BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iaşi,
Tomul LXI (LXV), Fasc. 1, 2015
Secţia
CONSTRUCŢII DE MAŞINI

FRICTION BEHAVIOR OF THE POLYMERS OPERATING AT LOW LOADS SLIDING CONDITIONS

BY

MIHAI ADRIAN RUSU, ALEXANDRU BARNEA, GEORGE ALEXANDRU ENACHE, VLAD CÂRLESCU, CEZAR OPRIŞAN and DUMITRU OLARU*

"Gheorghe Asachi" Technical University of Iaşi, România,
Department of Mechanical Engineering, Mechatronics and Robotics

Received: February 19, 2015
Accepted for publication: March 26, 2015

Abstract. By using the Micro Tribometer UMT 2 from the Tribology Laboratory, the authors experimentally determined the friction forces and friction coefficients between cylindrical objects and elastomer for normal loads between 1 N to 5 N and linear speed between 0.1 mm/s to 10 mm/s. Between the cylindrical objects and elastomer sample have been evidenced processes of adhesion, elastic deformations, sliding and elastic relaxation of the elastomer during the displacement of the sample. Also the friction coefficient as function of cylinder material, normal load and linear speed has been experimentally determined.

Key words: friction; polymers; sliding motion; adherence; friction coefficient.

1. Introduction

In a lot of micro actuators and micro prehension devises the various polymers are usually used both as bulk materials and as surface layers. In the micro actuators when sliding friction must be at lower level it is necessary to be

*Corresponding author; *e-mail*: dolaru@mail.tuiasi.ro

used low friction polymers. In the micro prehension devices the adherence and friction between the polymers and prehensed small objects must be at high level.

The finger prehension is based both on the adhesive forces with the objects and on the tactile skin sensors to evaluate the slip tendency of the object. Actual tendency to develop prehension systems based on the human hand manipulation generated new and complex devices. One of these complex prehension devices for small objects having five fingers has been developed by (Odhner *et al*., 2014) where the finger pads were realized by elastomers. In order to simulated the prehension of only two fingers (Barnea, 2013; Barnea *et al*., 2014) investigated the friction in sliding motion between the small cylindrical surfaces and human fingers for a normal load of 1N to 5 N. Depending on the materials of cylindrical objects and, the normal load and linear speed Barnea obtained various combinations for the friction force dominated both by adhesion and sliding. Original "butterfly" diagrams have been obtained as a result of the successive elastic deformations, adhesion, sliding and relaxations of the finger skin in the contact with the cylindrical objects during the experimental tests. The experiments realized by (Kwiatkowska *et al*., 2009) evidenced the friction and adherence between steel balls and skin fingers and obtained for friction coefficient values between 0.8 and 1.5 for normal load between 0.19 N and 0.5 N. Other experiments to determine friction coefficient between fingher skin and plane surfaces were realized by (Liu, 2013).

Modifi and Prakash (2012) experimentally determined the friction coefficient between a steel cylinder in rotational motion and plate elastomer specimens having module of elasticity of about 10 MPa. The experiments were carried out at a normal load of 3.5 N and the contact pressure determined according to Hertz theory was estimated to be about 0.37 MPa. The values of friction coefficient obtained for very low speed (0.2 mm/s) varied between 0.25 to 0.5, depending of the elastomer type. Quaglini and Dubini (2011) established an analytical equation for the friction coefficient in sliding of the polymers and smooth metals by considering the nominal contact pressure and the shear stress at the interface between metal and polymer.

In the present paper the authors investigated experimentally the friction and adherence of the small cylindrical objects in contact with the plane elastomer specimen. The experiments were realized with normal loads between 1 N to 5 N and sliding speed between 0.1 mm/s to 10 mm/s.

