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Abrasive wear and abrasion testing of PA 6 and PEEK composites in small-scale model system
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Abrasive wear and abrasion testing of PA 6 and PEEK composites in small-scale model system

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Abstract: Abrasion is the most common and aggressive type of wear in industrial practice. As a solution we can replace original metal components by up-to-date engineering polymer composites. However, it is not so easy to choose from the wide choice of polymers (mechanical properties, price, etc.), therefore we investigated two polymer composite groups (PA 6 and PEEK) with different mechanical properties and price. The main objective of our study was to compare the tribological properties of different PA 6 and PEEK composites, based on the results of different laboratory friction model tests. Also we wanted to investigate the effect of different additives against abrasive surface. 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 (band) model system, where the friction force and the wear were continuously measured. Our present work is connected to a research project, which aims to map the tribological features of different polymer composites.

Keywords: abrasion, PA 6, PEEK, friction, tribology

1 Introduction

Abrasion is the most common type of wear in industrial practice. It means, that micro-roughness's of the harder counter body plough through softness's on the other, removing material by micro cutting or micro cracking, so the wear is caused by sharp and rigid particles or peaks of roughness. The wear gaps are created the scratch (cut) of the surface. The particles which go away from the gaps are called the wear. Abrasive wear can occur in 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. Briscoe and Sinha [3] mentioned that the Cohesive wear results from surface and subsurface deformations caused by the harder asperities of the counterface. Abrasion and fatigue wear processes are termed, 'cohesive wear'.

We can use machine elements and technologies to the reduce the abrasion (for example: efficient seals and optimally smooth surfaces), but if it is not possible perfectly (heavy dust circumstances, like agriculture, building and mine industry) we have to use tough or elastic materials or coatings with high strength to reduce the abrasion wear. Because of the good deformation ability of polymers and composites, they can be chosen as sliding material in abrasive applications of machine construction. The sliding surface remains in elastic condition almost perfectly at abrasion wear of polymers. Despite the metals, where the cutting is the most important abrasion process, in the case of polymers the tearing-sheller effects are dominant. Composites created from base polymers can be used to avoid the negative qualities or produce new ones.

Several publications deal with the base mechanism of the abrasion wear [7,8,15] and its role in machine industry applications [25] and the abrasion features of the polymers also [9,13,16,27].

The abrasion friction test instruments develop parallel with former ones. Several standards (ASTM, DIN and ISO) deal with the abrasion tests of the polymers: ASTM D1242 standard test method for resistance of plastic materials to abrasion [11], ASTMD 3389 for coated fabrics (rotary platform, double-head abrader), ASTM G 75 for determination of slurry abrasivity (miller number) and slurry abrasion response of materials (SAR Number) and ASTMG 132-96 for pin abrasion testing. DIN 52 347 testing of glass and plastics and DIN 53 516 testing of rubber and elastomers. ISO 4649 for rubber, vulcanized or thermoplastic using a rotating cylindrical drum device and ISO 5470-1 for rubber – or plastics-coated fabrics and ISO 23794 rubber, vulcanized or thermoplastic [33]. These rigs are available in the technical market like a professional product [30], and in the research centres with unique making [6] also.

The present paper describes the linear abrasion friction measurements of the different polymers on emery cloth using a pin-on-plate (band) test apparatus with one-way continuous motion (modeling most applications well, for example: sliding bearings, V-belt, gears). 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. We selected two polymer groups with special characteristics, significantly different between their mechanical properties and prices. Among many types of polyamides (PA), four PA were tested (PA 6 E reference, PA 6MO, PA 6G ELS, PA 6GLIDE), and the relatively expensive PEEK (Poly-Ether-Ether-Ketone) such as base and composites (PEEK PVX and PEEK GF30) which are widely used nowadays (f.e. medical implants, industrial sealings) were included in the experiments.

Many results can be found in the literature, which are connected to the mechanical and abrasion behaviour of the tested polymer groups. The polyamides 6 are well known polymers [26,24,40], therefore we will give a short overview mainly about the mechanical and tribological properties of PEEK composites.

Several literature datas are connected with the mechanical properties of PEEKs. We emphasize among these papers Swallowe's work [12], which describes the modulus of elasticity and the tensile strength at yield increase due to increasing crystallisation but at the same time strongly decrease the elongation at rupture in case of PEEK. The author writes about the water absorption also which can cause a plasticising effect in some polymers (e.g. Nylon) with a resultant reduction of modulus and strength [10]. Briscoe and Sinha [4] consider that the data for amorphous polymers (f.e. PMMA) do not show any dependence of hardness with the depth of indentation whereas those for crystalline polymers (PEEK and PA 6) show a small decrease in the hardness with the depth of indentation. This may be due to the presence of a transcrystalline layer on the outer surfaces of the crystalline polymers.

