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A REVIEW OF THE TRIBOLOGICAL PROPERTIES OF PTFE COMPOSITES FILLED WITH GLASS, GRAPHITE, CARBON OR BRONZE REINFORCEMENT

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Abstract: *Polytetrafluroethylene (PTFE) is currently finding increasing utility due to its unique properties like high chemical resistivity, low coefficient of friction and high temperature stability. However, PTFE exhibits poor wear resistance, especially abrasion. The wear resistance of PTFE can be significantly improved by addition of suitable reinforcement (filler) materials. Among the most common filler materials are glass fibers, graphite, carbon and bronze. In this paper, it is presented a review of tribological properties of composite materials with PTFE matrix and above mentioned filler materials.*

Keywords: *PTFE, composites, glass fibres, graphite, carbon fibres, bronze, friction, wear.*

1. INTRODUCTION

Nowadays, there is very intensive growth in the large scale production of the fibre reinforced polymer composites since they posses certain advantages over the metals. The advantages include lower density, less need for maintenance and lower cost [1]. Polymers and polymers reinforced with fibres are used for producing of various mechanical components, such as gears, cams, wheels, brakes, clutches, bush bearing and seals [2]. Considerable efforts are being made to extend the range of applications. Such use would provide the economical and functional benefits to both manufacturers and consumers. Many researchers have studied the tribological behaviour of polytetrafluroethylene (PTFE). Studies have been conducted with various shapes, sizes, types and compositions of fibres. In general these composites exhibit lower wear and friction when compared to pure PTFE.

The most commonly used reinforcements (fillers) for tribological applications are carbon, graphite, bronze and glass. Generally the fillers improve the wear resistance from 10 to 500 times, depending on the filler type and shape. On the other hand, coefficient of friction of various PTFE composites is strongly dependent on filler crystal structure and improvements are not so significant.

Subject of this paper are composites with PTFE matrix. Filler materials investigated in this paper are glass, graphite, carbon and bronze. Analysed tribological characteristics are coefficient of friction and wear. In most cases, friction and wear tests were carried out on pin-on-disc tribometer at ambient conditions (temperature and humidity). Counterpart material used in the experiments was always harder than composite. In most cases, counterpart material was steel. All tests were carried out at dry sliding conditions. Overall results from all analysed papers are summarized and presented in Table 1.

2. FACTORS AFFECTING POLYMER COMPOSITE WEAR AND FRICTION

There are many factors that affect material tribological properties. For polymer composites the most influential are [6]:

Normal load: In order for a polymer composite to function as a solid lubricant it must be able to support the load, as well as the tangential stresses induced by sliding. At high loads severe wear

Table 1. Overview of the results from the analysed papers (for pure PTFE and its composites at dry sliding conditions)*

Ref.	Test rig**	Type (amount and size) of the filler***	Counterpart material	Load, N (MPa)	Sliding speed, m/s	Sliding distance, m	Coefficient of friction		Specific wear rate, $mm^3/Nm \times 10^{-6}$	
							PTFE	Composites	PTFE	Composites
[7]	Ball-on-disc	1. C particles (18 %; 10 – 25 μm) + Gr flakes (7 %; 25 – 50 μm); 2. E-glass fibres (15 %; 10 × 50 – 75 μm); 3. E-glass fibres (25 %; 10 × 50 – 75 μm)	AISI 440C steel ball (d = 9 mm)	5 (point contact)	0.1	1000	0.11	0.13 – 0.16	950	90 – 700
[8]	Pin-on-disc	1. Glass fibres (17 %); 2. Bronze (25 %); 3. C (35 %)	AISI 440C steel disc	5 – 30 (0.2 – 1.1)	0.32 – 1.28	1152 – 4608	0.13 – 0.79	0.11 – 0.71	476 – 943	6 – 290
[9]	Pin-on-disc	1. Glass particles (25 %; 40 μm); 2. Bronze particles (40 %; 48 μm)	EN 32 hardened steel disc	60 (0.6)	1.5	2500	–	–	app. 567	app. 4.4 – 335
[10]	Pin-on-disc	1. Gr flake (2 %; 10 μm); 2. Gr flake (5 %; 10 μm); 3. Gr flake (10 %; 10 μm)	Stainless steel disc	25 (0.2)	1	8000	0.24	0.20 – 0.26	1650	10 – 190
[11]	Pin-on-disc	1. Bronze (25 %); 2. Bronze (40 %); 3. Bronze (60 %)	AISI 400C steel disc	5 – 200 (0.2 – 7.1)	0.32 – 2	2000	app. 0.12 – 0.22	app. 0.12 – 0.18	1000	1 – 100

