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IN INDUSTRIAL SYSTEMS

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Abrasion Testing of PA 6, POM and PET Composites in Small Scale Tribology Model System

L. Zsidai[1], G. Pistai[2], R. Keresztes[1], R. Cotetiu[3], O. Eberst[4]

Abstract: *Our present work is connected to a research project, what aims at mapping the tribology features of different polymer composites (PA 6, POM, PEEK etc.). In this paper, we analyse the friction and the wear of PA 6, POM and PET composites with the accomplishment of abrasion small scale tribo tests. The tests were carrying out with different load (11,5N and 23N) relations. We used emery-(grinder)-cloth to produce the abrasion mating surfaces in a special test rig. The friction tests were prepared in pin on plane model system, where the friction force and the wear were continuously measured. This special tribology test system is extremely suitable to investigate the abrasion wear in continuous "one-way" sliding motion.*

Keywords: *abrasion, engineering polymer, friction, wear, small scale, PA 6, POM, PET*

1 INTRODUCTION

The abrasion is the most common wear type in the industrial practice. It is created all places, where rigid particles can go between the sliding surfaces (like in dusty work zone), the surface roughness is high, the hardness of the sliding elements is very different or the machine works with abrasion material. The abrasion wear is caused by sharp and rigid particles or peaks of roughness, that wear gaps are created the scratch (cut) of the surface. The particles what go away from the gaps will be the wear.

Several literatures deal with the base mechanism of the abrasion wear [1], [10], [5], [4] and the abrasion features of the polymers [11], [3], [2], [7], [8].

The abrasion friction test instruments develop parallel with former ones. These rigs are present on the technical market like a professional product [9], and in the research centres with unique making [6] also.

We have to close the abrasion effect to increase the lifetime (for example: efficient seals and optimally smooth surfaces). If it is not possible perfectly (heavy dust circumstances, like agriculture, building and mine industry) we have to use tough materials or coatings with high strength to reduce the abrasion wear.

As a solution for the former problem, we can use the elastic engineering polymers and their composite because they have good deformation ability.

The sliding surface remains in elastic condition about perfectly at abrasion wear of polymers. Despite the metals, where the cutting is the most important abrasion process, in case of the polymers the tearing-sheller effects are dominant.

Composites created from base polymers can be used to except the negative qualities or produce new ones.

The present paper describes the linear abrasion friction measurements of the different polymers on emery cloth using a pin-on-plate test apparatus with one-way continuous motion. No external lubricants were added to the tribological system.

The selected polymers were investigated with respect to friction and wear characteristics. The selection was based on a base polymer and different composites as applied by manufacturers and users. Among many types of polyamides (PA), three PA were tested (PA 6 E reference, PA 6Mo, PA 6G ELSG). Also polyacetals such as polyoxymethylenes (POM-AD AF and POM AH LA), and polyethylene (PET TF) were included in the experiments.

Let us shortly mention the most important results from the literature what are connected to the abrasion behaviour of the tested polymer groups:

Seabra and Baptist [12] investigated the abrasion behaviour of the PA 6, PETP and POM-C. They described the higher friction of the PA 6 than PETP and POM-C. In their work the PETP was a little favourable than POM-C in view of the friction. The wears of PA 6 and POM-C were similar, but in case of PETP was significantly smaller.

In opposite with the formers Yamaguchi [16] described the bigger wear of the POM via polyamide. Kislinder and Kozma [6] investigated the POM and different polyamide composites all in the adhesion all in the abrasion systems, where they found a worst wear resistance of the POM among all tested materials.

The main objectives of our investigation are comparison of friction and wear behaviour of different engineering polymer composites and determination of optimal operational conditions of the selected polymers.

This article aims to be helpful to the selection of a proper polymer for a given operational condition.

2. EXPERIMENTAL PROCEDURE

2.1. Apparatus

The experimental set-up as pictured in Figure 1, is an unique building abrasion tribotester.

