SZENT ISTVÁN UNIVERSITY **Dr. Kalácska Gábor**

FACULTY OF MECHANICAL ENGINEERING, Gödöllő professor

director of the institute

Institute for Mechanical Engineering Technology /www.geti.gek.szie.hu/

H-2100 Gödöllő, Páter Károly u. 1.

Department of Material and Engineering Technology Tel.: +36-28 522-949 Fax: +36 28 522-000/1457

Department of Maintenace of Machinery e-mail: kalacska.gabor@gek.szie.hu

Department of Mechatronics www.gek.szie.hu

Magyar Tudományos Akadémia
Doktori Tanács Titkársága
Budapest
Nádor u. 7.
1051

Kiss Mihályné Asszony
részére

Elfogadó nyilatkozat

A „Mechanical Engineering Letters" (ISSN 2060-3789) nemzetközi szakfolyóirat szerkesztőjeként igazolom, hogy

Dr. Zsidai László, Dr. Szakál Zoltán :

EFFECT OF THE DIFFERENT LOADS ONTO THE FRICTION AND STICK-SLIP OF POLYAMIDE COMPOSITES

című közleményét, mely a Bolyai János Kutatási Ösztöndíj (BO / 00127 / 13 / 6) támogatásával készült, közlésre elfogadtuk. A cikk megjelenése előreláthatólag a folyóirat 2015 októberi számában várható. A szerzők további munkájához sok sikert kívánunk.

Tisztelettel:

Budapest, 2015. szeptember 23.

Dr.Kalácska Gábor
szerkesztő, az MTA doktora

Effect Of The Different Loads Onto The Friction And Stick-Slip Of Polyamide Composites

László ZSIDAI[1], Zoltán SZAKÁL
Szent István University, Faculty of Mechanical Engineering –
Institute for Mechanical Engineering Technology
Gödöllő H-2100. Páter K. str. 1.
[1]Tel/fax: +36-28-522-949, E-mail: zsidai.laszlo@gek.szie.hu

Abstract:

Our present work is connected to a research project, which is based on PA6, POM, PET and PEEK polymer matrix and aimed at making a map of the features of tribology. Our work analyses the friction and connection with this, and the stick-slip behaviour of polyamide composites with different load relations. The friction tests are prepared in alternating (Reciprocating) cylinder/plane model system, developed in both the dynamic and the static friction force which is continuously measured. This special tribology test system is extremely suitable to investigate among other things the stick-slip phenomenon also. You can find detailed presentation in our earlier articles. Expected results from our research may serve in a context the effect of the different loads have on a static and dynamic friction. Our research shows the effects of friction on different levels and susceptibility of the tested materials in this direction in the stick-slip PA6 and PA66 composites.

Keywords

friction, PA6, load, polymer, composites, stick-slip

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 friction results of the different polyamide composites/steel pairs in connection with the different loads (50N and 150N). We used a reciprocating cylinder-on-plate test apparatus, no external lubricants were added to the tribological system. Our research shows an overview about the results (static and dynamic friction coefficients) and the effects of different loads in connection with their stick-slip behaviours also.

Base Principles

The tribological properties of polymers strongly depend on the sliding surface [Zsidai, Szakál (2014)] and the tests parameters (velocity, ambient temperature, humidity etc.) mainly on the load. 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 find in the research character in connection with base polyamide, Byett (1992), De Velde, De Baets (1997), Keresztes (2010) 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), G. Kalácska, ed. (2007), Sumer et al. (2008) and Schroeder et al. (2013).
The tribology examinations nowadays are mainly done with small-scale and large-scale tests which are available in literature to be referenced, e.g. G. Kalácska, et al. (1999), Sukumaran, et al. (2012), Zsidai, et al. (2002). These several benefits, e.g. simple test rig with low forces and power, reduced cost for preparing test specimens, easier to control the environment.
From our earlier examinations: Zsidai, Szakál (2014), Zsidai et all. (2014), Zsidai, Kalácska (2014), Zsidai et all.(2015) it is clear already, that the alternating tribo examination system is very useful in

examining the characteristics of the stick-slip, therefore we continue to use this system. We can find more publications about the role of the stick-slip tribology also e.g. Bruska at all (2006).
Among the examined materials from the engineering polymers, are there the several of the variant composites based on PA6 (polyamide 6), and one type of PA66 polymer matrix (with a charged lubricant and/or with thread strengthening), we used mating plates made of steel for this application.