More authers [33,2] wrote, that the friction coefficient of PEEK decreases with increasing temperature, passes through an optimum point (around the glass-transition temperature at 143 °C) and then increases slightly. Shao et al. [39] and Wang et al. [32] found that micro- and nanosized abrasive (SiO2) fillers in PEEK provided lower wear rates and lower coefficients of friction than the unfilled polymer and he reported also [31], that nanoparticles of ZrO2 as the filler were effective in reducing the wear rate of PEEK.

The literature [28,29,35] shows a wide variety of different fillers available like solid lubricants for reducing friction, reinforcing fibers for high mechanical strength or hard particles for abrasion resistance. In the literature we can see that the addition of carbon fibre (CF) to polymers resulted in increased hardness, tensile and flexural strength [17] and increased glass transition temperature [18]. Unlubricated sliding wear behaviour of short glass fibre (GF) and carbon fibre (CF) reinforced PEEK have been investigated by Voss et al. [14] and Friedrich et al [22,23]. They concluded that short carbon fibres proved better for improving wear resistance as compared to short glass fibres, but this trend can change under certain "pv limit" (contact pressure multiplicity sliding velocity) conditions.

To create a continuous transfer layer, solid lubricants, like graphite and PTFE are commonly used [1,19]. More investigations describe that the 10-25 wt% of PTFE give an optimal wear resistance and minimum frictional coefficients for the PEEK composites PTFE [5,34,41,42]. However other paper points at important effects of the filling manner of PTFE, where the wear rates obtained from the inclusion of expanded PTFE filaments were better than conventional powder filled PTFE–PEEK composites. [20]

Friedrich and Alois K. Schlarb [21] refer to the tribological differences between PEEK and PA 6. They emphasize that for the low wear rate of PEEK mates a relative higher friction coefficient, but in case of the PA 6 the both properties are low. For PEEK, the role of nanoparticles is to increase the load-bearing capacity of the material and thus the actual contact area is reduced leading to lower frictional stress for the nanocomposite.

The main objectives of our investigation are comparison of friction and wear behaviour of different PA and PEEK 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 Fig. 1, is a 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 nuts, preventing it from rolling during the test and thus simple sliding is guaranteed. The continuous one-way motion of the emery cloth 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 vertical column and the linear gauge with supporting spindles are built in the console head (12).

The more detailed close-up of the equipment (upper-center) shows the manual load system and the special form of the measure head.

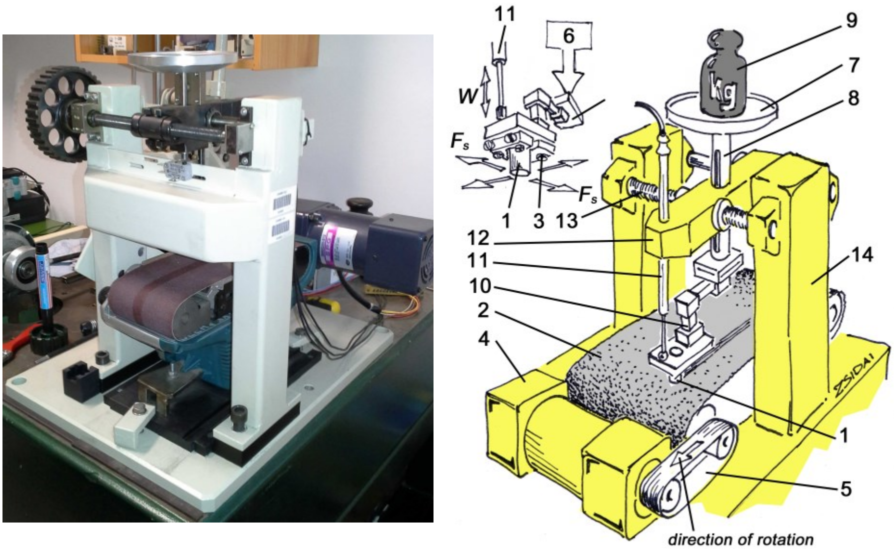

Figure 1

Abrasion testing equipment (photo and schematic view):

(1) polymer specimen; (2) emery cloth; (3) nuts and clamp; (4) electrical motor; (5) twin roll driving system; (6) manual loading system; (7) plate; (8) vertical column ; (9) weights; (10) load-cell; (11) linear gauge (for vertical displacement as a result of wear); (12) console head unit; (13) spindle for cross movement (it wasn't used for present tests)

2.2 Test conditions

All experiments were performed at ambient conditions of temperature and humidity (25°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)	240
Normal load, F_N [N]	11,5 and 23
Perimeter of emery-cloth [mm]	610
Velocity, v [m/s]	0,05
Total sliding distance [m]	12

Humidity, RH [%]	50
Ambient temperature, T (◦C)	25

Tests were conducted with normal load: 11,5N and 23N. The running time (240 sec.) of the tests were chosen in order 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 6 polymers and composites were made by cutting with a diameter 8mm and a length 10-15mm. The materials can be divided into two main composites groups. One of them is with PA6 and the other is with PEEK base matrix are included in the experiments.

