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Experimental Study of Sliding Friction for PET Track Membranes

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Abstract. The article is presented results of a study of the process for a dry friction metal-polymer couple on scheme disc- finger. Track membrane from polyethylene terephthalate was a research material. Membrane had pores with 0.4 and 0.8 μm diameters. The effect of the sliding velocity for membranes with pores of 0.8 microns was determined. Research was shown that increasing pore's diameter caused a reduction of the friction coefficient and downturn its magnitude vibrations. The study showed that track membrane have adequate resistance to wear and can be successfully used in surgical procedures in the layers of the cornea.

1. Introduction

Polyethylene terephthalate (PET) is the one of the most common materials used for the manufacture of track membranes well-established in such areas as electronics, food, chemical and automotive industries, cryogenics and medicine [1-5].

PET has hydrophobic, non-hygroscopic, biologically passive, non-radioactivity properties, resistance to most acids and organic compounds, a high gear transmission of the light flux.

There is the need for further processing of PET materials due to expansion of its application. Further processing of PET materials includes chemical etching, ionic raying, and plasma process. PET physical-chemical and mechanical material's properties change after reworking. These changes remain understudied.

The study of friction and wear thin films of PET was performed in scratching single crystal natural diamond. Film thickness was 14.2 μm. Also the study of friction and wear PET films was made with reciprocating sliding friction regime of flat finger along the surface of the 80.0 μm thickness film and reciprocating sliding friction regime of steel ball along the surface of the 125 μm thickness film.

We can identify the following features of PET thin films friction based on works of authors [6-8].

1) Plastic deformation of the film is done by scratching. Changing the coefficient of friction depends on the unevenness of the film surface [6].

2) Authors [7] have shown that the change of surface topography and the creation of projections and depressions result in a change of the wear and friction coefficient. The friction coefficient of film with projections is higher than that of films with depressions.

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3) Authors [8] have shown that the friction coefficient is 0.2-0.5. Wear and destruction of films increase in the center of the track wear after increasing numbers of sliding circles. Microcutting occurs as a result of delamination of the film surface under the influence of rider. Wear particles are removed from the path of friction under the influence of the hard counter body. Friction process is accompanied by the transfer of the polymer to the surface of rider.

Application of PET track membranes is of the utmost interest in the medical field such as ophthalmology [9]. According to the authors [10] implantation PET track membrane into corneal layers can cause mechanical damage of film. Therefore, the PET membrane should be resistant mechanical properties.

Purpose of the work is conducting tribological research of PET thin track membranes in sliding friction in contact with a metal rider.

2. Research method

The research was made with Tribometer THT-S-AX0000. Sliding friction was done according to the scheme finger-disc with a normal load 1 N. The diameter of friction surface was 10.0 mm. The metal rider was steel ball with 3.0 mm diameter. Tests were done under dry friction at room temperature 27±1°C and a relative humidity of 50%. Sliding speed for track membrane with 0.4 μm pore's diameter was 4.2 m/min. Sliding speeds for track membrane with 0.8 μm pore's diameter were 3 m/min and 4.2 m/min.

Samples of track membrane were fixed on metal substrate (figure 1). The steel ball was attached to cylindrical finger motionlessly.

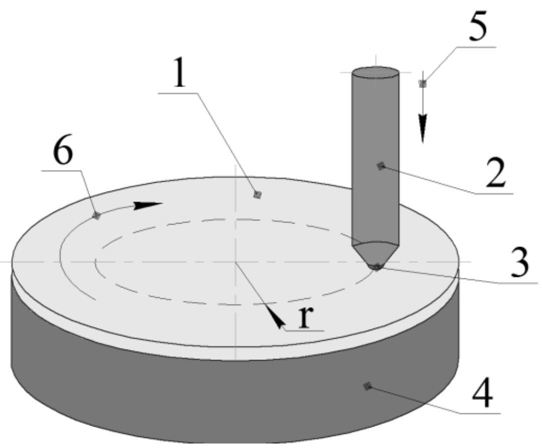
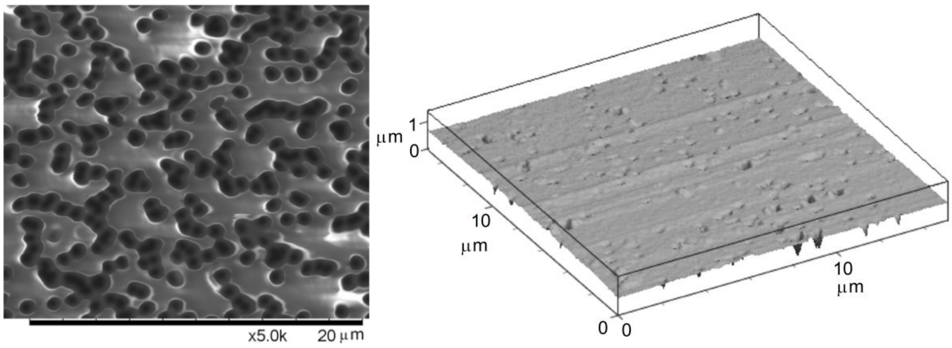