I characterize the polymers with tribology examinations, taken into consideration a results of the friction (static and dynamic).

Goals:

The main objectives of the investigation is, the comparison of reciprocating friction of different polyamide composites in connection with the effect of different normal load and describe their stick-slip behaviours.
Further goals of the research are to determine the optimal operational conditions of the selected polymers, to help with the selection of a proper polymer for certain conditions, 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.

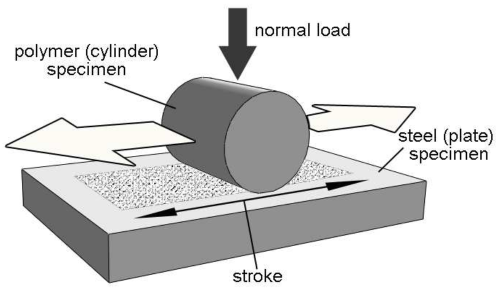

Figure 1. Reciprocating model system

Detailed description of the test system and evaluation of the test results can be found in my publication see. [Zsidai, Kalácska (2014), Zsidai, Szakál (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]	50 and 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: 50 and 150 N. The running time (130 sec.) of the tests is chosen to observe the first (running in stage) period of the friction. For each test, the surface roughness's of the steel specimen that 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 5 tested polyamide composites was based on the database of polymer producers, end-users and expertizing companies in this field. The finally selected engineering polymers can be taken as generally used engineering materials in the industry in sliding systems. Some of these polyamides are well-known but some composites are just being introduced in the market.
The materials are PA composites group. One of them is PA66 (PA 66MH) and the other is with PA6 (PA 6E, PA 6GELS, PA 6MO, PA6GLIDE) base matrix are included in the experiments.

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 grinding is used for the preparation of steel surfaces (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. The PA 6E favourable combination provides the rigidity, toughness, mechanical damping ability and resistance wear 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 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.

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.

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

(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.

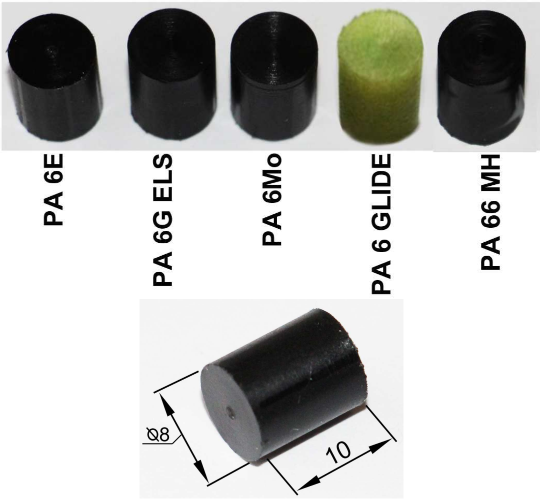

Figure 2. Original forms, colours and dimensions of the tested polymers and composites.

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 test results

I reported on the results of the examinations made on the higher load (150N) in detail in my earlier work already [Zsidai, Kalácska (2014)], I disregard this now because of this. I present the summary diagram in the interest of the better comparability in the (discussion) chapter 3.
These examinations represent our present work, where we measured the polymers on a lower load (50N), like this the effect of the changing load direct we may have analysed it. Let's see these measurements in the next. One typical test is shown in the figure 3-7 from the repeated (three times) investigations in cases of all polymers.

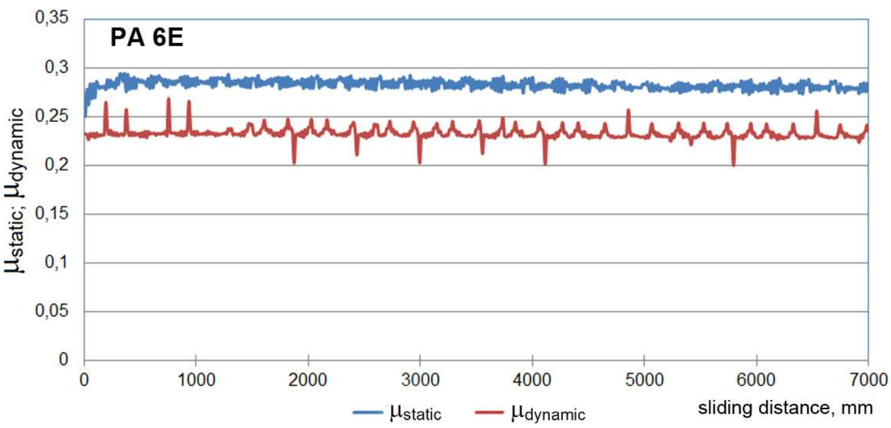

Figure 3. Static and dynamic friction coefficient of PA 6E
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

The PA 6E started the tests silently, after it with slow strengthening his end I experienced medium (or big) noise. A measurement a mild vibration was sensible. A wear gap was not observable in one of the cases on the surface.