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. [36]

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.

Table 2

Mechanical and physical properties of the tested polymers [37], [38]

Material code	colour	density [g/cm^3]	Tensile strength at yield/ Modulus of Elasticity [MPa]$^{(1)}$
PA 6E natural	black	1,14	80/3200
PA 6G ELS	black	1,15	90/3400
PA 6MO	black	1,16	80/3400
PA 6 Glide	green	1,13	76/3200
PEEK natural	beige	1,31	116/4200
PEEK PVX	black	1,44	84/5500
PEEK GF 30	yellow	1,53	105/6400

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

Let's see the short description of the tested polymers [37]; [38]:

- The extruded type polyamide PA 6E were used as a reference material in the investigations. This polyamide has been a strategic engineering plastic 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 6E 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.
- PA 6 Glide is a hard semi-crystalline cast thermoplastic with lubricant addition. It has a good sliding properties, wear resistance and better tensile strength and machinability than PA 6E. Typical applications: gears, rollers, cable rollers, universal material – wherever there are no special requirements.
- Natural unfilled PEEK (polyetheretherketone) is a semi-crystalline advanced material exhibits a unique combination of high mechanical properties, temperature resistance and excellent chemical resistance. The main properties are a high service temperature (permanently around 250 °C, briefly to 310 °C can be used), high mechanical strength, stiffness, excellent chemical, hydrolysis, wear resistance and good dimensional stability.
- PEEK PVX is a real bearing grade. It is filled with carbon fibres (CF), PTFE and graphite.
- PEEK GF30 composite contains 30% glass fibre (GF) reinforced for greater dimensional stability and higher strength properties.

The original forms, colours and dimensions of the small-scale specimens are included in Fig. 2. The polymer cylinder has a diameter of 8 mm and length of 10-15 mm.

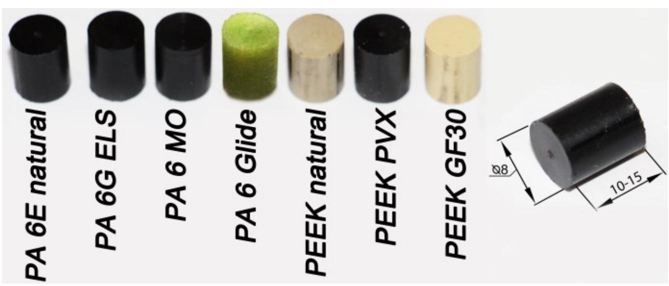

Figure 2

Original form and dimensions of the tested polymers and composites.

The cylindrical specimens are in conformal connection with the abrasive (emery-cloth). The components of composites are homogenously spread in the bulk of polymers.

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 Figs. 3 and 5. For each material, the first column refers to maximum value of the friction and the second one refers to dynamic friction coefficient. The white arrow marks the instable tendency (slowly growing, slowly decreasing). The wear is represented in Fig. 7. For each material the first column refers to the wear value of the lower load (11,5N) and the second one refers to 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 Fig. 4 and Fig. 6 for a given load and emery-cloths. 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. It has to be mentioned, that the periodically repetitive more or less similar instabilities can be seen on the curves at the joint of the emery clothe bands, they appear caused by it.

3.2 Lower load (11,5N) test category

Figs. 3-4 show the dynamic and maximum friction coefficient of polymers tested under the lower 11,5N loads.

