Wear Analysis of Polymer Composites for Biomaterials

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Abstract: The word "composite" refers to the combination on a macroscopic scale of two or more materials, different composition, morphology and general physical properties. In many cases, and depending on the constituent properties, composites can be designed with a view to produce materials with properties tailored to fulfill specific chemical, physical and mechanical requirements. Therefore over the past 40 years the use of composites has progressively increased. Consequently many composite materials have recently been studied and tested for biomedical applications.

PolyTetraFluoroEthylene and Titanium Dioxide composites were developed as alternative materials for orthopaedic applications. The amount of Titanium Dioxide (TiO_2) incorporated into the PolyTetraFluoroEthylene (PTFE) polymer matrix with the ranges of 5%, 10% and 15% of weight proportion and these materials were successfully fabricated by compression moulding. Wear analysis is carried out on prepared specimens, wear rate and co-efficient of friction are within proper limits of orthopaedic implants.

Keywords: Polymer Composites, Biomaterials, PTFE, Titanium dioxide, Wear.

I. INTRODUCTION

Tribological behaviour may be evaluated by several qualitative and quantitative parameters. We select friction coefficient and wear rate parameters are relevant for this study. PTFE based materials are notable for their characteristics such as very low friction coefficient and good resistance to heat and corrosion in different application environments. Unfortunately, pure PTFE is not performing satisfactory in wear resistance and needs to be modified. The use of fillers and additives in PTFE is the most common way to improve its tribological and mechanical properties. The influence of fillers on the tribological behaviour of the composites can be tested experimentally [1].

Unfortunately PTFE has poor thermal conductivity, high coefficient of thermal expansion and relatively not so strong. PTFE suffers from poor wear resistance too. PTFE is suitable only for light loads and at low speeds. 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 [2].

1.1 Literature Review

Deepak Bagle [3] studied the tribological behaviour of PolyTetraFluoroEthylene and its composites with filler materials such as carbon and bronze under dry conditions. It is found that addition of filler materials such as bronze and carbon to PTFE cause an increase in hardness and wear resistance, while the coefficient of friction is slightly increased. From the results the highest wear resistance was found for PTFE with carbon filler followed by PTFE with bronze filler and pure PTFE.

Jaydeep Khedkar [4] studied the tribological behaviour of PolyTetraFluoroEthylene (PTFE) and PTFE composites with filler materials such as carbon, graphite, glass fibres, MoS_2 and poly-*p*-phenyleneterephthalamide (PPDT) fibres. The present filler additions found to increase hardness and wear resistance in all composites studied. The highest wear resistance was found for composites containing (i) 18% carbon + 7% graphite, (ii) 20% glass fibres + 5% MoS_2 and (iii) 10% PPDT fibres.

It was proposed by Lancaster [5] that addition of high aspect ratio filler materials (carbon fibres, glass fibres) to PTFE can improve its wear resistance due to preferential load supporting action by these fibres. There have also been some reports on the use of particulate filler materials like MoS_2 and graphite to modify the tribological properties of PTFE.

V.B. Raka [6] has studied and analyzed the effect of applied load, sliding velocity and sliding time on friction and wear behaviour of PolyTetraFluoroEthylene (PTFE) and its two composites viz. 25% carbon filled PTFE and 60% bronze filled PTFE, is experimentally examined and analytically analyzed. Adding fillers to pure PTFE matrix reduces wear rate for both the composite used in the study.

D.S. Bajaj [7] examined the tribological properties of PTFE can be improved by adding some filler materials such as glass fibres, carbon, bronze, graphite. Friction and wear are very important surface phenomenon. The parameters studied include wear rate and coefficient friction under varying load and for different surface roughness.

1.2 Purpose of Present Study

The present study will be aimed at developing a new alternative material for orthopaedic applications, composite consists of PTFE and TiO_2 with different proportions. Fruitful research in this area could lead to development of superior and less expensive wear resistant material. The new material will be developed during the present investigation and the properties of this material will be evaluated. Following are the main objectives of the study.

a. To find the effect of TiO_2 in PTFE on wear rate.

b. To study the wear behaviour of the selected material with 5%, 10% and 15% weight proportion of TiO_2.

II. METHODOLOGY

2.1 Rule of Mixture

The properties of components of composites are determined with Rule of Mixture.

