Vol. 37, No. 1 (2015) 88-96

Tribology in Industry

www.tribology.fink.rs

RESEARCH

# Estimation of Wear Behavior of Polyphenylene Sulphide Composites Reinforced with Glass/Carbon Fibers, Graphite and Polytetrafluoroethylene, by Pin-on-disc Test

M.A.C. Besnea[a], D.C. Trufasu[a], G. Andrei[a], M. Bastiurea[a], M.S. Rodeanu[a]

[a] *"Dunarea de Jos" University of Galati, Romania.*

Keywords:

*Polyphenylene sulphide*
*Glass/carbon fiber*
*Polytetrafluorethylene*
*Wear*

Corresponding author:

*Gabriel Andrei*
*"Dunarea de Jos" University of Galati, Romania.*
*Email: gabriel.andrei@ugal.ro*

A B S T R A C T

*Wear behavior of polyphenylene sulphide composites was investigated according to load and test speed. Two types of materials were studied: first, with 40 wt% glass fiber, and second, with 10 wt% carbon fiber, 10 wt% graphite and 10 wt%. Tribological tests were performed on the universal tribometer UMT-2, using a pin-on-disc device. The friction coefficient and wear rate for the composites were analyzed. As a result of experimental tests, it was established that polymer composite with polyphenylene sulphide matrix, carbon fibers, graphite and polytetrafluorethylene exhibit good wear behavior under operating conditions.*



## 1. INTRODUCTION

Generally, certain polymers feature good mechanical behavior which could be improved by mixing them with various types of materials [1-4]. Polyphenylene sulphide (PPS) is a thermoplastic semi-crystalline polymer from the category of advanced plastics used as polymer matrix for composite materials. Although PPS has low viscosity and considerable fragility, when mixed with various reinforcement materials often exhibit remarkable physical, chemical and mechanical properties. PPS based composites, reinforced with glass fiber [5,6] and carbon fiber [7,8] are thoroughly studied due to their good potential to become more suitable for mechanical and tribological applications [9,10]. Moreover, a proper dispersion of additives into the polymer matrix [11-13] could enhance the mechanical, thermal [14] and electrical properties [15]. Considering that lately, in the scientific literature, data on the characterization of PPS composites are increasing, this study aims to investigate the tribological behavior of these polymer composites.

## 2. MATERIALS AND METHODS

Pin-on-disc wear tests were conducted on the universal tribometer UMT-2 (CETR®, USA), where the pin is held in permanent contact with



*Paper presented at the International Tribology Conference BALKANTRIB'14*

a rotating disc. The cylindrical pin, with 6.25 mm diameter and 25 mm height, is perpendicularly placed to the surface of the disc, with 96 mm diameter and 6 mm thickness that is horizontally positioned. All the discs were manufactured from polymer composite while pins were made from steel (41MoCr11, HRC 55-58). Before being tested, both pin and disc were cleaned with tension active agent. Each test was repeated five times on a new pair of pin and disc, at the same parameters. The tests were carried out under dry sliding regime, at ambient temperature, along 10000 m sliding distance. Three values of sliding speed were used, 0.25, 0.5 and 0.75 m/s, and also three values of contact pressure between pin and disc were applied, i.e. 0.25, 0.5, 0.75 MPa (Table 1).

**Tabel 1.** Test parameters.

| **Sliding speed** ***v*** **[m/s] ± 5 %** | **Contact pressure** ***p*** **[MPa] ± 5 %** | **Contact load** $F_N$ **[N] ± 5 %** | **Test duration [h,min]** |
|---|---|---|---|
| 0.25 | 0.25 | 5.41 | 11 h 7 min |
| 0.50 | 0.50 | 10.82 | 5 h 33 min |
| 0.75 | 0.75 | 16.23 | 3 h 42 min |

The coefficient of friction and wear rate were determined for two types of composites with PPS matrix: PPS GF 40 (PPS + 40 % glass fibers) and PPS PVX (PPS + 10 wt% PTFE+ 10 wt% carbon fibers + 10 wt% graphite). All the PPS composites were produced and supplied by Ensinger GmbH (Germany). A precision analytical balance, type Denver Instrument PK-352, was used to weigh the specimens, pins and discs, before and after test. All the tests were thermaly monitored by an infrared thermal camera of high resolution, type FLIR ThermaCAM™ QuickView. In order to investigate the microgeometry of the worn surfaces, use was made of a 3D surface stylus profilometer, type 3D PRO 500. Optical (Neophon 2 apparatus) images of the specimens were obtained for the subsequent morfological analysis.

## 3. RESULTS AND DISCUSSIONS

### 3.1 Wear of PPS PVX composite

Basically, in case of PPS PVX composite tested at the speed of 0.75 m/s, the variation of coefficient of friction meets the four known stages: increase, reaching maximum value, decrease and steady-state phase. The results show that the coefficient of friction increases almost monotonically and differently, according to the value of the contact pressure, up to 2000 - 3000 m (Fig. 1). Then, the maximum values are recorded between 2000-3000 m and 3000-4000 m. The decrease in coefficient of friction occurs in the interval 3000-4000m up to 4000-5000 m, after which the values stabilize at about 0.13-0.17, depending on the domain of contact pressure.