Figure 1. Tribological scheme of track membrane's research: 1 – track membrane, 2 – finger, 3 – steel ball, 4 – disc, 5 – normal load, 6 – rotating direction

Track membranes (TM) were made from polyethylene terephthalate. Technique of producing porous track structures is based on irradiated different polymers by high-energy heavy ions. These ions induce latent narrow tracks through the entire thickness of the polymeric material. Latent tracks are defective area with a diameter of 5-12 nm. Subsequent selective etching can remove these defective areas and receive the porous material with nano pores density from 10^6 cm^{-2} to 10^9 cm^{-2}. Oriented polymer films are irradiated by Ar ion beam with a maximum energy of 41 MeV in a specially designed vacuum chamber with a tape transport mechanism. Accelerated beam of argon ions was extracted from the chamber with an electrostatic deflector. Argon ion beam was directed into the channel, in which there were a uniform system for scanning the ion beam and the camera exposure film. The original scheme with electrostatic scanning beam in the horizontal direction was designed and used to scan the beam in the horizontal direction. A beam of argon admitted to the vacuum chamber, where the irradiation of the film was done after passing through the scanning system. Energy of the accelerated ions was measured before irradiation of the film with high accuracy using the method of recording backscattered ions (POP). It allowed to identify the acceleration ions by mass and to determine the energy of the incident ions . The intensity distribution of the beam on the film was controlled by measuring the current on the lamellae arranged in the film over its entire width. Ions passing through the film created an area of high density ionization. It was the track of the ion. Selective etching of the alkaline material in the region of track allowed to get a porous film in the original system with cylindrical holes with a typical symmetric structure The film was irradiated with UV light for an additional sensitization before etching. The etching was carried out in an aqueous solution of NaOH 1.5 N concentration at temperatures in the range 72- 82C .

The density and pore sizes were controlled with the electron microscope Hitachi TM – 1000. Pore diameters were 0.4 and 0.8 µm. Density was $5 \cdot 10^6$ pores/cm^2. Electron micrograph TM with pore's diameter of 0.4 µm is shown in figure 2a. Research of surface properties was made on Scanning AFM/Confocal/Raman/Fluorescence system «Centaur HR». 3D-surface TM profile with a pore's diameter of 0.4 µm is shown in figure 2b.

Membrane thickness measure was performed using an electronic thickness gauge «Tesa Unit». Measurement accuracy was ± 0.1 µm. Thickness of TM was 7.0 µm.



a) b)

Figure 2. Electron micrograph TM fragment (a) and its profile surface (b)

3. Results and discussions

Results of track membranes friction coefficient are shown on the figure 3 received 6000 laps at a constant speed drive slip of 4.2 m/min. Curve 1 shows the friction coefficient of the TM with 0.4 µm pores. Curve 2 shows the friction coefficient of the track membrane with 0.8 µm pores.

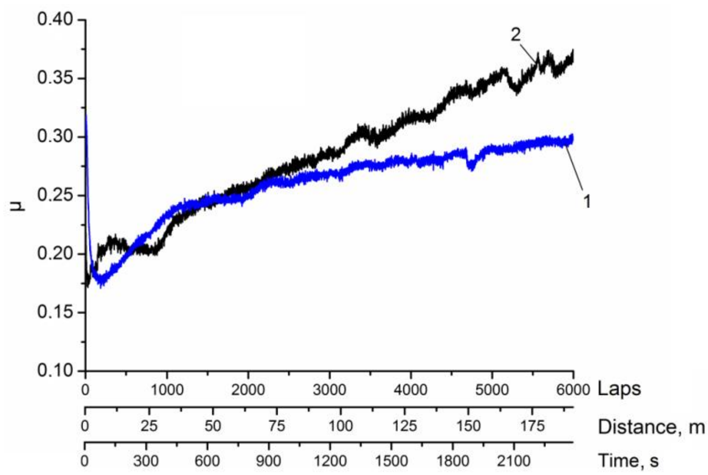


Figure 3. Friction coefficient of track membranes with 0.8 µm (1) and 0.4 µm (2) pore's diameters. Sliding speed is 4.2 m/min

Friction coefficient (μ) is 0.3 for the TM with 0.4 μm and 0.8 μm pore's diameters at the initial stage μ of 0.4 pore's diameters TM drops to 0.17 in the first 30 laps. Friction coefficient increases to 0.2 from 30 to 175 laps, and after coefficient of friction is stabilized to 850 laps. In the figure we can observe μ increasing to 0.29 after 850 laps and sudden upsurge to 0.37 before the end of the test.

