**Trends in Polymer Tribology**

**P. De Baets**, G. Kalacska, P. Neis, M. Andò, R. Cotetiu

**Abstract:** Polymer based materials have become popular in a wide range of tribological applications because of interesting characteristics such as good corrosion resistance, self-lubrication properties and acceptable wear resistance. However, a considerable number of questions remain unresolved both regarding fundamental understanding and engineering design issues. Despite the large amount of factual data available in literature application engineers tend to fall back on basic catalogue information. To obtain better confidence in their design solutions they complement these literature data with results of dedicated tribological tests. The present paper discusses some trends related to the use and tribological testing of polymer based components. Some basic influencing parameters (contact load, sliding/rolling velocity, environmental conditions, mating surface conditions, etc.) are discussed. New experimental strategies for observation of the dynamic nature of transfer film formation and wear are also considered. Finally, modern trends in reinforcements and lubricant additives are presented.

**Keywords:** polymers, polymer based composites, friction, wear, tribotesting

1 INTRODUCTION

Because of some advantageous properties polymers and polymer composites (PaPBC’s) have found their way in numerous applications in a wide variety of industrial sectors. They are used for machine components such as gears and bearings, as guide ways and sliding systems in civil constructions, biomedical implants etc. Small but also very large size components are used in engineering and domestic applications. Since many decades research on their tribological behaviour has been conducted [1][2]. There are, however, still numerous open questions and unknowns about PaPBC’s. This paper aims at pointing out some of the trends and problems related to the use of PaPBC’s and at giving some direction to future research activities in this field.

2 TRIBOLOGICAL DATA

Practice has shown that the relying solely on technical catalogues and scientific literature for the design of PaPBC-based tribocomponents can lead to unexpected underperformance. For that reason this information is often complemented with dedicated experimental campaign. Often small-scale tribotests (e.g. pin-on-disc tests) are preferred due to their cost- and/or time-effectiveness. They provide fundamental information and are useful for preliminary material classification. But they tend to show important errors when extrapolated towards real working environments [3]. Good criteria for material selection require the tribological characterization under conditions that closely simulate the practical functionality, including the structure of the material sliding couple, the contact geometries, the contact pressures, the type of sliding motion, environmental conditions, mechanical stiffness, energy dissipation, fixation method, etc. As a result, tribological effects are expressed on different geometries and on scales ranging from nano up to tera. Some full-scale experiments have been reported in literature [4][5][6][7]. High cost and many practical obstructions often hinder tribotesting in the real operating system. For this reason scalability of in lab tribotests to real working conditions is important. Good scaling models should be developed. The traditional models with (i) one single mechanical parameter (normal load or contact pressure), (ii) two mechanical parameters (normal load and sliding velocity) and (iii) the contact pressure–sliding velocity model (pv-temperature limit) are only applicable within one testing scale, but not between tests of different scales. Soete Lab [8] therefore introduced a scaling model based on the definition of a scaling parameter that depends on a macroscopic geometry parameter, the Péclet number and the contact pressure. Although this model seemed to be successful with respect to friction, it failed in extrapolating wear coefficients. Better models should thus be developed. Meanwhile, lacking appropriate models, tribotesting with large size specimens still offers most valuable information. Some features, such as macroscopic reinforcements, fibre reinforcement, debris evacuation groves etc. cannot be scaled down to the size of traditional in lab tribotesters. As an example Figure 1 shows a hybrid sliding pad that is used in a 10 m diameter spherical hinge [9], that has been tested with Soete lab’s 6500 kN flat-on-flat reciprocating tribometer.
An important problem related to PaPBC tribotesting concerns the impossibility of accelerated testing. Increased sliding velocity and/or normal load leads to a surface temperature increase that results into different friction and wear mechanisms [11]. But also when keeping the contact temperature constant, other friction and wear mechanisms come into play with increased velocity or load. Typically high load tests underestimate friction coefficient and wear rate (Figure 2) and increased velocity tests overestimate friction.

