Tribological performance of the blend PBT and short aramid fibers

Mihail BOTAN*,[1], Igor ROMAN[1], Constantin GEORGESCU[1],
Alina CANTARAGIU[1], Lorena DELEANU[1]

*Corresponding author
*,[1]"Dunarea de Jos" University, Faculty of Engineering
Domneasca 47, 800008, Galati, Romania
mihai.botan@ugal.ro*, igor.roman@ugal.ro, constantin.georgescu@ugal.ro,
acantaragiu@ugal.ro, lorena.deleanu@ugal.ro

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Abstract: *Polybutylene terephthalate (PBT) and its aramid fiber composite (10 wt.%) were investigated in order to measure their wear and frictional properties under variations of applied load (5 N, 10 N, 15N) and velocity (0.25 m/s, 0.5 m/s and 0.75 m/s), in dry regime. The tribological properties of the composite were evaluated using a block-on-ring tribotester. The worn surface was investigated with a scanning electronic microscope and the authors pointed out particular processes taking place into the superficial layers of the friction couple. During the tests, temperature was measured by an infrared camera near to the contact of bodies that are involved and the friction coefficient was monitored by the help of the tribometer UMT-2 (Brucker-CETR®).*

Key Words*: composites, temperature survey, Polybutylene terephthalate (PBT), short aramid fiber, friction, wear, dry regime.*

1. INTRODUCTION

Polymeric materials, including blends, composites and sandwiches, have conquered the market because of their advantages related to manufacture and also by the set of properties, easy to direct by mixing them with different kind of fillers, such as reinforcements, solid lubricant, adhesives. Fibers' ability to succeed in the market is also due to the easy way of directing the set of properties for the obtained materials, by shape, dimensions, concentration and nature [3, 19, 21, 25, 30, and 32].

The polymeric matrix could accept different types of fibers and powders, including both of them in the same composite [6, 7, 18]. Aramid fibers were introduced in many polymeric materials, either thermorigid [17], thermoplastic [5, 9, 12, 17] or elastomers [21], for instance, in polyamide [15], polyimide [31], either as short fibers and pulp [30], or as long fibers and fabrics [2, 3, 24, 26].

Research has been reported for mixture of additives, including aramid fibers in polymers [30]. Many tribological applications of aramid fibers in polymeric matrix include brakes [1, 8, 10, 11, 13, 17, 20, 28, 29].

Gordon at al. [15] tested polyamide 4,6 (PA46) and its aramid fiber composites (6 wt.%, 12 wt.% and 15 wt.%) as candidates for tribological applications, using a twin-disc test rig, under different parameters: number of cycles (10^3 to 10^6), load (300–600 N) and velocity (500, 1000 and 1500 rpm), all at a slip ratio of 2%. The average coefficient of friction showed that the PA46 + 15% aramid fibers had the lowest values as compared to the other samples; but it had the highest wear rates, especially at higher loads and velocities.

Xian [30] developed an epoxy-based nanocomposite containing graphite powder (7 vol.%) and nano-scale TiO (4 vol.%) for tribological application. Composites containing additional fillers, such as short carbon fibers, aramid and polytetrafluoroethylene particles were developed and evaluated in adhesive and low amplitude oscillating wear modes. The incorporation of short carbon fibers and aramid particles resulted in a remarkable improvement in the sliding wear resistance.

Zhao [31] reported that incorporating fibers into polyimide (PI) matrix affects the tribological properties. Under dry sliding conditions, reinforcement by fibers results in improved wear resistance of these composites. Under three-body abrasion conditions the fibers are not effective in reducing wear rate. Only glass fiber reinforced polyimide performs quite well during sliding against SiC sandpaper. Low friction coefficient recorded during tests does not always result in a low wear rate of the investigated material. Type of reinforcement influences the friction coefficient, wear mechanisms and wear rates, serving as indicators for selecting PI composites for specific applications.

Variation in nature of organic fibre inclusion in a selected friction composition influenced the magnitude of the friction coefficient, as well as the wear resistance and their sensitivity to operating parameters. The magnitude of the coefficient of friction remained always higher at lower braking pressure and sliding speed, irrespective of the nature of organic fiber. From the wear performance point of view, aramid fiber proved to be beneficial. Incorporation of fibers of carbon and PAN rendered the friction composites least sensitive to dynamic variations in braking pressure and sliding speed [25].