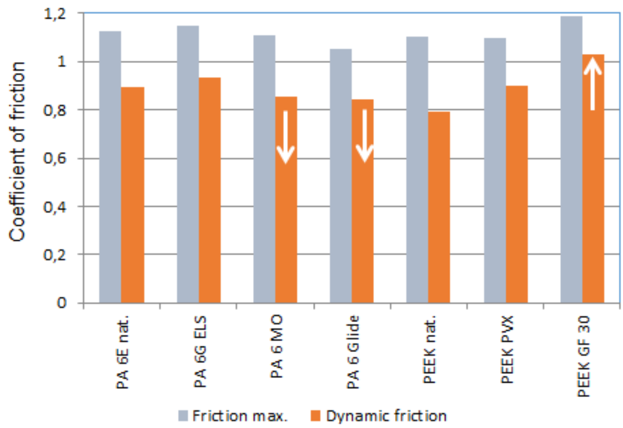

Figure 3

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

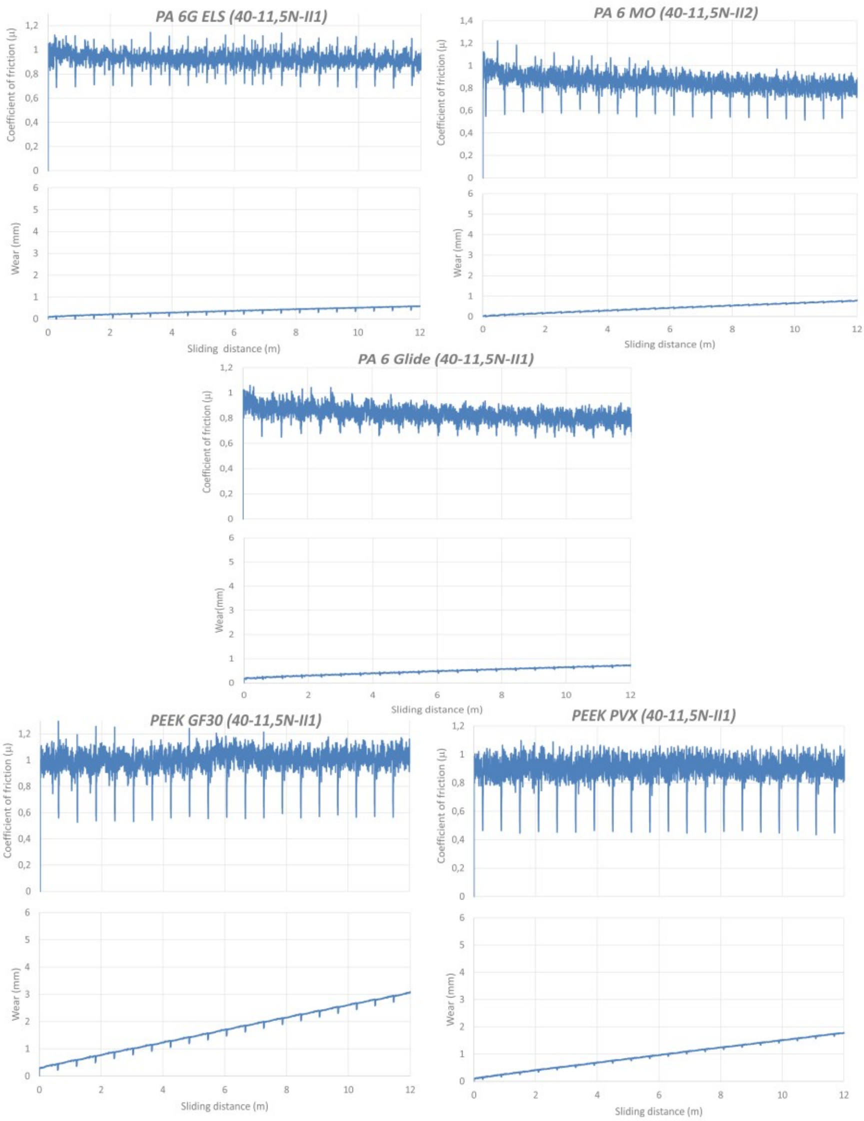

Figure 4

Dynamic friction and wear characteristics of tested composites against emery clothes at 11,5N load

- From the point of view of dynamic friction, PEEK natural is most favourable and seems to have the lowest values over the total sliding time. However, there is a highest instability in the friction which is shown by the maximum value of it's. PEEK PVX has a similar value of maximum friction but a higher dynamic value than natural PEEK. The highest frictions (maximum and dynamic) are represented by PEEK GF 30 on abrasive surfaces, this value is not constant but shows a slight increase during the running-time (Fig. 4).

- The friction behaviours are similar for PA 6E and PA 6G ELS, and they are very stable during the test (Fig. 4). The figure 4. shows the friction and wear curves of PA 6 MO and PA 6 Glide, these values are not constant but show a slight decrease during the running-time.
- The PA composites (mainly PA 6 Glide and PA MO) show a lower friction in opposite the PEEK composites. PA 6 Mo (Fig. 4) shows better sliding properties than PA 6E and PA 6G ELS. This behaviour is interesting, because 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 PA composites 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. 5–6.