Table 1: Weights of Virgin PTFE and TiO_2 for each proportion

95% PTFE & 5% TiO_2	90% PTFE & 10% TiO_2	85% PTFE & 15% TiO_2
PTFE – 6.44 gms TiO_2 – 0.34 gms	PTFE – 5.96 gms TiO_2 – 0.66 gms	PTFE – 5.5 gms TiO_2 – 0.97 gms

2.2 Specimen Preparation

The purchase of materials used for preparation of composites such as Titanium dioxide (TiO_2) from Ramdev Chemicals and PolyTetraFluoroEthylene (PTFE) from Micro Polymer Products.

The standard rod of Virgin PTFE and TiO_2 composite with different weight proportions is prepared by Micro Polymer Products Pvt. Ltd, Bangalore.

The dimensions of the wear specimen are as follows:

1. Diameter of Specimen: 10 mm
2. Length of Specimen: 40 mm

Fig.1 Specimens for wear test

2.3 Procedure to prepare the specimen

The sample specimen has been prepared by performing necessary steps as follows:

- Weighing of PTFE & TiO_2 with proper proportions.
- Mixing of PTFE & TiO_2.
- Cleaning of mould (or) die.
- Filling the mixture into mould (or) die.
- Compressing the Mixture using Hydraulic Press to the standard size and shape.
- Removal of compressed composite from the mould (or) die.
- Loading the compressed composite into the industrial oven.
- Unloading the compressed composite from the industrial oven (after 8-10 hours of heating with certain temperatures and cooling for some period of time).
- Machining operations such as Facing and Turning to the required size standard.

III. EXPERIMENTAL WORK

3.1 Experimental Setup

The Ducom Wear and Friction Monitor – TR 20 Series has been designed and developed by DUCOM INSTRUMENTS PVT. LTD. The Ducom Wear and Friction Monitor – TR 20 Series has become the industry standard in wear and friction analysis. The TR 20 Series tribometer is specifically designed for fundamental wear and friction characterization. This instrument consists of a rotating Disk against which a test pin is pressed with a known force. A provision for measurement of compound wear and frictional force is provided.

The Ducom TR 20 Series along with select options provide researchers with very wide test capabilities. Options for lubrication recirculation, environment chamber, pin temperature measurement, elevated temperature tests, and low temperature tests, tests in corrosive environments and vacuum tests are available. The TR 20 Series comes with the WinDucom software for data acquisition and display of results. The WinDucom instrumentation and Data Acquisition permits users, the measurement of:

- RPM
- Wear
- Frictional force
- Temperature (optional)

Using the WinDucom Data Acquisition System, a PC acquires test data online and displays it in several ways. Graphs of individual tests can be printed. Results of different tests can be superimposed using the WinDucom CompariView feature for comparative viewing of results. Data can be exported to other software.

3.2 Specifications

- Description: PIN/BALL ON DISC TESTER TR 20LE
- Model No: TR 20LE
- Pin diameter: 3-12 mm
- Ball diameter: 10 mm
- Disc (diameter x thickness): 165 x 8 mm
- Wear track diameter: 50-140 mm
- Sliding velocity: 0.5-10 m/s
- Disc speed: 200-2000 rpm
- Normal load: 5-200 N
- Frictional force: 0-200N

3.3 Testing Procedure

- Cleaned samples are fixed in the chuck of the wear testing machine.
- Select the Wear Track Diameter and Speed of the Rotating Disc.
- Select the loads (10N, 15N & 20N) to be applied.
- Start the machine.
- Take the Wear readings and Frictional force at equal time intervals.
- Calculate Wear rate and Co-efficient of friction by using suitable formulae.
- Plot the graph of Wear rate v/s Sliding Distance and Co-efficient of friction v/s Sliding Distance.
- Repeat the steps for different materials.