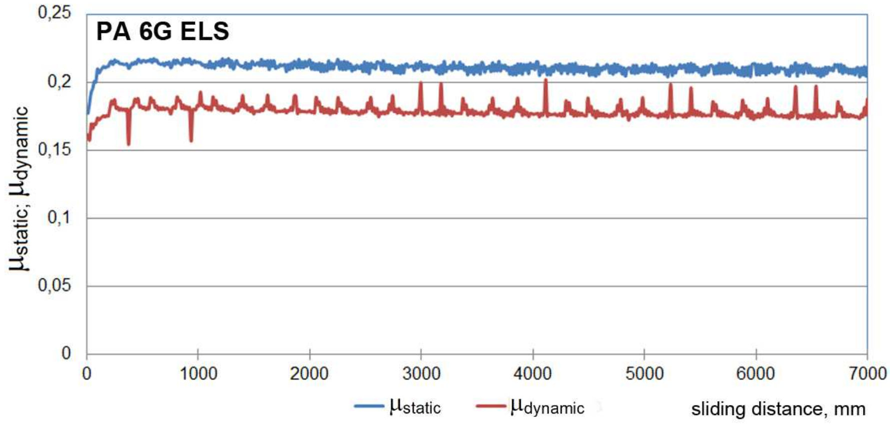

Figure 4. Static and dynamic friction coefficient of PA 6G ELS
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

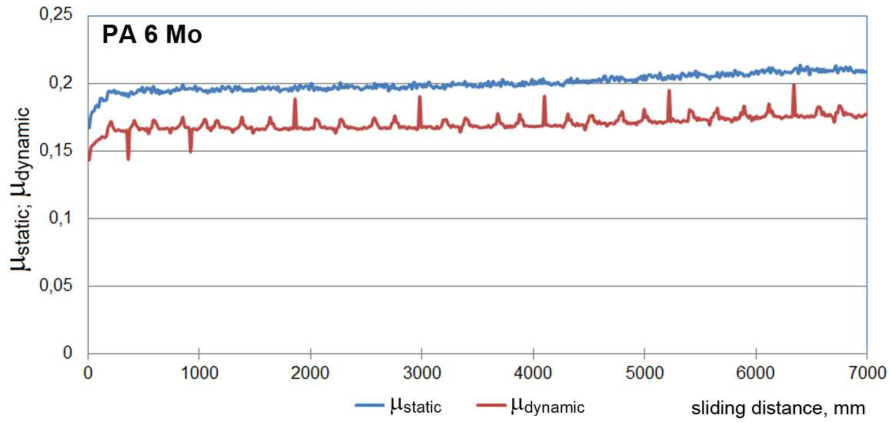

Figure 5. Static and dynamic friction coefficient of PA 6 Mo
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

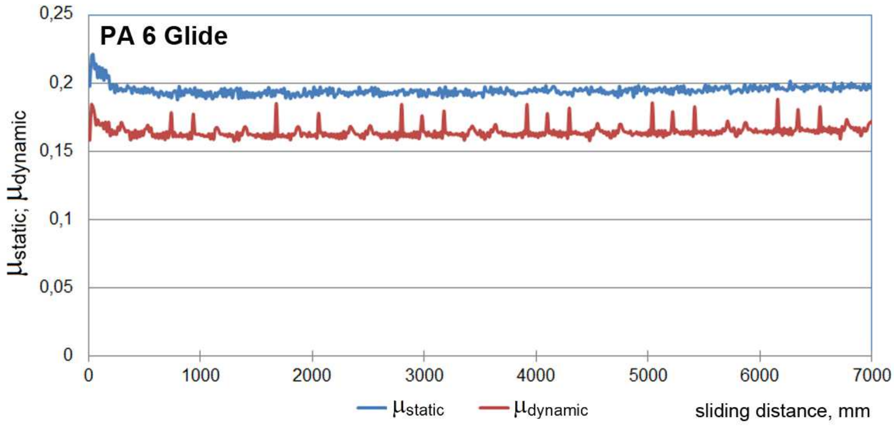

Figure 6. Static and dynamic friction coefficient of PA 6 Glide

(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

All of the examinations of the PA 6G ELS, PA 6 Mo and PA6 Glide were quiet, a shake were free and a wear gap were not observable.