* The friction and wear values in the table are approximate and can be used only as a guidance, since the authors in most cases did not presented the results in appropriate way; ** Pin – cylindrically shaped specimen (flat contact); *** C – carbon, Gr – graphite

occur, characterized by brittle fracture or severe plastic deformation. On the other hand, at low loads usually mild wear occur, characterized by the local plastic flow of the thin transfer film and surface layers (decreasing friction), together with delamination wear.

Contact area: The contact area will determine the projected contact stresses. If the load cannot be reduced, one way of reducing stress is to increase the projected contact area. However, if the area of contact becomes too large instead of the material flowing across the counterpart surface, it will have a tendency to build up, forming ridges, which can cause high localized stresses and higher adhesion, thus higher friction and wear. It is important to design a part with correct match up of load and contact area.

Sliding speed: The high sliding speeds can produce high temperatures due to friction heating. This may cause the polymer or the polymer composite additives to degrade. However in some cases higher temperature might be beneficial to the lubricating process. In order to develop a surface shear film and/or a transfer film, the molecular chain must have time to reorient. If one slides too fast over these un-oriented chains, instead of reorienting, they will fracture, leading to the production of large wear particles and high wear. Thus it is important to choose sliding speed for each particular polymer to ensure the optimum performance.

Counterpart topography: If the counterpart material is too rough it can abrade the composite and not allow a shear film or transfer film to form. Therefore, it could be generally accepted that, the smoother the counterpart the lower the wear. This has certain limits, since it is also found that over-polishing tend to remove the counterpart softer matrix material, leaving the harder phases and/or particles protruded above the surface.

Temperature: At lower temperature the friction and wear properties of most polymers are not as exceptional as they are at or above the ambient temperature. At lower temperatures polymers lose their relaxations ability, i.e. the movement of their main molecule chain do not obtains adequate degree of freedom, and thus the polymer does not obtain a great deal of plasticity. High temperatures can affect bonding between the filler material and polymer matrix. They can also affect the lubricating properties of some additives in polymer composite, since these additives might desorbs gases at certain temperature or even decompose.

3. STATE-OF-THE-ART OF PTFE COMPOSITES TRIBOLOGICAL RESEARCHES

Tribological behaviour of PTFE and its composites with filler materials such as carbon particles, graphite flakes and E glass fibres (Table 2) was investigated by Khedkar et al. [7]. Experiments were performed under the normal load of 5 N and sliding speed of 0.1 m/s. They found that the used filler additions increase wear resistance in all composites that were studied. The highest wear resistance was found for composite containing 18 vol. % of carbon and 7 vol. % of graphite (Figure 1). The coefficient of friction values were from 0.11 to 0.16 (Figure 2). This behaviour can be attributed to the presence of hard carbon particles, which are embedded within the matrix and impart additional strength to the composite. Wear testing and SEM analysis showed that three-body abrasion was probably the dominant mode of failure for PTFE + 18 vol. % carbon + 7 vol. % graphite composite.

