIABLES AS APPLICABLE TO PIN ON DISC MACHINE**

| Level | Low | Medium | High |
|---|---|---|---|
| Load (Kg) | 2 | 4 | 6 |
| Sliding Velocity(Rpm) | 300 | 600 | 900 |
| Sliding Time (Min.) | 30 | 60 | 90 |

**TABLE 2 ASSIGNING OF LEVELS TO THE VARIABLE AS APPLICABLE PRACTICALLY**

| Level | Low | Medium | High |
|---|---|---|---|
| Load (MPa) | 0.175 | 0.35 | 0.525 |
| Sliding Velocity(m/s) | 1.57 | 3.14 | 4.71 |
| Sliding Time (Min.) | 30 | 60 | 90 |

**TABLE 3 DESIGN MATRIX FOR TAGUCHI EXPERIMENTATION**

| Trail No. | Applied Load (MPa) | Velocity (m/s) | Time (min) |
|---|---|---|---|
| 1 | 0.175 | 1.57 | 30 |
| 2 | 0.175 | 3.14 | 60 |
| 3 | 0.175 | 4.71 | 90 |
| 4 | 0.35 | 1.57 | 60 |
| 5 | 0.35 | 3.14 | 90 |
| 6 | 0.35 | 4.71 | 30 |
| 7 | 0.525 | 1.57 | 90 |
| 8 | 0.525 | 3.14 | 30 |
| 9 | 0.525 | 4.71 | 60 |

The L9 orthogonal array is selected as shown in the table 3. Analysis of S/N Ratio: The desirable value for the output characteristics is referred by the term signal in taguchi method whereas the undesirable value is referred as noise (Standard Deviation) for the output characteristics. To measure the quality characteristic deviating from the desired S/N ratio is used. In S/N ratio S is calculated as S= -10 log (M.S.D.) where, M.S.D. is the mean square deviation for the output characteristic. The M.S.D. for higher-the –better quality characteristic can be expressed

Where R = Number of repetitions

The experiments were carried out on Pure PTFE and its three composites and the results are tabulated in the table 4, table 5, table 6 and table 7 respectively.

**TABLE 4 EXPERIMENTAL DATA FOR MATERIAL PTFE MATERIAL**

| Trail No | Applied Load (MPa) | Velocity (m/s) | Time (min) | Wear (mg) |
|---|---|---|---|---|
| 1 | 0.175 | 1.57 | 30 | 87.7 |
| 2 | 0.175 | 3.14 | 60 | 158.8 |
| 3 | 0.175 | 4.71 | 90 | 260.3 |
| 4 | 0.35 | 1.57 | 60 | 185.5 |
| 5 | 0.35 | 3.14 | 90 | 406.1 |
| 6 | 0.35 | 4.71 | 30 | 201.3 |
| 7 | 0.525 | 1.57 | 90 | 387.3 |
| 8 | 0.525 | 3.14 | 30 | 215.7 |
| 9 | 0.525 | 4.71 | 60 | 301.2 |

**TABLE 5 EXPERIMENTAL DATA FOR 55% BRONZE + 5% $MOS_2$ FILLED PTFE MATERIAL**

| Trail No | Applied Load (MPa) | Velocity (m/s) | Time (min) | Wear (mg) |
|---|---|---|---|---|
| 1 | 0.175 | 1.57 | 30 | 3.7 |
| 2 | 0.175 | 3.14 | 60 | 5.2 |
| 3 | 0.175 | 4.71 | 90 | 6.7 |
| 4 | 0.35 | 1.57 | 60 | 6.5 |
| 5 | 0.35 | 3.14 | 90 | 7.5 |
| 6 | 0.35 | 4.71 | 30 | 5.3 |
| 7 | 0.525 | 1.57 | 90 | 7.0 |
| 8 | 0.525 | 3.14 | 30 | 5.8 |
| 9 | 0.525 | 4.71 | 60 | 7.2 |

**TABLE 6 EXPERIMENTAL DATA FOR MATERIAL 60% BRONZE FILLED PTFE MATERIAL**

| Trail No. | Applied Load (MPa) | Velocity (m/s) | Time (min) | Wear (mg) |
|---|---|---|---|---|
| 1 | 0.175 | 1.57 | 30 | 2.5 |
| 2 | 0.175 | 3.14 | 60 | 3.2 |
| 3 | 0.175 | 4.71 | 90 | 4.0 |
| 4 | 0.35 | 1.57 | 60 | 3.8 |
| 5 | 0.35 | 3.14 | 90 | 6.2 |
| 6 | 0.35 | 4.71 | 30 | 2.7 |
| 7 | 0.525 | 1.57 | 90 | 5.8 |
| 8 | 0.525 | 3.14 | 30 | 4.1 |
| 9 | 0.525 | 4.71 | 60 | 5.2 |