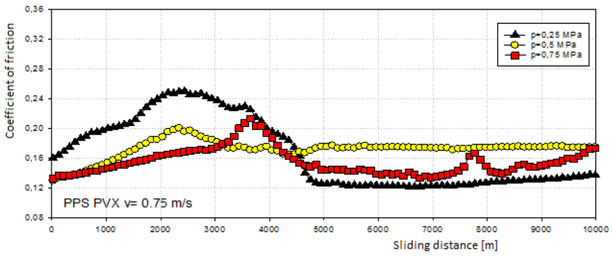



**Fig. 1** Coefficient of friction in case of PPS PVX composite, for test speed v = 0.75 m/s.

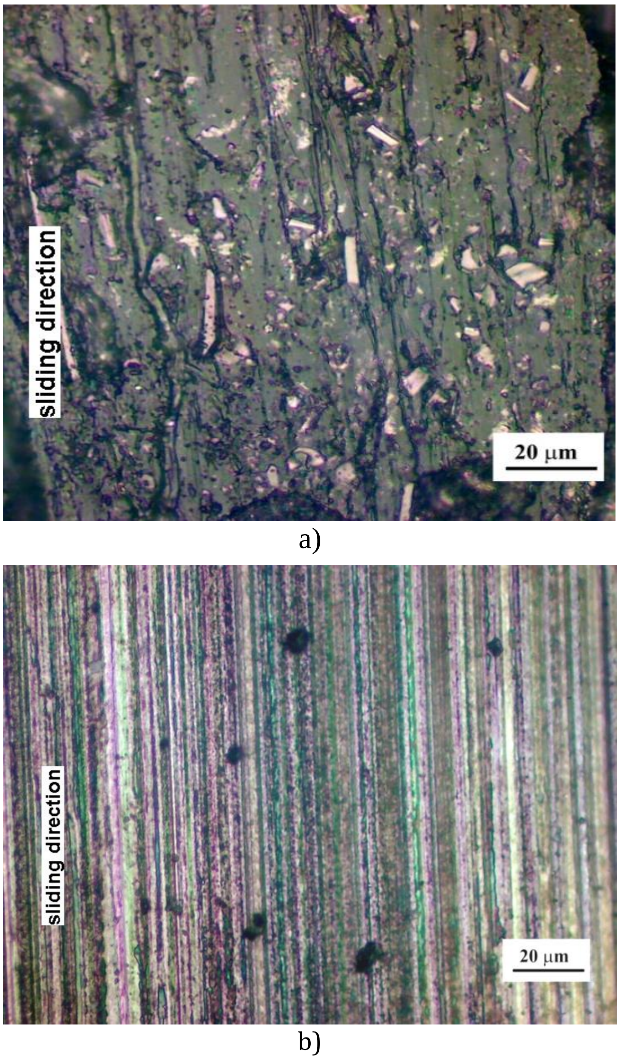



**Fig. 2.** Optical microscopy images of disc and pin worn surfaces (v = 0.75 m/s, p = 0.5 MPa); a) surface of PPS PVX disc; b) surface of steel pin.

The morphological analysis reveals the occurrence of adhesion wear on worn surface, which is specific to the thermoplastic polymers (Fig. 2). It is obvious that small values of the coefficient of friction are determined by the presence of graphite and PTFE in the composite. In the first two stages, the growth of the coefficient of friction is due to the process of run-in of the surfaces in contact. In the first part of the test, an increase in temperature and the formation of a polymeric transfer film can be noticed, from the disc surface to the steel pin.

Transfer film is formed by joining and by blocking particles of polymer (PTFE and PPS) between the asperities on the pin surface. Optical microscopy images of worn disc surface reveal the orientation of polymer texture in sliding direction and also wear traces and transfer particles on the pin surface (Fig. 2).

As regards PPS PVX composite, for contact pressure of 0.25 MPa, the study of the friction as a function of sliding speed confirms the same trend in the coefficient of friction and highlights the same four steps discussed above (Fig. 3).

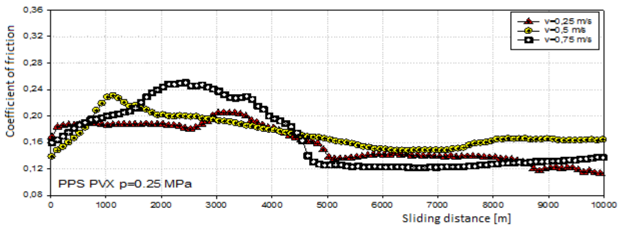



**Fig. 3.** Coefficient of friction in case of PPS PVX composite, for contact pressure p = 0.25 MPa.

The run-in takes place up to about 2000 m and steady-state phase of the friction occurs after 5000 m. The intensity of wear is influenced by the formation of a transfer film of polymer material (PPS / PTFE) and graphite [16-18] which adhere to the contact surface of the steel pin. Meanwhile, on the wear traces, structural changes occur under the influence of contact pressure and sliding velocity, which decrease the friction and the intensity of wear. However, during stabilized stage of the test, oscillations of the coefficient of friction can take place, caused by the local breaking and recovering of the transfer film.

