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RESEARCH

Tribological Characterisation of PBT + Glass Bead Composites with the Help of Block-on-Ring Test

C. Georgescu[a], M. Botan[a], L. Deleanu[a]

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

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Corresponding author:

C. Georgescu
"Dunarea de Jos" University of Galati, Romania
E-mail: constantin.georgescu@ugal.ro

A B S T R A C T

The materials involved in this research study were produced by die moulding in order to obtain bone samples type 1A (SR EN ISO 527-2:2003). These composites have a matrix of polybutylene terephthalate (PBT) commercial grade Crastin 6130 NC010, DuPont. The values for the glass beads concentrations were established at 10 % and 20 %(wt). Block-on-ring tests were run in order to characterize the tribological behaviour of this friction couple (PBT and PBT composites with glass beads on steel). The block was manufactured by cutting parts from the bone samples, having the dimensions of 16.5 mm × 10 mm × 4 mm. The other triboelement was the external ring of the tapered rolling bearing KBS 30202, having dimensions of Ø35 mm × 10 mm and was made of steel grade DIN 100Cr6. There were analysed the following characteristics: friction coefficient (mean value over a test and scattering range), wear (wear rate). There are also presented particular aspects of the worn surfaces, as investigated from SEM images.

1. INTRODUCTION

Materials based on PBT are obtained both by adding very different materials (nano and micro fibre reinforcements [1], [22], metallic or/and ceramic powders [21], minerals [2-3]), the result could be included in the class of composites, and by blending with other polymers polytetrafluoro-ethylene (PTFE) [4], polycarbonate (PC) [5], polyethylene (PE), SAN, epoxy resin, with fire resistant additives [6], both solutions directioning one or a set of the properties of PBT matrix.

The adding materials in PBT are very diverse, almost all types known for the polymeric composites (long and short fibres, particles and their mixtures), both at micro scale and nano scale. For tribological applications, the fibre nature is also diverse: glass, carbon, aramidic, titanates.

Even if the specialized literature emphasis the influence of the adding materials in PBT, upon some mechanical characteristics (traction limit and elasticity modulus) [2-3,7], these properties do not also reflect the tribological behaviour of these materials. This is why the testing of the polymeric composites is of high importance and, even if the results could not be extrapolated from the laboratory tests on tribotesters, to the actual friction couple, these studies are useful in materials' ranking, when the designer is interest in a particular parameter or a set of characteristics [8-10].

2. MATERIALS AND TESTING METHODOLOGY

The tested materials were produced by die moulding in order to obtain bone samples type 1A (as required by the tensile test ISO 527-2) at the Research Institute for Synthetic Fibres Savinesti, Romania, taking into account the producer specification for moulding and heat treatment [11].

These composites have a matrix of polybutylene terephthalate (PBT), commercial grade Crastin 6130 NC010, DuPont.

The recipes for the composite materials based on PBT, included in this study, were elaborated by the authors based on up-to-date documentation [1,4,11] and were designed in order to point out the influence of matrix and adding materials on the tribological behaviour in dry regime. Table 1 presents their compositions and the abbreviations used in this paper. The polyamide (PA) was added in low concentration in order to have a better dispersion of the micro glass beads. The black carbon was added for both technological and tribological reasons.

Table 1. The tested materials.

Material symbol	Concentration [%, wt]			
	PBT	Micro glass beads	PA	Black carbon
PBT	100	-	-	-
GB10	88	10	1.5	0.5
GB20	77.5	20	2	0.5

The tests were done using a block-on-ring tribotester, functioning on a CETR tribometer UMT-2 Multi-Specimen Test System.

The ring was the external ring of the tapered rolling bearing KBS 30202 (DIN ISO 355/720), having the dimensions of Ø35 mm × 10 mm and was made of steel grade DIN 100Cr6, having 60-62 HRC and *R*a = 0.8 μm on the exterior surface.

The block was manufactured by cutting parts from the bone samples, having the dimensions of 16.5 mm × 10 mm × 4 mm.

The tests were run in dry condition, for combination (F, v), F being the normally applied load (F = 1.0 N, F = 2.5 N and F = 5.0 N) and v being the sliding speed (v = 0.25 m/s, v = 0.50 m/s and v = 0.75 m/s). The sliding distance was the same for all tests, L = 7500 m.

For evaluating the mass loss of the blocks, an analytical balance METTLER TOLEDO was used, having the measuring accuracy of 0.1 mg.

The SEM images were done with the help of the scanning electron microscope Quanta 200 3D, having a resolution of 4 nm, a magnification ×1.000.000.