Zhu et al. [33] carried out the optimization on tribological properties of non-metallic friction material modified with aramid fiber and CaSO whisker. The formulation of 70 wt.% NBR modified PF with 12 wt.% CaSO whisker and 4 wt.% aramid fiber exhibits the optimal properties.

The tribological behaviors of nanosize CuO-filled and fiber-reinforced polyphenylene sulfide (PPS) composites and the synergism as a result of the incorporation of both the nanoparticles and the fibers (short carbon fibers - CF and aramid - Kevlar fibers) were investigated by Chou [7], on a pin-on-disk tribotester. The proportions of the filler varied from 1 to 4 vol.% and of the reinforcement material from 5 to 15 vol.%. The counterface was made of hardened tool steel. Wear tests were run at a sliding speed of 1 m/s and over a sliding distance of 21.6 km. In case of the filler only, the lowest steady state wear rate was observed for PPS+2% CuO composite and of the fiber reinforcement only for PPS+10% Kevlar composite.

Based on studied documentation, it seems that the engineers have to make a compromise when dealing with composites with aramid fibers, that is to accept an increase of the friction coefficient as the wear behavior is much improved.

2. MATERIALS AND METHODOLOGY

Polybutylene terephthalate (PBT) and the blend PBT with 10 wt.% aramid fibers were investigated in order to measure their wear and frictional properties, under variations of applied load (5 N, 10 N, 15 N) and sliding speed (0.25 m/s, 0.5 m/s and 0.75 m/s), after analyzing a solid documentation [11, 23, 27]. The tribological properties of these materials against steel were measured, using block-on-ring wear tester (Fig. 2). During the tests, the temperature was measured by an infrared camera near to the contact of involved bodies and the friction coefficient was monitored by the help of the tribometer UMT-2 (CETR®).

The tested materials they were obtained by molding at ICEFS (Reseach Institute for Synthetic Fibres Savinesti) Romania, using a molding equipment type MI TP 100/50, in order to obtain bone samples type 1A, as recommended by SR EN ISO 527-2:2000. After the samples' molding, they were heat treated, being maintained for 2 hours at a constant temperature of 175-180ºC. For technological reason, black carbon was used (in small concentrations, less than 1%). Short aramid fibers, as supplied by Teijin [26] could be seen in Fig. 1. An EDX study pointed out the following concentrations of elements included into the fibers: Carbon 68.41...71.86, Oxygen 27.16...23.68, Natrium 2.77...2.39 and Sulphur 1.66...2.08 (wt%). The shape of the fibers is the result of the applied technology and seems to improve the anchorage of the fibers into the soft matrix.

The grains of PBT were dried before molding in order to eliminate undesired humidity, the residual humidity content has not to be over 0.04 % (wt). The drying process was done in an oven for 2 hours, at a temperature of ~120ºC. After molding (after 24 hours), the samples were heat treated, being maintained for 2 hours at a constant temperature of 100-120ºC.