2. Experimental Procedure and Equipments

The experiments were realized by using the Tribometer CETR UMT2 from the Laboratory of Tribology as is presented in Fig. 1. The cylindrical objects are fixed on the top of the pin and the pin is mounted in the sensor of the Tribometer. The sensor indicate the values both for normal force Fz and friction force Ff. On the linear table of the Tribometer was mounted the elastomer sample and the cylinder is put in contact with the sample as is presented in Fig. 2. The sample realize linear displacement on a distance of 8 mm in one direction and in opposite direction. The friction force between cylindrical object and elastomer for various linear speed and normal loads are registered in the computer of the Tribometer. The tests were realized by using stainless steel and aluminum cylinders having diameter of 10 mm.

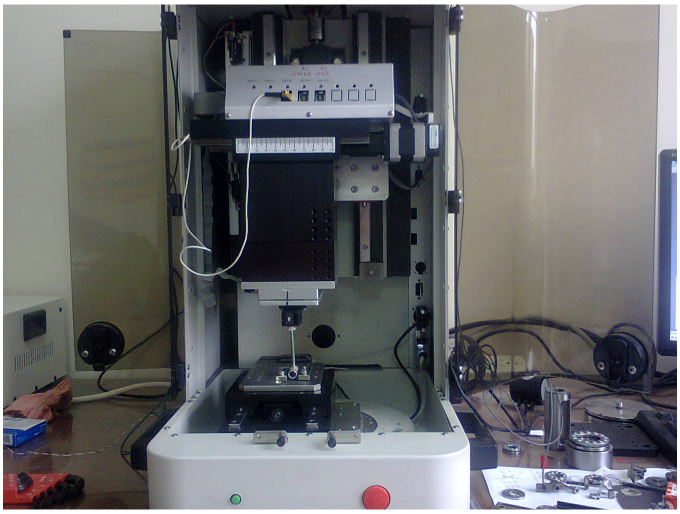

Fig. 1 − The Tribometer CETR UMT 2 with the cylindrical object attached on the pin.

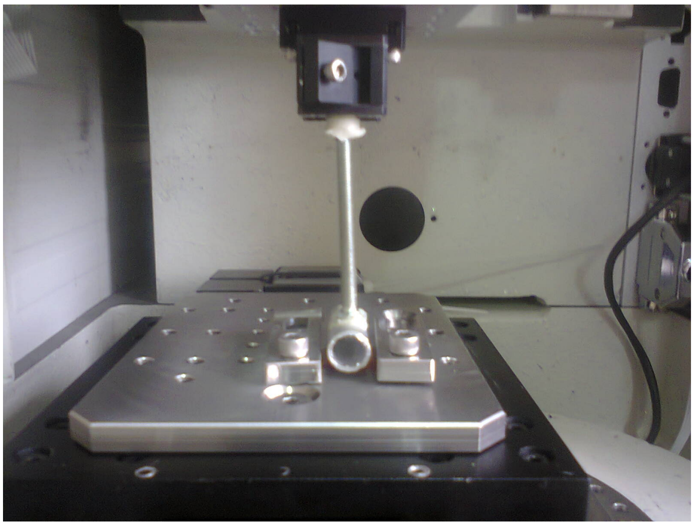

Fig. 2 − Detail of the cylindrical object attached on the pin and the elastomer sample fixed on the linear table of the Tribometer.

The tests were realized for linear speed between 0.1 mm/s and 10 mm/s and normal load Fz varied between 1 N and 5 N. All the experiments were realized in dry conditions. The tests were realized with elastomer sample obtained from Polydimethylsiloxane-α,ω-diol (PDMS) as matrix with 20% oxide hematite (Fe_2O_3) (Marcu *et al.*, 1994). The dimensions of the sample were: 30 mm length, 10 mm wide and 2 mm thickness.

3. Experimental Results

3.1. Stainless Steel Cylinder in Contact with Elastomer

The experimental results are presented as variations of the friction force Ff in function of the displacement of the sample on the distance Y for a number of strokes, depending of the linear speed. In Fig. 3 is presented a typical variation of the friction force as function of linear distance Y for some alternative motions during the distance of 8 mm. The diagram from Fig. 3 is realized for the stainless steel cylinder in contact with the elastomer loaded with normal force Fz = 5 N and for a linear speed of 1 mm/s.

