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Friction of PA6 and peek composites in the light of their surface characteristics

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Abstract

Our present work is connected to a broad tribology research project with different polymer composites on PA6, POM, PET and PEEK matrix and targeted to create a detailed map of tribological features. Measuring the hardness and surface energy of the tribology tested materials gave some new approach about friction results. The small-scale laboratory friction tests were carried out with an alternating (reciprocating) cylinder/plate model system, which is able to measure the dynamic and the static friction force on-line during the sliding process. This special test system opens up new possibilities for understanding the phenomena of friction. In the article we give a short introduction from the surface energy and the shore D hardness test methods also.

The research results plot a connection between the surface (polar and adhesion components) energy and the friction (static and dynamic) behaviour. Furthermore the experienced difference between the static and dynamic friction coefficients and its time function will offer a new approach during evaluation of the stick-slip behaviour of PA6 and PEEK composite materials.

Keywords

friction, PA6, PEEK, polymer, composites, surface energy, shore D

1. Introduction

Our work is part of a larger research project that deals with the tribology behaviour of engineering polymer composites. The present paper shows the results of the linear sliding friction measurements of the different polymer/steel pairs using a reciprocating cylinder-on-plate test apparatus. No external lubricants were added to the tribological system. We give an overview about the results of hardness and surface energy measurement of tested polymers and intern alia the mapping of stick-slip is also.

This work is trended towards the examination of the reliability of engineering plastics in sliding (tribology) polymer-polymer and polymer-metal contact systems, through the complex tribology exploration of characteristics.

Base Principles

The tribological properties of polymers strongly depend on the properties of the sliding surface. To create we used so-called, small-scale tests are quite obvious, e.g. simple test rig with low forces and power, reduced cost for preparing test specimens, easy of control of environment. Moreover many small-scale results are available in literature to be referenced, e.g. Sukumaran, et al. (2012), Zsidai, et al. (2002). They are useful to compare the properties of different materials, but induce unrealistic edge effects.

As an examined materials from among the engineering polymers are the several of the variants composites based on PA6 (polyamide 6), PEEK (Polyether ether ketone) PET (Polyethylene terephthalate) and POM (Polyoxymethilen) polymer matrix (with a lubricant charged and/or are with thread strengthening), and the mating plates are steel (and polymer) we used his application.

Several studies on the tribological behaviour of common engineering plastics e.g. Uetz, Wiedemeyer (1985), Kalácska, et al., (1997), Yamaguchi (1990), Kalácska (2007, 2013) in contact with steel have been published and compared by, e.g., Tanaka (1982), and Evans (1982). We can found in the research character in connection with base polyamide, Byett (1992), De Velde, De Baets (1997), Keresztes (2010) and the base PEEK, Yamamoto et al. (2002) in sources also. The number of the articles dealing with the composites is growing nowadays, e.g., Friedrich et al. (1995), Sumer et al. (2008) and Schroeder et al. (2013). We can found more publications about the role of the stick-slip tribology also e.g., Kátai at all (2001, 2013).

I characterize the polymers with complex tribology examinations, taken into consideration the material testing (tensile and hardness examinations) his results.

Aims

The main objectives of the investigation are the comparison of friction and surface morphology of different engineering polymers in connection with their surface energy and hardness properties. There is also important to describe of optimal operational conditions of the selected polymers.

Further aims of the research: to determine the optimal operational conditions of the selected polymers, and to give a help for the selection of a proper polymer for a certain condition and to find out the causes of friction.

2. Test rigs, materials and results

The present paper describes the linear sliding friction measurements of the different polymer/steel pairs using a reciprocating cylinder-on-plate test apparatus. No external lubricants were added to the tribological system.

The experimental tribo- model system as pictured in figure 1 is essentially a variant of the commercially available reciprocating tribotest.