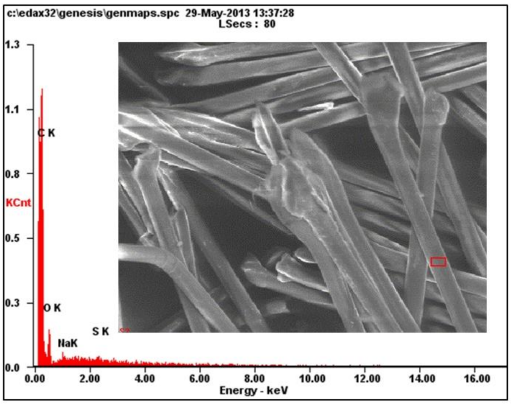


Fig. 1 – Short aramid fibers, as supplied by Teijin

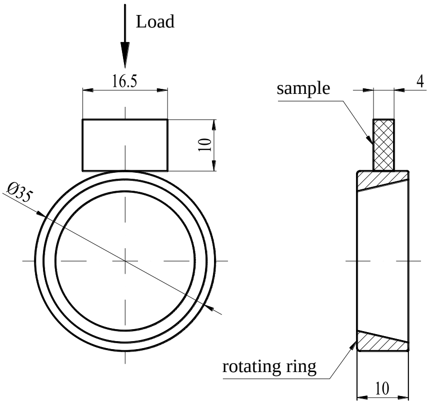


Fig. 2 – The shapes and dimensions of the friction couple block-on-ring

3. RESULTS AND DISCUSSION

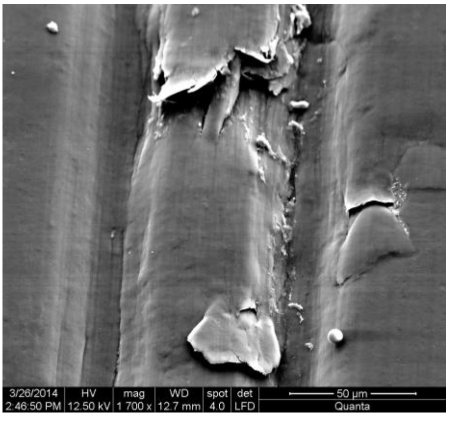
It was concluded that the presence of aramid fibers in PBT matrix gradually increased the friction coefficient and the temperature near the contact, with the applied load and the sliding speed. However, the temperatures that were recorded during the tests by infrared camera show a good correlation between the friction coefficient, which seems to follow it, with an initial rise, a slow decrease and a plateau of almost constant temperature.

As Narisawa underlines [22], the selected speed range for these tests could be considered as medium values, very often applied to friction couple polymeric blend – metallic body in practice.

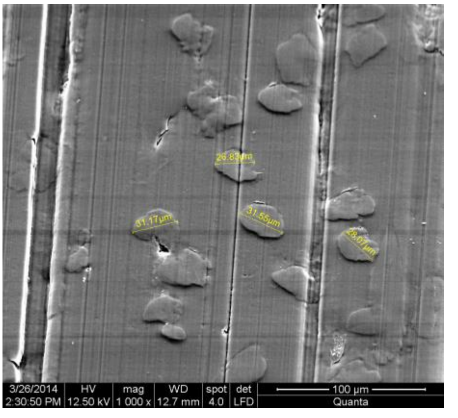
Problems often arise, however, when engineers attempt to use tabulated friction coefficients to solve specific problems in mechanical design or failure analysis. The systems-dependence of frictional behavior is sometimes ignored, leading to misapplication of published data. This is particularly true for applications in nano-technology and others that differ from typical laboratory size scales [4, 23]. Thus, the authors reported the range of the friction coefficient for each type of test (v, F, material), because the engineer is interested not only by the mean value over a period of time, but also by the extreme values that could give rise to energy consumption and heating.

Taking into account the set of commanding parameters (v, F - the sliding speed and the load) and the recent documentation on wear parameterization [16, 27, 31, 32], the authors selected mass loss as wear parameter, calculated as the difference between the initial mass of the block and that measured after the test.

The worn surface was investigated with a scanning electronic microscope (Fig. 3) and the images revealed specific processes: the matrix made of PBT is scratched, but not fragmented as it is happened with other softer polymers (polyamide), the polymer is preferentially worn and thus, the fibers support the load but they remain well anchored into the matrix (Fig. 3b).



a) Failure of an aramid fiber that was positioned almost parallel to the superficial layer



b) SEM image of the polymer blend PBT + 10% aramid fibers, after being tested

Fig. 3 – SEM images of superficial layers of block made of PBT + 10% aramid fibers (dry regime on steel, normal load F=15 N, sliding speed v=0.25 m/s, sample angle 45°)

Wear behavior of the obtained materials was pointed out with the help of a block-on-ring tester and the ranking was in the favor of PBT + 10% aramid fibers, as the wear parameter was the lowest and the friction couple has a very poor sensitivity to the variation of the sliding speed (0.25-0.75 m/s).