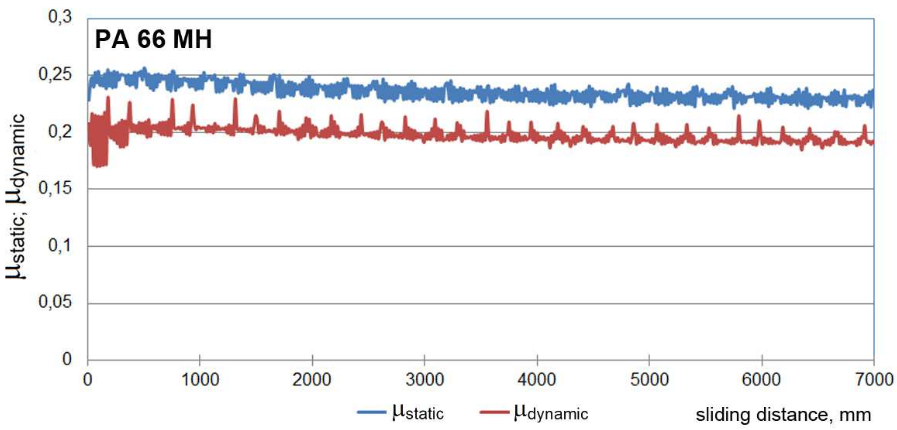

Figure 7. Static and dynamic friction coefficient of PA 66 MH
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

During the examinations of the PA 66 MH, at the start period adhering a strong sound was a referrer can be experienced that later blunted one. Wear track was not possible observed.

3. Discussion

The dynamic friction coefficients are represented in Figure 8 and 9. 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.

Let's see the figure 8, where the polymers were tested on higher load (150 N). Here are a similar friction coefficient (~0,18-0,21) in case of polyamides 6E, 6G ELS and 6MO. The lowest friction is present by polyamides 66 (PA66 MH). From the point of view of friction, PA6 GLIDE is more favourable than in case of other polyamides 6.

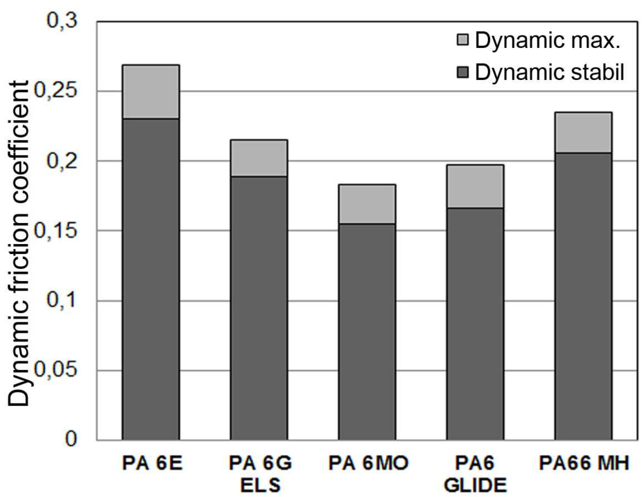

Figure 8. Dynamic friction coefficients of different PA composites
(sliding distance = 7m; load = 150 N; surface roughness R_z= 1,7µm)

The figure 9 shows other range between the same polymer composites with lower load (50 N). We can see a different friction towards the polymers. One of the lowest frictions is shown by PA6 GLIDE and one of the higher by PA6E, similar than it was in higher load category. However, there is just a little effect on the lower load on polyamides 6G ELS (and Pa6 GLIDE also). There are interesting results by PA6MO (lowest friction) and PA66MH (higher friction than in previous category).