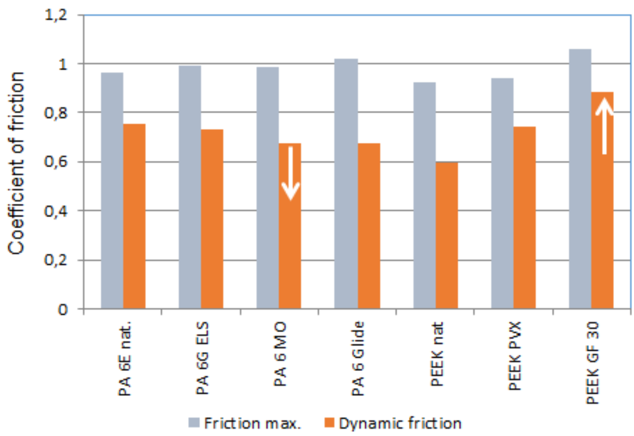

Figure 5

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

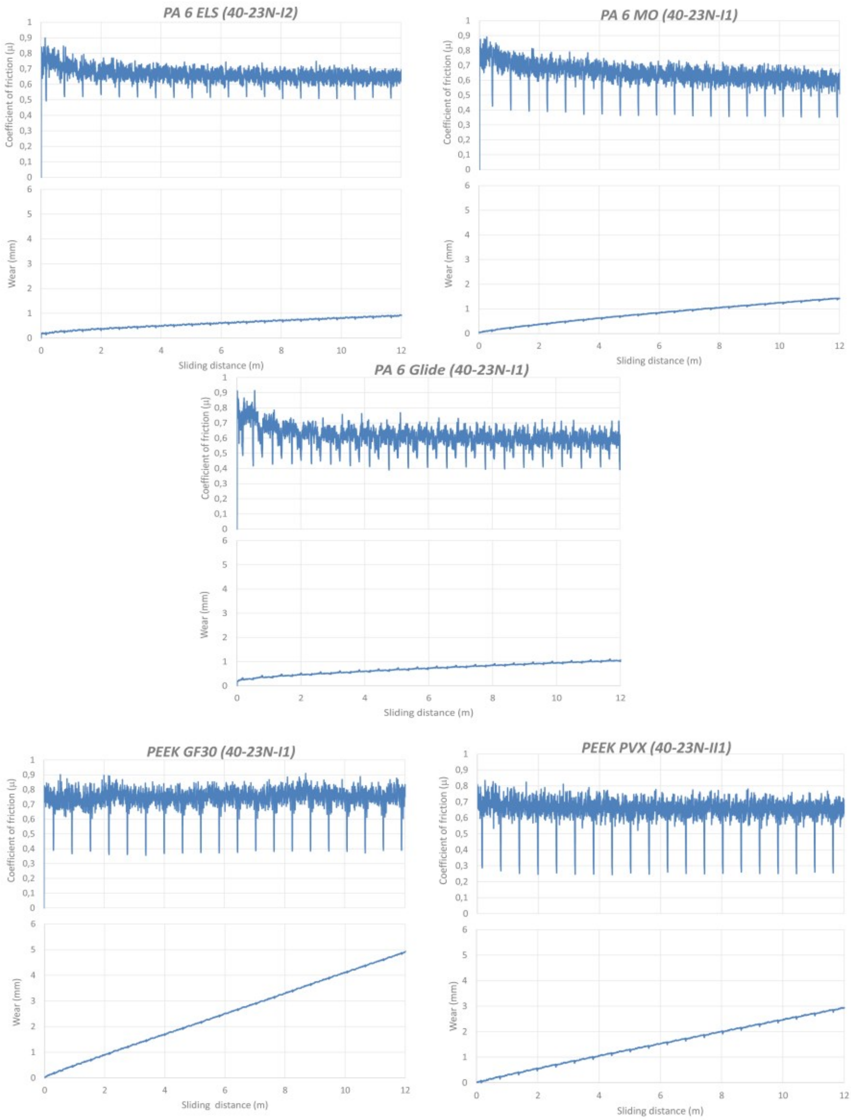

Figure 6

Dynamic friction and wear characteristics of tested composites against emery clothes at 23N load

Comparing Fig. 3 and Fig. 5, it appears that under high loads globally the friction coefficient is lowered. We can see a similar difference and range among the friction behaviours of tested polymers at lower load categories.

- In accordance with the formers the PEEK natural has the lowest friction coefficient under higher load (similar to lower load also).

- In contrast the results of lower load category an other range occurs between PA 6G ELS and PA 6E natural, in favour of PA 6G ELS.
- The friction of PA 6 Glide is more stable than it was at lower load. PA 6 Mo (Fig. 6.) has similar favourable sliding properties than PA 6 Glide but shows a slight decrease during the running-time.
- PEEK GF30 shows the worst results in connection to friction coefficients and wear among the tested polymers.

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. 7 for both load categories.

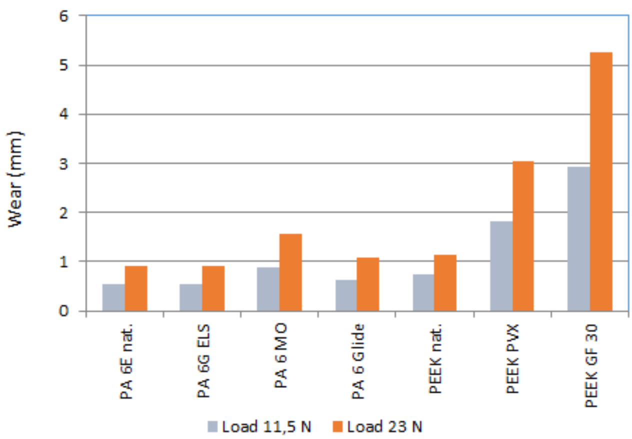

Figure 7

Wear values for different materials in 11,5N and 23N load categories

Let's see a comparison between these results. It can be observed from the figure that the higher load has increased proportionally (~1,6 times) the wear of most of them polymer composites.