Similar to graphite, PTFE has shown favorable tribological performance as solid lubricant [19-22] and facilitates the sliding of the pin on disc. During the test, under the action of loading, PTFE particles undergo a cyclic process of rolling that contribute to the formation of an interface film which, together with graphite particles, cause the decrease and stabilization of the wear. At the same time, particles of wear are driven by the disc movement on the contact trace and they cause the interface layer to change.

Also, as indicated (Fig. 2b), graphite and polymer particles adhere to the pin surface through the roughness and, in this way, influence the intensity of wear. A careful observation of the wear traces in correlation with the graph of the coefficient of friction reveals that the oscillations recorded during the test are due to local tearing /remaking of transfer film at the contact interface.

### 3.2 Wear of PPS GF40 composite

In case of the composite PPS GF 40 (Fig. 4), the coefficient of friction is generally higher compared to that of PPS PVC composite (Fig. 1).

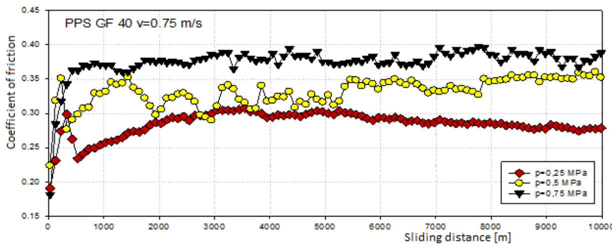



**Fig. 4.** Coefficient of friction in case of PPS GF40 composite, for test speed v = 0.75 m/s.

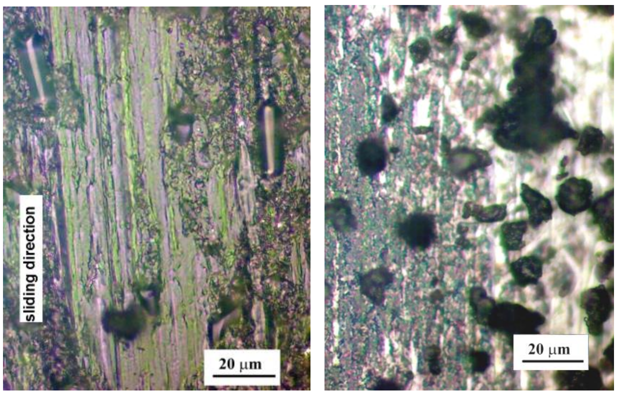



**Fig. 5.** Images by optical microscopy, for p=0.5 MPa and v=0.5 m/s; a) worn surface of disc made from PPS GF40; b) worn surface of steel pin.

It was clearly observed that the highest value of the coefficient of friction is obtained for the pressure of 0.75 MPa, at *v* = 0.75 m/s. The run-in period is much smaller, up to 500 m. Steady-state phase of the friction and wear occurs rapidly, after 3000 m. Increased contact pressure causes a corresponding increase in the value of the friction coefficient. Here, the mechanism of wear is abrasive and in a lesser extent adhesive, due to the presence of glass fibers that are broken during the test and exercise the abrasive action. Thus it happens that the steel pin surface is scratched and a material loss takes place (Fig. 5).

For $p$ = 0.75 MPa, there is no stabilization of the coefficient of friction, only a change of its value in the range of 0.32 to 0.36. The cyclic increase and decrease of the friction coefficient can be explained by the formation of wear particles which tend to be eliminated from contact. When the sliding speed is $v$ = 0.75 m/s, the stabilized values of the coefficient of friction are in the values range from 0.28 up to 0.40, for all the three contact pressure applied during the tests.

At high sliding speed (v = 0.75 m/s), PPS GF40 composite has shown a strong abrasive action with a high coefficient of friction and significantly wear of the pin, characterized by scratches and micro cracks on surface. For $p$ = 0.50 MPa, the friction coefficient has a slow upward trend with values fluctuating at irregular intervals of time. These variations are due to the random distribution of glass fibers in the surface layer and the formation of local clusters. On the sliding traces, oriented glass fibers are visible on the surface, due to the detachment of polymer particles which adhere to the surface of the steel pin.

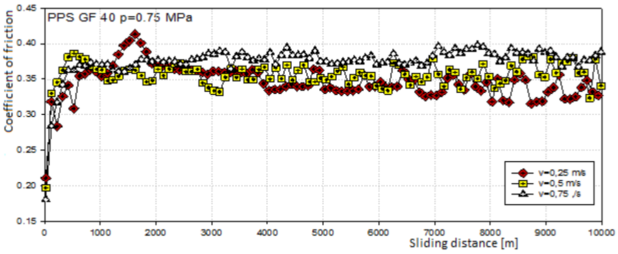



**Fig. 6.** Coefficient of friction in case of PPS GF40 composite, for contact pressure p = 0.75 MPa.

The influence of the test speed, in the case of PPS GF40 composite, at a contact pressure of 0.75 MPa, is shown in Fig. 6, where it can be seen that the coefficient of friction is proportional to the sliding speed. In this case, except for the speed of 0.25 m/s, the period of run-in ends at about 1000 m, and the steady-state phase of friction occurs at 2000 m.