**TABLE 7 EXPERIMENTAL DATA FOR MATERIAL PTFE MATERIAL 40% BRONZE FILLED PTFE MATERIAL**

| Trail No | Applied Load (MPa) | Velocity (m/s) | Time (min) | Wear (mg) |
|---|---|---|---|---|
| 1 | 0.175 | 1.57 | 30 | 4.0 |
| 2 | 0.175 | 3.14 | 60 | 7.1 |
| 3 | 0.175 | 4.71 | 90 | 11.5 |
| 4 | 0.35 | 1.57 | 60 | 7.8 |
| 5 | 0.35 | 3.14 | 90 | 19.3 |
| 6 | 0.35 | 4.71 | 30 | 5.1 |
| 7 | 0.525 | 1.57 | 90 | 15.2 |
| 8 | 0.525 | 3.14 | 30 | 11.3 |

## ANOVA ANALYSIS

Using the analysis of variance (ANOVA) technique, the adequacy of the models is tested. This is statistical tool for testing null hypothesis for experimentation design, where all the variables of the experiment are studied simultaneously so as to check the performance and contribution of the individual input parameter on the optimality of the solution. ANOVA is used to quickly analyse the variances occurred in the experiment with the help of fisher test. This analysis was performed for a level of significance of 5%, i.e. the level of confidence 95%. Table shows the result of ANOVA analysis. One can observe from the ANOVA analysis that the value of P is less than 0.05 in all three parametric sources. Following Table 8, table 9, table 10, table 11 shows the result of ANOVA analysis.

**TABLE 8 MANUAL ANOVA FOR PTFE MATERIAL DATA**

| Factor | Df | SS | MSS | F ratio |
|---|---|---|---|---|
| P | 2 | 2801.63 | 14009.3 1 | 5.25 |
| V | 2 | 1840.30 | 920.15 | Pool |
| T | 2 | 53015.50 | 26507.7 5 | 18.34 |
| Error | 2 | 82874.43 | 2601.31 | |
| Total | 8 | 88077.06 | | |

**TABLE 9 MANUAL ANOVA FOR 55% BRONZE + 5% $MOS_2$ FILLED PTFE MATERIAL**

| Factor | Df | SS | MSS | F ratio |
|---|---|---|---|---|
| P | 2 | 3.73 | 1.863 3 | 5.42 |
| V | 2 | 0.69 | 0.34 | Pool |
| T | 2 | 7.01 | 3.50 | 10.20 |
| Error | 2 | 0.38 | 0.19 | |
| Total | 8 | 11.80 | | |

**TABLE 10 MANUAL ANOVA FOR 60% BRONZE FILLED PTFE MATERIAL**

| Factor | Df | SS | MSS | F ratio |
|---|---|---|---|---|
| P | 2 | 4.88 | 2.44 | 9.63 |
| V | 2 | 0.51 | 0.25 | Pool |
| T | 2 | 7.53 | 3.76 | 14.85 |
| Error | 2 | 0.99 | 0.49 | |

| | | | | |
|---|---|---|---|---|
| Total | 8 | 13.90 | | |

**TABLE 11 MANUAL ANOVA FOR 40% BRONZE FILLED PTFE MATERIAL**

| Factor | Df | SS | MSS | F ratio |
|---|---|---|---|---|
| P | 2 | 48.98 | 24.49 | 2.38 |
| V | 2 | 20.53 | 10.26 | Pool |
| T | 2 | 115.01 | 57.50 | 5.60 |
| Error | 2 | 0.97 | 0.485 | |
| Total | 8 | 10.50 | | |

## RESULT AND DISCUSSION

The results obtained from the experimentation have been expressed in the form of tribo- graphs shown in the Fig 3, Fig 4, and Fig 5.