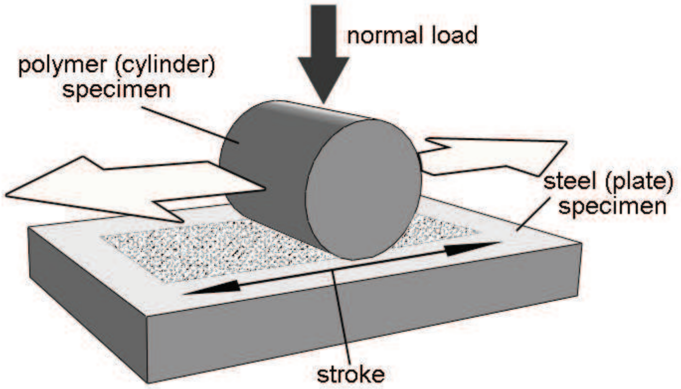


Figure1. Reciprocating model system

Accurate description of the test system and evaluation of the test results prior publication in view. [Zsidai 2013, 2014]

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
Surface of steel specimen, R_z [μm], (R_a [μm])	1,7 (0,16)
Running time, t (sec)	130
Normal load, F_N [N]	150
Frequency, f [Hz]	10
Velocity, v [m/s]	0,05
Stroke, s [mm]	6
Humidity, RH [%]	50
Ambient temperature, T (◦C)	30

Tests are conducted with normal load: 150 N. The running time (130 sec.) of the tests is chosen for to observe the first (running in stage) period of the friction. For each test, the surface roughness's of the steel specimen were used R_z 1,7. 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 10 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 systems. Some of the like polyamides are well-known but some composites are just being spread.

The materials are two main composites groups. One of them is with PEEK and the other is with PA6 base matrix are included in the experiments. In addition to the foregoing I tested other polymers (POM and PET) also.

Material of the mating plate

The counter plates are made of widely used, C45 general purpose steel. The application area of C45 is a less demanding but wear-proof. The heat conduction: 46 W/(mK) and the standard is EN 10083. The plate dimensions are 200×100×12mm and for preparing the steel surfaces are used grinding (R_a=0,11-0,18 μm ≈ R_z=1,4-1,7μm) The grinding grooves are made parallel to the sliding direction during the wear tests. Roughness is measured perpendicular to the sliding direction.

Materials of the polymer cylinders

- 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. The PA 6E favourable combination provides the rigidity, toughness, mechanical damping ability and wears resistance of polyamide product „general purpose „type called.
- The PA 6G ELS is the conductive version of magnesium catalysed cast polyamide 6.
- The PA 6MO (PA 6E+MoS2) for molybdenum disulphide (MoS2) content greater strength and stiffness than the PA 6E. The heat and wear resistance are also improved, but the toughness and mechanical damping capacity worse.
- PA6 GLIDE is a hard semi-crystalline cast polyamide with good sliding properties, wear resistance, oil-, grease-, gasoline-, gas oil resistance and easy machinability.
- PA next 66 MH shows good sliding properties, stiff, high resistance to oils, greases, petrol, gas oil, UV and weather resistance, electrical insulation and easy machinability. In shipping, packaging structures, electronic equipment, printers, and precision engineering are used.
- Natural unfilled PEEK, reinforced poly (ether-ether-ketone). Briefly to 310 ° C can be used, suitable for permanently around 250 ° C.
- PEEK PVX (PEEK CF+PTFE+graphite) real bearing grade. Carbon fibres, graphite and PTFE filler.
- PEEK GF30 (PEEK GF+30) 30% glass fibre reinforced for greater dimensional stability and higher strength properties.
- PET TF amorphous or semi-crystalline thermoplastic material as is also available. Low moisture absorption properties due to extremely useful in areas where complex components and high dimensional accuracy, surface quality is required.
- POM AH LA solid lubricant is added which improves the sliding properties and wear compared to the normal behaviour of POM,

however, impairs the mechanical properties (strength, hardness). Excellent electrical insulation, good to work with, but in terms of weak bonding authority. The conveyor technology, the automobile industry, electronic equipment and precision instruments are used.

– POM AD AF semi-crystalline thermoplastic bearing material has a low coefficient of friction, high strength, stiffness and excellent process ability. Application area: Engineering, automotive, transport and conveyor technology, electronics, precision mechanics, medicine.