### 3.3. Correlation between temperature and coefficient of friction

Pin-on-disc tests performed on the two types of polymer composite were continuously monitored by infrared thermography in order to prevent excessive heating of materials, device seizing and tribometer damage. The thermal regime of the test is influenced by the type of materials in contact, surface quality, test parameters and the dominant type of wear. In the present study, the materials tested have different composition, although the same polymer matrix (PPS). In the first case, the composite PPS PVC contains 10 wt% carbon fiber, 10 wt% PTFE and 10 wt% graphite. Due to the anti-friction properties of graphite and PTFE, both wear and thermal regime will be of relatively reduced intensity. As for composite PPS GF40 with 40 wt% glass fibers, it was noticed a dominant abrasive wear, higher values of coefficient of friction and temperature.

Infrared thermal camera, FLIR ThermaCAM™ QuickView, was used to record thermal field over three points on the disc. The first point was placed after the contact point (AR01-Tuc), the second recording point was even the contact point (AR02-Tc), and the third point was placed in opposite direction (AR03-Tdc), as shown in Fig. 7.

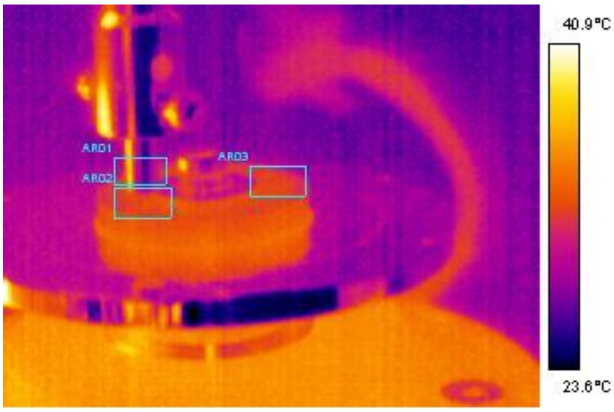



**Fig. 7.** Infrared image of the experimental setup.

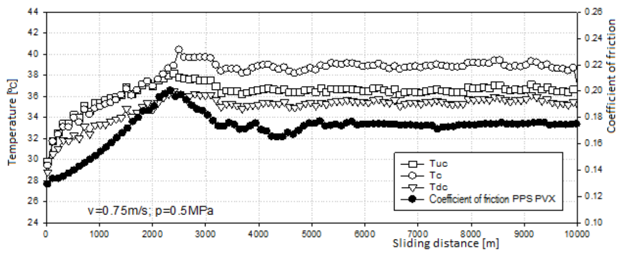



**Fig. 8.** Correlation temperature-coefficient of friction for PPS PVX (v = 0.75 m/s, p=0.75 MPa).

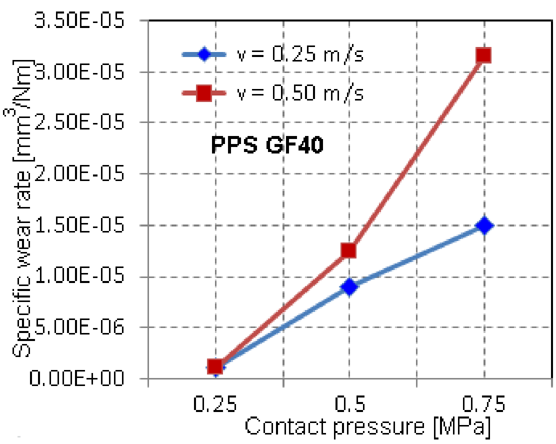
The Figure 8 shows graphically the influence of contact pressure on thermal field for the three measurement points and the correlation temperature-coefficient of friction, at the speed of test $v$ = 0.75 m/s, along the sliding distance. It can be noticed that the maximum temperature value was recorded in the second stage of the test, at the end of the run-in period, when the coefficient of friction reach maximum value.

### 3.4 Wear rate

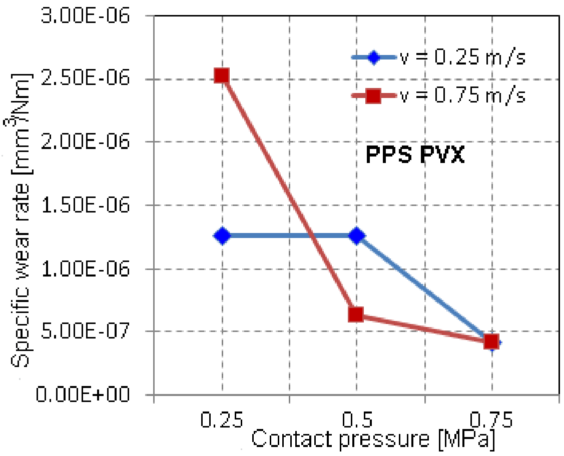
In case of polymer composites, recent studies report the decrease in specific wear rate, by using various types of fillers mixed with the matrix [23-26]. Specific wear rate $W_S$ [mm³/Nm], for the composite disc, was calculated by the following equation:

$$W_S = \frac{\Delta m}{\rho\, d\, F_N}\,. \tag{1}$$

where $\Delta m = m_i - m_f$ is the mass loss of the disc [g], $m_i$ and $m_f$ – initial respectively final mass of the disc [g], $\rho$ – density of the disc [g/mm³], $d$ – sliding distance [m], $F_N$ – contact load [N]. The results show that, in case of composite PPS GF40, the specific wear rate is significantly higher than specific wear rate of composite PPS PVC (Figs. 9 and 10). When the contact pressure increases, the specific wear rate increases for the PPSGF40 composite and decreases for PPS PVX composite (Fig. 9). This is explained by the different types of dominant wear that occur in the two cases: abrasive for PPS GF40 composite and adhesive for PPS PVX composite.



