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THE INFLUENCE OF THE MOTION PARAMETERS ON THE SURFACE LAYER OF METAL-POLYMER SLIDING PAIRS AT LOW TEMPERATURES

WPLYW PARAMETRÓW RUCHOWYCH NA WARSTWĘ WIERZCHNIĄ PARY ŚLIZGOWEJ METAL-POLIMER W NISKIEJ TEMPERATURZE

Key words:

surface layer, polymers, friction, low temperature

Słowa kluczowe:

warstwa wierzchnia, polimery, tarcie, niska temperatura

Abstract

The surface layer of the polymeric sliding materials co-operating with steel has an impact on the tribological properties at low temperatures. The goal of the present study was to determine the impact of the friction process parameters on the change in the surface layer of the polymeric materials. Three polymeric materials, namely PA6, PEEK, and PTFE, were tested. The materials were used for the sliding pairs with the typical construction steel C-45. At first, the tribological investigation at a low temperature $T = (-50-0)^{\circ}\text{C}$ was performed. Before and after that, the friction surface of the polymers, including the surface

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roughness and microhardness, were evaluated. During the experiment, variable parameters were the sliding velocity ($v = 0.5 - 2$ [m/s]) and the unit pressure ($p = 0.5 - 3$ [MPa]). The research has shown changes in the surface layer after the tribological tests at low temperatures. Strengthening and smoothing of the friction surface were observed, depending on the assumed process parameters.

INTRODUCTION

The condition of the surface layer has an obvious impact on the quality of the sliding elements collaboration. As a result of the interactions of two collaborating elements, modifications in the surface layer of the polymeric material structure are observed [L. 2]. Evaluation of the materials' surface can be done in a variety of ways. Some of the most popular methods are the hardness measurement (microhardness) as well as the measurement of the roughness of the surfaces participating in the friction process [L. 1, 5, 6, 7, 8].

Hardness of the collaborating materials significantly influences a number of phenomena occurring in the friction process, mainly the abrasive wear. In paper [L. 3], the effect of the friction process on the microhardness change in the environmental conditions was described and a relative increase in the microhardness during the friction process (resulting in a change in the abrasive wear resistance value) was accepted as a measure of the strengthening of the polymer's surface layer. The surface microhardness change does not depend only on the kind of the tested material, but also on the motion character (uniform or non-uniform) assumed in the research [L. 4]. In the case of uniform motion, the direction of the polymer chains is determined by the friction forces. However, with non-uniform motion, due to the force distributions, the polymer chains shift is performed in a different way.

Shaping of the sample's surface (of the element) affects the utility characteristics of the collaborating sliding pair, concerning friction, wear, tightness, deformation, or the liquid flow [L. 7]. Paper [L. 6] clearly presented the relation between the geometric features defined during the manufacturing process (TSL – technological surface layer) and the tribological characteristics and that they have an influence on the changes in the surface layer during the operation of the element (OSL – operational surface layer). In paper [L. 9], the author emphasizes the fact that both the surface roughness and the orientation of the machining traces in relation to the sliding direction affect the tribological characteristics of the collaborating elements.

A definite majority of the research on surface layers is carried out at room temperature. There is no information, however, concerning the change in the discussed parameters at temperature below $T = 0^{\circ}\text{C}$. Therefore, an attempt at the evaluation of the influence of the friction process on the metal-polymer sliding pair surface layer condition at negative temperatures seems to be justified.

RESEARCH METHOD

The tribological research on the metal-polymer sliding pair was conducted on the standard pin-on-disc connection type. The friction node was enclosed in a climatic chamber which enabled setting and maintaining the required temperature with accuracy up to $T = 0.1^\circ\text{C}$. Pin-shaped polymer samples of $\phi = 4$ mm diameter were made of three types of material, namely PA6, PEEK, and PTFE. The materials collaborated in the sliding mode with the construction steel C-45 of ~ 40 HRC hardness and of $Ra \approx 0.5$ surface roughness.

The temperature at which the experiment was conducted ranged from $T = -50^\circ\text{C}$ to $T = 0^\circ\text{C}$, with intervals of 10°C . The entire tribological research process (**Fig. 1**) of the sample consisted in cooling the friction node from room temperature down to $T = 0^\circ\text{C}$, and maintaining the set temperature for at least one hour (in order to stabilize the ambient conditions in the climatic chamber), and in the carrying out of the tribological research at specific process parameters. After the test, the ambient temperature was reduced by 10°C , to $T = -10^\circ\text{C}$, at which time the sliding pair was in motion for at least one hour, after which the tribological tests were carried out. The entire cycle was repeated until a temperature of $T = -50^\circ\text{C}$ was reached. While increasing the set temperature, the polymeric sample remained in continuous relative motion with the countersample at a velocity of $v = 0.05$ m/s.