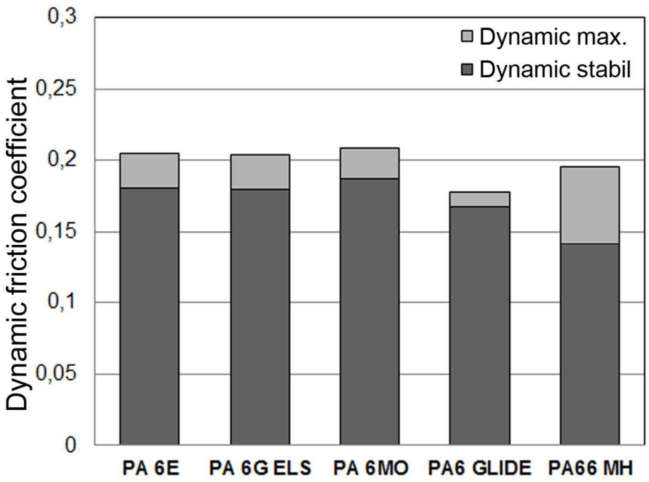

Figure 9. Dynamic friction coefficients of different PA composites
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

Differences are visible on the figure 10 between the static and dynamic friction of the examinations published earlier (150 N load level).

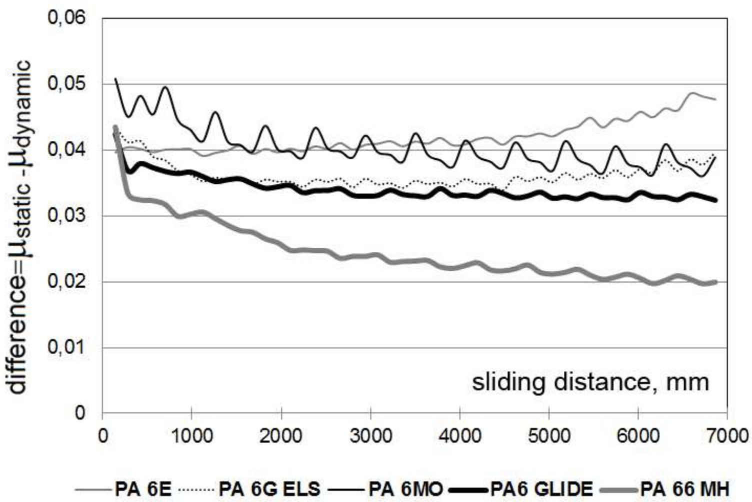

Figure 10. The difference between static and sliding friction for all tested Polyamide with higher load
(sliding distance = 7m; load = 150 N; surface roughness R_z= 1,7µm)

During the examinations the following were observed:

– The creaking sound (with vibration) was getting stronger continually in the course of this PA 6E examination was observable. Polymer transfer layer and wear gaps were observable.

– The experiment showed a quiet, vibration-free running in case of the PA 6G ELS and PA 6MO.

– The initial strong noise weakens continuously until the end of the measurement in case of the PA66 MH.

The differences between frictions (static and dynamic on 50N load level) which can be seen on the figure 11 are in good harmony with the single measurements (figures 3-7) as mentioned.

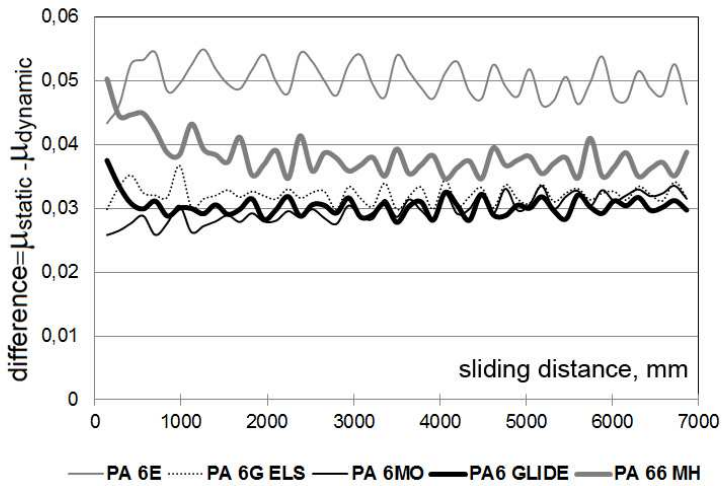

Figure 11. The difference between static and sliding friction for all tested Polyamide with lower load
(sliding distance = 7m; load = 50 N; surface roughness R_z= 1,7µm)

During the examinations the following were observed:

– The highest difference belongs to the PA 6E curve. It correlates well with the continuous strong noise and vibrations.