Friction coefficient of 0.8 pore's diameters TM decrease to 0.2 in the first 50 laps. The next 150 laps μ continues smooth decreasing to 0.17. We can observe an increase of the friction coefficient from 0.17 to 0.23 in the range 200-850 laps and smooth growth period of μ to 2000 laps. In the range of 2000-6000 laps μ increases skippingly and reaches a value of 0.3.

Results of friction coefficient of TM with 0.8 μm pore's diameters are shown in the figure 4 received 6000 laps at a constant speed drive slip of 4.2 m/min and 3.0 m/min. Curve 1 shows 3.0 m/min sliding speed. Curve 2 shows 4.2 m/min sliding speed.

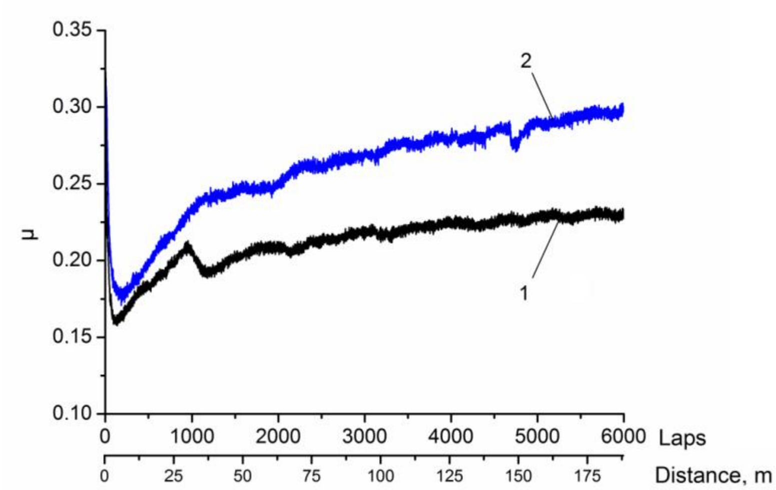


Figure 4. Friction coefficient of track membranes with 0.8 μm pore's diameters. Sliding speeds are 3.0 m/min (1) and 4.2 m/min (2)

The initial value of friction coefficient is 0.347 (3.0 m/min sliding speed). After 35 laps μ gradually decreases to 0.16. Coefficient of friction increases to 0.21 in the period of 100-950 laps. Decline to 0.19 μ magnitude happens in between 950-1200 laps, and after this the friction coefficient increases to 0.233. Also it should be noted that the reduction sliding speed from 4.2 to 3 m/min leads to a decrease the coefficient of friction.

Reduction of the friction coefficient at the initial stage dues to the formation of the friction transfer film. It is typical for a pair of metal-on-polymer [12] and also for a smoothing of surface roughness TM counterbody. The coefficient of friction decreases with decreasing sliding speed.

Figures 5-7 are shown the surface profiles of the track membranes, and cross-sectional view of wear track. Surface profile of wear track of track membrane with 0.4 μm pore's diameters has cross-undulation, which is a result of the plastic edging. Using software Gwydion we determined that fluctuation of depths and holes is 2 μm. Wear track has flat surface for a TM with 0.8 μm pore's diameters. Therefore, plastic edging of TM doesn't happen. Surface profile of wear track of track membrane with 0.8 μm pore's diameters doesn't change longitudinally with decreasing sliding speed of 4.2 m/min to 3 m/min.

Sections of track wear have a wavy profile with heights of 0.5-1 mm in all cases. The maximum depth of wear of track membrane with 0.8 μm pore's diameters is 4.41 μm (sliding speed of 4.2 m/min). Wear depth is reduced to 2.34 m with reducing the sliding speed of 3 m/min. The maximum depth of wear of track membrane with 0.4 μm pore's diameters is 4.2 μm (sliding speed of 4.2 m/min).

Wear depth increases from 0.38 to 0.63 mm with increasing pore's diameter from 0.4 to 0.8 μm. It appears that it is the result of pushing material TM counter body on the side surfaces of the track wear. With decreasing sliding speed the wear depth reduces from 0.63 to 0.52 μm.