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. [19], [20]

Table 2. Mechanical and physical properties of the tested polymers [1], [2]

Material code	**colour**	**density [g/cm^3]**	**Tensile strength at yield/ Modulus of Elasticity [MPa]$^{(1)}$**
PA 6E	black	1,13	85/3000
PA 6G ELS	black	1,15	70-110/-
PA 6MO	black	1,14	82/3300
PA 6 GLIDE	green	1,13	76/3200
PA 66 MH	black	1,14	75/2500
PEEK	brown	1,31	100/4100
PEEK PVX	black	1,44	84/5500
PEEK GF30	brown	1,53	180/9500
PET TF	grey	1,44	73/2900
POM AH LA	blue	1,34	45/2300
POM AD AF	black	1,54	50/2900

$^{(1)}$ Values referring to material in equilibrium with the standard atmosphere 23 °C/50% RH

The polymer cylinder has a diameter of 8mm and length of 10mm and made by cutting. The figure 2 shows the tested polymers in original form.

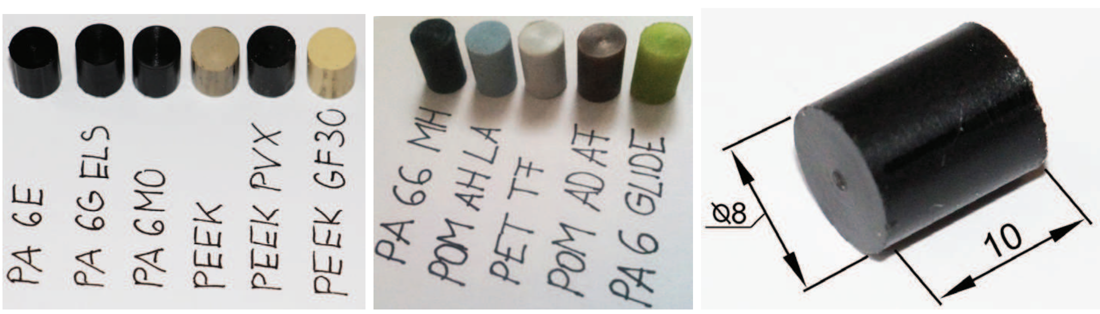


Figure 2. Original form and dimensions of the tested polymers and composites.

The cylindrical specimens are in counter formal connection with the steel plate. The components of composites are homogenously spread in the bulk of polymers.

The measurement method and results of the surface energy
The dynamic friction coefficient is represented in Figure 3. For each material, the dark part of column refers to the regime value of dynamic friction coefficient and the lighter one refers to the maximum value of dynamic friction coefficient. All values are averaged from three test runs with identical parameters.