Following processes have been identified in the friction force's variation. The point O represent the start of the displacement in positive direction. From the point O to the point A it can be observed the adhesion between cylinder and elastomer with an continuum increasing of the force Ff caused by the elastic deformation of the elastomer. From the point A to the end of the stroke (point B) the cylinder sliding on the elastomer with a friction force of about 2 N, that means a constant friction coefficient having value of about 0.4. At the end of stroke in point B the direction of the displacement is changed and the elastomer is under a relaxation process from point B to point C. A new elastic deformation of the sample start in the point C during to the point D. Follows a sliding process from point D to the end of the negative stroke in point E with a friction force of about 2 N. From the point E the direction of the displacement is changed, the elastomer realize a relaxation process to the point F and the alternative processes including elastic deformation, sliding and elastic relaxation have been repeated. In Fig. 3 the blue colour is used for positive displacement and red colour is used for negative displacement. Excepting the first elastic deformation (the segment between the points A and B) all elastic deformation and relaxation of the elastomer can be approximated as linear curves.

The similar processes have been observed for the experiments realized with normal load of 1 N for linear speed between 0.1 mm/s and 1 mm/s as are presented in Fig. 4 and Fig. 5. It can be observed that under the normal load of 1N the elastic deformation and relaxation of the elastomer presents a good linearity between adherence force Ff and linear displacement Y.

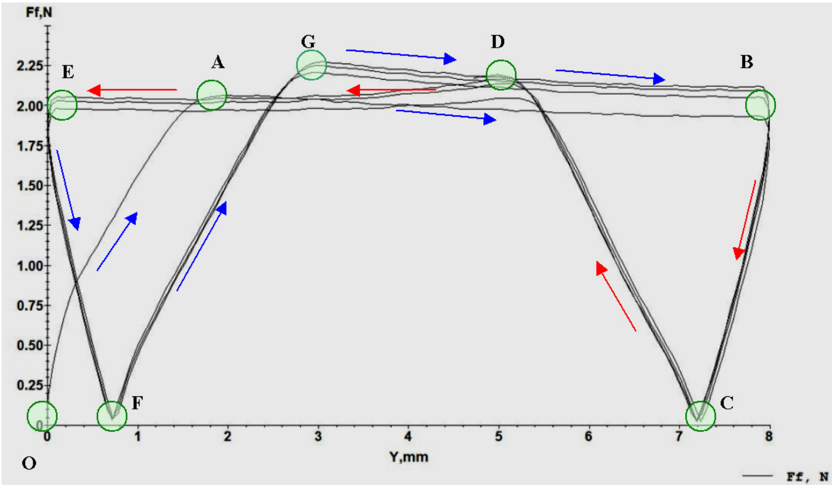

Fig. 3 − A typical variation of the friction force with the alternative displacement of the sample: normal load Fz = 5 N, linear speed v = 1 mm/s.

By increasing of the speed from 1 mm/s to 10 mm/s the variation of the friction force Ff with the displacement of the sample evidenced the development of the stick – slip processes both for normal load of 1N and 5 N. In Figs. 6 and 7 are presented the variation of the friction force Ff for the normal force Fz =1 N and Fz = 5 N, respectively. For the normal load of 1 N the stick – slip process are developed both in the elastic deformation and adherence of the elastomer. For the normal force of 5 N the stick – slip process can be observed only in elastic deformation and relaxation of the elastomer.