The detailed figure shows that continuous sliding friction is created by a polymer cylinder (1), which moves against a lower emery cloth (2) in conformal contact. The polymer specimen is fixed to the fixture (3) by a nut, preventing it to roll during the test and thus simple sliding is guaranteed. The continuous one-way motion of the emery clothe is provided by a controlled variable speed motor (4) through a twin roll power transmission (5) for the produce the sliding motion. The abrasive emery cloth is tightened to a driving roll pair, and the friction contact

is placed between these in the middle position. Under the moving slide is placed a metal plate, therefore the contact abrasive surface will be a plane.
The machine is equipped with a manual loading system (6), which consists of a plate (7) and a vertical column (8), mechanically pulled down by loading weights (9). A head (load-cell) with strain gauge stamps (10) is used to measure the friction force. The normal displacement of the cylindrical specimen towards the steel plate, as a result of the wear, is measured by a linear gauge (11).
The more detailed close-up of the equipment (lower) shows the manually load system and the special form of the measure head.

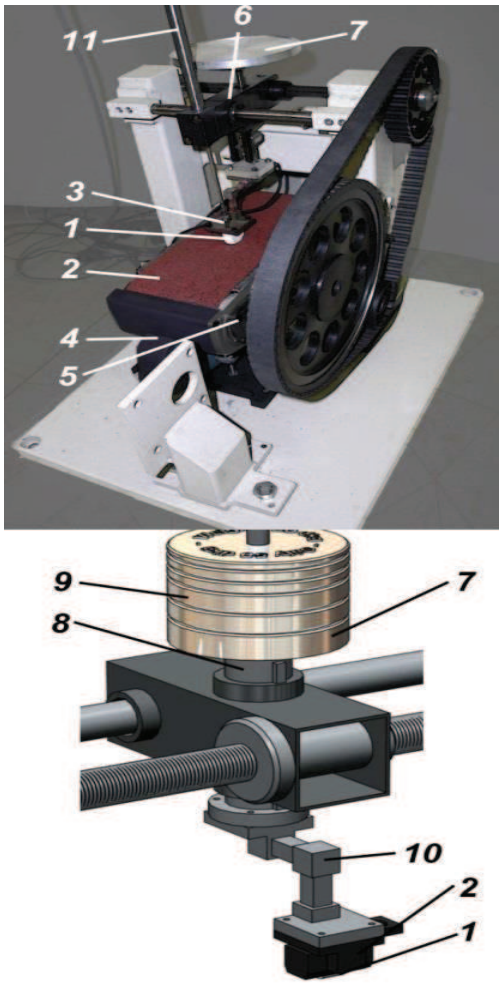

Fig. 1. *Abrasion testing equipment : (1) polymer specimen; (2) emery cloth; (3) nuts and clamp; (4) electrical motor; (5) twin roll driving system; (6) fixed steel plate; (4) nuts and clamp; (5) load distributor; (6) manual loading system ; (7) plate; (8) vertical column ; (9) weights; (10) load-cell; (11) linear gauge;*

2.2 Test conditions

All experiments are performed at ambient conditions of temperature and humidity (30°C and 50%RH). The various conditions of the performed small-scale tests are gathered in Table 1.

Table 1. *Parameters of tests*

Parameters	**Values**
Type of the emery-cloth	DEER XA167AA-100
Running time, t (sec)	300
Normal load, F_N [N]	11,5 and 23
Perimeter of emery-cloth [mm]	610
Velocity, v [m/s]	0,042
Total sliding distance [m]	12,5
Humidity, RH [%]	50
Ambient temperature, T (◦C)	30

Tests are conducted with normal load: 11,5N and 23N. The running time (300 sec.) of the tests is chosen for to observe the wear value and the first (running in stage) period of the friction. For each test, the surface roughnesses of emery-cloth were given by the type of abrasive DEER XA 167 AA-100. The tribological data described below result from an average of three runs with identical experimental parameters.

Materials and preparation of test specimens

The selection of the tested 5 polymers and composites was made on the database of polymer producers, end-users and expertizing companies at this field. The finally selected engineering polymer materials can be taken as generally used engineering materials in the industry in sliding adhesion and abrasion systems. Some of the like polyamides are well-known but some composites are just being spread.
The materials can be divided to two main composites groups. One of them is with PA6 and the other is with POM base matrix are included in the experiments. In addition to the foregoing I was tested other polymer (PET).