– In the case of the PA 66 MH the initial friction noise was becoming blunt quickly. We can see it well on the figure, where the curve decreases step by step during the test.

– In case of the other polymers the tendencies and values are similar and the curves horizontal.

4. Conclusions

The reciprocating cylinder-on-plate test rig is not able to provide absolute data representative of actual applications. The tribological behaviour of different polymers can be compared successfully and we can declare that most of their friction strongly depends on the load level.

The experimental friction data (figures 8 and 9) suggest the following conclusions:

– The higher load reduces the effect of the additive component significantly in case of the polyamide 6 base matrix. It is observable that the friction values on category of 150 N loads are identical. The PA66 differs from this tendency, but there the base material is not the same as PA6.

– The additive components receive an important role already on a lower load (50N), like the molybdenum disulphide is able to reduce the friction of PA6 MO.

- The load change has little effect on the friction of PA6 GLIDE and PA 6GELS. At the same time the lower elasticity modulus of PA66MH causes instability on the starting period of the friction on a lower load, the perceived halting friction noise (supposed stick-slip) supports this too.

We may consider the definition of the differences between the static and dynamic frictions and depicting it in a diagram (during the whole examination time) the most important results of our present work. We can call this difference the instability of friction. These diagrams are in good correlation with the friction noises and vibrations, experienced during the tribology tests.

In summary what can be established from the diagram of the friction instability (let's see the previous figures 10 and11):

- The PA6 GLIDE and the PA6G ELS each were observed along an identical straight and in a similar value on both load levels (similar as in the case of friction column diagram). This common character on lower load came true around a smaller value.
- The PA66 MH started with high friction instability, which decreased to the end of the test continuously, in case of both load levels (the initial strong frictional noise indicated this).
- The reference polymer PA6E indicated the worst instability in both cases, but in opposite with PA66 MH the increasing tendency is continuous during all tests.

It is clear from the results, that the difference between static and dynamic friction coefficient can characterize the stick-slip behaviour of polyamide composites. The results presented in the former tests show that we can create an index number to mark the stick-slip behaviours of the polymers, the role of our future work.

Acknowledgements

The author (László Zsidai) would like to thank MTA (Hungarian Academy of Sciences) for supporting this work in the frame of the research fellowship BOLYAI (BO/00127/13/6).

Special thanks go to QuattroPlast for the delivery of material specimens.

References

Bruska Azhdar, Bengt Stenberg, Leif Kari (2006): Determination of dynamic and sliding friction, and observation of stick-slip phenomenon on compacted polymer powders during high-velocity compaction, Polymer Testing, Volume 25, Issue 8, December 2006, Pages 1069–1080)

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

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.

Friedrich, K; Lu, Z; Hager, AM (1995): Recent advances in polymer composites' tribology ,WEAR Volume: 190 Issue: 2 Pages: 139-144

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.

G. Kalácska, ed. (2007): Műszaki polimerek és kompozitok a gépészmérnöki gyakorlatban. 3C-Grafika Kft. p. 1-315. ISBN-10: 963-06-1566-5, ISBN 13: 978-963-06-1566-2

G. Kalácska, et al., (1997): Műszaki műanyagok gépészeti alapjai (Mechanical Basics of Polymers), Minervasop Bt. Sopron,

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

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

J.H. Byett, C. Allen (1992): Dry sliding wear behaviour of polyamide-66 and polycarbonate composites, Trib. Int. 25 (1992) 237, Pages: 237-246

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

L. Zsidai, G. Kalácska (2014): „Stick-slip" PA és PEEK kompozitok súrlódásánál, henger/sík modell vizsgálati rendszerben, Műanyag és Gumi 2014.51. Vol. 12.

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, HU ISSN 2060-3789

L. Zsidai, Z. Szakál (2014) : Friction of PA6 and peek composites in the light of their surface characteristics Research & Development, Mechanical Engineering Letters, Szent István University 2014, p.:165-184, HU ISSN 2060-3789

L. Zsidai, R. Keresztes, A. Eleőd (2015): A "stick-slip" jelentősége és tribológiai vizsgálatának lehetséges irányvonalai polimer gépelem alkalmazásokhoz, Polimerek P021 (in print)

R. Keresztes, G. Kalácska (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.

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

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

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

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