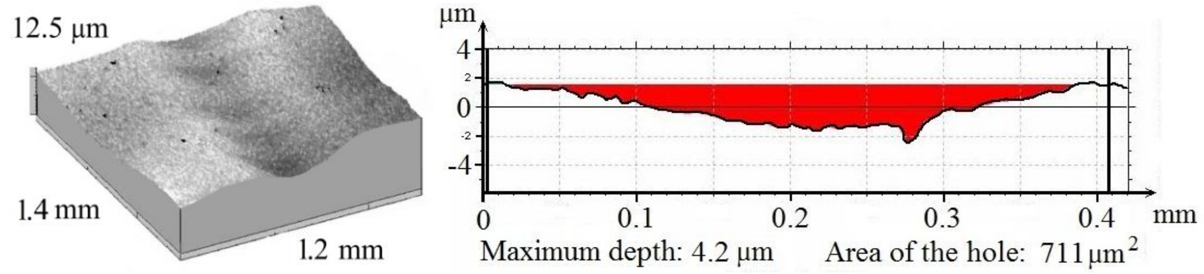


Figure 5. Profile of track membrane surface and sections of wear track of track membrane with 0.4 μm pore's diameters. Sliding speed is 4.2 m/min

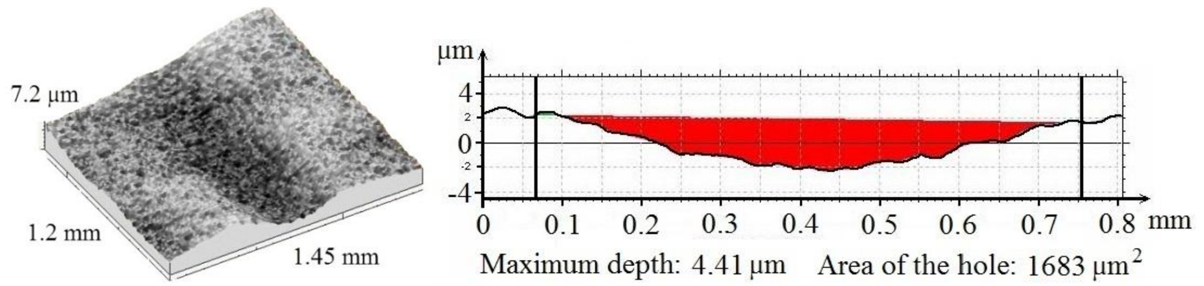


Figure 6. Profile of track membrane surface and sections of wear track of track membrane with 0.8 μm pore's diameters. Sliding speed is 4.2 m/min

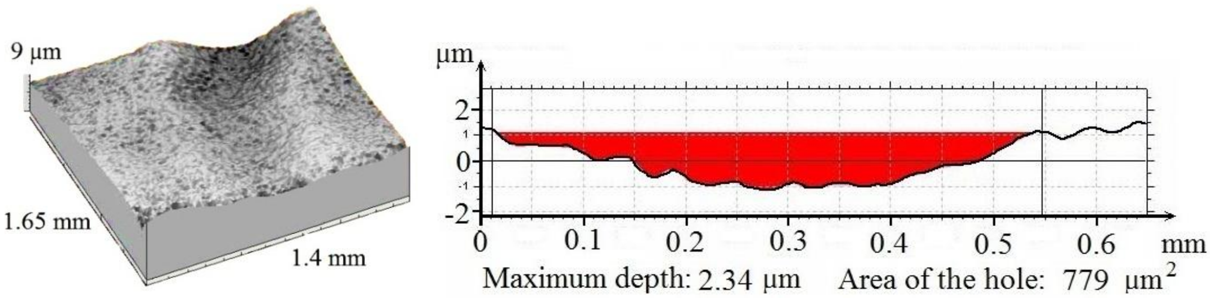


Figure 7. Profile of track membrane surface and sections of wear track of track membrane with 0.8 μm pore's diameters. Sliding speed is 3.0 m/min

4. Conclusion

The process of unlubricated friction in contact "metal-polymer" has next stages. These are a sharp decline of the coefficient of friction (1 stage), a rapid increasing of friction coefficient (2 stage), gradual increasing of friction coefficient (3 stage), stepped variation (4 stage).

The coefficient of friction decreases with increasing pore diameter TM.

Based on the results of determining the depth of wear track we can say that increasing the amount of wear of the pore diameter does not change significantly.

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Implantation of the track membrane takes about 10-15 minutes during surgery. According to research active period corresponds to considerable variations of the friction coefficient, but it does not destroy the TM. PET track membrane have adequate resistance to wear and can be successfully used in surgical procedures in ophthalmology.

Acknowledgments
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