Material of the mating plate

The counter plates are abrasive industrial emery cloth. The type of abrasive is DEER XA 167 AA-100. It was choose for the most typical abrasion effect of the industry. The grain type of the grinder is Aluminium-Oxide and the bonding resin over resin. [13]

Table 2. *Mechanical and physical properties of the tested polymers [14], [15]*

Material code	**colour**	**density [g/cm^3]**	**Tensile strength at yield/ Modulus of Elasticity [MPa]**(1)
PA 6E	black	1,14	80/3200
PA 6G ELS	black	1,15	90/3400
PA 6MO	black	1,16	80/3400
PET TF	grey	1,44	75/2800
POM AH LA	blue	1,36	48/2100
POM AD AF	black	1,54	50/2900

(1) Values referring to material in equilibrium with the standard atmosphere 23 ◦C/50% RH

Materials of the polymer cylinders

Table 2 gives an overview of the properties of the tested engineering plastics. Among these properties the E-modulus can be used to characterise the adhesion friction component, since it is correlated with the chain flexibility. Besides, the deformation ability is determined by tensile stress and strain, since their product is equivalent to the work of rupture and the material's toughness.
Let's see the short description of the tested polymers [14]; [15]:

- The polyamides PA 6E of the extruded type, were used as a reference material in the investigations. This polyamide is strategic engineering plastics for many years all over the world, thanks to the favourable performance / price ratio. It offers a favourable combination of strength, toughness, mechanical damping ability and wear resistance. The product can be regarded as a polyamide type "for general use".
- The PA 6G ELS is the conductive version of magnesium catalysed cast polyamide 6.
- In comparison the PA 6MO (PA 6E+MoS2) with the PA 6 E material, it has a higher degree of strength and rigidity due to the molybdenum disulphide (MoS_2) content. Its heat and wear resistance are better, but its toughness and mechanical damping ability are worse. It can be readily machined with automatic cutting machines.
- PET TF grey is a material featuring an added solid lubricant with extremely good sliding friction properties which can also be used in the food processing sector. Through the addition of PTFE as a solid lubricant, the material demonstrates excellent sliding properties and low wears behaviour alongside the familiar excellent properties of natural PET.
- POM AH LA blue is a material benefiting from an added solid lubricant. The addition of solid lubricant improves the sliding friction properties and wear behaviour compared to natural POM AH. However, the addition of lubricant compromises the strength and hardness of the material. The conveyor technology, the automobile industry, electronic equipment and precision instruments are used.
- POM AD AF natural is a POM homopolymer with special PTFE fibres designed to optimize the material's sliding friction properties. The fibres are homogenously distributed in the material and result in an improved slide-friction coefficient and abrasion resistance coupled with minimal susceptibility to stick-slip effects... Application area: Engineering, automotive, transport and conveyor technology, electronics, precision mechanics, medicine.

The original forms, colours and dimensions of the small-scale specimens are included in Figure 2. The polymer cylinder has a diameter of 8 mm and length of 10-15 mm. The cylindrical specimens are in conformal connection with the abrasive (emery-cloth). The components of composites are homogenously spread in the bulk of polymers.

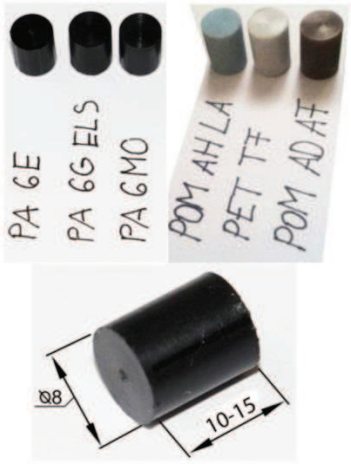

***Fig. 2**. Original form and dimensions of the tested polymers and composites.*

3 TEST RESULTS AND DISCUSSION

3.1. General

Friction and wear results of the small-scale abrasion tests for both load categories (11,5N and 23N) are described in this section. For the correct interpretation of the graphs and tables mentioned below, the following annotations are emphasised:
Column charts. The dynamic and the maximum friction coefficient are represented in Figure 3 and Figure 7. For each material, the first column refers to maximum value of the friction and the second one refers to dynamic friction coefficient. The wear is represented in Fig. 8. For each material the first column refers the wear value of the lower load (11,5N) and the second one refers the wear of the higher load (23N) tests. All values are averaged from three test runs with identical parameters.
Dynamic friction characteristics: The real friction curve as a function of sliding distance is shown in Figures 4-6 and Figures 8-10 for a given load and emery-clothes. For some example polymer, only one typical curve of the three runs is shown to reveal the differences in friction behaviour, during the running-in stage and steady state regime.