Finally it should be emphasized that attention should be paid to the applied testing parameters; also to the environmental conditions and properties of the counter surface. As many polymers have mechanical properties varying with ambient humidity, this last one should be properly controlled. Also in case of lubricated contact the properties of the lubricant should be taken into account. As an example Figure 3 shows the coefficient of friction of a radial PETP bearing in water lubricated conditions. Four different types of water have been used (river, tap demineralised and distilled) resulting into significantly different friction behaviour, mainly in the lower velocity range for which a (semi-) hydrodynamic film could not be developed [12]. For the same bearing the steel counter face roughness has also been examined. It was observed that increasing the shaft roughness form Ra 0.02 µm (ground surface) to 0.4 µm (finely turned) resulted into an increase of the coefficient of friction by a factor 2.5 [13].

![Fig. 1. Hybrid UHMWE sliding pad](image1)

![Fig. 2. Wear testing of Polyacetal (POM) at two different scales](image2)

![Fig. 3. Friction of water lubricated PETP radial bearing](image3)

### 3 STRENGTHENING FILLERS AND LUBRICANTS

To enhance self-lubricating properties of PaPBC's solid lubricants are inserted, such as PTFE, MoS₂, graphite or their mixtures. Practical use has proved that these lubricants can be beneficial although their lubricating mechanisms are yet not fully understood. Most researchers hypothetically attribute the favourable tribological characteristics to the mechanism of transfer film formation. A better understanding and possible confirmation of this hypothesis requires observation techniques that are able to observe transfer film dynamics. Its formation on the counter surface and its removal during sliding should be observed in detail and eventually quantified.

The beneficial action of solid lubricants on the other hand results into a diminished wear resistance. It is possible to counteract this effect by strengthening the polymer matrix by means of long or short fibres (polymer fibres, carbon, glass). Today also nanofillers come into play, that are uniformly distributed in the polymer matrix. Examples of such nanofillers are titanium dioxide (TiO₂), silicon dioxide (SiO₂) and zinc sulphide.
(ZnS). Due to the almost infinite number of combinations of matrix, strengthening agent and lubricant the complexity rises exponentially. Numerous are the papers describing facts and figures, but scarce are the explanations of the fundamental mechanisms. Figure 4 shows the influence of different filler/lubricant combinations in PEEK with respect to the coefficient of friction obtained by flat-on-flat reciprocating experiments (specimen area 30 x 30 mm, stroke 80 mm, sliding velocity 20 mm/s, load 4/8/10 MPa, test duration 15 hours). As can be seen the same mixtures can result into different results, depending on the sliding direction with respect to the fibre orientation. A load dependency of the lubricant performance is also observed. In this particular situation the friction of PEEK could be halved from 0.4 to 0.2 by addition of a mixture of short carbon fibres (Ø 7 µm, L = 6 mm), TiO$_2$ (size 340 nm), ZnS (size 300 µm) and SiO$_2$ (size 12 µm).

![Fig. 4. Wear of PEEK against steel](image)

**Fig. 4. Wear of PEEK against steel** (specimen contact area 30 x 30 mm, stroke 80 mm, sliding velocity 20 mm/s, load 4/8/10 MPa, test duration 15 hours)

A new trend towards the use of natural fibres in PBC’s should also be highlighted. Natural fibres have some attractive properties related to environmental and energy related issues. The first one is rather obvious, the second one is attributed to the high energy consumption in the production of synthetic fibres and the high cost related to it. Diverse classes of natural fibres can be distinguished (vegetal versus animal fibres, seed hair fibres, bast fibres and leaf fibres). In order to obtain optimal structural and tribological properties natural fibres have to be adequately treated. Figures 5 and 6 show the friction and wear behaviour of unsaturated polyester reinforced with either 48 wt % of glass fibres, or 48 wt % of coconut sheath fibres against steel as a counter face. The results have been obtained with pin-on-disk experiments using hardened alloy steel (64 HRC) with Ra of 0.54 µm, sliding velocity of 3.5 m/s, load 40 N and sliding distance of 2100 m. The figures show that fibre treatment mainly positively influences wear resistance [14].