- But in cases two of PA 6MO and PEEK GF 30 we can see bigger differences between the wear results. The wear is measured at higher load let be more then 1,77 times than measured at lower load. These polymers are a little bit more sensible against the different loads.

- PA 6E natural has the lowest wear results close to PA 6G ELS. It can be observed from the wear result of these polymers that they have increased deformation ability, due to the lower tensile stress and lower strain at break.
- The highest wear values are shown by PEEK PVX and mainly PEEK GF30, they are said to be more rigid because of their higher modulus of elasticity. So in our abrasion case the rigid behaviours can cause a higher value of wear.
- The polyamides show the better wear results among tested polymers in both categories, 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.

Fig. 8 shows polymer films of all tested polymers (at first the PEEK after tha PA 6) in the wear track, which are studied after the test by the aid of a digital camera. The forms and filling in the abrasive surface give information about the wear behaviour of tested pomyners.

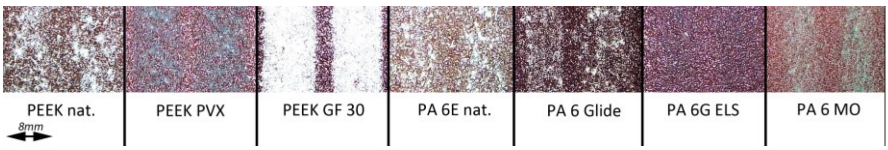

Figure 8

Different wear tracks on the emery cloth at 11,5N load

- In case of PEEK natural non-continuous plastic layers cover the surface with several large and bitty wear particles.
- For both PEEK composites (PVX and GF30), the polymer films are thick and a more or less homogenous track (mainly GF30) is observed.
- The least and thinnest transfer layer is shown by polyamides, this good correlation makes them preferable for their 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 [13, 15]. Their relative contribution depends on the several conditions like load level as well as on the chemical, mechanical and geometrical properties, however the surface roughness is most important among them. The deformation ability of the polymers, basically determine the abrasion resistance of the tested polymers, therefore we have to see the mechanical properties of polymers. The tensile strength at yield and modulus of elasticity were shown in Table 2, and the hardness (type: Shore D for rigid polymer tested by Zorn Stendal 8036 hardness tester) due to wear are illustrate in Fig. 9.

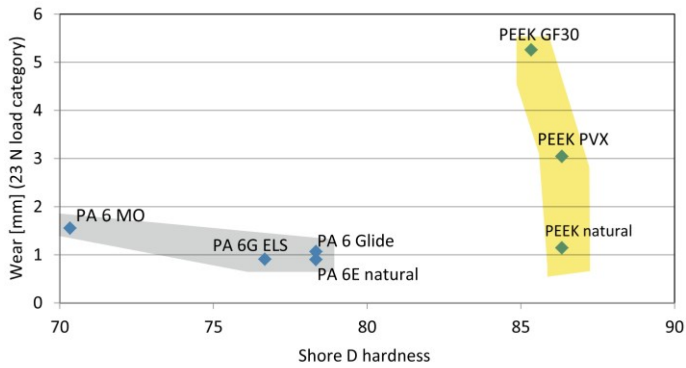

Figure 9

The Shore D hardness of the tested polymers are plotted against the measured wear (23N load category)

From the trend lines, the following conclusions are drawn in the figure:

- We can see a correlation between the hardness and the wear for the higher wear resistance of polyamides. Wear decrease with increasing Shore D hardness.
- However the previous trend is not so clear in cases of PEEK because of similar hardness of PEEK composites, but the PEEK GF30 has the highest wear with lower hardness among PEEKs.

4 Conclusions

Based on the results of the experiments, the following conclusions can help and improve the further tribotesting of polymers, the proper material selection and design. The experimental data suggests the following conclusions:

- There is a general trend from present investigations that the dynamic friction coefficient decreases with increasing normal load, and the wear is found to be ~1.6-1,8 times higher at double load.
- Among the investigated polymers and composites taken from the engineering practice the PA 6Glide and PEEK natural are most suitable sliding materials, because their friction is lowest and their wear resistance is higher.
- The effect of the internal lubrication in case of cast PA 6Glide composite is different from the effect of solid PTFE lubrication in PEEK PVX. In case of PA 6 the efficiency of the lubrication gives an excellent friction coefficient and high wear resistance at both load categories. Opposite the PA 6Glide the addition of PTFE has a weak effect on the friction. The solid PTFE lubricant can’t decrease the friction of the PEEK PVX (due to PEEK natural).