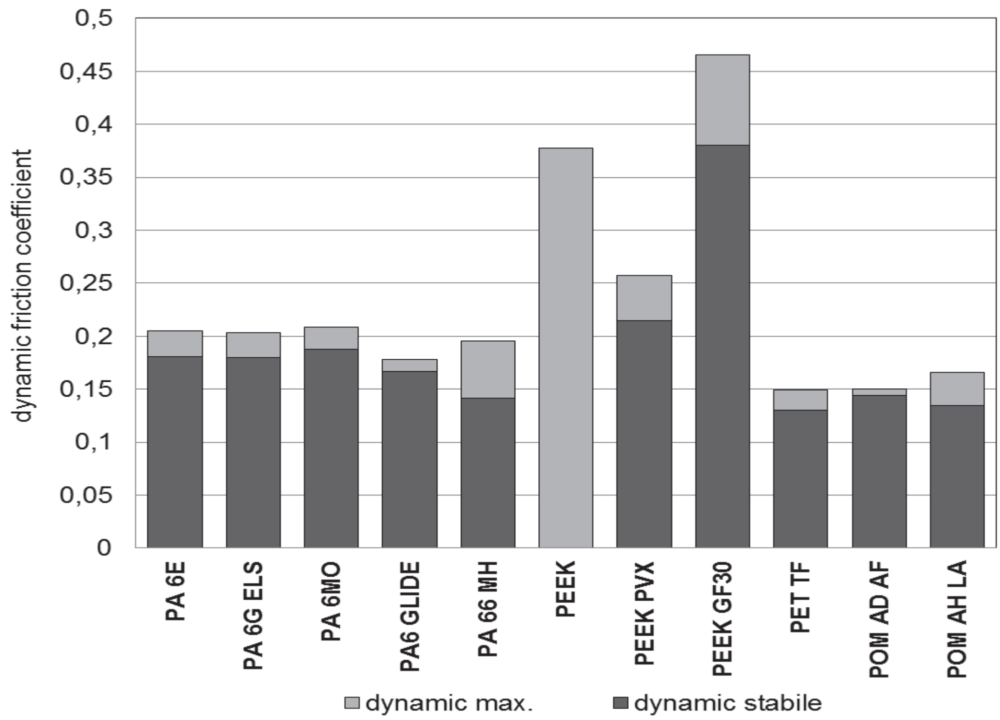


Figure 3. Dynamic friction coefficient for different polymers (sliding distance = 7m; load = 150 N; surface roughness R_z= 1,7μm)

Let's see the figure. 3, there is a general tendency that friction coefficient is similar and low (0,15-0,2) in case of polyamides (PA). The lowest frictions are present by POM and PET. From the point of view of friction, PEEK is unfavourable and in case of natural PEEK not stabilized friction.

Measurement of the hardness test polymers
For examined in the research of hard polymers called polymers I had to use this „Shores D" measurement device is shown in figure 4. The Quattroplast Ltd. courtesy of the tool used in material testing labour.

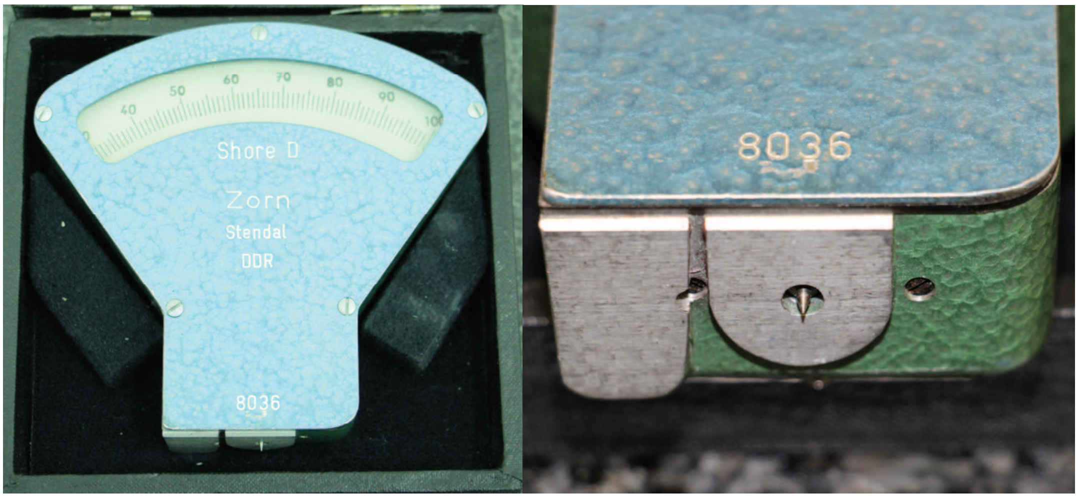


Figure 4. The „Shore D" hardness tester and the sharpe pin for measure the „hard polymer" (type: Zorn Stendal, 8036)

The tests were carried out after calibration the instrument. Each measurement was repeated three times and the specimens are checked several sides but did not observe differences.

The results are depicted in the diagram as seen in figure 5 in order to enhance comparability.