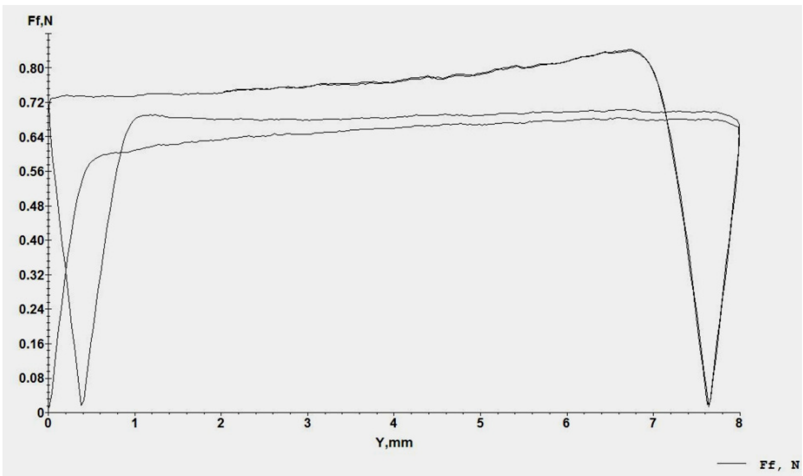

Fig. 4 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 1 N, v = 0.1 mm/s.

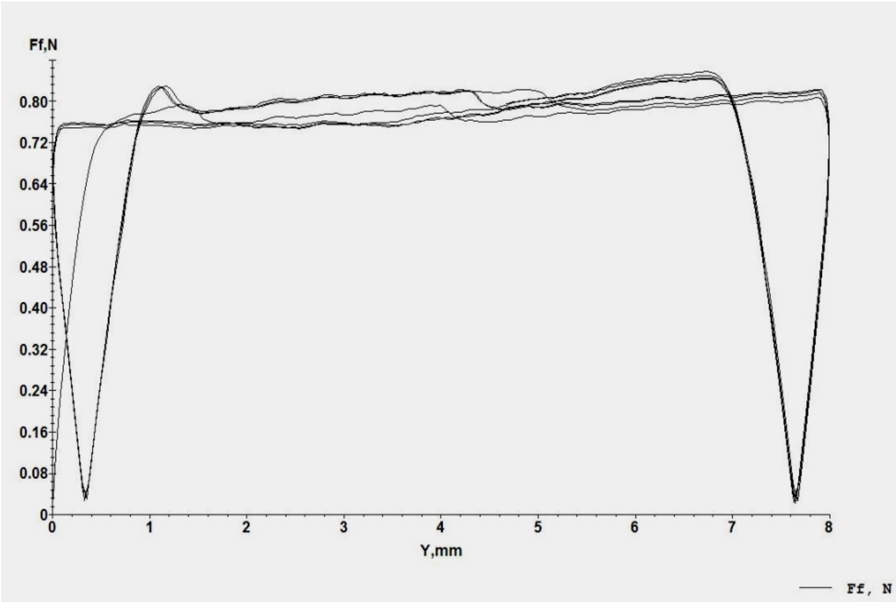

Fig. 5 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 1 N, v = 1 mm/s.