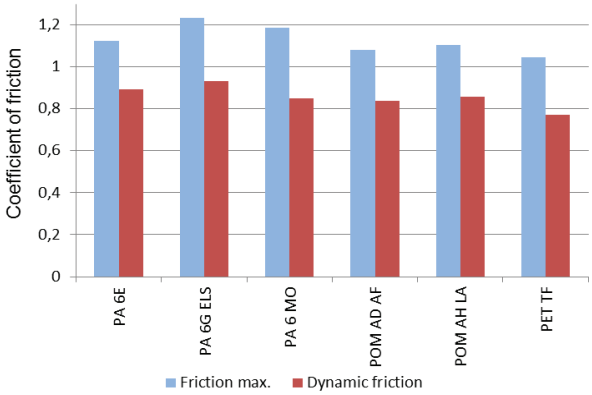

***Fig. 3**. Dynamic friction coefficient (dark) and its maximum value (light) for different materials at lower 11,5N load*

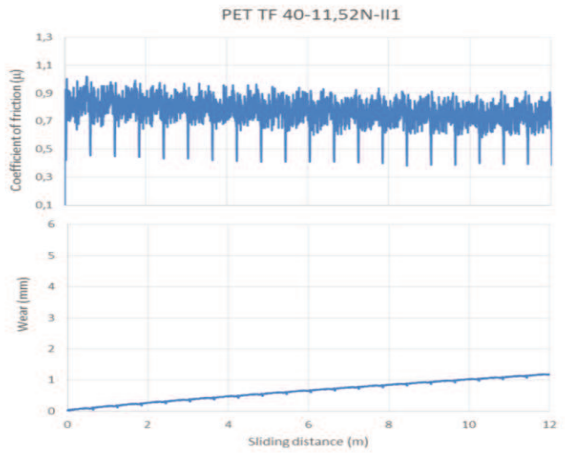

Fig. 4. *Dynamic friction characteristic of PET TF against emery clothes at 11,5N load*

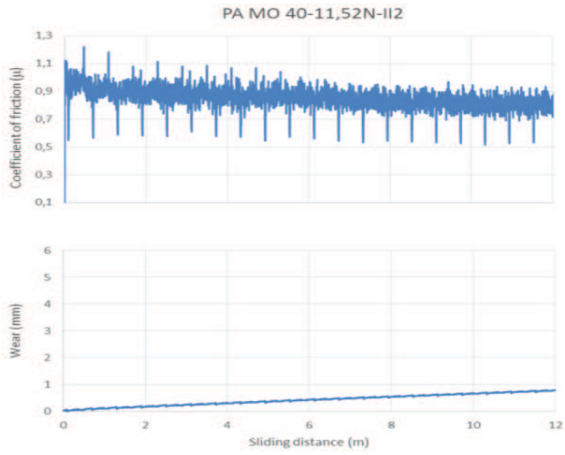

Fig. 5. *Dynamic friction characteristic of PA 6 Mo against emery clothes at 11,5N load.*

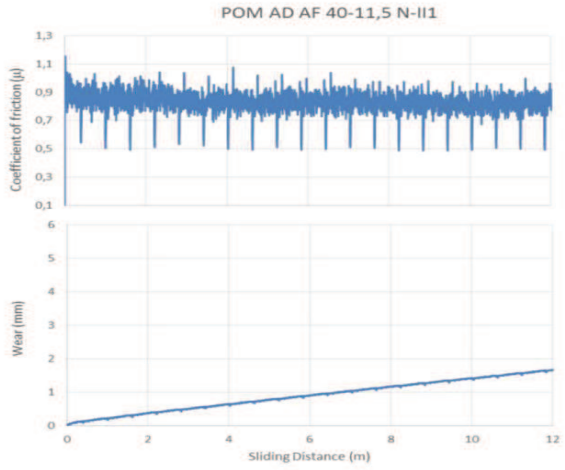

Fig. 6. *Dynamic friction characteristic of POM AD AF against emery clothes at 11,5N load.*

3.2. Lower load (11,5N) test category

Figures 3-6 show the dynamic and maximum friction coefficient of polymers tested under the lower 11,5N loads.

- From the point of view of friction, PET TF is most favourable and seems to have the lowest values over the total sliding time. However, on abrasive surfaces (Figure 4) its value is not constant but shows a slight decrease during the running-time.
- The friction behaviours are very similar for both POMs (AD AF and AH LA). The Fig. 6 shows the friction and wear curves of POM AD AF what are very stable during the test.
- PA have higher friction coefficient and wear rate than the previous three polymers. PA 6 Mo (Fig. 5) shows better sliding properties than PA 6E and PA 6G ELS. This behaviour is interest, because of it is opposite to the effect of molybdenum addition (it would mean a bigger toughness). The highest friction is presented by PA 6 ELS among all tested polymers in lower load category.

