Influence of Adding Materials in PBT on Tribological Behaviour

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This paper presents the tribological behaviour of four polymeric materials, polybutylene terephthalate (PBT), PBT + 10% micro glass beads, PBT + 10% polytetrafluoroethylene (PTFE) and PBT + 10% aramid fibers, in order to rank them in dry sliding regime. Tests were done using a block-on-ring module. The test parameters were: the sliding speed was set for 0.25 m/s, 0.50 m/s and 0.75 m/s, respectively, the load and the sliding distance being kept constant (5 N and 5000 m, respectively). There were analyzed the dependence of friction coefficient and linear wear rate on the adding material. Particular wear mechanisms were identified with the help of SEM images.

Keywords: PBT-based materials, PTFE, glass beads, aramid fibers, friction coefficient, linear wear rate

Polymeric materials, including composites, have a short but fruitful history as concerning their manufacturing and tribological applications [1-3], including health care [4, 5] and automotive industries [6].

PBT has been used on industrial scale since the 7th decade of the XXth century [7-9]. Because of the longer sequence of methyl groups in the repeating unit, the chains are both more flexible and less polar than polyethylene terephthalate, leading to lower values for the melting temperature (~224°C) and the glass transition temperature, Tg, (22-43°C), which allows for a fast crystallization when the material is mold, shorter molding cycles with faster molding speed [1, 9, 10]. PBT is appreciated because of its balance of good properties rather than of a few outstanding ones, especially in water (but not in boiling water) and in a highly humid environment, its good chemical resistance in hydrocarbons. It has good mechanical properties (table 1) and excellent electrical properties, but a lower deflection temperature (54°C) under 1.8 MPa. Its reduced water absorption, less than 0.1% in 24 h of immersing, is one of the most reduced absorptions among thermoplastic polymers. Its lubricity is responsible for the very good wear resistance [11, 12].

Today, there is a major interest in composites based on PBT. Adding glass (as fibers or beads) has a benefit effect on the elasticity modulus in bending, the impact resistance and the creep resistance [12-14]. PBT is prone to hydrolysis and its grains have to be well dried before molding. At a temperature above 270°C, PBT is rapidly decomposed and that is why the molding temperature is in the range of 240...270°C [23]. As PBT is a polyester, there will be a substantial number of common chemicals that will either attack it or cause swelling, particularly above Tg [15]. This is the reason of the specialists' interest in tribological applications in dry regime. After a systematical review of polymeric composites and their response to wear and friction, Dasari [16] wrote the following conclusions: there is no validation of the assumption that adding nano-materials always improves the tribological properties and the material properties (elasticity modulus, hardness, toughness) and the wear rate or the scratch depth are not the only parameters in selecting and ranking the materials for a tribological application. Thus, the adding materials in this study are at micro level. Generally, adding materials with reinforcement and/or lubricating roles improves the tribological behaviour [11, 17-22]. The solid lubricants act for reducing the superficial energy, but they are responsible for weak links into the material. The reinforcements increase the resistance, but drastically modify the abrasivity on the counterpart. Thus, the friction coefficient might be greater, the surface roughness could be worse and the protective transfer film could not be initiated, the sliding regime being characterized by a high "third body" wear [23]. The materials added into polymers do not improve all properties of the basic material. In certain conditions, the fiber presence could make the wear worsen. Evans and Lancaster [24] asserted that the introduction of fibers in polymers has generally worthy effects upon wear and only rarely they make the wear worsen [25]; some adding materials facilitate the rapid evacuation of the heat, etc. The great interest and requirement of composites in the last years have pointed out their limits in optimization as the user has to do some compromises [3, 21, 26].

Table 1
PROPERTIES OF PBT GRADE CRASTIN 6130 NC010® [9]

Characteristics	Values
The maximum work temperature, [°C]	110…180
Traction limit, MPa	55...65
Hardness, Shore	90...95
Thermal conductivity, [W/m·K]	0.25
Thermal expansion coefficient, [K^{-1}]	$90 \cdot 10^{-5}$
Elasticity modulus, [MPa]	3300
Elongation at yield, [%]	23

Experimental part

Materials and testing methodology

The tested materials are presented in table 2 and they were obtained by molding at ICEFS Savinesti, Romania, in order to obtain bone samples type 1A, as recommended by SR EN ISO 527-2:2000. These have a matrix of PBT, the commercial name being Crastin 6130 NC010 (as supplied in grains by DuPont, table 1). Polyamide (PA) was added both for technological and tribological reasons into the material containing glass beads or aramid fibers. After the samples' molding (after 24 h), they were heat treated,