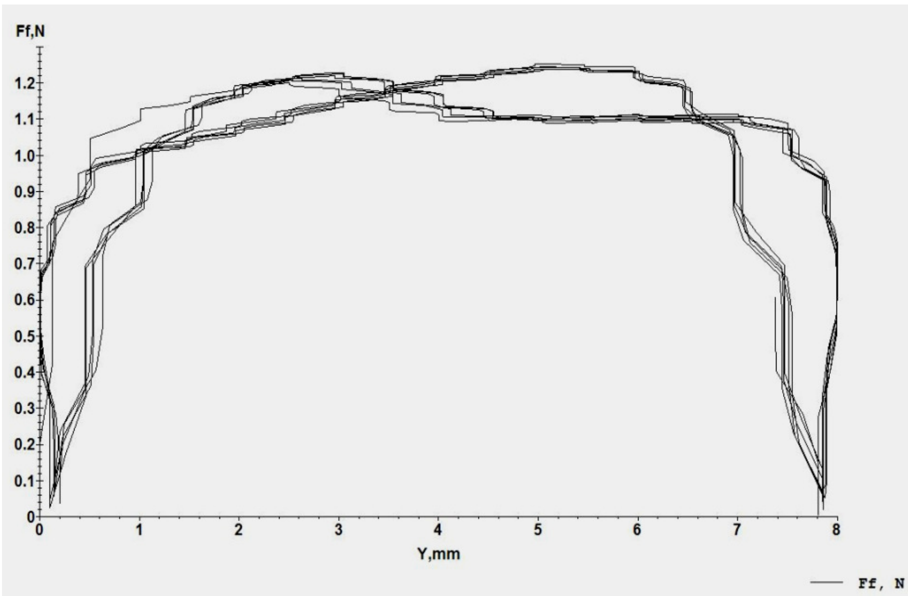

Fig. 6 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 1 N, v = 10 mm/s.

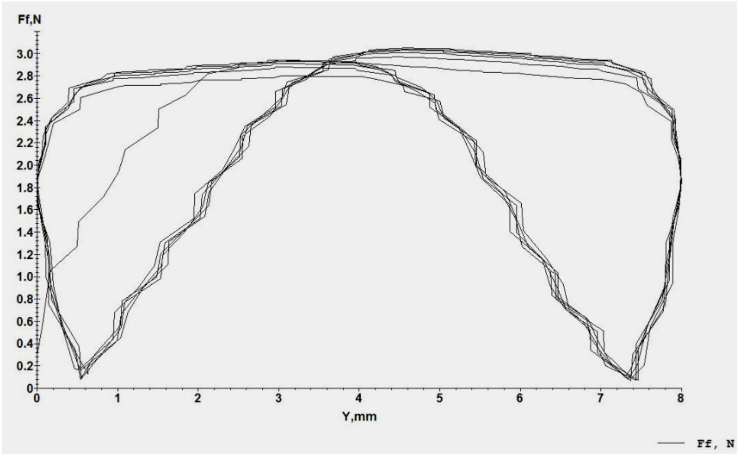

Fig. 7 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 5 N, v = 10 mm/s.

3.2. Aluminum Cylinder in Contact with Elastomer

The variation of the friction force as function of linear distance Y for aluminium cylinder in contact with elastomer have similar configurations like these obtained for stainless steel cylinder and elastomer. In Figs. 8 and 9 are presented the variation of the friction force for a linear speed of 1 mm/s for the normal load Fz = 1 N and Fz = 5 N, respectively. It can be observed alternative processes of elastic deformations, sliding and elastic relaxation during the alternative displacement of the elastomer sample on the aluminium cylinder.

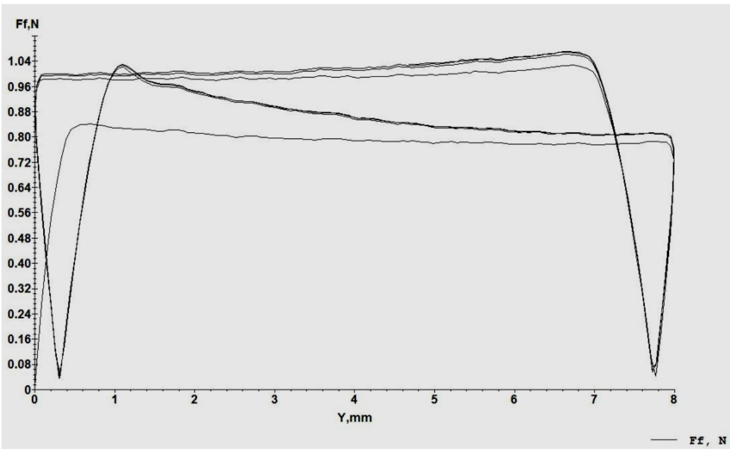

Fig. 8 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 1 N, v = 1 mm/s.