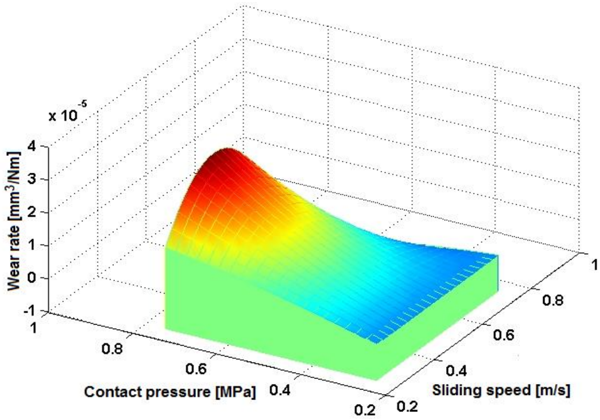
a)



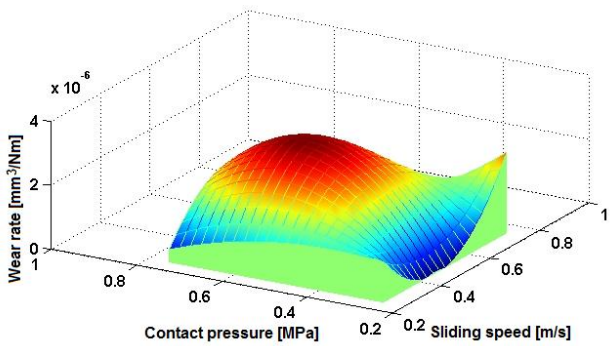
b)

**Fig. 9.** Specific wear rate depending on contact pressure; a) PPS GF40; b) PPS PVX .

Furthermore, when the disc is made from PPS PVC, the contact pressure causes the formation of anti-friction film of PTFE and graphite particles, which reduces the intensity of wear (Figs. 9 and 10).

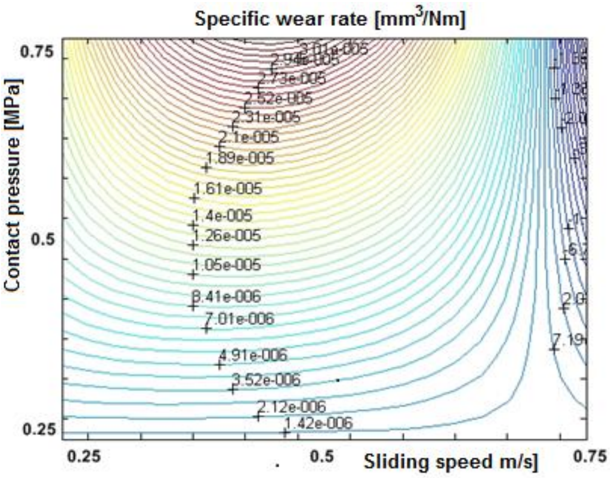


a)

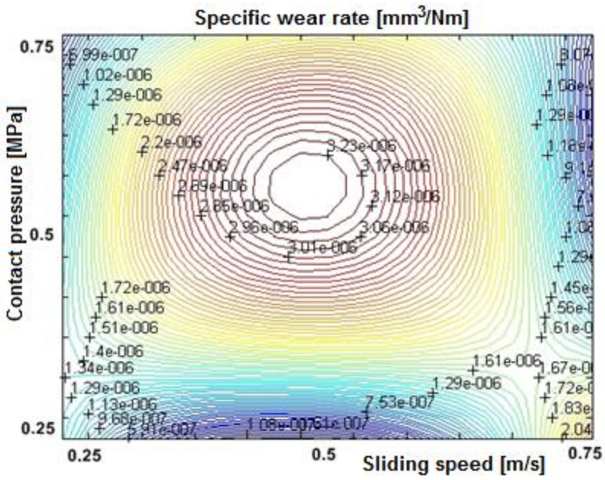


b)

**Fig. 10.** 3D graphs of specific wear rate after pin-on-disc test; a) PPS GF 40; b) PPS PVX.

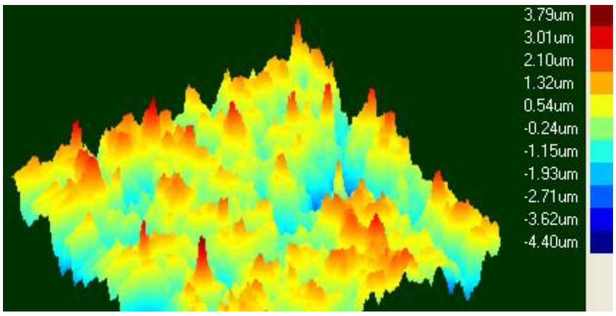



a)

