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Evaluation of polymer wear assessment methods

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1. Introduction

Polymer tribology is of outermost importance for machine elements in e.g. medical devices. Controlled friction and wear are prerequisites in these to ensure dose accuracy for the safety of the patients. Most of the sliding contacts in medical devices are polymer against polymer and the tribology of such combinations has been less investigated than metal-metal or polymer-metal contacts [1].

It has been established that the friction between polymers is mainly due to adhesion as the contact pressure is low, usually less than 50 MPa, compared to metal-metal combinations which could reach GigaPascals [2,3].

Most polymer parts in medical devices are injection moulded which means that the outer layer which solidifies against the colder mould has a different morphology than the bulk material. This “skin layer” defines the frictional properties of the part and it is relatively insensitive to moulding temperature and polymer injection velocity [4].

Polymer wear is even more complicated than polymer friction as the unknown mechanisms behind this phenomenon could result in a slow removal of material or in a sudden breakdown or seizure. This makes the prediction of the lifetime of a contact very difficult [5].

In the literature wear evaluation is mainly done by weighing the pin in a pin-on-disk experiment before and after testing [6] or by measuring the dimensional change of the specimens [7]. The challenge of these methods is that a considerable worn volume is needed and this can only be achieved by a very long testing time or acceleration of the wear by increasing the load and/or the sliding velocity. The latter will result in a rapid heat buildup of the polymers due to their poor thermal conductivity. The wear then reflects the conditions in the test and not real life in medical devices. The large worn off volume will also mainly consist of bulk material and not the outer skin layer of an injection moulded specimen. Another method to evaluate wear is to scratch the polymer surface with a steel conical indenter and then to analyse the resulting wear scar [8]. Again mainly bulk material is involved and the method is not suited for polymer against polymer experiments.

In a former paper we presented a polymer wear method that permits to measure the wear over time in a polymer-polymer contact [9]. The principle is to measure the wear track width evolution between two injection moulded specimens using the Novo Nordisk Tribotester which is described elsewhere [10]. The method can

discriminate between the wear extent of different polymer pairs but the relation to practical device wear is not obvious. The aim of the present paper is to demonstrate a wear evaluation method that can be directly correlated with reality.

2. Experimental procedure and methodology

The experiments are performed in the Novo Nordisk Tribotester [10] which is shown in figure 1.

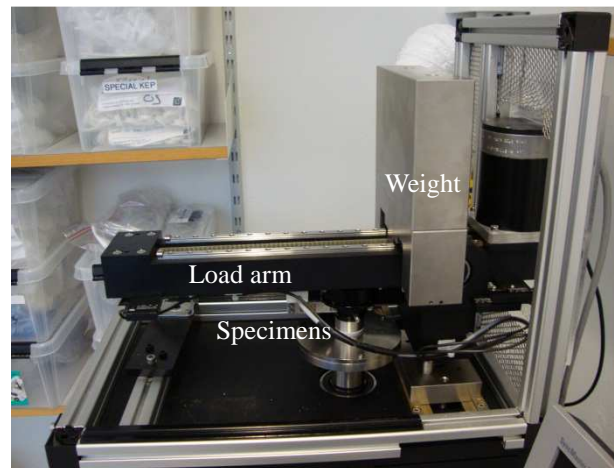


Figure 1 The tribotester: The mobile weight controls the contact pressure between the specimens.

The tribotester can slide two polymer specimens against each other with controlled sliding velocity and contact pressure. This is obtained by rotating a disk and moving a dead weight respectively.

The used specimens are injection moulded just as it is the case for most medical devices components.

A small specimen is fixed to the rotating disk as shown in figure 2.

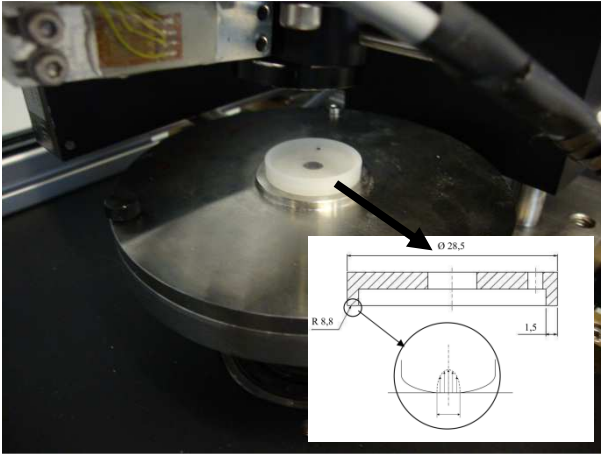


Figure 2 Small specimen in the tribotester. The specimen contact surface is curved as shown in the insert.