3. EXPERIMENTAL RESULTS

a. Friction coefficient

In order to compare the three tested materials, the extreme values and the average value of the friction coefficient were graphically presented in Fig. 1 as a function of the sliding speed and the normal load. These values (the lowest value, the highest value and the average one) were calculated based on the recorded values during each test (sampling rate being 10 values per second). Thus, it could be appreciated the stability of the friction coefficient by the size of the scattering interval and an average energy consumption by the average value of the friction coefficient.

For actual applications working under similar conditions of speed and load, the author would recommend the materials with a smaller scattering interval and lower values of the average friction coefficient.

The low loads and speeds produce a larger scattering interval for the friction coefficient, but the load and speed increase makes the friction coefficient diminish the average value and to narrow the scattering interval. A research report from NASA [12] had evidenced high average values of the friction coefficient of over 0.6, for three polymers sliding against steel (the tribotester: polymeric ball on steel disk).

From these research reports and the experimentally obtained data during this study, the authors point out the importance of the laboratory tests for evaluating the friction coefficient and other tribological characteristics.

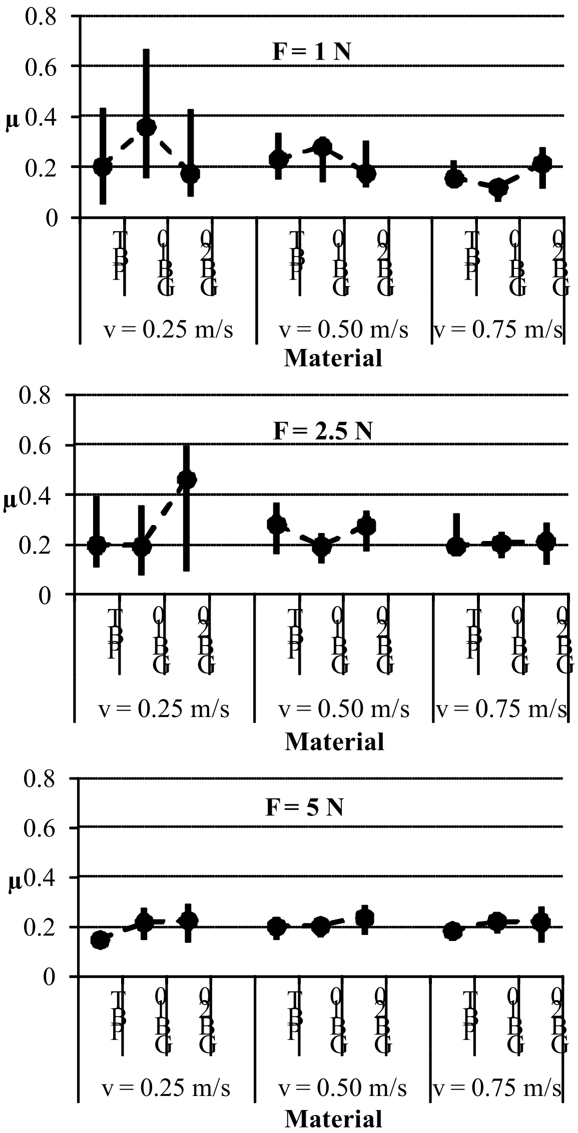


Fig. 1. Variation of friction coefficient of PBT and composites with different micro glass beads content, for the sliding distance L = 7500 m.

PBT has the average values of the friction coefficient, μ, in the narrowest range, around the value 0.2. The increase of this average could be explained by the elimination of the relatively big wear particles that are characteristic for this polymer (see Fig. 4). The values obtained for F = 5 N are grouped under 0.2 for all the tested sliding speeds.

The composites GB10 (PBT + 10 % micro glass beads) and GB20 (PBT + 20 % micro glass beads) have the average value of the friction coefficient scattered on larger intervals, especially for the smaller normal loads (F = 1 N and F = 2.5 N). For F = 1 N, it is hard to establish a dependency relation of the friction coefficient on the adding material concentration and the sliding speed. It could be noticed that for blocks made of GB20, there are larger intervals.

At the sliding speed of v = 0.25 m/s, the abrasive wear is predominant, the polymer being hung (torn) and drawn from the superficial layers as micro-volumes, their size being greater at higher speeds (Fig. 2). At the sliding speed of v = 0.75 m/s, the influence of the normal load on the average value of the friction coefficient is similar: μ increases from 0.12 for F = 1 N, to ~ 0.2 for F = 5 N.