Table 2. Composition (vol. %) of materials

Designation	Material	Characteristic of filler material
A	Pure PTFE	99 % pure PTFE powder
B	75 % PTFE + 18 % amorphous carbon + 7 % hexagonal graphite	Carbon particles (diameter: 10 – 25 µm); graphite flakes (size: 25 – 50 µm)
C	85 % PTFE + 15 % E-glass	E-glass fibres (diameter: 10 µm; length: 50 – 75 µm)
D	75 % PTFE + 25 % E-glass	

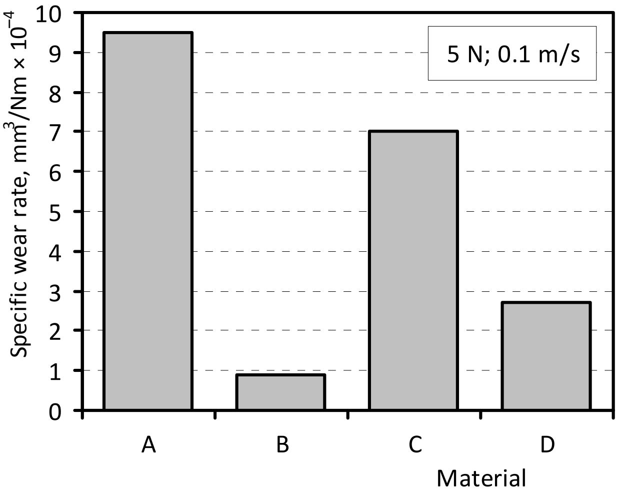

Figure 1. Average specific wear rate of PTFE and PTFE composites (adopted from [7])

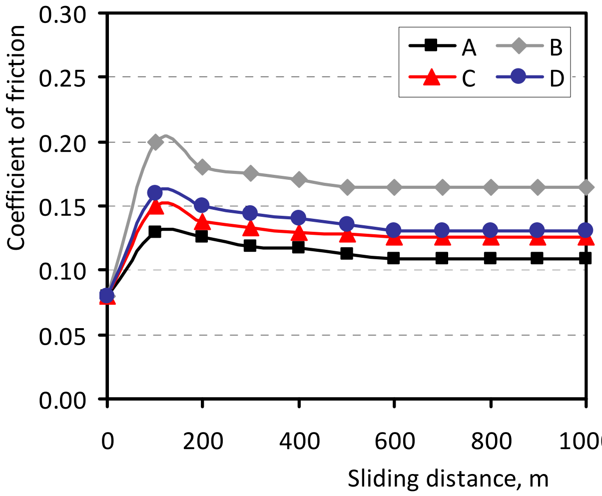

Figure 2. Frictional behaviour of PTFE and PTFE composites (adopted from [7])

Unal et al. [8] studied PTFE composites filled with glass fibres (17 %), bronze (25 %) or carbon (35 %). Experiments were performed under load range from 5 to 30 N (0.18 – 1.06 MPa) and speed range from 0.32 to 1.28 m/s. The results showed that, for pure PTFE and its composites, the coefficient of friction decrease with the increase in load. For the ranges of load and speed used in this investigation, the coefficient of friction showed very little sensitivity to the sliding speed and large sensitivity to the applied load, particularly at high load values. Figure 3 shows that sensitivity for the pure PTFE, but it is quiet similar for composites, as well. Adding glass fibres, bronze and carbon fillers to PTFE were found effective in reducing the wear rate. The maximum reductions in wear rate and coefficient of friction were obtained by PTFE reinforced with 17 % of glass fibres. The specific wear rate for PTFE + 17 % glass fibres was almost two orders of magnitude lower than for pure PTFE. By means of microscopy, it is noticed that the PTFE with glass fibre filler form a good thin and uniform transfer film which have positive influence to the wear rate.