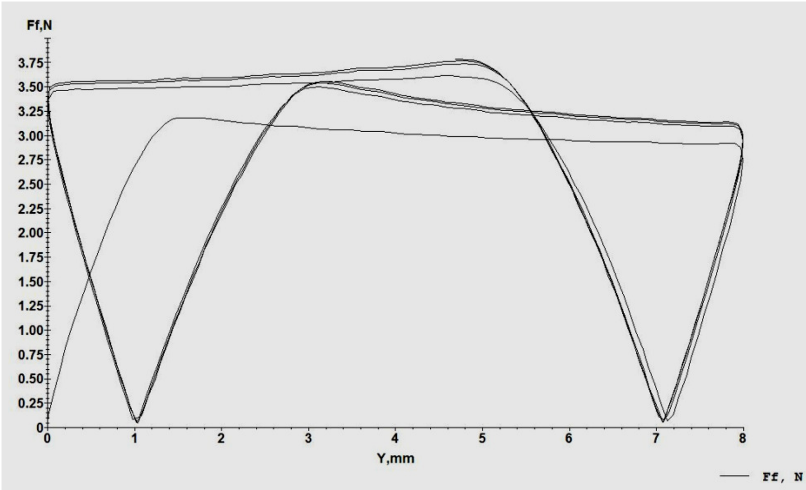

Fig. 9 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 5 N, v = 1 mm/s.

By increasing the linear speed to 10 mm/s it can be observed the processes of stick – slip more accentuated at the normal load of 1N.

In Fig. 10 is presented the variation of the friction force for normal load of 1 N and in Fig. 11 is presented the variation of the friction force for normal force of 5 N.

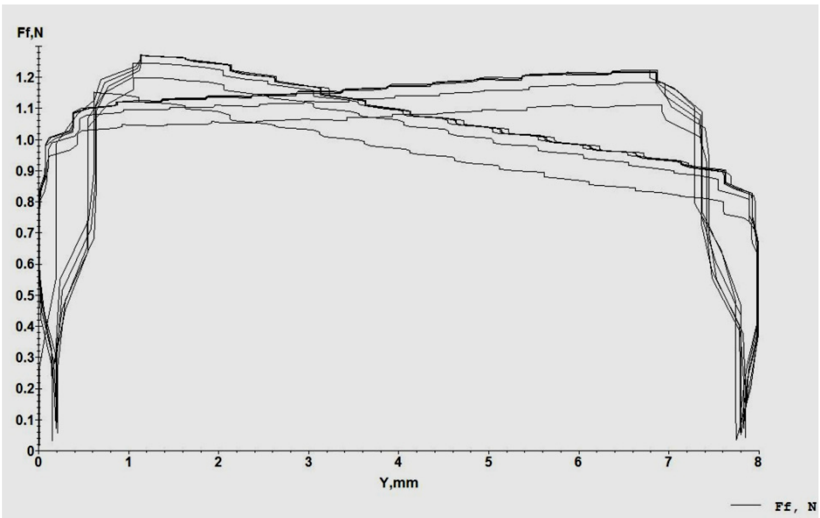

Fig. 10 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 1 N, v = 10 mm/s.

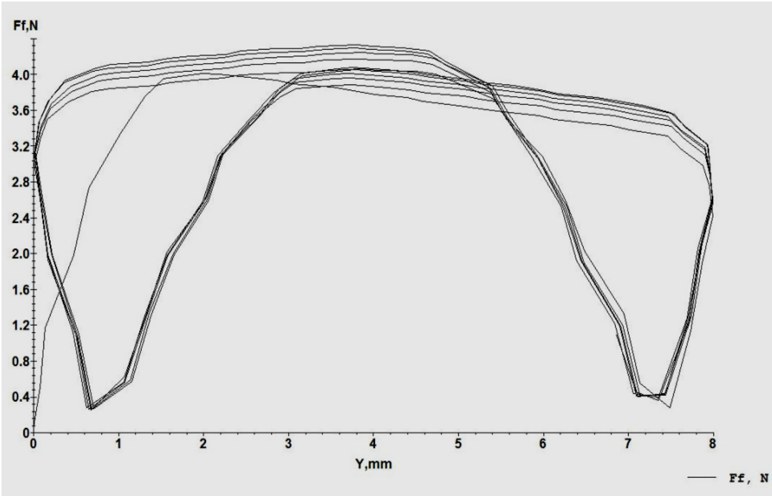

Fig. 11 − Variation of the friction force Ff with the alternative displacement of the sample: Fz = 5 N, v = 10 mm/s.