Fig.2 Experimental Setup

3.4 Tabulation and Calculations

The following Wear readings and Frictional force for different load with constant speed were observed for the composites of different proportions:

Table 2: Wear readings and Frictional force

Sl. No.	Proportion	Time, min	Wear, mm		Frictional Force, N	
			Load		Load	
			10 N	20N	10 N	20 N
1	95% PTFE & 5% TiO_2	2	0.02	0.02	2	2.4
		4	0.02	0.02	2.1	2.5
		6	0.03	0.03	2.2	2.6
		8	0.02	0.02	2.4	2.5
		10	0.03	0.02	2.4	2.6
2	90% PTFE & 10% TiO_2	2	0.02	- 0.08	2.5	2.6
		4	0.02	- 0.07	2.6	2.3
		6	0.03	- 0.07	2.1	2.6
		8	0.02	- 0.07	2.4	2.2
		10	0.03	- 0.08	2.4	2.2
3	85% PTFE & 15% TiO_2	2	0.02	- 0.12	2.3	2.4
		4	0.02	- 0.06	2.2	2.6
		6	- 0.07	- 0.06	2.1	2.3
		8	- 0.09	- 0.08	2.3	2.3
		10	- 0.08	- 0.06	2.4	2.5

The data required for the calculations are as follows:

- Diameter of the specimen (d) = 10 mm
- Track radius (R) = 60 mm
- Speed of rotating disc (N) = 500 rpm
- Normal Load (L) = 10N, 15N & 20N
- Density of the Specimen = 2.120×10^{-3} gm/mm^3 (95% PTFE & 5% TiO_2)
  2.135×10^{-3} gm/mm^3 (90% PTFE & 10% TiO_2)
  2.112×10^{-3} gm/mm^3 (85% PTFE & 15% TiO_2)

The calculations for the Wear rate and Co-efficient of friction are as follows

- Area of the specimen = $\frac{\pi}{4}d^2$ in mm^2 = $\frac{\pi}{4}(10)^2$ = **78.539 mm^2**

- Sliding Distance = (2 π R N x Time in mins) in mm = 2 x π x 60 x 500 x 2 = **0.376 x 10^6 mm**

- Co-efficient of friction (μ) = $\frac{Frictional force\ (F)}{Normal load\ (L)} = \frac{2.4}{10}$ = **0.24**

- Wear rate = $\left(\frac{Wear\ Indicator\ reading * Cross\ sectional\ area\ of\ the\ specimen * Density\ of\ the\ specimen}{Sliding\ Distance}\right)$

  = $\left(\frac{0.02 * 78.539 * 0.00212}{376000}\right)$= **8.8 x 10^{-9} mm^3/mm**

IV. RESULTS AND DISCUSSION

4.1 Result Tabulation

The calculated values of wear rate and co-efficient of friction for corresponding sliding distance is tabulated.

Table 3: Wear rate and Co-efficient of Friction

Sl. No.	Proportion	Sliding Distance, mm	Wear rate, mm^3/mm		Co-efficient of Friction	
			Load		Load	
			10 N	20N	10 N	20 N
1	95% PTFE & 5% TiO_2	0.376×10^6	8.8×10^{-9}	8.85×10^{-9}	0.2	0.12
		0.75×10^6	4.4×10^{-9}	4.43×10^{-9}	0.21	0.125
		1.13×10^6	4.41×10^{-9}	4.41×10^{-9}	0.22	0.13
		1.5×10^6	2.21×10^{-9}	2.21×10^{-9}	0.24	0.125
		1.88×10^6	2.61×10^{-9}	1.77×10^{-9}	0.24	0.13
2	90% PTFE & 10% TiO_2	0.376×10^6	8.91×10^{-9}	$- 3.5 \times 10^{-8}$	0.25	0.13
		0.75×10^6	4.47×10^{-9}	$- 1.56 \times 10^{-8}$	0.26	0.115
		1.13×10^6	2.96×10^{-9}	$- 1.03 \times 10^{-8}$	0.21	0.13
		1.5×10^6	2.23×10^{-9}	$- 7.8 \times 10^{-9}$	0.24	0.11
		1.88×10^6	1.76×10^{-9}	$- 8.91 \times 10^{-10}$	0.24	0.11
3	85% PTFE & 15% TiO_2	0.376×10^6	8.82×10^{-9}	$- 5.2 \times 10^{-8}$	0.23	0.12
		0.75×10^6	4.42×10^{-9}	$- 1.32 \times 10^{-8}$	0.22	0.13
		1.13×10^6	$- 1.02 \times 10^{-8}$	$- 8.8 \times 10^{-9}$	0.21	0.115
		1.5×10^6	$- 9.95 \times 10^{-9}$	$- 8.84 \times 10^{-9}$	0.23	0.115
		1.88×10^6	$- 7.05 \times 10^{-9}$	-5.2×10^{-9}	0.24	0.125

4.2 Graphical Representation

- The graphical representation of wear rate for corresponding sliding distance.