***Results Related to Friction***

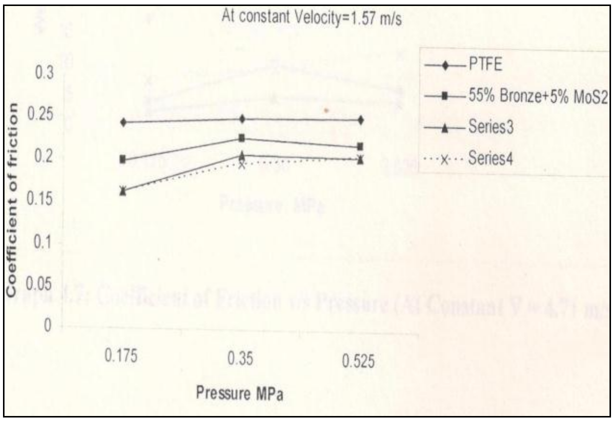


**Fig.3 Coefficient of Friction Vs Pressure at constant velocity 1.57 m/s.**

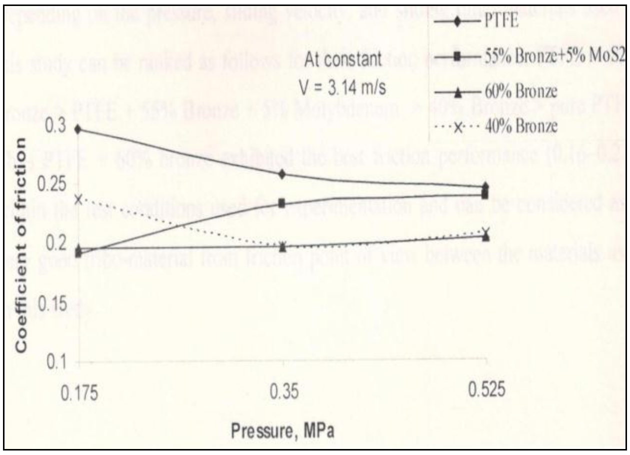


**Fig.4 Coefficient of Friction Vs Pressure at constant velocity 3.14 m/s.**

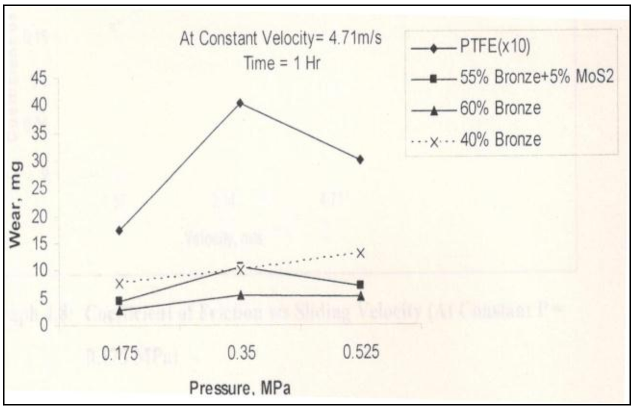


**Fig.5 Coefficient of Friction Vs Pressure at constant velocity 4.71 m/s.**

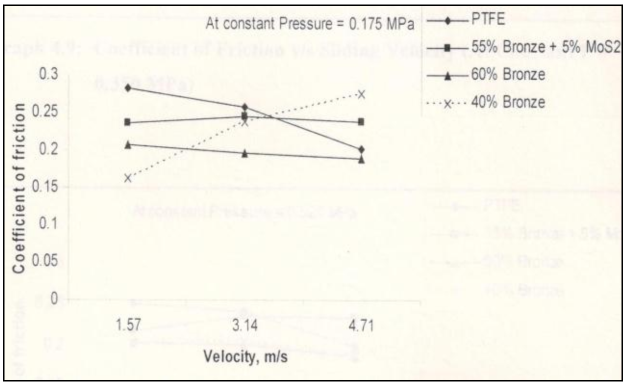


**Fig.6 Coefficient of Friction Vs sliding velocity at constant pressure 0.175MPa.**

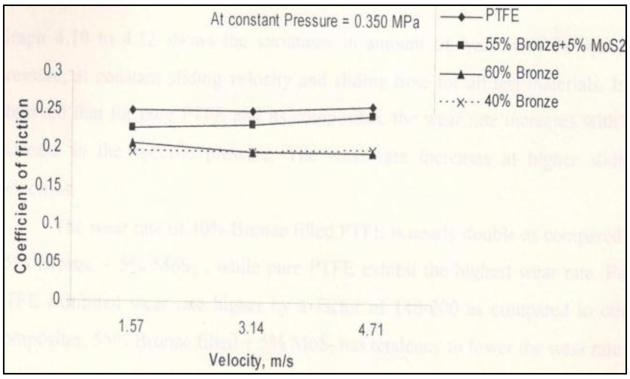


**Fig.7 Coefficient of Friction Vs Sliding velocity at constant pressure 0.350MPa.**


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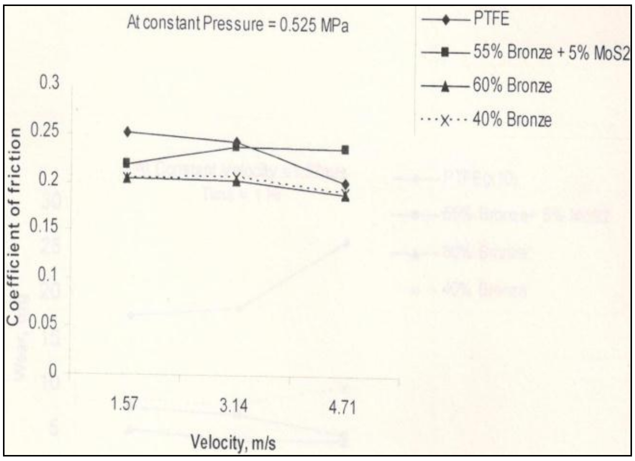