![Fig. 5. Friction of unsaturated polyester (glass fibre / coconut sheath fibre reinforced) against hardened alloy steel (load 40 N, sliding velocity 3.5 mm/s)](image)

**Fig. 5. Friction of unsaturated polyester (glass fibre / coconut sheath fibre reinforced) against hardened alloy steel (load 40 N, sliding velocity 3.5 mm/s)**

4 OPTICAL SURFACE OBSERVATION

Advanced methods of surface observation should be used to trace and quantify the formation and removal of polymer transfer films. There are many analytical techniques which can aid to understand local nature of wear process. But, a common mistake in wear studies is trying to explain the tribological influences from the local features observed in the worn surface. Hypotheses based on the local information might be rather inaccurate [15]. This problem can be efficiently solved by using reference mapping techniques (relocation profilometry or micrography) [16] [17]. Relocation micrography has been effectively used to track the evolution of surface change in both polymer and counterface material surface.

The evolution of the contact surface is understood by comparing micrographs taken at different time periods. This methodology elucidates the formation of a transfer layer on the steel surface, its partial removal and the readherence to the original polymer surface. These micrographs
are valuable for developing image processing 

tools allowing for semi-automated wear 

assessment [18] which is often followed in bio-

tribological investigations [19]. It has, however, the 
drawback of interrupting the equilibrium of the 
ongoing wear process because of the repeated 
standstill of the tribometer. Hence an advanced in-
situ monitoring technique was developed in Soete 
lab for the observation of moving surfaces at a 
micron scale resolution. This in situ microscopy 
has the capability of acquiring images at a speed of 
(35000 fps) in combination with blur estimation 
techniques. It allows to observe large wear area, 
and has been applied to a twin disc set-up.

Figure 6 shows a stitched series of images taken of 
a disk (Ø90.84 mm, width 10 mm) made of 
phenolic resin, reinforced with polyester fibres and 
filled with PTFE rotating at 200 rpm and 19% slip 
ratio against a cylindrical steel (S355-J2, Ø74.95 
mm, width 22 mm) counter surface. Careful 
examination reveals craters and cracks and multiple 
recurrent of these surface scars as a function of 
time.

5 CONCLUSIONS

This paper showed the inherent richness of 

copolymers as a tribological material. It has also been 
demonstrated that there is still a need for better 
understanding. More adequate analysis tools will 
first have to be developed in order to better follow 
wear process and wear mechanisms, in real time 
preferably. But besides these scientific need there is 
a growing demand for review research and 
comprehensively gathering dispersed scientific and 
technological data.

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**Authors addresses**

1 De Baets, Patrick, Ghent University, Department of Electrical Energy, Systems and Automation, Technologiepark 903, 9052 Zwijnaarde, Belgium, +32-9-331-04-94, Patrick.DeBaets@UGent.be

2 Kalacska Gabor, Szent István University, Institute for Mechanical Engineering Technology, Páter K. út 1, 2100 Gödöllő, Hungary, +36-28-522-949, Kalacska.Gabor@gek.szie.hu

3 Neis, Patric, Universidade Federal do Rio Grande do Sul, hent University, Laboratorio de Mecatronica e Controle, Rua Sarmento Leite, 425 - Sala 204, Centro Histórico, Porto Alegre – RS, CEP: 90050-170, Brazil, engmecpatric@yahoo.com.br

4 Sukumaran, Jacob, Ghent University, Department of Electrical Energy, Systems and Automation, Technologiepark 903, 9052 Zwijnaarde, Belgium, +32-9-331-04-75, JacobPremKumar.Sukumaran@UGent.be

5 Mátyás, Andó, PhD, associate professor West-Hungarian University, Szombathely, Hungary

6 Cotetiu, Radu, Technical University of Cluj-Napoca, North Univ. Center of Baia Mare, Faculty of Engineering, Baia Mare, str. Dr. V.Babes 62A, radu.cotetiu@cutmb.utcluj.ro

**Contact person**

1 De Baets, Patrick, Ghent University, Department of Electrical Energy, Systems and Automation, Technologiepark 903, 9052 Zwijnaarde, Belgium, +32-9-331-04-94, Patrick.DeBaets@UGent.be