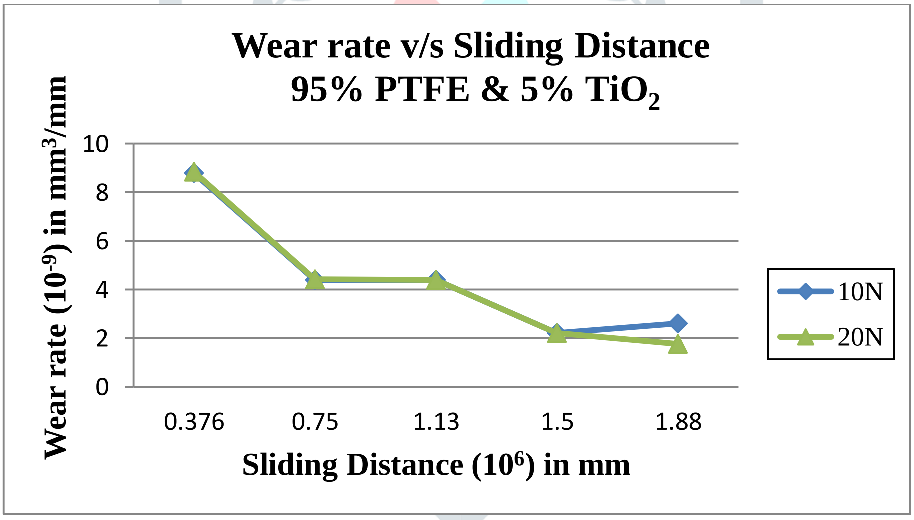

Fig.3 Graph of Wear rate v/s Sliding Distance for 95% PTFE & 5% TiO_2

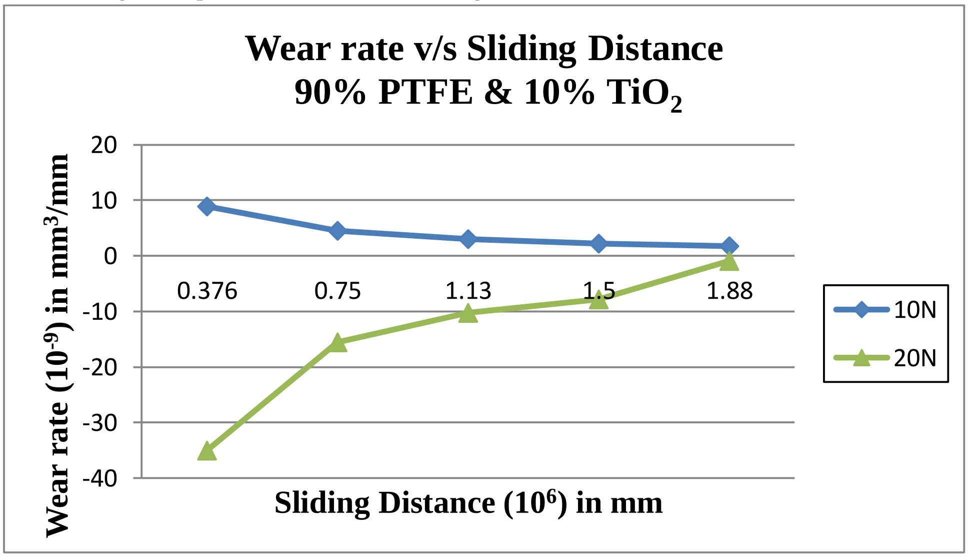

Fig.4 Graph of Wear rate v/s Sliding Distance for 90% PTFE & 10% TiO_2

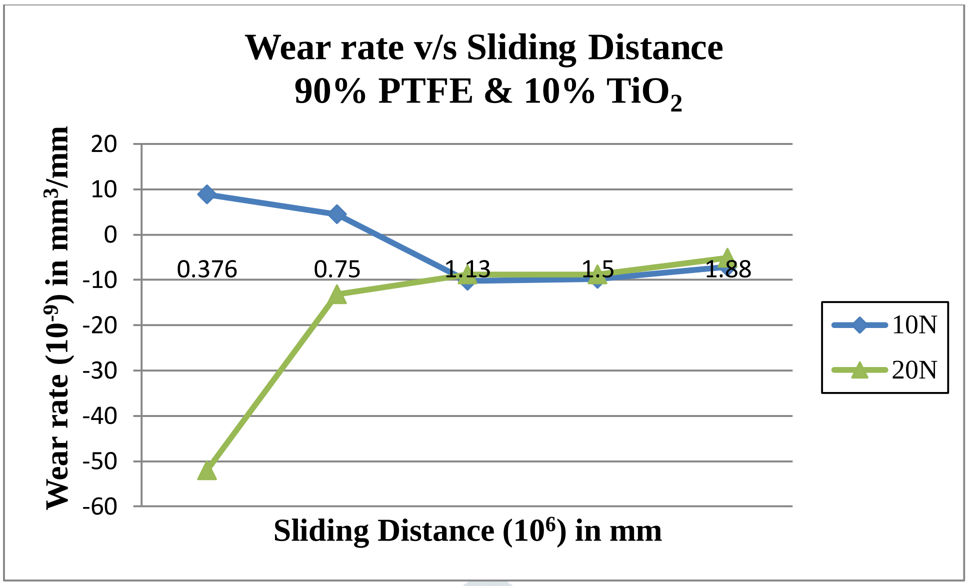

Fig.5 Graph of Wear rate v/s Sliding Distance for 85% PTFE & 15% TiO_2

The Figures 3,4&5 shows the graphical representation of Wear rate and sliding distance for different proportions with constant speed and