3.3. Higher load (23N) test category

With the application of higher (23 N) load, the dynamic friction coefficients and maximum friction of the polymers are represented in Figs. 7–10.

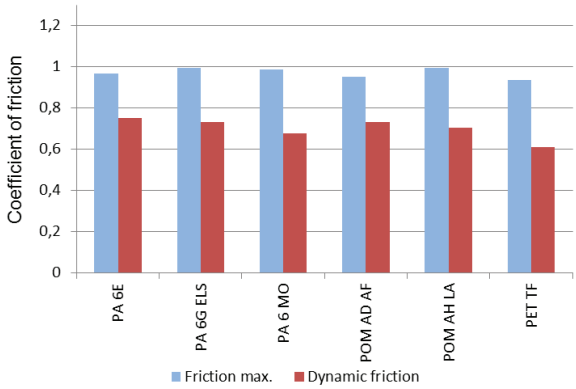

Fig. 7. *Dynamic friction coefficient (dark) and its maximum value (light) for different materials at 23N load.*

Comparing Figure 3 and Figure 7, it appears that under high loads globally the friction coefficient is lowered.

- PET TF has the lowest friction coefficient under higher load (similar to lower load also).
- PA 6 Mo (Fig. 9.) shows better sliding properties than PA 6E and PA 6G ELS similar to the case of the lower load category. It value is not constant but shows a slight decrease during the running-time.
- PA 6 E and PA 6 G ELS still show the worst results in connection to dynamic friction coefficients among the tested polymers.
- The dynamic friction coefficient of the POM AD AF is high and very close to the previous polyamides.
- In case of POM AH LA the friction is lower than in case of POM AD AF. This range is converse between these POMs than it was in lower category. The fig. 8 shows the friction and wear curves of POM AD AF what is very stable during the tests.

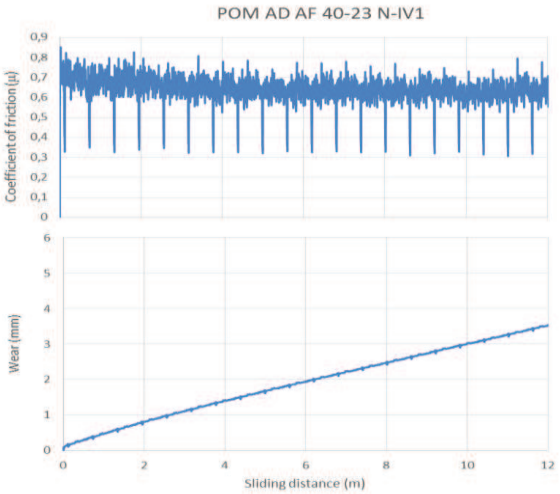

***Fig. 8**. Dynamic friction characteristic of POM AD AF against emery clothes at 23N load.*

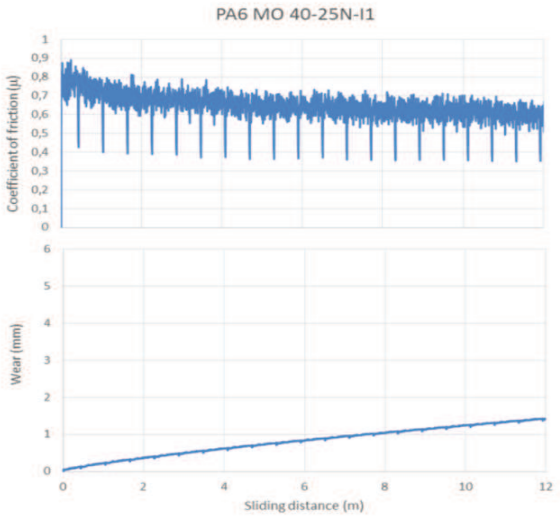

***Fig. 9**. Dynamic friction characteristic of PA 6 Mo against emery clothes at 23N load.*

3.4 Comparison the wear between the different load categories

It is clear that the effect of adhesion decreases with increasing load and increasing surface roughness. Now in our case abrasion becomes more important. The abrasion wear results of the tested polymers are shown in the Fig. 10 for both load categories.