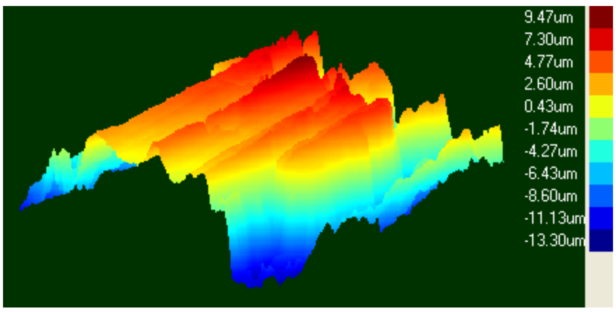



b)

**Fig. 11.** Contour plots of specific wear rate; a) PPS GF40; b) PPS PVX.

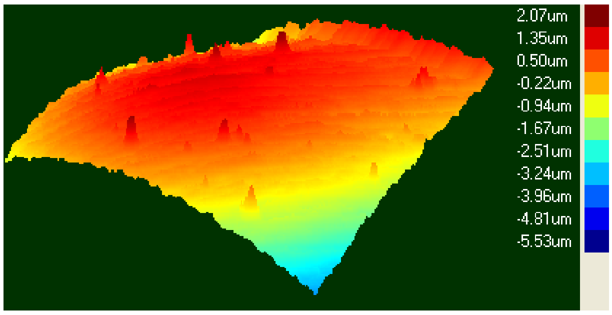



*p*= 0 MPa, *v*= 0 m/s

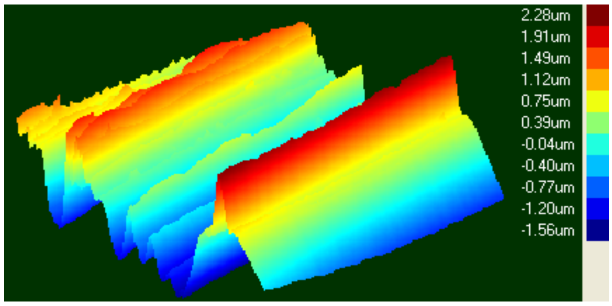



*p*= 0.75 MPa, *v*= 0,75 m/s

a)



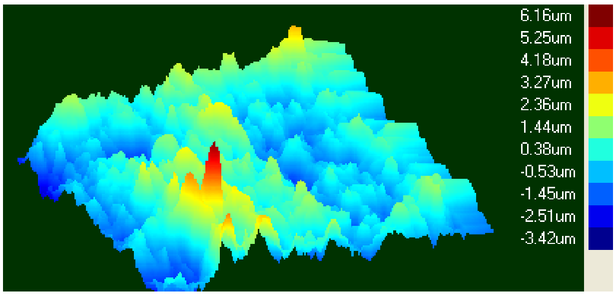

*p*= 0 MPa, *v*= 0 m/s



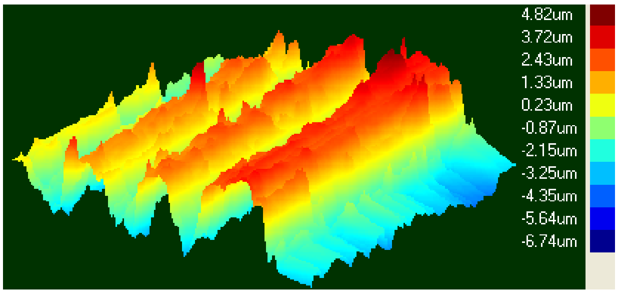

*p*= 0.75 MPa, *v*= 0,75 m/s

b)

**Fig. 12.** 3D isochromatic virtual images of initial (p= 0 MPa, v= 0 m/s), respectively worn surfaces (p= 0.75 MPa, v= 0.75 m/s); a) PPS GF40 disc;b) steel pin.

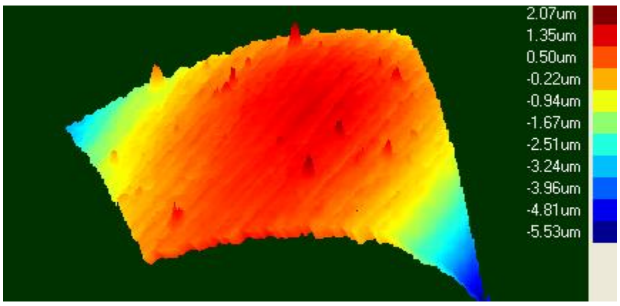



*p*= 0 MPa, *v*= 0 m/s

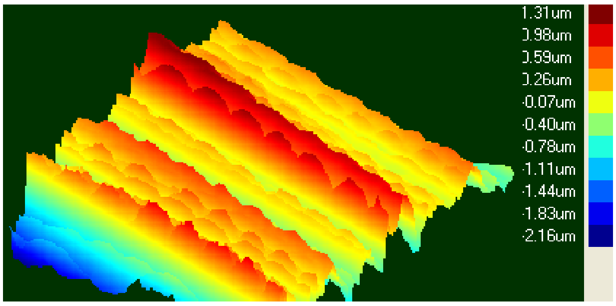



*p*= 0.50 MPa, *v*= 0,50 m/s

a)




*p*= 0 MPa, *v*= 0 m/s




*p*= 0.50 MPa, *v*= 0.50 m/s
b)

**Fig. 13.** 3D isochromatic virtual images of initial (p= 0 MPa, v= 0 m/s), respectively worn surfaces (p= 0.75 MPa, v= 0.75 m/s); a) PPS PVX disc; b) steel pin.