**Fig.8 Coefficient of Friction Vs Sliding velocity at constant pressure 0.525MPa.**

The relation between coefficient of friction and sliding velocity are as shown in the Fig 6, Fig 7, and Fig 8.

***Results Related to Wear:***

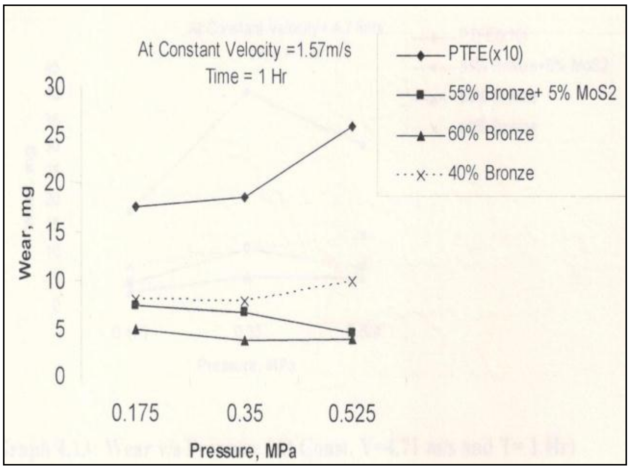


**Fig.9 Wear Vs Pressure at constant velocity 1.57 m/s. and T = 1 Hr.**

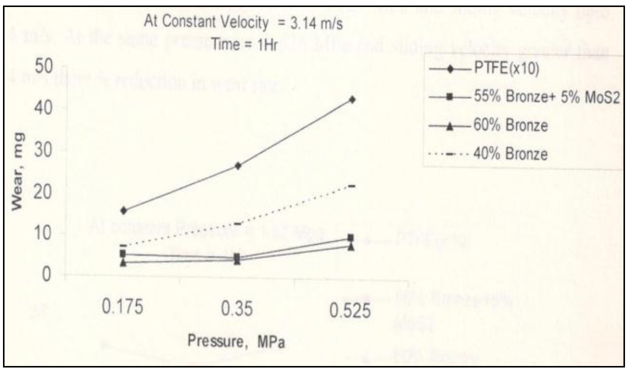


**Fig.10 Wear Vs Pressure at constant velocity 3.14 m/s. and T = 1 Hr.**

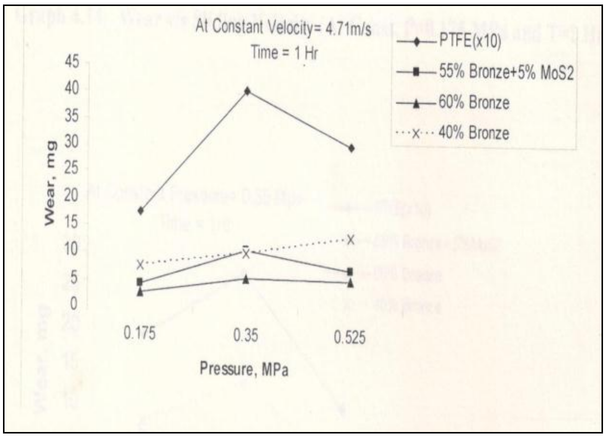


**Fig.11 Wear Vs Pressure at constant velocity 4.71 m/s. and T = 1 Hr.**

The results obtained from the experimentation have been expressed in the form of tribo- graphs shown in the Fig 9, Fig 10, Fig 11.