varying of loads. As it states that among these proportions, the proportion of 85% PTFE & 15% TiO_2 has minimum wear rate.

- The graphical representation of co-efficient of friction for corresponding sliding distance.

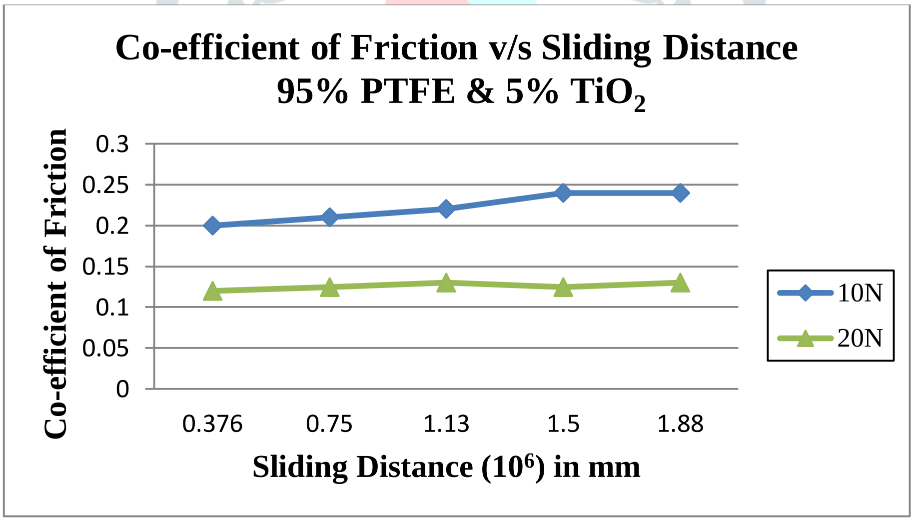

Fig.6 Graph of Co-efficient of Friction v/s Sliding Distance for 95% PTFE & 5% TiO_2

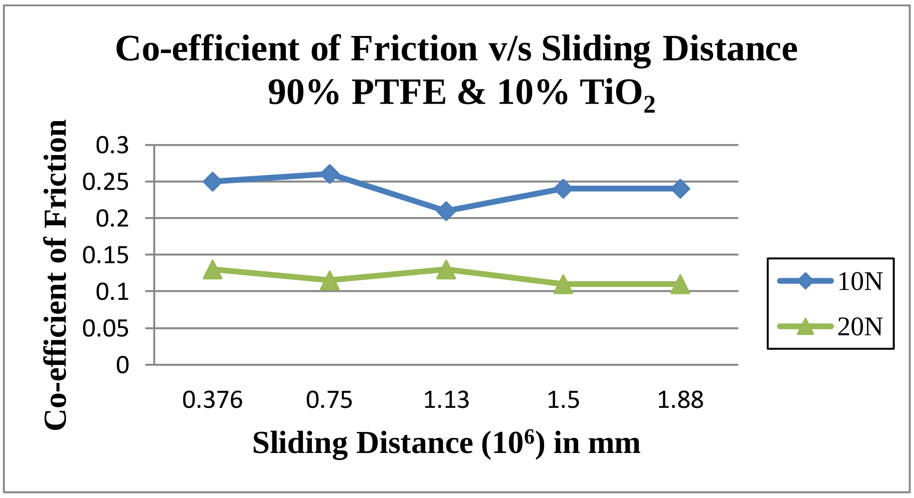

Fig.7 Graph of Co-efficient of Friction v/s Sliding Distance for 90% PTFE & 10% TiO_2