The steady-state phase of the friction process between pin and disc is facilitated by the formation of PTFE and graphite particles which reduce the intensity of wear during the test. The contour plots resulted from 3D graph of specific wear rate (Fig. 11) allows locating the critical values of wear, depending on the testing regime (sliding speed and contact pressure). Investigation of initial, respectively worn surface, by 3D profilometry allowed noticing the traces of wear both on disc and pin surfaces, as shown in Figures 12 and 13. The values of micro geometry parameter reveal that during the test a flattening of the highest peaks occurred along with the formation of deep grooves parallel to the sliding direction.

## 4. CONCLUSION

After the pin-on-disc tests, we noticed that friction coefficient and specific wear rate values are lower for PPS PVX composite, compared to those of PPS GF40 composite. These results are explained by the different content of the two composites, which consequently exhibit different dominant types of wear. In case of PPS PVC composite, the particles of graphite and PTFE produce the decrease in friction between the contacting surfaces, adhesion wear is dominant, and the formation of a transfer film occurs. The transfer film, consisting of particles of PTFE, PPS and graphite, has an important effect on the tribological behavior of the composite PPS PVX, along the sliding distance. After the run-in period, the coefficient of friction stabilizes in the range of 0.13-0.17. During the stabilized stage of the test, oscillations of the coefficient of friction can occur, caused by the local breaking and recovering of the transfer film. Optical microscopy and SEM images revealed structural changes on the surface of the wear traces. We noticed wear particles adhering to the worn surface of the pin and disc.

On the contrary, the glass fibers from composite PPS GF40 exercise a dominant abrasive action, as shown by the high values of the coefficient of friction. The results obtained for composite PPS GF 40 show that the increase in sliding speed has a major influence on the tribological behavior compared to the increase in contact pressure applied during pin-on-disc test. PPS GF40 composite shows a strong abrasive wear causing a high coefficient of friction and scratches / micro cracks on the surface of the pin, due to the broken fragments of glass fiber. Thus, the surface of steel pin is scratched and undergoes a material loss. On the stabilized portion of the test, the values of the coefficient of friction are in the range of 0.28 - 0.40, that is significantly higher than those of PPS PVX composite.

Specific wear rate of PPS PVC composite is about one order of magnitude smaller compared to that of composite PPS GF 40. When the contact pressure increases, the specific wear rate increases for the PPSGF40 composite, and decreases for PPS PVX composite. When testing PPS GF40 composite, partial loss of material from the steel pin could adhere on the wear trace of the disc. However, we could notice a mutual transfer of material between disk and pin, which has effect on the specific wear rate.

Thermographic monitoring of the contact between pin and disc, for the duration of the tests, showed that the temperature recorded near the contact point does not reach the softening temperature of the composites. Finally, the results provide data and recommendation for possible tribological application of PPS PVX and PPS GF40 composites.

**Acknowledgement**

The work has been funded by the Sectorial Operational Program Human Resources Development 2007-2013 of the Ministry of European Funds through the Financial Agreement POSDRU/159/1.5/S/132397 ExcelDOC.

## REFERENCES


[1] L. Deleanu, I.G. Birsan, G. Andrei, M. Ripa and P. Badea, 'PTFE Composites and Water Lubrication: 1.Tribological Characterization', *Materiale Plastice*, vol. 44, no.1, pp. 66-72, 2007.

[2] L. Deleanu, G. Andrei, L. Maftei, C. Georgescu and A. Cantaragiu, 'Wear maps for a class of composites with polyamide matrix and glass spheres', *Journal of the Balkan Tribological Association*, vol. 17, no. 3, pp. 371–379, 2011.

[3] G. Andrei, D. Dima, I.G. Birsan, L. Andrei and A. Circiumaru, 'Effect of Ferrite Particles on Mechanical Behaviour of Glass Fibers Reinforced Polymer Composite', *Materiale Plastice*, vol. 46, no. 3, pp. 284-287, 2009.

[4] G. Andrei, D. Dima and L. Andrei, 'Lightweight magnetic composites for aircraft applications', *Journal of Optoelectronics and Advanced Materials*, vol. 8, no. 2, pp. 726-730, 2006.

[5] H. Yasuda, Y. Chiba and M. Ishikawa, 'Effect of the glass fiber length on the mechanical properties of long glass fiber reinforced polyphenylene sulfide', *Journal of Polymer Engineering*, vol. 31, no. 5, pp. 427–434, 2011.

[6] A.P. Costa , E.C. Botelho and L.C. Pardini: 'Influence of environmental conditioning on the shear behavior of poly(phenylene sulfide)/glass fiber composites', *Journal of Applied Polymer Science*, vol. 118, no. 1, pp. 180-187, 2010.

[7] K. Zhang, G. Zhang , B. Liu , X. Wang , S. Long and J. Yang, 'Effect of aminated polyphenylene sulfide on the mechanical properties of short carbon fiber reinforced polyphenylene sulfide composites', *Composites Science and Technology*, vol. 98, pp. 57-63, 2014.