The small specimen has a curved surface as it can be observed in the insert of figure 2. The counter part is the large specimen with a flat surface shown in figure 3.



Figure 3 Large specimen with flat interface surface

The resulting interface between the specimens is then a line contact (a ring against a flat) for which the contact pressure can be calculated using Hertzian equations.

The tribotester setup is shown in figure 4.

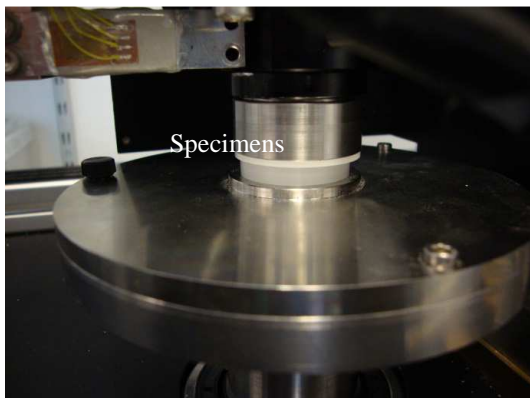


Figure 4 The tribotester setup: The large specimen is fixed and strain gauges monitor the friction torque. The small specimen is rotating.

A laser measuring device is monitoring the displacement of the load arm (see figure 1) and thereby the thickness of the specimens pair. This distance is then a measure of the wear extent of the polymer contact.

The experimental settings in the present paper have adjusted so that significant wear can be observed within the testing period without any significant heating of the polymers. A load of 387 N and a sliding velocity of 0.01 m/s have been chosen. This results in a PV (pressure-velocity) value of 0.1-0.2 MPa.m/s which is below the recommended PV value of the weakest polymers at most plastic suppliers. See e.g. [11]. The test duration is 12 hours, about a factor of three longer than the average operational time for a durable medical device. To make sure that the frictional heating does not influence the result significantly, a test break of three minutes is performed for every half hour running.

3. Results and discussion

The used materials are listed in table 1.

Table 1 The polymers used in this paper.

Material name	Youngs Modulus (MPa)	Strength at yield (MPa)
POM (Polyoxymethylene)	2850	64
PBT (Polybutylene terephthalate)+32% mineral fill	5800	50 (at break)
Polypropylene (PP)	1650	28
Tribologically modified POM (with silicone oil)	2450	55

The materials listed in table 1 are all commercially available.

It has been chosen to present two sets of measurements. One pair with unfilled materials: PP against POM, both as large and small specimens and tribologically modified POM against PBT with 32% mineral fill also present in both sorts of specimens.

Figure 5a) shows the wear evolution between POM (small specimen) and PP (large specimen). The blue lines are the noisy signal of the laser and the red line is an averaged presentation. The horizontal line indicates the distance when the curvature of the small specimen (see figure 2) is completely immersed into the large specimen.

Figure 5b) shows the coefficient of friction (CoF) as a function of test time. The CoF is the friction force divided by the load.

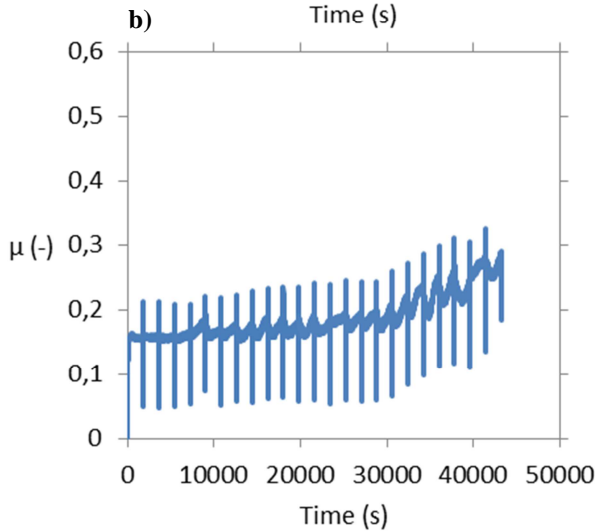
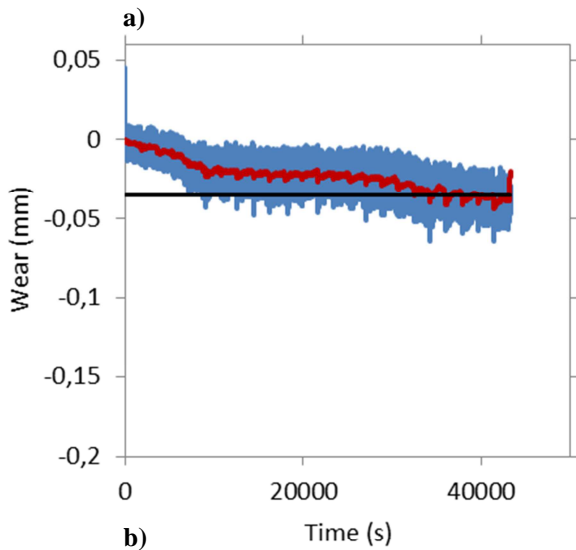


Figure 5 The wear (a) and friction (b) evolutions of a pair consisting of an unfilled POM (small specimen) against an unfilled PP (large specimen). For details see text.