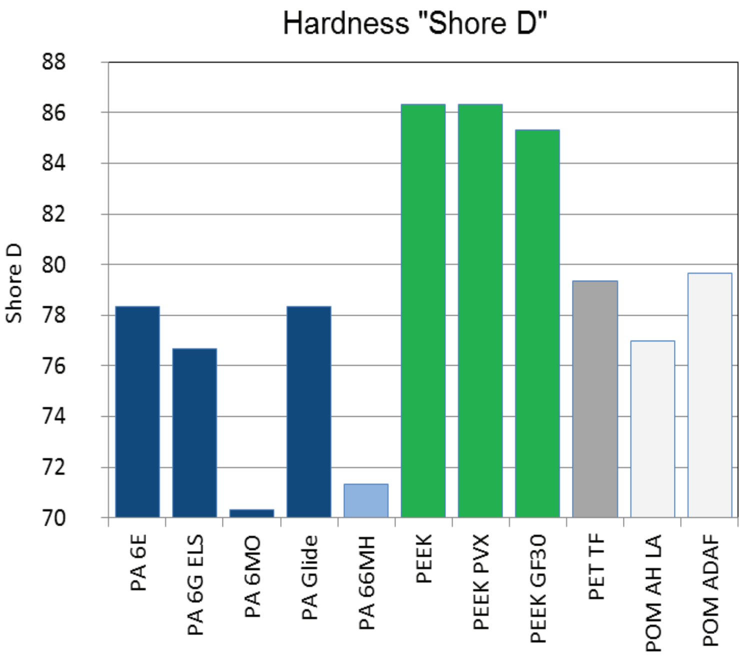


Figure 5. The results of „Shore D" hardness test

The results will be used later in the analysis of the tribology characteristics and phenomena.

The measurement method and results of the surface energy

Contact angle measurements were performed by the static sessile drop method. Double distilled water and N,N-dimethylformamide (DMF, Sigma-Aldrich) were applied as test liquids. An automatic pipette (Biohit Proline, 2-20 µl) was used to inject 10 µl droplets. The measurements were done at 25 °C. Images were made by a digital microscope (dnt DigiMicro 2.0 Scale, Dietzenbach, Germany) with image resolution of 65 pixel/mm. The contact angles were determined using image analysis software (ImageJ 1.48v, Wayne Rasband, National Institute of Health, USA) with "Low Bond Axisymmetric Drop Shape Analysis" (LB-ADSA) [Aurélien (2010)] and Drop Snake [Stalder (2006)] plugins. The results of contact angle are an average of three measurements, performed always on dry parts of the samples. The method of Owens and Wendt was used for the calculation of the total surface energy and its polar and dispersive components. [Owens (1969)]

Figure 6. Water drop on the specimen surface during the test.

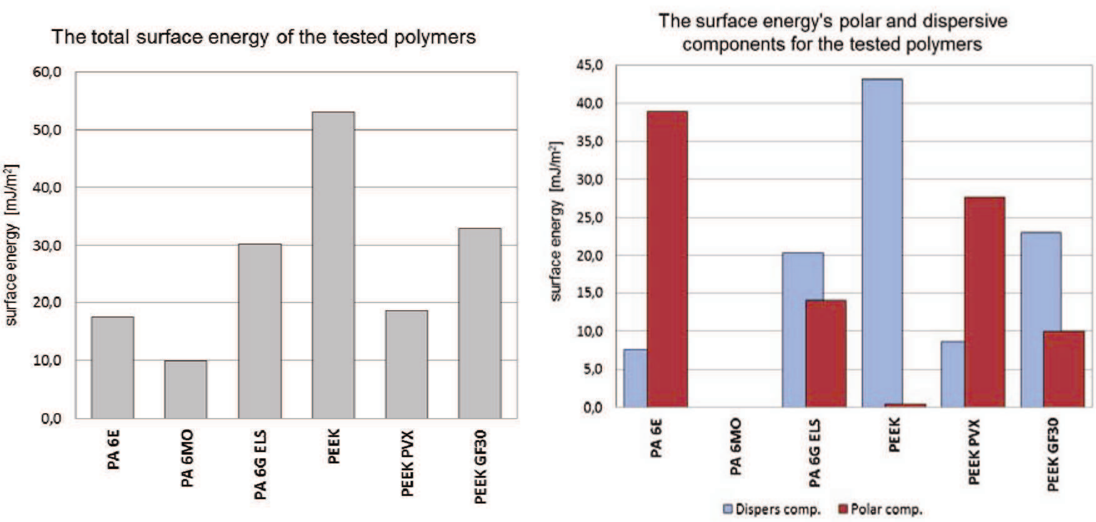


Figure 7. The result of the drop test (total, polar and disperse components of surface energy)

3. Discussion

According to generally accepted friction models, two mechanisms contribute to the friction force between a polymer (composite) and steel: adhesion in the contact zone and deformation of the polymer [Hutchings (1992), Wiedemeyer (1985), and Zsidai (2002)].