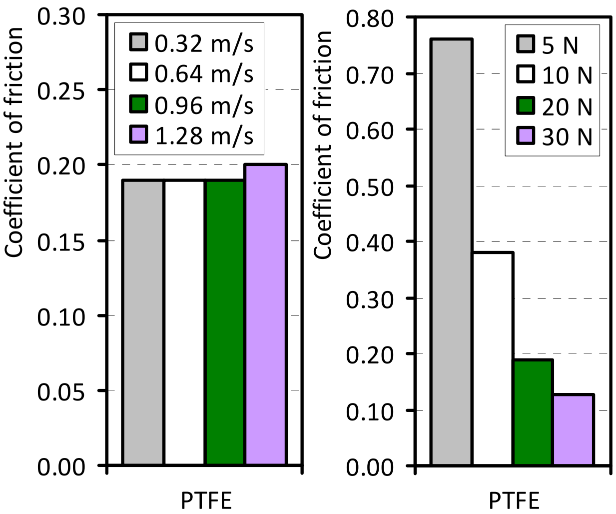

Figure 3. Sensitivity of PTFE coefficient of friction to the sliding speed (for 20 N load) and applied load (for 0.32 m/s speed) (adapted from [8])

A single influence of glass particles (25 vol. %; 40 µm) and bronze particles (40 vol. %; 48 µm) on wear behaviour of PTFE based composites was studied by Mudasar Pasha et al. [9]. The tests were done on a pin-on-disc tribometer with different normal loads (20 – 100 N, i.e. 0.2 – 1 MPa), sliding speeds (1.5 – 5.5 m/s) and distances (500 – 2500 m). The experimental results indicate that the weight loss increases with increasing load and sliding speed (Figure 4). The PTFE + 40 % bronze composite exhibits better wear resistance compare to the others (Figure 5). The transfer film formed on the counterpart surface, sliding against PTFE + 40 % bronze, is smooth, thin and uniform, which indicates that the formation of adhesive strength between the transfer films and the counterpart surface is strong. In the case of the counterpart sliding against the pure PTFE, the transfer film is very thick.

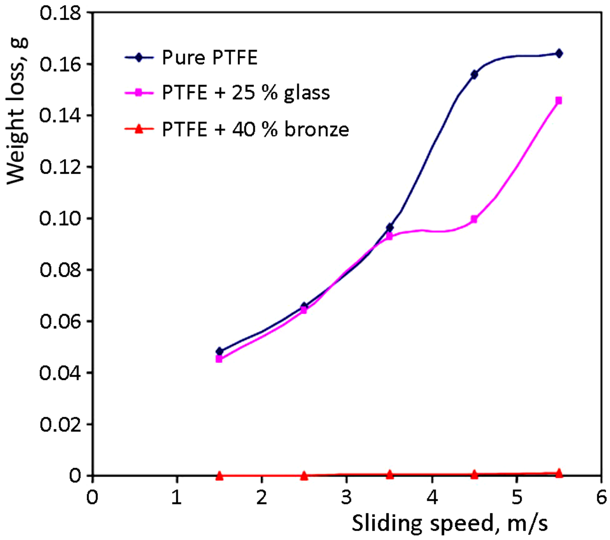

Figure 4. Weight loss vs. sliding speed at constant applied load of 60 N and sliding distance of 1500 m