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Paper presented at The 3rd International Polymer Processing Conference - IPPC 2013, 7-8 November, Sibiu, Romania

Material symbol	Composition (%wt.)
PBT	100% PBT
GB10	PBT + 10% glass bead + 1.5% PA + 0.5% black carbon
PF10	PBT + 10% PTFE
AF10	PBT + 10% aramid fibers + 1% PA + 1% black carbon

Table 2
COMPOSITE MATERIALS BASED ON PBT

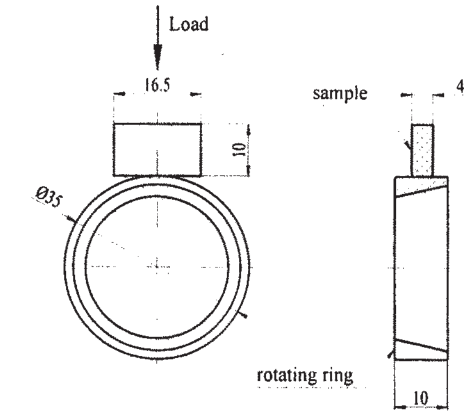


Fig. 1. Geometry of the tribotester

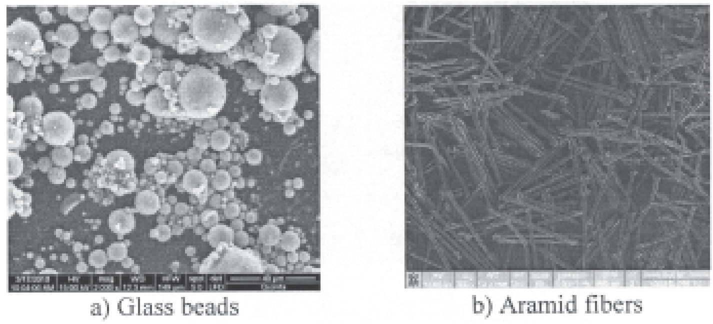


Fig. 2. Adding materials

being maintained for 2 h at a constant temperature of 175-180°C.

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

The other triboelement was the external ring of the tapered rolling bearing KBS 30202 (DIN ISO 355/720) [19], having the dimensions of ∅35 mm × 10 mm (fig. 1) and was made of steel grade DIN 100Cr6, having 60-62 HRC and Ra=0.8μm on the exterior surface. The shape and dimensions of the friction couple (Timken type) are presented in figure 1. The aramid fibers were supplied by Teijin (Netherlands), having an average length of 125 μm (fig. 2.b) and the glass beads have diameters in the range of 0.5 μm...40 μm, the most numerous being of 5 μm...10 μm (fig. 2.a).

Tests were done on a CETR tribometer (CETR®-Bruker), using a block-on-ring module. The test parameters were: the sliding speed (0.25 m/s, 0.50 m/s and 0.75 m/s, respectively), the load and the sliding distance being kept constant (5 N and 5000 m, respectively). The dependence of friction coefficient and linear wear rate on the type of adding material was analyzed.

Results and discussions

PBT has the average values of the friction coefficient, μ, in the narrowest range (fig. 3). The local increase of its value could be explained by the elimination of the relatively big wear particles that are characteristic for this polymer [19]. The values are grouped around 0.2 for all tested sliding speeds.

GB10 has the value of friction coefficient scattered on larger intervals (fig. 4). For the sliding speed of v = 0.25 m/s, the abrasive wear is dominant, the polymer being hung (torn) and drawn from the superficial layers as micro-volumes (fig. 3.a). Some of the detached wear particles are transferred on the steel counterface in micro-lamps,