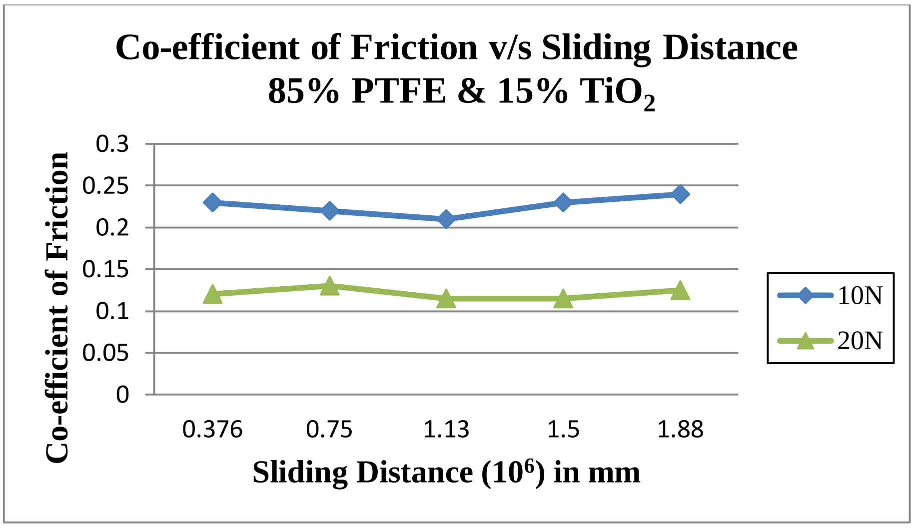

Fig.8 Graph of Co-efficient of Friction v/s Sliding Distance for 85% PTFE & 15% TiO_2

The Figures 6,7&8 shows the graphical representation of co-efficient of friction and sliding distance for different proportions with constant speed and varying of loads. As it states that among these proportions, the proportion of 90% PTFE & 10% TiO_2 has maximum co-efficient of friction.

V. CONCLUSIONS

- The wear rate of composites is in permissible limit. As per our study, the proportion of 95% PTFE & 5% TiO_2 has the maximum and 85% PTFE & 15% TiO_2 has the minimum.

- The co-efficient of friction of composites is acceptable. As per our study, the proportion of 90% PTFE & 10% TiO_2 has the maximum and 95% PTFE &5% TiO_2 has the minimum.

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References

[1] Meigin Shi, F. Miyazawa, S. Tobe, T.A. Stolarski, “The friction and wear properties of PTFE composite- Thermal spray metallic binary coatings”, Material transactions, Vol. 46, No. 1(2005) pp. 84-87.

[2] S.Basavarajappa and G.Chandramohan, “Wear studies on metal matrix composites: A Taguchi Approach”, J. Mater. Sci. Technol. 21 (2005) pp. 845-850.

[3] Deepak D. Bagale, “Wear analysis of PTFE and its composites under dry conditions using design expert”, ME dissertation, SSBT‟s COET, Bambhori, Jalgaon, 2011-12.

[4] Jaydeep Khedkar, Ioan Negulescu and Efstathios I. Meletis, “Sliding wear behavior of PTFE composites”, Wear 252 (2002) pp. 361–369.

[5] H. Unal, A. Mimaroglu, U. Kadıoglu, H. Ekiz, “Sliding friction and wear behaviour of polytetrafluroethylene and its composites under dry conditions”, Materials and Design 25 (2004) pp. 239-245.

[6] V.B.Raka, “Tribological behaviour of PTFE and its composites”, Innovations in Mechanical Engineering (IME‟ 10) (2010) pp.148-155.

[7] D.S.Bajaj, G.J.Vikhe, Y.R.Kharde, “An investigation of tribological behavior of PTFE+ glass fiber against variable surface roughness of counter surface”, Indian Journal of Tribology 3 (2008) pp. 47-54.