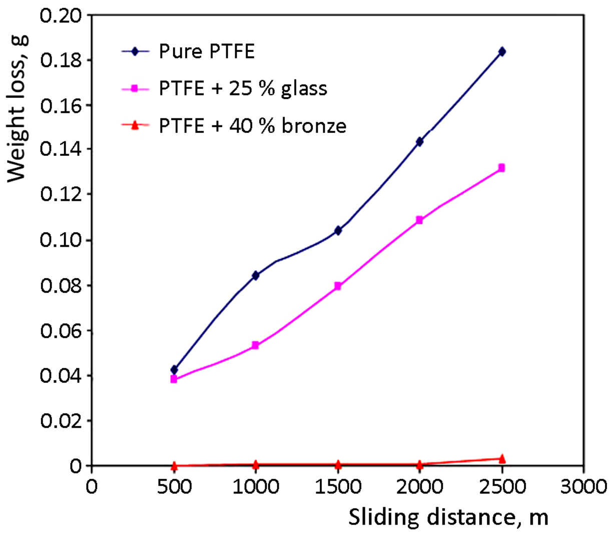

Figure 5. Wear curves of tested materials for 60 N load and speed of 1.5 m/s

Evaluation of the wear rate and coefficient of friction for graphite flake (2, 5 and 10 wt. %; 10 μm) filled PTFE composites were studied by Goyal and Yadav [10]. It was performed on a pin-on-disk tribometer under dry sliding conditions, at sliding speed of 1 m/s and 25 N load (0.19 MPa), during 8000 m. A significant decrease in wear of composites in compare to pure PTFE is noticed. The wear rates of composites with 5 and 10 wt. % of graphite were decreased 22 and 245 times, respectively (Figure 6). This decrease in wear rate is also attributed to the formation of a thin and tenacious transfer film on the counterpart surface.

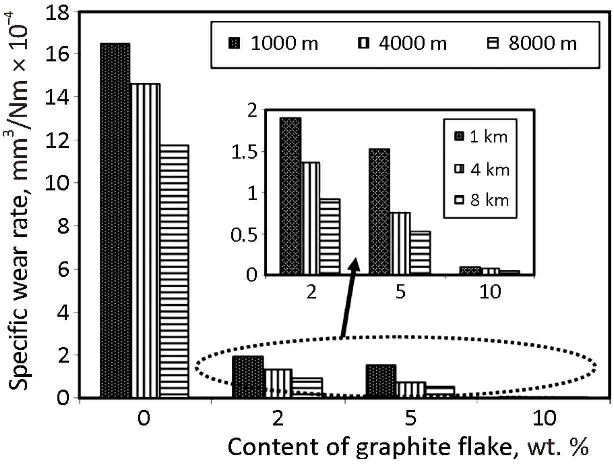

Figure 6. Specific wear rate of PTFE with various content of graphite flakes

Compared to pure PTFE, composites showed stable coefficient of friction (Figure 7). The lowest coefficient of friction was 0.20 for composites with 2 and 5 wt. % of graphite. For composite with 10 wt. % of graphite, the coefficient of friction was slightly higher and close to the value obtained with pure PTFE. Anyway, variations of the coefficient of friction are very small.

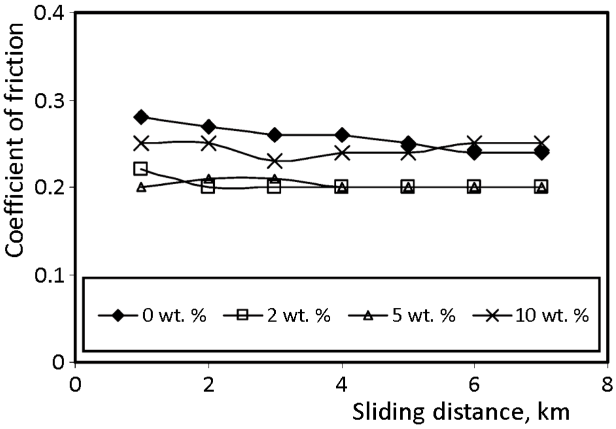

Figure 7. Coefficient of friction with various content of graphite flakes

Unal et al. [11] also studied the friction and wear behaviour of pure PTFE and bronze (25, 40 and 60 %) filled PTFE polymer composites under applied load range from 5 to 200 N (0.18 – 7.07 MPa) and sliding speed range from 0.32 to 2.0 m/s, using a pin-on-disc tribometer. The results showed that bronze filled PTFE composite exhibited lower coefficient of friction (Figure 8 and Figure 9) and higher wear resistance (Figure 10) compared to pure PTFE. The coefficient of friction of both – pure PTFE and bronze filled PTFE composites decreases when the applied load is increased from 5 to 30 N (light condition). Above 30 N the coefficient of friction remains stable.

The PTFE filled with 60 % of bronze showed higher wear resistance than pure PTFE. This behaviour can be attributed to the presence of bronze, which is embedded within the matrix material and impart additional strength to the composite. The applied load has shown more influence on the wear behaviour of PTFE and PTFE composite than the sliding speed.