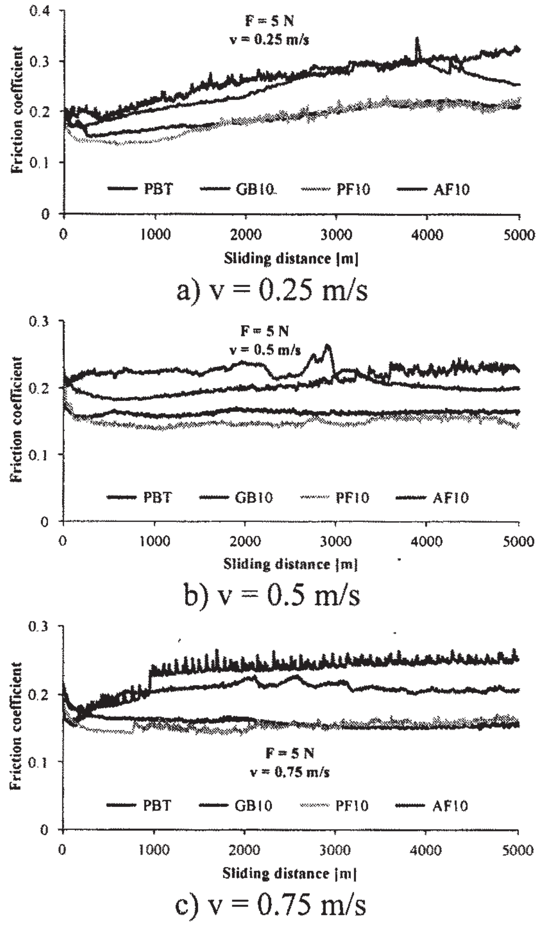


Fig. 3. Friction coefficient for the materials based on PBT

non-uniformly distributed on the hard surface (fig. 3.b and fig. 9.b).

Based on the evolution in time of the friction coefficient (fig. 3), the tested materials may be grouped in two categories: two with low values of this parameter (PBT

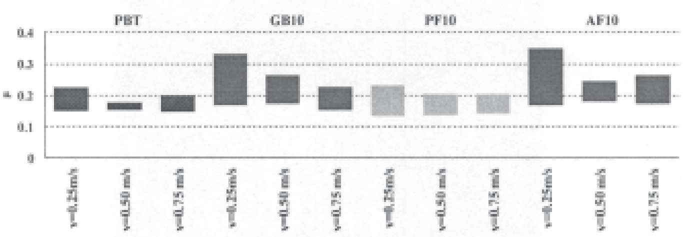


Fig. 4. Ranges of the friction coefficient as a function of sliding speed and material

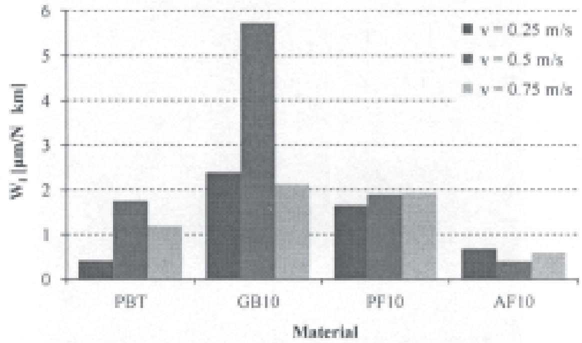
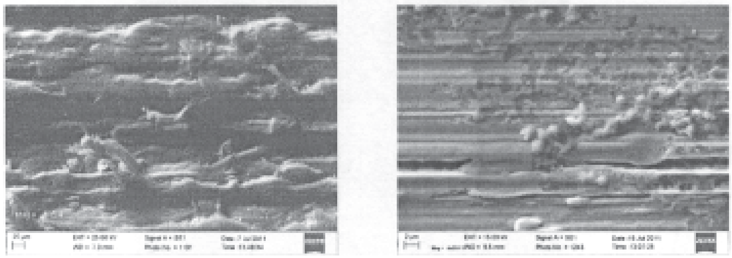


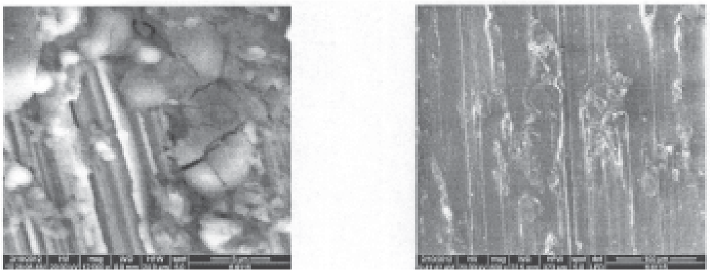
Fig. 5. Linear wear rate of the tested materials, for F = 5 N and L = 5000 m



a) Aspect of PBT superficial layer

b) Aspect of steel ring

Fig. 6. SEM images of the friction couple PBT and steel



a) Glass fragments trapped in steel topography

b) Block made of PBT + 10% glass beads

Fig. 7. GB10 after being tested at v = 0.5 m/s, F = 5 N and L = 7500 m [19]

and PF10) and also with narrow ranges and the other two materials with larger ranges and rough aspect of the lines (GB10 and AF10). If this parameter is the main one in selecting the materials, the neat PBT offers the best choice as the evolution of the friction coefficient is smooth and very low, less sensitive to the sliding speed. The next material with lower and stable friction coefficient is PF10, its good behaviour being the result of the solid lubricant (PTFE).

Analyzing figure 5, one may notice that adding materials into PBT is not always beneficial from tribological point of view. For the lowest tested speed, v = 0.25 m/s, the smallest linear wear rate was obtained for the neat polymer. The value for AF10 was almost double, but for the other two tested materials (GB10 and PF10), this value is three to..five times higher as compared to that for the neat PBT. Adding aramid fibers into PBT makes the blend have a better response to wear, meaning low values of linear wear rate and also a very poor sensitivity with the sliding speed.