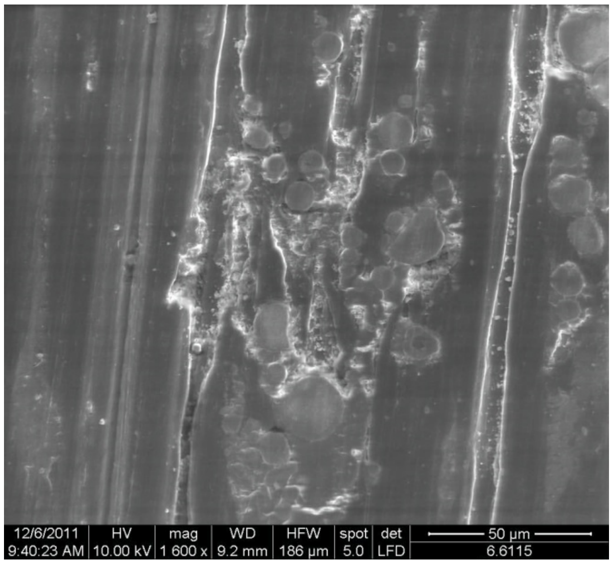


Fig. 2. SEM image of the block made of GB10, for v = 0.25 m/s, F = 5 N, L = 7500 m.

For the blocks made of GB20, under F = 2.5 N, the scattering of the values for the friction coefficient is the largest. The probable cause would be the micro-cutting processes that will have a more reduced intensity when the sliding speed increases. There were not noticed processes of dragging the micro glass beads on the block surfaces, meaning that the interface between the micro glass beads and the polymeric matrix is harder to damage, as compared to, for instance, the mobility of the micro glass beads in the sliding direction, but also in the depth of the superficial layer, as noticed in testing the composites with same type of micro glass beads added in a polyamide matrix [13].

The values of the friction coefficient have the tendency of being less dependent on the sliding speed for the normal load F = 5 N; this recommends these materials for an exploitation regime with different working speeds (differentiated speeds imposed by the technological process), without having very different energy consumption levels when the speed is changing.

The extreme values of the friction coefficient are caused by the generation and the detaching of the wear debris, the ring passing over a bigger micro glass beads, an agglomeration of micro glass beads or fragments of some broken ones on the surface as remained after a preferential elimination of the polymer from the superficial layer. In other studies on the polymeric composites with micro glass beads, there were no reports on fracturing the hard particles.

For the composites with PBT matrix, the authors noticed breakings of the micro glass beads, generally those of bigger diameters (20...40 μm) being broken. Figure 3 presents four broken micro glass spheres (A, B, C and D) on an area of ~ 600 μm × 600 μm in the central zone of the contact; the resulted fragments are embedded into the polymeric matrix. Such events taken place in the contact create high oscillations of the friction coefficient.

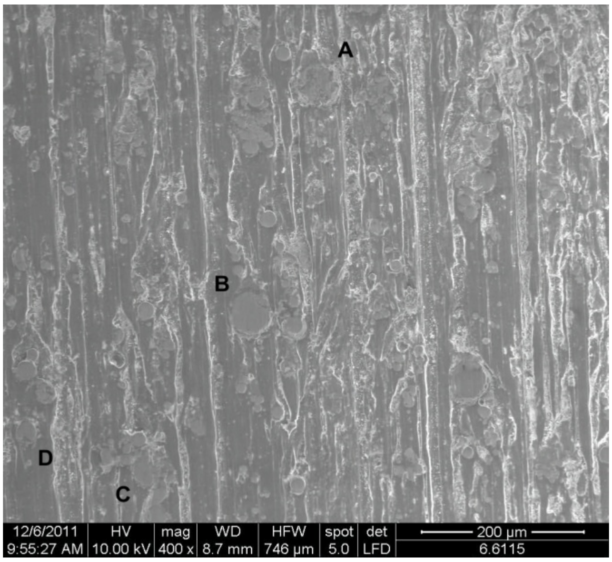
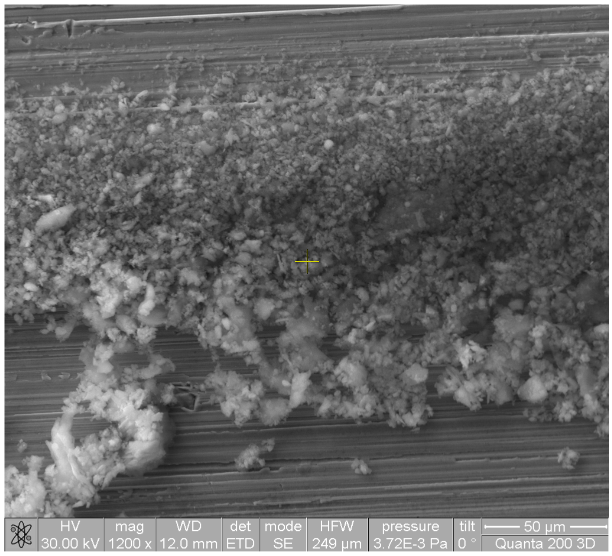
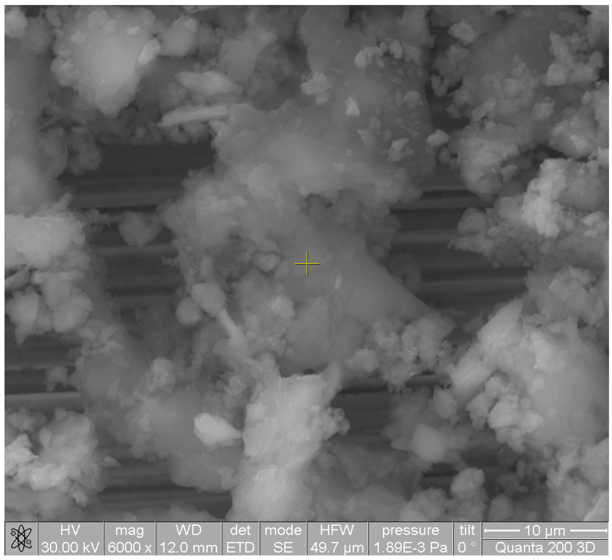