In figure 6 the POM and PP are inverted with respect to specimen configuration.

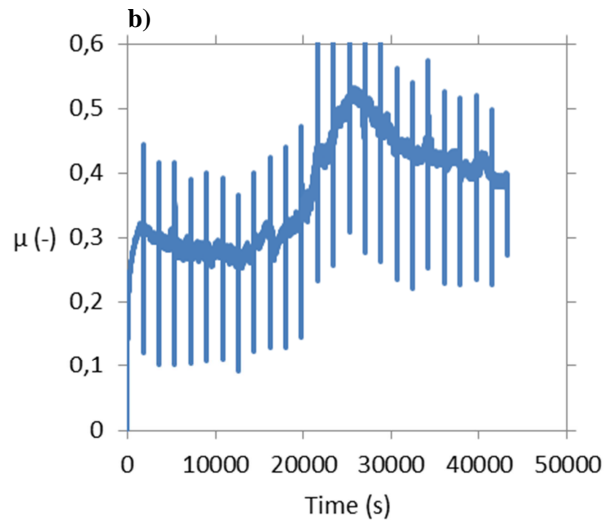
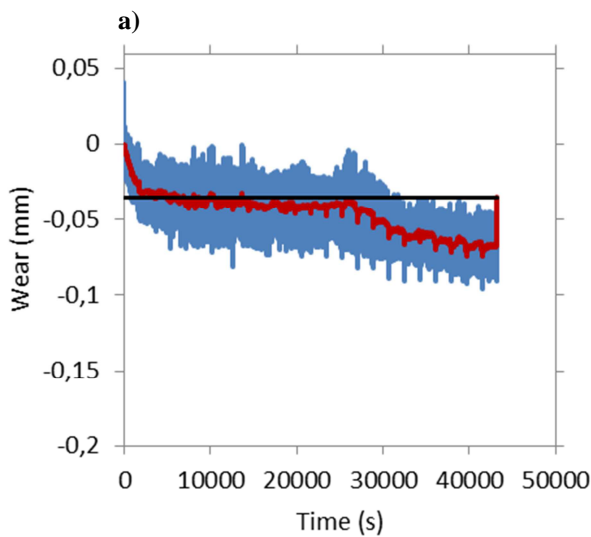


Figure 6 The wear (a) and friction (b) evolutions of a pair consisting of an unfilled PP (small specimen) against an unfilled POM (large specimen)

In figure 7 the PBT with 32% mineral fill (small specimen) is sled against the tribologically modified POM (large specimen).

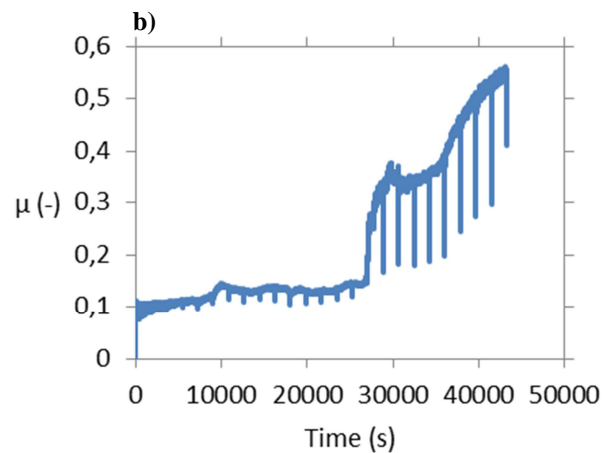
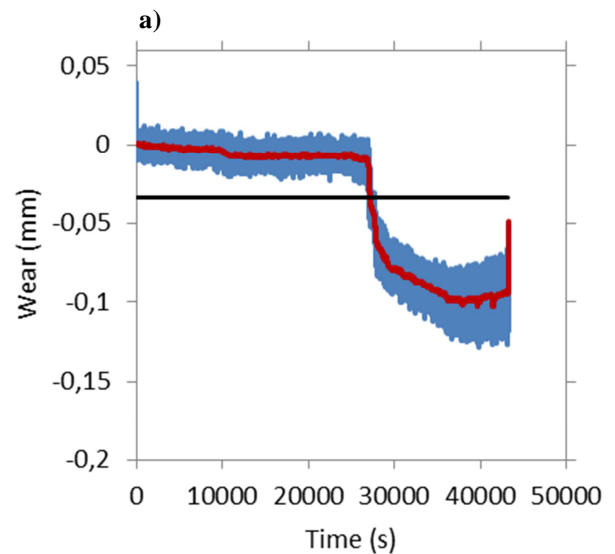