[8] P. Carnevale, S. Rasool and H.E.N. Bersee, 'Fibre-matrix interfaces in carbon fibre reinforced PPS composites: Damage initiation and propagation in tensile tests', *Composite Interfaces*, vol. 21, no. 4, pp. 337-352, 2014.

[9] L. Jian and S. Tao, 'The mechanical and tribological properties of CF/PPS composite filled with PA6', *Journal of Thermoplastic Composite Materials*, vol. 27, no 5. pp. 594-602, 2014.

[10] S. Zhou, Q. Zhang, C. Wu and J. Huang, 'Effect of carbon fiber reinforcement on the mechanical and tribological properties of polyamide 6/polyphenylene sulfide composites', *Materials and Design*, vol. 44, pp. 493-499, 2013.

[11] D. Dima and G. Andrei, 'Investigation of the Effect of $Fe_3O_4$ Particles on the Interface of Gf-Pr-Fa Magnetic Composite', *Materialwissenschaft und Werkstofftechnik*, vol. 34, no. 4, pp. 349-353, 2003.

[12] D. Dima, M. Murarescu and G. Andrei, 'Dispersion of carbon nanotubes coated with iron (III) oxide into polymer composite under oscillating magnetic field', *Digest Journal of Nanomaterials and Biostructures*, vol. 5, no. 4, pp. 1009-1014, 2010.

[13] M. Murarescu, D. Dima, G. Andrei and A. Circiumaru, 'Synthesis of polyester composites with functionalized carbon nanotubes by oxidative reactions and chemical deposition', *Digest Journal of Nanomaterials and Biostructures*, vol. 9, no. 2, pp. 653 –665, 2014.

[14] L. Ciupagea, G. Andrei, D. Dima and M. Murarescu, 'Specific heat and thermal expansion of polyester composites containing singlewall-, multiwall- and functionalized carbon nanotubes', *Digest Journal of Nanomaterials and Biostructures*, vol. 8, no. 4, pp. 1611 – 1619, 2013.

[15] A. Circiumaru, G. Andrei, I. Birsan and A. Semenescu, 'Electrical Conductivity of Fabric Based Filled Epoxy Composites', *Materiale Plastice*, vol. 46, no. 2, pp. 211-214, 2009.

[16] T. Onodera, K. Kawasaki, T. Nakakawaji, Y. Higuchi, N. Ozawa, K. Kurihara and M. Kubo: 'Effect of tribochemical reaction on transfer-film formation by poly(tetrafluoroethylene)', *Journal of Physical Chemistry C*, vol. 118, no. 22, pp. 11820-11826, 2014.

[17] S.M. Yeo and A.A. Polycarpou, 'Fretting experiments of advanced polymeric coatings and the effect of transfer films on their tribological behavior', *Tribology International*, vol. 79, pp. 16-25, 2014.

[18] J.T. Shen, Y.T. Pei and J.T.M. De Hosson: 'Tribological behavior of TiC/a-C:H-coated and uncoated steels sliding against phenol-formaldehyde composite reinforced with PTFE and glass fibers', *Tribology Letters*, vol. 52, no. 1, pp. 123-135, 2013.

[19] N.L. McCook, D.L. Burris, P.L. Dickrell and W.G. awyer, 'Cryogenic friction behavior of PTFE based solid lubricant composites', *Tribology Letters*, vol. 20, no. 2, pp. 109-113, 2005.

[20] Y.-L. You, D.-X. Li, G.-J. Si and X. Deng: 'Investigation of the influence of solid lubricants on the tribological properties of polyamide 6 nanocomposite', *Wear*, vol. 311, no.1-2, pp. 57-64, 2014.

[21] J. Ye, H.S. Khare and D.L. Burris, 'Quantitative characterization of solid lubricant transfer film quality', *Wear*, vol. 316, no. 1-2, pp. 133-143, 2014.

[22] D.-Y. Zhang, P.-B. Zhang, P. Lin, G.-N. Dong and Q.-F. Zeng, 'Tribological properties of self-lubricating polymer-steel laminated

composites', *Tribology Transactions*, vol. 56, no. 6, pp. 908-918, 2013.

[23] N. Rajini, J.W. Jappes, B. Suresha, S. Rajakarunakaran, I. Siva and N. Azhagesan, 'Effect of organically modified montmorillonite clay on wear behavior of naturally woven coconut sheath/polyester composite', *Proceedings of the Instion of Mechanical Engineers, Part J: Journal of Engineering Tribology*, vol. 228, no. 5, pp. 483-497, 2014.

[24] M.T. Albdiry and B.F. Yousif, 'Morphological structures and tribological performance of unsaturated polyester based untreated/silane-treated halloysite nanotubes', *Materials and Design*, vol. 48, pp. 68-76, 2013.

[25] U. Nirmal, B.F. Yousif, D. Rilling and P.V. Brevern, 'Effect of betelnut fibres treatment and contact conditions on adhesive wear and frictional performance of polyester composites', Wear, vol. 268, pp. 1354-1370, 2010.

[26] B.F. Yousif and N.S.M. El-Tayeb, 'Wear characteristics of thermoset composite under high stress three-body abrasive', *Tribology International*, vol. 43, pp. 2365-2371, 2010.