Fig. 3. SEM image of a block made of GB10 – four broken micro glass beads (A, B, C and D). Test conditions: v = 0.25 m/s, F = 5 N, L = 7500 m.

From SEM images (Fig. 4), the wear debris were characterized as size and shape, many are made especially of polymer with only small glass debris (from fragmented micro glass beads) or small micro glass beads (but rare). During the test, the wear debris adhere one to each other and are generally big and rare (as compared to the wear debris resulted from other polymer in dry sliding against steel) and they are volumic (Fig. 4), not laminated and thin, as it is happening in the case of PTFE [14]. Generally, small micro glass beads are evacuated from the superficial layers and the polymer around the bigger ones is detached. In this scenario, one or more micro glass beads will support an individual load great enough to be broken.



a) At the edge of the wear track from the ring.



b) Wear particles made of polymer and very small fragments from the broken glass beads.

Fig. 4. Aspect of the wear particles generated during the test involving the sliding of the block made of GB20 on the metallic ring. Test conditions: F = 5 N, v = 0.75 m/s, L = 7500 m.

At F = 1 N and v = 0.25 m/s, a larger scattering interval of the friction coefficient had resulted; there are prevailing the micro-cutting process and events implying the glass beads (overrunning of the hard asperities of the metallic ring, the breakage of the micro glass beads and rare shear of the hard asperities, the micro glass beads embedding into the polymeric matrix). A doubling of the sliding speed (v = 0.5 m/s) determines diminishing the average value of the friction coefficient characterizing these composites, from 0.15...0.28, to 0.12...0.22. At v = 0.5 m/s, both composites behave well, the friction coefficient becoming stable around the average value of 0.2. The polymer is warming and, thus, it is reducing its mechanical properties and allows for generating a very thin viscous film that is not expelled from the contact (as it happens with other polymer under high speed) and becomes a favourable factor in reducing friction also by embedding the glass beads in the soften matrix.

At F = 2.5 N, the average value of the friction coefficient has a slightly tendency of increasing when the micro glass beads concentration are increased.

At F = 5 N, the values of the analysed parameters of the friction coefficient have been reduced (figure 1), confirming the results obtained in other research [12] that the small loads generate a more intense friction for the friction couple element(s) made of polymer or polymeric composites and hard counterpart (steel). The normal force, for which the friction coefficient begins to decrease, is depending on the shape and size of the triboelement and on the working conditions [15-16].

b. Wear

Taking into account the commanding parameters involved in this study (the material, by the concentration of the adding materials, the sliding speed and the load) and the recent documentation on wear parameterization [15-20], the authors selected the wear rate (k) for analysing the experimental wear results obtained during this research.

$$k = \frac{V}{F \cdot L} = \frac{\Delta m}{\rho \cdot F \cdot L} \ [\mathrm{mm^3/(N \cdot m)}] \qquad (1)$$

where F [N] – the normal force and L [m] – the sliding distance, V [mm^3] is the material volume lost by wear, Δm [g] is the mass loss of a block, calculated as the difference of the initial mass of the block and its mass after being tested, ρ [g/mm^3] is the density of the tested block material.

The wear maps (see Fig. 5) were plotted using MATLAB R2009b, the wear parameter being represented for each material as a function of the sliding speed and the normal force, with the help of a cubic interpolation.