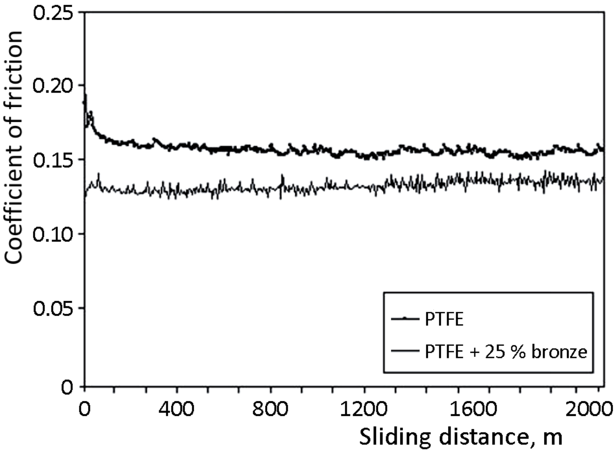

Figure 8. Variation of coefficient of friction with sliding distance (normal load: 50 N; sliding speed: 1.5 m/s)

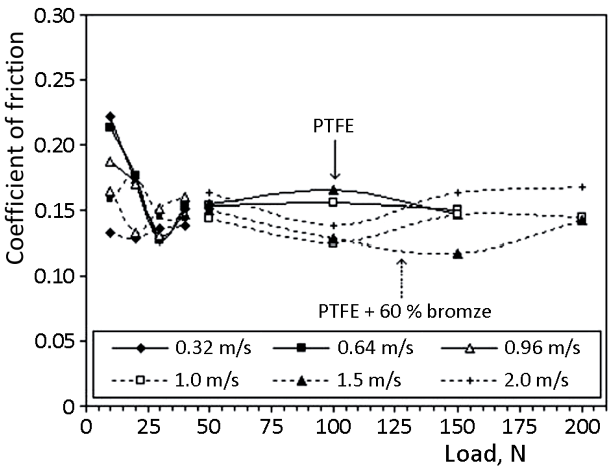

Figure 9. Variation of coefficient of friction with applied load and sliding speed for PTFE and PTFE + 60 % bronze composite

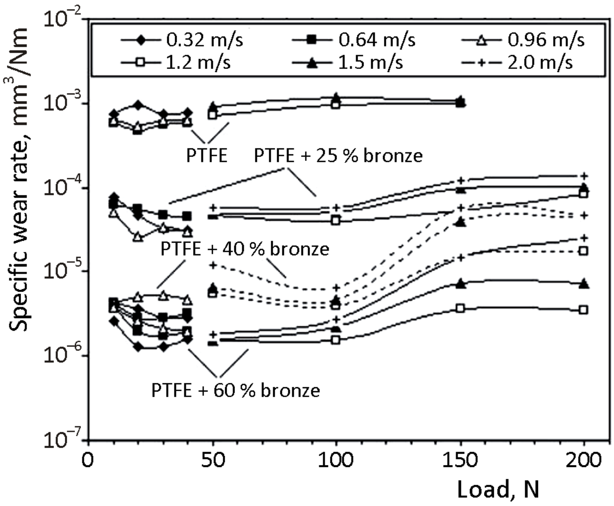

Figure 10. Variation of specific wear rate with applied load and sliding speed for PTFE and PTFE composites

In addition, it could be interested to present a diagram that shows dependence of specific wear rate on wt. % of filler materials (Figure 11) [12]. Although there are filler materials which are not subject of this paper, it might be interesting to compare specific wear rate for different polymer composites.