4. Friction Coefficient

The friction coefficient have physical signification only in the sliding zones from the diagrams. Following limits of the friction coefficient as function of cylinder material, normal load and linear speed have been presented in Fig. 12 for normal load Fz = 1 N and in Fig. 13 for normal load Fz = 5N.

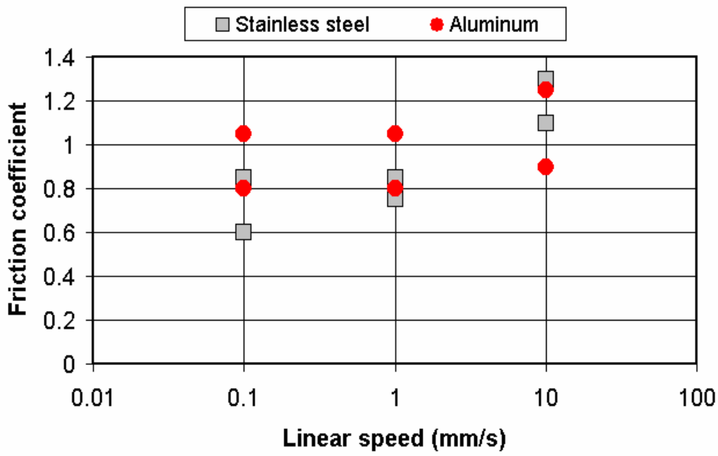

Fig. 12 − Limits of the friction coefficient as function of material and linear speed: Fz = 1 N.

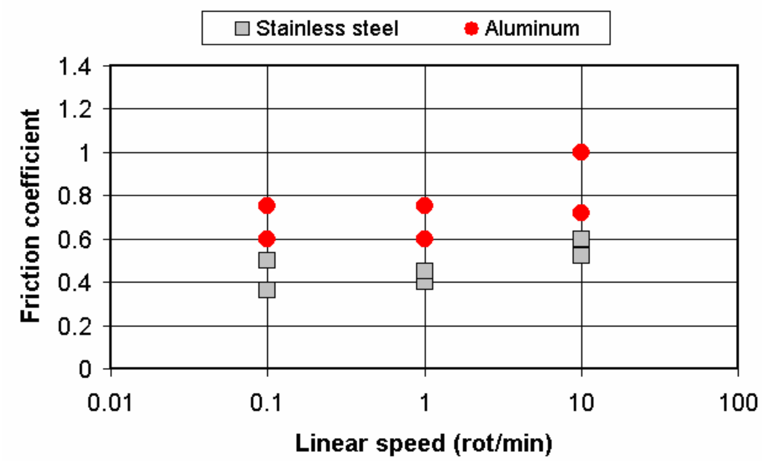

Fig. 13 − Limits of the friction coefficient as function of material and linear speed: Fz = 5 N.

5. Conclusions

An experimental methodology to determine the friction forces between cylindrical objects in contact with elastomer having sliding motion has been developed by the authors. The experiments were realized by using stainless steel and aluminum cylinders in contact with an elastomer sample in linear sliding motion with 0.1 mm/s, 1 mm/s and 10 mm/s, the contact between cylinders and elastomer being loaded with 1 N and 5 N.

The experiments were evidenced a succession of the physical processes in alternative motion on a distance of 8 mm. So, elastic deformation of the elastomer, sliding of the cylinder on the elastomer surface and relaxation of the elastomer have been evidenced in the adequate diagrams obtained with the CETR UMT 2 Tribometer.

By increasing of the linear speed from 1 mm/s to 10 mm/s was observed the development of the stick- slip process, more accentuated at the normal force of 1 N.