Figure 7 The wear (a) and friction (b) evolutions of a pair consisting of a PBT with 32% mineral fill (small specimen) against a tribologically modified POM (large specimen)

In figure 8 the tribologically modified POM is now the small specimen and the large one is PBT with 32% mineral fill.

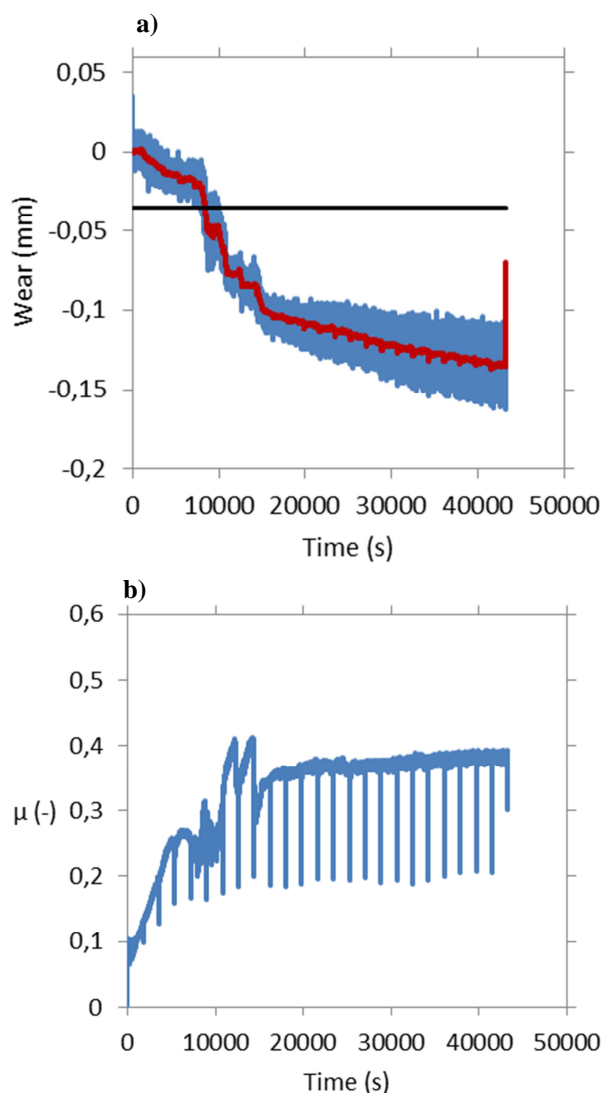


Figure 8 The wear (a) and friction (b) evolutions of a pair consisting of a tribologically modified POM (small specimen) against a PBT with 32% mineral fill(large specimen)

It is clear that the specimen configuration plays a significant role in the wear result. Especially in the case of the filled polymers, the large specimen should have the highest lubricity. If the materials are inversed the expected lifetime is divided by three. In the case of the unfilled polymers the difference is less visible but PP is the best candidate for a large specimen. This phenomenon is also valid for friction measurements. The large specimen should be tribologically the best material as its contact area to the small specimen is larger than the smaller area due to variations in the dimensions of the specimens. They are all moulded in the same mould so there is differences for reasons of warpage and shrinkage.

The wear progress seems to have three phases which are different in the measured combinations. The first phase could be slow (figures 5 and 7) or fast (figures 6

and 8). The second phase can also be slow (figures 5 and 6) or fast (figures 7 and 8). The third phase is in all cases a leveling out. From a practical point of view it seems that the first phase is the most important, this is the behavior in devices within normal lifetimes. Based on this the PBT with 32% mineral fill as small specimen against the tribologically modified POM as large one gives the longest lifetime in this test series.

Is the method reliable? The method likely renders the most useful results as the overall dimensional change in the polymer pair includes the role of third-bodies and material transfer between the specimens. A measurement of the specimens individually would not include these effects.

4. Outlook

The idea of measuring the overall thickness of polymer specimens during sliding provides new insights to the wear resistance of polymers. The role of specimen configuration has been discussed as well as the wear phases. These results give inputs to the designers who should keep in mind that the right location of a component could multiply the lifetime by three.

An increase in the number of measurement can be expected soon.

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