Let's see a comparison between these results. It can be observed from figure that the higher load has increased proportional (~1,8 times) the wear of most of them polymer composites.

- But in case one of them, (POM AD AF) we can see bigger differences between the wear results. The wear is measured at higher load will be more then 2,2 times than measured at lower load. This POM is more sensible against the different loads.
- PET TF has a middle wear results close to POM AH LA. It can be observed from wear result that PET TF and POMs have reduced deformation ability, due to the higher tensile stress and lower strain at break. They are said to be more rigid. On the other hand, the higher elasticity modulus can cause a lower surface energy, expecting less sticking and a lower friction coefficient in opposite to PA in adhesion friction. But in our case in abrasion friction the rigid behaviour of PET and POMs can cause a higher value of the wear in opposite to PA.
- The polyamides show the better wear results among tested polymers, according to the low elasticity modulus of this polymer. Since for soft materials (reflected by a low elasticity modulus) the flexibility of the polymer chains is enhanced, transfer can occur more strongly. The PA 6E and PA 6G ELS have the best wear results.

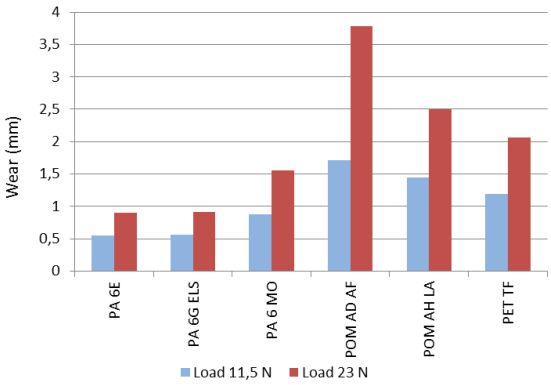

***Fig. 10.** Wear values for different materials in load category both (light colour to 11,5N and dark colour to 23 N)*

Fig. 11 shows some different polymer films, which are studied after the test by the aid of digital camera. The forms and percentages of mostly polymer phases (wear particles) on the surface give informations about the effect of the friction between abrasive surface and tested polymers.

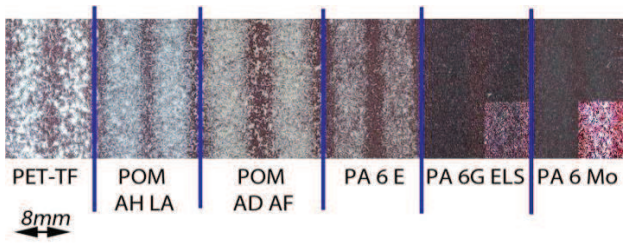

***Fig. 11**. Different wear tracks on the emery cloth (two little segments for the PA 6G ELS and PA 6 Mo are filtered because of better visibility)*

- In case of PET TF, non-continuous plastic layers cover the surface with several large and bitty wear particles.
- For both POM, the polymer film is thin and a more or less homogenous track is observed.
- The less and most thin transfer layer are shown by polyamides, it is good correlations them favourable wear properties.

According to generally accepted friction models, two mechanisms contribute to the friction force between a thermoplastic and steel: adhesion in the contact zone and deformation of the polymer [3, 5]. Their relative contribution depends on the load level as well as on the chemical, mechanical and geometrical properties. On rough surfaces the deformation component increases in our case.

4 CONCLUSIONS

Although the used abrasive pin-on-plate test rig is not able to provide absolute data representative for actual applications, the abrasion tribological behaviour of different polymers can be compared successfully and correlated to materials properties.
The experimental data suggest the following conclusions:

- There is a general rule that the dynamic friction coefficient decreases with increasing contact load.
- There is a general tendency that wear is found to be 1.8 times higher at double load.
- PET TF has the lowest friction coefficient in both load categories.
- The polyamides have a good abrasion wear resistance in connection their increased deformation ability, but their friction coefficients are higher than the more „rigid" polymers (PET and POM).
- The POM AD AF shows individual wear properties. This polymer is more sensitive onto the change of the load in opposite with other tested polymers.

For practical use:

- Polyamides are suitable as machine elements in abrasion, as they resist again abrasion wear with relatively slow sliding speed as they worse friction properties.
- PET and POMs are not so suitable for application with abrasion wear. Their wear results are higher than polyamides; they could be more suitable for adhesion sliding systems with smoother surfaces.

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