Was evaluated the limits of the friction coefficient in the sliding zone and following comments can be made:

i) The friction coefficient is not constant during the sliding process having variations from positive to negative directions of sliding;

ii) The friction coefficient is depending of the cylinder material, high values being obtained for the aluminum cylinder in contact with the elastomer;

iii) The friction coefficient increases by increasing the linear speed.

REFERENCES

Barnea A., *Cercetări privind optimizări constructive la nivelul sistemelor de actuaţie specifice roboţilor mobile.* Ph. D. Diss., The "Gheorghe Asachi" Technical University of Iaşi, 2013.

Barnea A., Oprişan C., Olaru D., *Prehension of the Small Cylindrical Objects by the Human Fingers. Friction and Adherence Processes*. Applied Mechanics and Materials-Advanced Concepts in Mechanical Engineering I, **658**, 721−727, 2014.

Kwiatkowska M., Franklin S., Hendriks C., Kwiatkowski K., *Friction and Deformation Behaviour of Human Skin.* Wear, **267**, 1264–1273, 2009.

Liu X., *Understanding the Effect of Skin Mechanical Properties on the Friction of Human Finger-Pads.* Ph. D. Diss., The University of Sheffield, Department of Mechanical Engineering, 2013.

Marcu M., Simionescu M., Cazacu M., Lazarescu S., Ibănescu C., *Obtaining Poly*(*Dimethylsiloxane*)*α,ω-Diols Using the Heterogeneous catalysis. The Optimization of the Reaction Conditions.* Iran. J. Polym. Sci. **3**, 95–104, 1994.

Mofidi M., Prakash B., *Frictional Behaviour of Some Sealing Elastomers in Lubricated Sliding Conditions.* Proc. of NORDTRIB Confeerence, 2012.

Odhner L.U. *et al*., *A Compliant, Underactuated Hand for Robust Manipulation.* The international Robotics Reasearch, **33**, 5, 736−752, 2014.

Quaglini V., Dubini P., *Friction of Polymers Sliding on Smooth Surfaces.* Advancesw in Tribology, Article ID 178943, 2011.

COMPORTAREA LA FRECARE A POLIMERILOR ÎN CONDIŢII DE ALUNECARE LA SARCINI REDUSE

(Rezumat)

În sistemele de prehensiune specifice unor tipuri de roboţi, pentru o bună aderenţă a obiectele manipulate, se utilizează diverşi polimeri cu caracteristici elastice şi de aderenţă cât mai apropiate de caracteristicile degetelor umane. O categorie de polimeri utilizaţi în acest scop o formează elastomerii. Pornind de la cercetări experimentale care au vizat comportarea la aderenţă şi alunecare a diverselor obiecte cilindrice de mici dimensiuni în contact cu suprafaţa degetului uman, cercetări realizate în Laboratorul de Tribologie din Facultatea de Mecanică, prezenta lucrare abordează comportarea la adeziune şi alunecare dintre o epruvetă plană din elastomer tip PDMS în contact cu cilindri din aluminiu şi oţel inoxidabil. Testările au vizat determinarea curbelor de variaţie a forţei de aderenţă (frecare) dintre cilindri şi epruveta de elastomer în condiţiile unor deplasări pe direcţie liniară cu viteze cuprinse între 0,1 mm/s şi 10 mm/s şi pentru sarcini normale cuprinse între 1 N şi 5 N. Au fost puse în evidenţă succesiunea unor zone de aderenţă cu zone de alunecare la schimbarea sensului de

deplasare a probei din elastomer. Testările au fost făcute pe Tribometrul CETR UMT 2 din Laboratorul de Tribologie. Pentru zona de alunecare s-au determinat valorile coeficienților de frecare dintre cilindri şi elastomer. Experimentele au pus în evidență faptul că valorile coeficienților de frecare se modifică odată cu schimbarea sensului de mişcare şi cresc odată cu creşterea vitezei de translație. S-a mai pus în evidență faptul că la viteze de 10 mm/s se dezvoltă fenomenul de stick – slip.