Table 1. The composite materials based on PBT

Material symbol	Composition (%wt)
PBT	100% PBT
PBX	PBT + 10% aramid fibers + 1% PA + 1% black carbon

Analyzing Fig. 4, one may notice that for block made of PBT, the higher values and also the larger range for the friction coefficient are obtained for test under low load (F=5 N) and low speed. At th higher tested speeds (v=0.50 m/s and v=0.75 m/s), the influence of the normal force on the friction coefficient becomes less evident. For the block made of PBR sliding against the steel ring, the friction coefficient varies in the range 0.2...0.25, this being an acceptable one for actual applications.

At v=0.25 m/s, the lowest force gives the highest value of the friction coefficient, witn oscillations, meaning that the rough metallic surface produces a torn-ff of the polymer superficial layer.

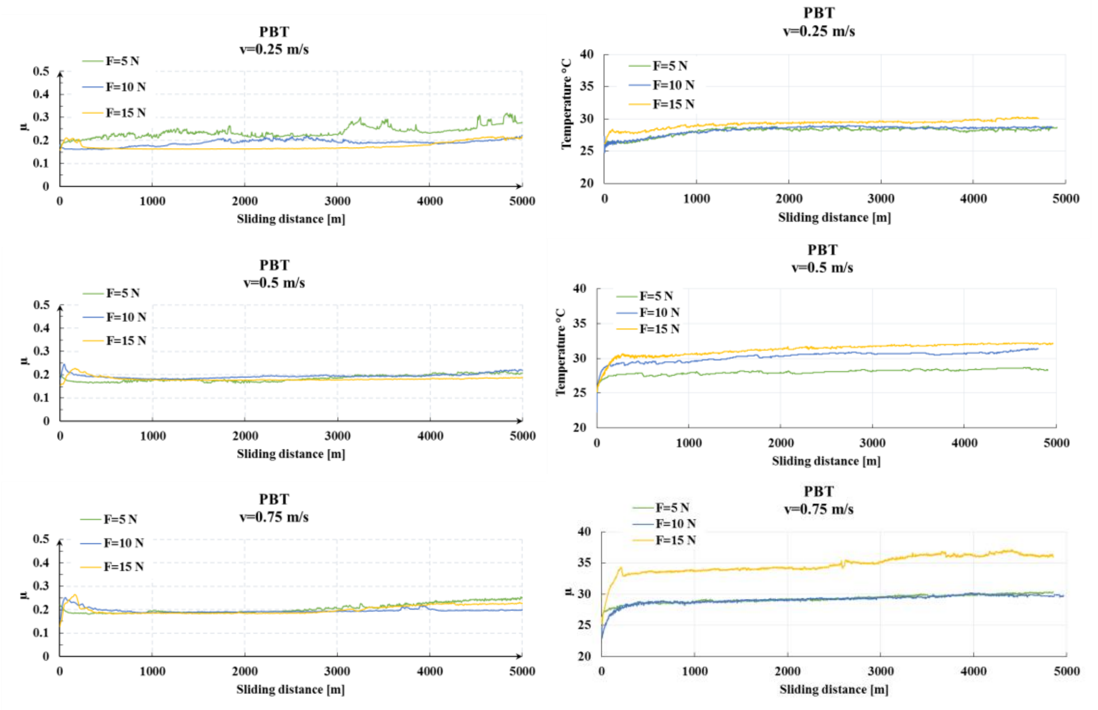


Fig. 4 – Evolution of the friction coefficient (left) and temperature in contact (lateral point, right) for blocks made of PBT