Their relative contribution depends on the load level as well as on the chemical, mechanical and geometrical properties. For softer polymer the deformation component increases, while for harder the adhesion becomes more important. The friction component resulting from adhesion equals the product of the real contact area and the strength of the polymer (softest) material [Bowden, Tabor (1950)].

Besides the hardness, the adhesion ability of polymers can differ to a great extent because of specific surface characteristics of the material, which is expressed by its surface energy. Lee [1974] considers that the surface energy plays an important role in controlling the friction of polymers. From literature, it is known that the total surface energy of PTFE is low, while PA has the highest surface energy. POM is also ranked among the polymers with higher surface energy [Kalácska (1997)]. This correlates with the low adhesion work in PETP/PTFE contacts and the high adhesion work between PA contacts.

In Figure 8. the dynamic friction results of the tested polymers are plotted against their Shore D hardness.

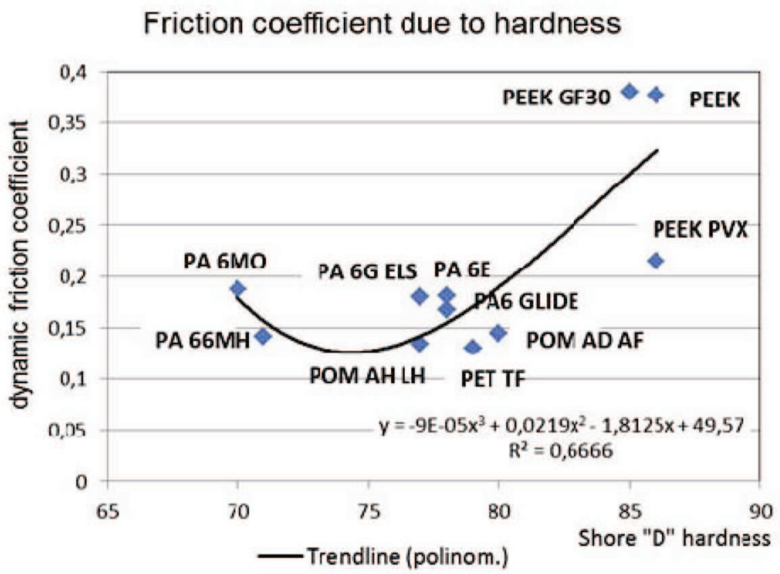
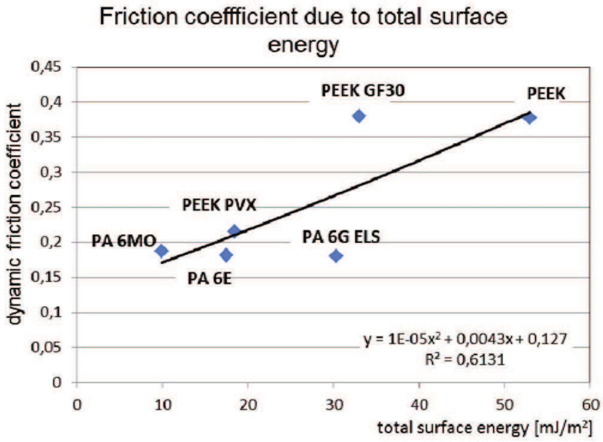


Figure 8. The dynamic friction results of the tested polymers are plotted against their Shore D hardness

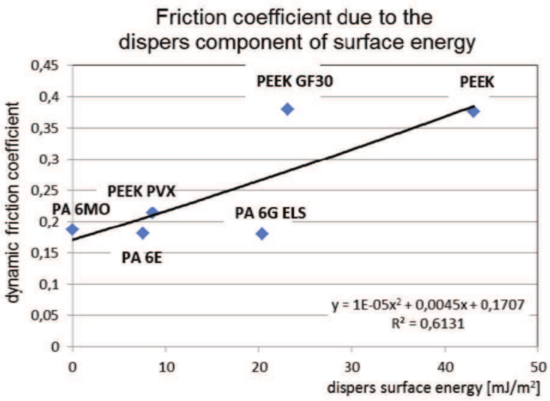
From the trend lines, the following conclusions are drawn in the figure:

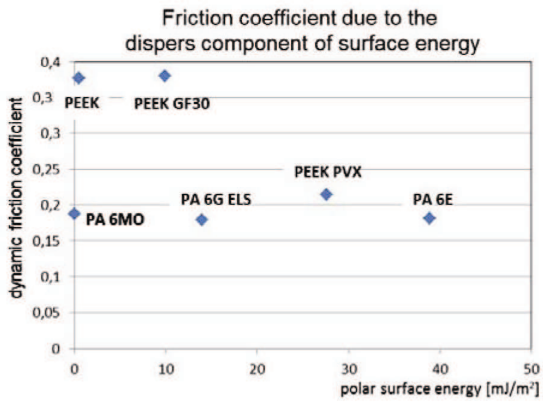
- For the lowest friction is an optimal hardness near Shore D 75, but after this value the friction increases with increasing hardness, this is mainly true in case of the PEEK and their composites. This phenomenon could be connecting with higher elasticity modulus near the harder surface properties of the PEEK. However the friction increases slightly in front of Shore D 75 in case of PA 6MO and PA 66MH also, now because of the weaker mechanical properties.

In Fig. the dynamic friction results of the tested polymers are plotted against their total-, disperse- and polar surface energy.



a.)





b.) c.)

Figure 9. The dynamic friction results of the tested polymers are plotted against their (a) total-, (b) disperse- and (c) polar surface energy.

From the trend lines, the following conclusions are drawn:

– Friction increases similar with increasing total and disperse surface energy. However, this trend was not observed in the polar energies, because it was not observed a clear trend in the evolution of results. This may cause the wide range of the mechanical properties of tested polymers.

The results of the surface energy due to friction obtained in the future by further studies need to be completed.

Conclusions

Although the used reciprocating cylinder-on-plate test rig is not able to provide absolute data representative for actual applications, the tribological behaviour of different polymers can be compared successfully and correlated to materials properties.

The experimental data suggest the following conclusions:

- There is possible to determine an optimum point between the hardness and the friction of the tested polymers, but this is largely depending on the material characteristics and the type of composite.
- The dynamic friction of the tested polymers increase with increasing total surface energy and also increase with increasing disperse component of the surface energy.
- There was not success to identify a clear trend between the friction and the polar component of the surface energy. Previously for other polymers that could [Zsidai (2002)], so further studies are needed.

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References

[1] A.F. Stalder, G. Kulik, D. Sage, L. Barbieri, P. Hoffmann (2006): A snake-based approach to accurate determination of both contact points and contact angles, Colloids and Surfaces A: Physicochem. Eng. Aspects 286 (2006) 92–103

[2] Aurélien F. Stalder, Tobias Melchior, Michael Müller, Daniel Sage, Thierry Blu, Michael Unser (2010): Low-bond axisymmetric drop shape analysis for surface tension and contact angle measurements of sessile drops, Colloids and Surfaces A: Physicochem. Eng. Aspects 364 (2010) 72–81

[3] D.K. Owens, R.C. Wendt (1969): Estimation of the surface free energy of polymers, Journal of Applied Polymer Science 13, 1741–1747.

[4] Evans, Dc; Senior, Gs (1982): Self-lubricating materials for plain-bearings, TRIBOLOGY INTERNATIONAL Volume: 15 Issue: 5 Pages: 243-248