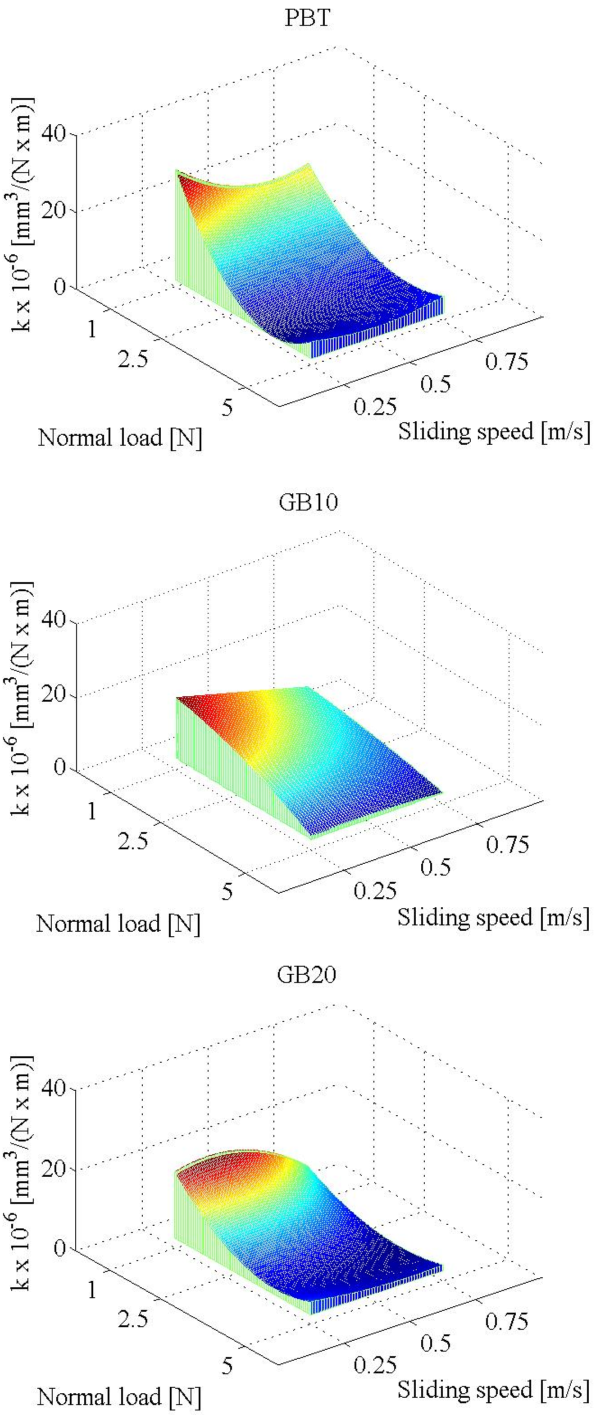


Figure 5. The wear rate for PBT and the composites PBT + micro glass beads.

For PBT (see Fig. 5), one may notice a significant increase of the wear parameter when the normal force is decreasing - the cause could be the increase of the heightening factor for the abrasive wear under low loads and the absence of a transfer film on the hard surface due to the absence of the mechanical pressure and thermal loading great enough for initiating and maintaining an adherence process.

For all tested sliding speeds, the tendency characterizing the wear variation as a function of load has a minimum zone around the value of 4 N.

For the composites PBT + micro glass beads, analysing Fig. 5, the following conclusions could be drawn:

- a zone with minimum values, for F = 5 N;
- an accentuated increase of the wear rate for loads smaller than 2.5 N, with higher values for the composite GB10;
- for the composite GB10, the wear rate is decreasing almost linearly when the load is increasing and it is insignificantly decreasing when the sliding speed is increasing; *k* is smaller for the two composites with micro glass beads as compared to the basic material (PBT), the lowest values being recorded for the composites, under the load F = 5 N;
- at F = 5 N, for all the tested materials, the wear rate has a very low sensitivity to the variation of the sliding speed, the smaller values being obtained for the composites.

Thus, the wear rate diminishes when introducing glass beads in PBT. The wear is diminishing due to the increase of the material resistance (see the results for the composite GB10), but when the micro glass beads concentration becomes 20 %, the abrasive component of the wear process increases, too.

4. CONCLUSIONS

Adding micro glass beads in PBT makes the friction coefficient increase almost linearly with the micro glass beads massic concentration, with ~15 % for each 10 % of micro glass beads.

An addition of 10% micro glass beads decreases the wear rate with ~20 %. When the concentration of micro glass beads is increased, the decrease of this wear parameter is smaller as compared to PBT, with ~18 %.

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