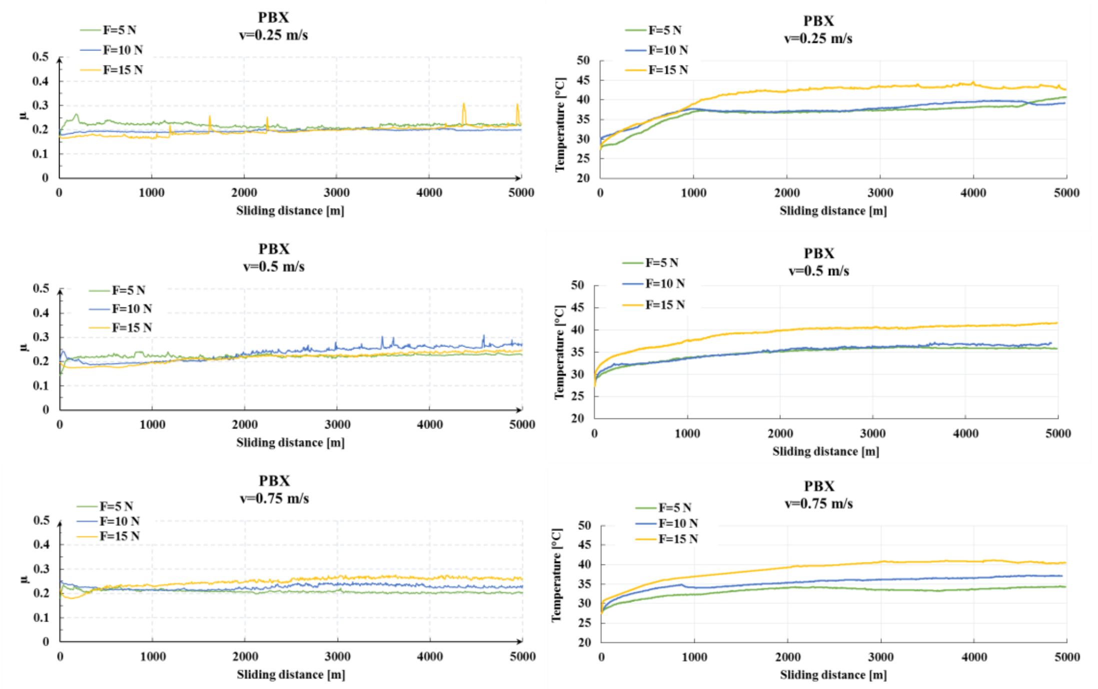


Fig. 5 – Evolution of the friction coefficient (left) and temperature in contact (lateral point, right) for blocks made of PBX

Using a thermal imager to record the temperatures created during the tests, it was found that there was always an initial rapid rise in temperature, followed by a slow decrease or a plateau, which seemed to follow the friction test results, with temperatures of up to 40...43°C being reached for the blend PBX and 27...35°C for PBT. This difference could be based on the poor thermal properties of the aramid fibers [35]. Both for PBT and PBX, the range of temperature recorded near the lateral contact between block and ring, are grouped for F=5 N and F=10 N, a higher value being obtained for F=15 N.

As for PBX (Fig. 5), the evolution of the friction coefficient is characterized by small peaks, especially for v=0.25 m/s and v=0.5 m/s, very probably dues to removal of wear particles, especially fibers.

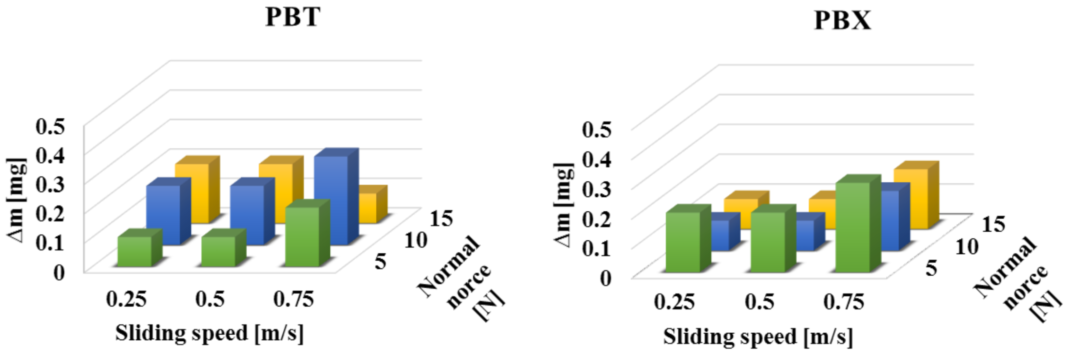
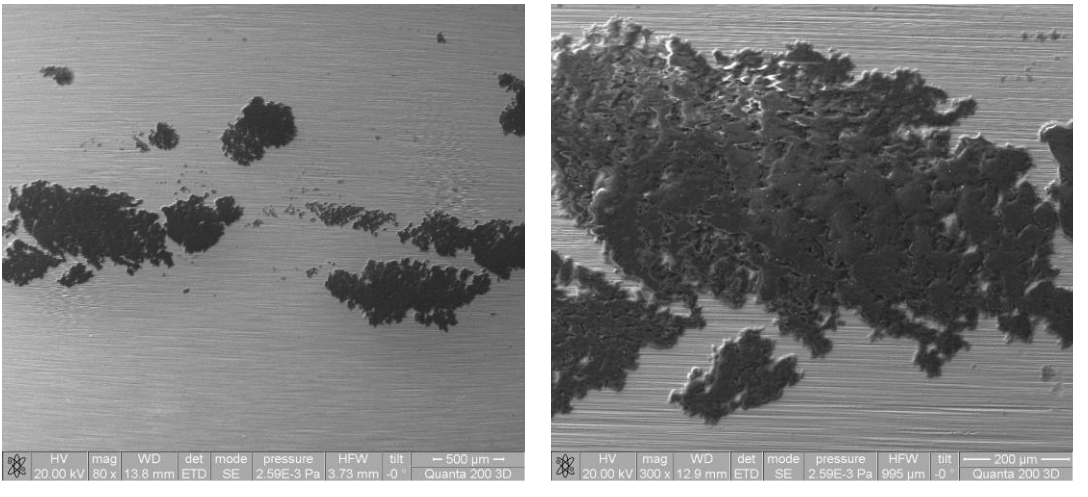