- The polyamides have a good abrasion wear resistance in connection with their increased deformation ability, but their friction coefficients do not differ significantly from the more „rigid" PEEKs.
- The addition fillings have a different effect on the PA and PEEK composites. While these fillings have a good effect for the friction coefficients of polyamides, in case of PEEK they have an unfavourable effect at both load categories. The former are true for the abrasion wear also where the PEEK composites suffer an essential higher abrasion in comparison with polyamide composites.
- Our abrasion investigations correlate with others [Voss et al. [14] and Friedrich et al [22,23], we mean that short carbon fibres proved better for improving wear resistance as compared to short glass fibres, in the given circumstances.
- The PA 6G ELS shows individual friction properties. The Mg-catalysed polymerisation of this polymer has a more efficient effect on the friction at higher load, but it does not have any individual effect on the wear between both load categories.
- The Shore D hardness of the polymers has a different effect on the wear, while it seems a correlation between them at polyamides, but does not have any at PEEKs.

For practical use we can mention by our results, that the polyamide composites are suitable as machine elements in normal abrasive applications, as they resist again abrasion wear. However if there are any extreme demands for example: high mechanical properties, temperature resistance and excellent chemical resistance etc., we can use PEEK composites also, but it is important to know the character of the filling. It is clear that the glass fibre (GF) has a bad effect on the friction and the wear at abrasive surface.

The small-scale abrasion tests with PA and PEEK polymers and composites with abrasive surface provided new information about their tribological behaviours. These results extend our tribological knowledge about polymers and show new possibilities for practical application.

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References

[1] A. Häger, M. Davies, Advances in Composite Tribology, Elsevier, Amsterdam, 1993.

[2] B. J. Briscoe (1986): Interfacial friction of polymer composites. General fundamental principles. In: Friedrich, K. (Ed.): Friction and Wear of Polymer Composites. Elsevier, Amsterdam (1986) 25-59

[3] B. J. Briscoe and S. K, Sinha (Ed. by: G.M. Swallowe) (1999): 59-Wear, Mechanical properties and testing ok polymers, Polymer Science and Technology Series, Volume 3 Springer-Science+Business Media, B. V. 1999, ISBN: 978-90-481-4024-4

[4] B. J. Briscoe and S. K. Sinha (Ed. by: G.M. Swallowe) (1999): 25-Hardness and Normal Indentation of Polymers, Mechanical properties and testing ok polymers, Polymer Science and Technology Series, Volume 3 Springer-Science+Business Media, B. V. 1999, ISBN: 978-90-481-4024-4

[5] D. Burris, W. Sawyer, A low friction and ultra low wear rate peek/ptfe composite, Wear 261 (2006) 410–418.

[6] E. KISLINDER, M. KOZMA (2000): Comparative investigation of the tribological properties of sliding polymer elements. Gépészet 2000, Budapest. Budapesti Műszaki és Gazdaságtudományi Egyetem,. május 25.-26., 1 210-214. p.

[7] E. RABINOVICZ (1965): The friction and wear of materials, John Wiley and Sons, New York

[8] F.P. Bowden, D. Tabor (1950): The Friction and Lubrication of Solids, Clarendon Press, Oxford, 1950.

[9] G. KALACSKA, et al. (1997): Műszaki műanyagok gépészeti alapjai (Mechanical Basics of Polymers), Minerva-sop Bt. Sopron, 1997.

[10] G. M. Swallowe (Ed. by: G.M. Swallowe) (1999): 14-Environmental Effects, Mechanical properties and testing ok polymers, Polymer Science and Technology Series, Volume 3 Springer-Science+Business Media, B. V. 1999, ISBN: 978-90-481-4024-4

[11] G. M. Swallowe (Ed. by: G.M. Swallowe) (1999): 46-Standards for Polymer Testing, Mechanical properties and testing of polymers, Polymer Science and Technology Series, Volume 3 Springer-Science+Business Media, B. V. 1999, ISBN: 978-90-481-4024-4

[12] G. M. Swallowe (Ed. by: G.M. Swallowe) (1999): Crystallinity, Mechanical properties and testing ok polymers, Polymer Science and Technology Series, Volume 3 Springer-Science+Business Media, B. V. 1999, ISBN: 978-90-481-4024-4

[13] H. Uetz, J. Wiedemeyer (1985): Tribologie der Polymere, Carl Hanser, Munich, 1985.

[14] H. Voss and K. Friedrich (1987): "On the Wear Behaviour of Short-Fibre-Reinforced-Peek," Wear, 116, 1, 1987, 1-18.

[15] I.M. Hutchings (1992): Tribology, Friction and Wear of Engineering Materials, Arnold, London, 1992.

[16] J. B. RATNER et al. (1964): Connection between wear resistance of plastics and other mechanical properties. *Soviet Plastics,* Vol. 12 (7) 37, 145 p.

[17] J. Hanchi and N. S. Eiss Jr. (1997) "Dry Sliding Friction and Wear of Short-Fiber-Reinforced Poly-Etherether-Ketone (PEEK) at Elevated Temperatures," Wear, 203-204, 1997, 380-386.

[18] J. J. Rajesh, J. Bijwe and U. S. Tewari (2001): "Influence of Fillers on Abrasive Wear of Short Glass Fibre Reinforced Polyamide Composites," Journal of Materials Science, 36, 2001, 351-356.