The linear wear rate, W_l, is defined as following

$$W_l = \frac{\Delta Z}{F \cdot L} \quad [\mu m / N \cdot km] \qquad (1)$$

where ΔZ is the approach between the two triboelements at the end of the test, F is the normally applied load and L is the sliding distance. Because the steel ring could be considered as a perfectly rigid body (as compared to the block material) and the wear of this triboelement could be neglected, this approach would be considered as the linear wear of the polymeric block.

Particular wear mechanisms were identified with the help of SEM images (figs. 6 to 9).

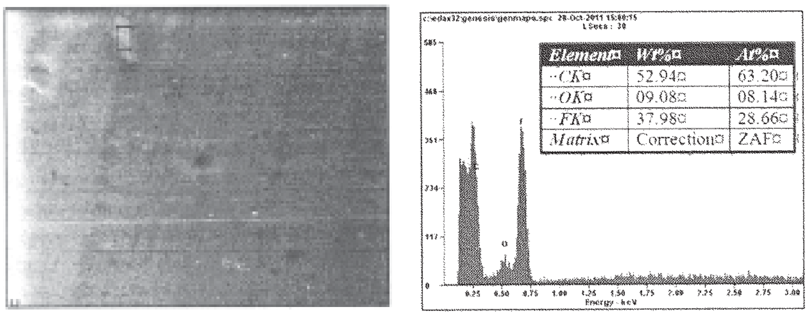
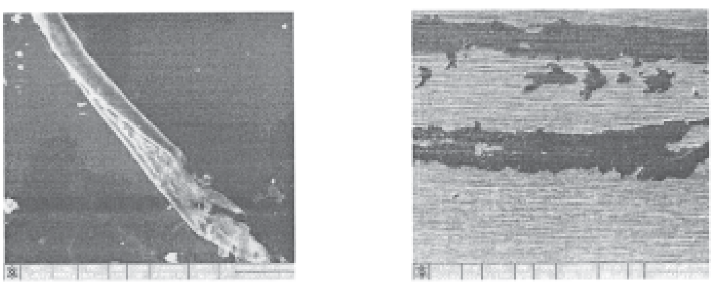


Fig. 8. Zone with an agglomeration of PTFE on the superficial layer of PF10 (with EDX confirmation: see the high percentage of Fluor)



a) An aramid fiber bearing the sliding of the metallic triboelement

b) PBT transfer on the steel ring

Fig. 9. Test on friction couple AF10 on steel, for L = 5000 m and v = 0.75 m/s

For PBT, an increase of the wear parameter was noticed when the sliding speed is increased from 0.25 m/s to 0.5 m/s, followed by a decreasing for 0.75 m/s; the cause could be the increase of the weightening factor for abrasive wear when the sliding speed does not change (soften) yet the superficial layers and the absence of a transfer film on the hard surface due to a too low mechanical and thermal loading for initiating and maintaining the adherence process. An almost linear increase of the linear wear rate, when the sliding speed increases, implies an intensification of wear processes without changing their nature.

The linear wear rate of GB10 is insignificantly decreasing when the sliding speed is increasing, W_l being greater for the composite as compared to PBT (a rare case among polymeric composites).

Adding PTFE in PBT caused a slight decrease of the average value of the friction coefficient, but not so obvious as reported in researches of the polymeric blends like PTFE in PEEK [2, 25], where a decrease with 30%...50% as compared to the value obtained for the neat polymer (without PTFE) was reported. In other words, the designer interested in having a low friction coefficient, could select PBT without PTFE additivation, if other required criteria are fulfilled (the thermal regime in functioning, reduced wear, etc.). PF10 (fig. 5) is characterized by a linear wear rate almost insensible of the speed increase. Generally, adding PTFE in a polymer diminishes the wear of the blend. One of the causes would be the generation of a transfer film, even discontinuous, made of a blend of polymer + PTFE. The quality of PTFE dispersion in PBT is very important in reducing wear; for instance, an agglomeration of PTFE will make the tribological behavior uneven worse: high oscillations of the friction coefficient and preferential wear of the zones rich in PTFE (fig. 8.b).

Conclusions

The authors presented test results for PBT used as matrix in composites or blends with different adding materials (glass beads, PTFE and aramid fibers, respectively). Wear behaviour 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 value and the friction couple has a very poor sensitivity to the variation of the sliding speed (at least for 0.25 m/s - 0.75 m/s).

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Manuscript received: 15.09.2014