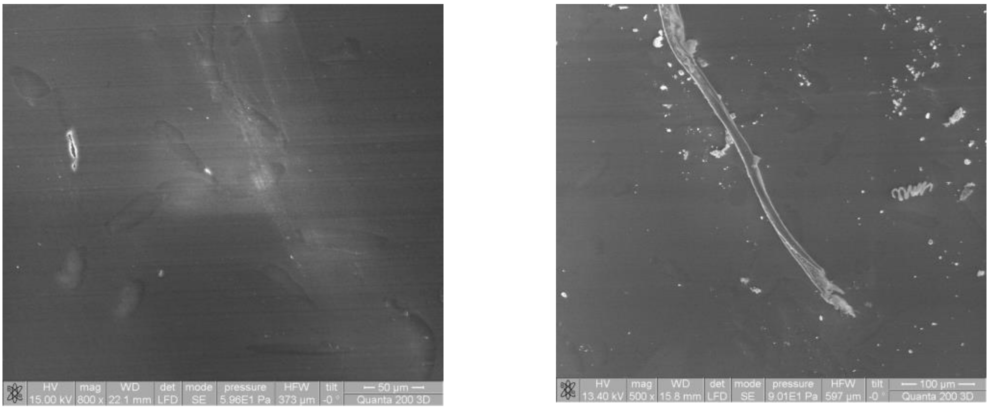
Fig. 6 – Wear of the polymeric block as mass loss after testing in dry regime on steel ring (L=5000 m)

For F=5 N, the blend PBX has greater values for the mass wear. It is possible that under such low load, the tear-off of the fibers become intense. Under greater load the fiber are compressed into the superficial layer and the counter face does not succeed to pull them out (Figs. 3a and 8a). Figure 8b presents a fiber just being dragged on the surface after being pull off from the polymeric matrix. This wear mechanism is also responsible for short oscillations of the friction coefficient, especially at lower speed when the matrix is harder as compared to that under higher speeds.



a) Adhesion on the steel ring b) Detail

Fig. 7 – Adhesion wear, F=15 N, v=0.25 m/s, L=5000 m



a) b)

Fig. 8 – Superficial layer of block made of PBX (F=15 N, v=0.25 m/s, L=5000 m)

4. CONCLUSIONS

Based on test results, it was concluded that the presence of aramid fiber in PBT matrix increased gradually the friction coefficient and the temperature near the contact, with the applied load and the sliding speed. However, the temperatures that were recorded during the tests by infrared camera show a good correlation with the friction coefficient, which seems to follow it, with an initial rise, a slow decrease and a plateau of almost constant temperature. Data obtained from this study recommend this composite in tribological applications with temperature variations in the range of 20…130ºC, for bearings, components that are under load in electronic and automotive technology. The blend PBT + 10% wt. aramid fibers is less sensitive to the variation of load and speed, at least for the investigated ranges (v=0.25...0.75 m/s and F=5...15 N)

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