[19] J. J. Rajesh, J. Bijwe and U. S. Tewari (2002): Abrasive wear performance of various polyamides, Wear, Volume 252, Issues 9-10, 769-776

[20] J. R. Vail, B.A. Krick, K.R. Marchman,W. Gregory Sawyer (2010): Polytetrafluoroethylene (PTFE) fiber reinforced polyetheretherketone (PEEK) composites, Wear, Volume 270, Issues 11–12, 5 May 2011, Pages 737–741, Elsevier B. V. 2010

[21] K. Friedrich and A. K. Schlarb (2008): Tribology of Polymeric Nanocomposites. Tribology and Interface Engineering Series, No. 55 (Ed.: B. J. Briscoe)

[22] K. Friedrich, J. Karger-Kocsis and Lu, Z. (1991) "Effects of Steel Counterface Roughness and Temperature on Friction and Wear of PEEK-Composites under Dry Sliding Conditions," Wear, 148, 2, 1991, 235-247.

[23] K. Friedrich, Z. Lu and A. M. Häger (1993): "Overview on Polymer Composites for Friction and Wear Application," Theoretical and Applied Fracture Mechanics, 19, 1, 1993, 1-11.

[24] L. C. SEABRA, A. M. BAPTISTA (2002): Tribological behaviour of grade polymers against stainless steel in dry sliding and with sugar. *Wear*, Vol. 253 394-402. p.

[25] L. Kátai, P.Gárdonyi, I. Szabó (2015): EXAMINATION OF DRIVE MISALIGNMENT AND V-BELT TEMPERATURE CONDITIONS International journal of science, technics and innovations for the industry, Vol. 12. pp. 56-59, ISSN 1313-0226

[26] L. Zsidai, G. Pistai, R. Keresztes (2016): Abrasion testing of PA 6, POM and PET composites in small scale tribology model system, THE 11th INTERNATIONAL CONFERENCE OF THE CARPATHIAN EURO-REGION SPECIALISTS IN INDUSTRIAL SYSTEMS *CEurSIS 2016,* 2 - 4 June, 2016, BAIA MARE, ROMANIA

[27] M. Kozma, G. Kalacska (1998): Abrasive wear of polymers, in: Proceedings of the First Conference on Mechanical Engineering (Gepeszet'98), May 28–29, 1998, pp. 157–161.

[28] N. Dyson, A. J. Kinloch, A. Okada (1994): The interlaminar failure behaviour of carbon fibre/polyetheretherketone composites. *Composites* 25 (1994) 189–196.

[29] P. Davies et al (1991): Round-robin interlaminar fracture testing of carbon-fibre-reinforced epoxy and PEEK composites. *Compos. Sci. Technol.* 43 (1991) 129–136,

[30] PLINT & PARTNERS LTD. (2001): Delivery programme edition. England: Newburry, Berkshire, RG20 6NB

[31] Q. Wang, Q. Xue, H. Liu, W. Shen, J. Xu, (1996): The effect of particle size of nanometer ZrO2 on the tribological behaviour of PEEK, Wear 198 (1–2) (1996) 216–219.

[32] Q. Wang, Q. Xue, W. Shen (1997): The friction and wear properties of nanometre SiO2 filled polyetheretherketone, Tribology International 30 (3) (1997) 193–197.

[33] W. Grellmann, S. Seidler (2007): Polymer Testing, Carl Hanser Verlag, Münich 2007

[34] W. Hufenbach, K. Kunze, J. Bijwe (2003): Sliding wear behaviour of PEEK–PTFE blends, Journal of Synthetic Lubrication 20 (3) (2003) 227–240.

[35] W. I. Broughton (2000): Shear. In: Hodgkinson, J.M. (Ed.): Mechanical Testing of Advanced Fibre Composites. Woodhead Publishing, Cambridge (2000),

[36] www.deerfos.com (28 .04. 2016) DEERFOS Products Information, 2008

[37] www.ensinger-online.com/modules/public/datapdf (28.4.2016)

[38] www.quattroplast.hu/files/file/B_kategoria.pdf (28.4.2016)

[39] X. Shao, Q.-J. Xue, (2004): Effect of nanometer and micrometer SiO(2) particles on the tribology properties of Poly (phthalazine ether sulfone ketone) composites, Materials and Mechanical Engineering (China) 28 (6) (2004) 39–42. 45.

[40] Y. Yamaguchi (1990): Tribology of Plastic Materials, Tribology Series 16, Elsevier, Amsterdam, 1990.

[41] Z. Lu, K. Friedrich (1997): High temperature polymer composites for applications as sliding elements, Materialwiss. Werkst. 28 (1997) 116–123.

[42] Z. P. Lu, K. Friedrich (1995): On sliding friction and wear of peek and its composites, Wear 181–183 (2) (1995) 624–631.