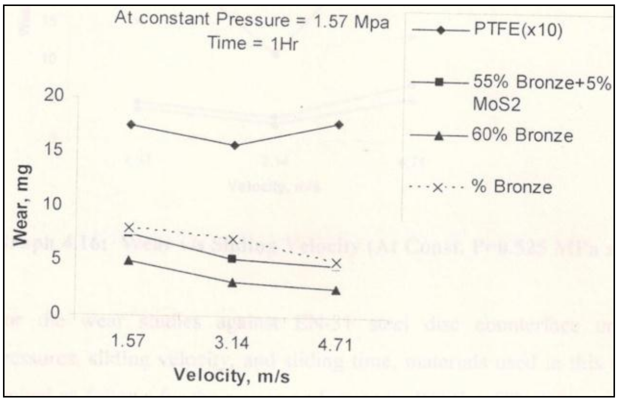


**Fig.12 Wear Vs Sliding velocity Pressure at constant pressure 0.175MPa and T = 1 Hr.**

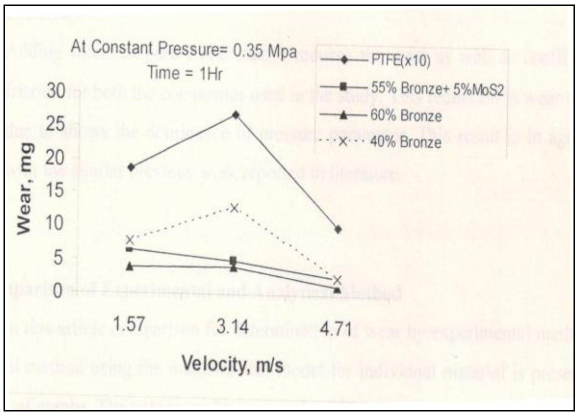


**Fig.13 Wear Vs Sliding velocity Pressure at constant pressure 0.35MPa and T = 1 Hr.**

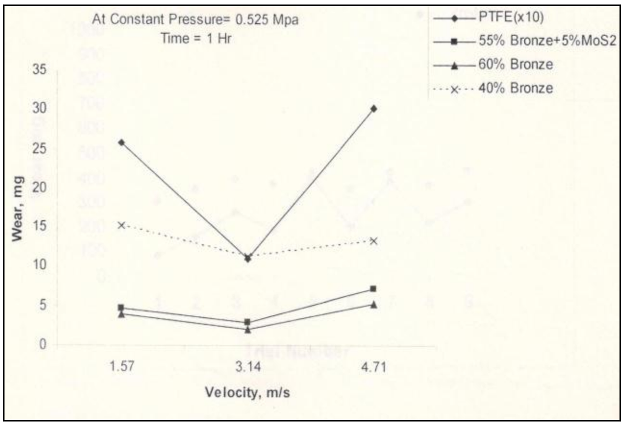


**Fig. 14 Wear Vs Sliding velocity Pressure at constant pressure 0.525MPa and T = 1 Hr.**

The relation between coefficient of wear and sliding velocity are as shown in the Fig 12, Fig 13, Fig 14.

## CONCLUSIONS

Following conclusions are drawn from the present study-

1. Depending on the pressure sliding velocity and sliding time materials use in this study can be ranked has follows for their friction performance. PTFE+60% bronze> PTFE+55% bronze+5% $MoS_2$> PTFE+40% bronze>pure PTFE. Thus PTFE+60% Bronze exhibited the best friction performance within the test conditions used for experimentation and can be considered as a very good tribo-material from friction point of view, between the materials used in this study.

2. From the wear studies against EN-31 steel disc counter face under various loads, sliding velocity and sliding time materials used in this study can be ranked as follows for their wear performance. PTFE+60% bronze> PTFE+55% bronze+5% $MoS_2$> PTFE+40% bronze>pure PTFE. Bronze filled exhibited the best wear performance, within the test conditions used for experimentation and can be considered as a very good tribo-material from wear point of view between the materials used in this study.

3. The coefficient of friction of pure PTFE decreases when applied load increases. For variation of loading conditions that is where the operating conditions are vary at such situations PTFE+55% bronze+5% $MoS_2$ is suitable as it gives the stable performance to varying loading.

4. It was observed that, the coefficients of friction of PTFE composites were lower than that of pure PTFE matrix for all ranges of loads and sliding velocities.

5. The wear rate for all the test materials increases with increase in specific pressure. The wear rate rises if high sliding velocities are used at high pressure.

6. Pure PTFE is characterized by high wear because of its poor mechanical properties. The addition of fillers showed high reduction in wear and also marginal reduction in coefficient of friction.

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