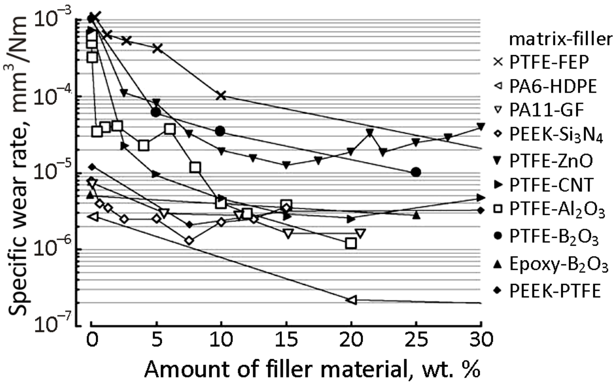

Figure 11. Specific wear rate vs. wt. % of filler material for various polymer composites (FEP – fluorinated ethylene propylene; PA6 – polyamide 6; HDPE – high-density polyethylene; PA11 – polyamide 11; GF – glass fibre; PEEK – polyether ether ketone; CNT – carbon nanotube)

4. CONCLUSION

In this review paper, the tribological behaviour of PTFE composites, filled with glass fibres, graphite flakes, carbon, bronze or combination of mentioned filler materials has been analysed.

It is noticed that coefficient of friction usually remains in the range from 0.1 to 0.3. When pure PTFE is compared with PTFE composites, there is only slight decrease in coefficient of friction with almost all analysed composites.

On the other hand, regarding to wear of pure PTFE and its composites, influence of filler materials is quiet significant. Presence of filler material can increase wear resistance (decrease wear) up to 2 to 3 orders of magnitude. However, it can be concluded that the best results, regarding to wear resistance, were obtained by PTFE + bronze composites. Nevertheless, if we compare it to the other composites, that difference is not that significant, i.e. similar wear resistance can be obtained with appropriate amount of other mentioned filler materials.

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REFERENCES

[1] W. Brostow, V. Kovačević, D. Vrsaljko, J. Whitworth: *Tribology of polymers and polymer-based composites*, Journal of Materials Education 32, pp. 273-290, 2010.

[2] K. Friedrich, P. Reinicke: *Friction and wear of polymer-based composites*, Mechanics of Composite Materials 34, pp. 503-514, 1998.

[3] W.A. Glaeser: *Materials for Tribology*, Elsevier, Amsterdam, 1992.

[4] N.K. Myshkin, A.Ya. Grigoriev, V.L. Basiniuk, A.I. Mardasevich, V.G. Kudritsky, I.N. Kavaliova: *Equipments and materials for tribotesting in open space on International Space Lab*, Tribology in Industry 33, pp. 43-46, 2011.

[5] I. Zidaru, R.G. Ripeanu, I. Tudor, A.C. Drumeanu: *Research regarding the improvements of tribological behavior in three cone bits bearings*, FME Transactions 37, pp. 99-102, 2009.

[6] P.V. Kulkarni, N.K. Chapkhhane: *Development and testing of PTFE based composite bearing material for turbine pump*, International Journal of Engineering and Advanced Technology (IJEAT) 1, pp. 15-20, 2012.

[7] J. Khedkar, I. Negulescu, E.I. Meletis: *Sliding wear behavior of PTFE composites*, Wear 252, pp. 361-369, 2002.

[8] H. Unal, A. Mimaroglu, U. Kadıoglu, H. Ekiz: *Sliding friction and wear behaviour of polytetrafluoroethylene and its composites under dry conditions*, Materials & Design 25, pp. 239-245, 2004.

[9] B.A. Mudasar Pasha, D. Abdul Budan, S. Basavarajappa, S. Manjunath Yadav, B.A. Nizamuddin: *Dry sliding wear behaviour of PTFE filled with glass and bronze particles*, Tribology – Materials, Surfaces & Interfaces 5, pp. 59-64, 2011.

[10] R.K. Goyal, M. Yadav: *Study on wear and friction behavior of graphite flake-filled PTFE composites*, Journal of Applied Polymer Science 127, pp. 3186-3191, 2013.

[11] H. Unal, E. Kurtulus, A. Mimaroglu, M. Aydin: *Tribological performance of PTFE bronze filled composites under wide range of application conditions*, Journal of Reinforced Plastics and Composites 29, pp. 2184-2191, 2010.

[12] D.L. Burris, W.G. Sawyer: *A low friction and ultra low wear rate PEEK/PTFE composite*, Wear 261, pp. 410-418, 2006.