[5] F. Van De Velde, P. De Baets, The friction and wear behaviour of polyamide 6 sliding against steel at low velocity under very high contact pressures, Wear 209 (1997) 106–114.
[6] F.P. Bowden, D. Tabor (1950): The Friction and Lubrication of Solids, Clarendon Press, Oxford, 1950.
[7] Friedrich, K; Lu, Z; Hager, AM (1995): Recent advances in polymer composites' tribology ,WEAR Volume: 190 Issue: 2 Pages: 139-144
[8] G. Kalácska- L. Zsidai- M. Kozma- P. De Baets: Development of tribological test-rig for dynamic examination of plastic composites. Hungarian Agricultural Engineering. N.12/1999. Hungarian Academy of Sciences. p. 78-79.
[9] G. Kalácska, et al., (1997): Műszaki műanyagok gépészeti alapjai (Mechanical Basics of Polymers), Minervasop Bt. Sopron,
[10] H. Uetz, J. Wiedemeyer, (1985): Tribologie der Polymere, Carl Hanser, Munich,
[11] I.M. Hutchings, (1992): Tribology, Friction and Wear of Engineering Materials, Arnold, London, 1992.2, 6H.
[12] Issue: 1 Page: 183-199
[13] J. Sukumaran, M. Ando, P. De Baets, V. Rodriguez, L. Szabadi, G. Kalacska, V. Paepegem (2012): Modelling gear contact with twin-disc setup, Tribology International 49 (2012) 1-7
[14] J.H. Byett, C. Allen (1992): Dry sliding wear behaviour of polyamide-66 and polycarbonate composites, Trib. Int. 25 (1992) 237, Pages: 237-246
[15] Kalácska G. (2013): An engineering approach to dry friction behaviour of numerous engineering plastics with respect to the mechanical properties. EXPRESS Polymer Letters Vol.7, No.2 (2013) pp. 199-210.
[16] Kalácska G. ed. (2007): Műszaki polimerek és kompozitok a gépész-mérnöki gyakorlatban. 3C-Grafika Kft. p. 1-315. ISBN-10: 963-06-1566-5, ISBN 13: 978-963-06-1566-2
[17] Kátai L., Szendrő P., Vincze GY., Szabó I. (2001): Determination of Inner Viscosity of V-belts by Bending Test. In: *Hungarian Agricultural Engineering*, 14/2001 p.31-33.
[18] Kátai László, Szabó István, Gárdonyi Péter (2013): EXAMINATION OF V-BELT TEMPERATURE CONDITIONS, GÉP, LXIV. évfolyam. 2013. 6. szám p.:58-61
[19] Keresztes R., Kalácska G. (2010): Research of machining forces and technological features of cast PA6, POM C and UHMW-PE HD 1000. Sustainable Construction & Design. 2010. Vol.1. p. 136-144.
[20] L. ZSIDAI, Z. SZAKÁL (2013): Development of tribology model systems for research of PA6 and PEEK polymer composites, Mechanical Engineering Letters, Szent István University p.:130-139
[21] L.H. Lee (1974): Effect of surface energetic on polymer friction and wear, in: L.H. Lee (Ed.), Advances in Polymer Friction and Wear, Vol. 5A, Plenum Press, New York, 1974, p. 31.
[22] Schroeder, R.; Torres, F. W.; Binder, C.; et al. (2013): Failure mode in sliding wear of PEEK based composites , WEAR Volume: 301 Issue: 1-2 Pages: 717-726
[23] Sumer, M.; Unal, H.; Mimaroglu, A. (2008): Evaluation of tribological behaviour of PEEK and glass fibre reinforced PEEK composite under dry

sliding and water lubricated conditions ,WEAR 265 Issue: 7-8 Pages: 1061-1065

[24] Tanaka K. (1982): Transfer of semi-crystalline polymers sliding against a smooth steel surface WEAR 75

[25] Y. Yamaguchi (1990): Tribology of Plastic Materials, Tribology Series 16, Elsevier, Amsterdam DIN 50322, Kategorien der Verschleißpru¨ fung, Deutsche Norm 50322, Beuth Verlag, 1986.

[26] Yamamoto, Y; Takashima, T Source (2002): Friction and wear of water lubricated PEEK and PPS sliding contacts ,WEAR Volume: 253 Issue: 7-8 Pages: 820-826

[27] Zsidai L., et al. (2002): The tribological behaviour of engineering plastics during sliding friction investigated with small-scale specimens. Wear, 253 673-688. p.

[28] Zsidai László, Kalácska Gábor (2014): „Stick-slip" PA és PEEK kompozitok súrlódásánál, henger/sík modell vizsgálati rendszerben, Műanyag és Gumi 2014/12 (in press)

[29] ENSINGER essentials. Technical know-how for plastic applications. www.plastic-metal.com

[30] www.quattroplast.hu/files/file/B_kategoria.pdf