For the tribological tests, three values of the sliding speed were assumed, namely, $v = 0.5$ m/s, $v = 1$ m/s, and $v = 2$ m/s, as well as three values of the unit pressure, namely, $p = 0.5$ MPa, $p = 1$ MPa, and $p = 3$ MPa. These parameters were used in all possible configurations for all the materials tested. The friction time assumed was $t = 900$ s. The time of stabilizing the temperature was the running-in period.

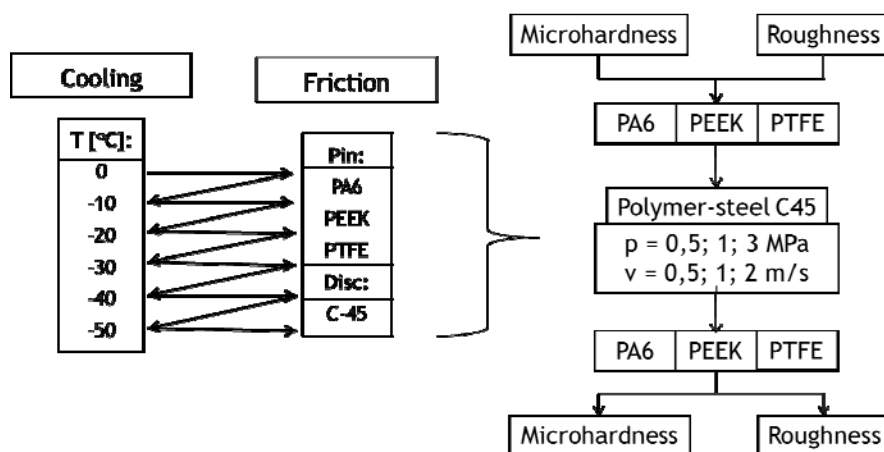


Fig. 1. Diagram of the tribological research performed at low temperatures

Rys. 1. Schemat programu badań tribologicznych wykonywanych w niskiej temperaturze

The tribological tests were supplemented by a complex instrumental study. Both before and after the tribological tests, the top layer condition was assessed by means of the roughness and microhardness parameters.

FINDINGS

The supplementary research was conducted before and after the tribological test. The microhardness test was performed using microhardness tester SHIMADZU HMV-2T. For the measurement, the Vicker's method was applied, and the test was performed at the lowest possible load of $F = 98.07$ mN (HV 0.01) and a longer indentation time of the diamond indenter of $t = 90$ s, due to the viscoelastic nature of the materials tested.

The roughness test was performed using the Phenom scanning electron microscope with the special Phenom Pro Suite software to measure the surface roughness.

In both cases, the tests were repeated four times and followed by static calculations presented in the tables and diagrams included in this paper. The research results are shown in **Tables 1** and **2**, and the diagrams illustrating the change in the surface layer parameters are presented in **Figures 2–5**.

Table 1. Change in surface microhardness μHV after the tribological tests for different parameters of the process calculated by the formula: $\Delta \mu HV = \mu HV_{after} - \mu HV_{before}$

Tabela 1. Zmiana mikrotwardości μHV powierzchni po badaniach tribologicznych dla poszczególnych parametrów procesu wyliczona ze wzoru: $\Delta \mu HV = \mu HV_{po} - \mu HV_{przed}$

PA6	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Deviation	Average	Deviation	Average
p = 0.5 MPa	0.37	1.16	0.24	0.29	-0.31	0.57
p = 1 MPa	0.40	0.37	1.06	1.05	-0.28	0.45
p = 3 MPa	-0.55	0.85	2.14	0.35	0.56	1.64
PEEK	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Deviation	Average	Deviation	Average
p = 0.5 MPa	12.27	1.08	16.53	0.99	17.43	2.03
p = 1 MPa	15.96	0.52	16.49	1.57	16.60	1.70
p = 3 MPa	17.43	2.03	15.23	1.33	16.09	0.53
PTFE	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Deviation	Average	Deviation	Average
p = 0.5 MPa	0.31	0.09	-0.41	0.58	-0.31	0.38
p = 1 MPa	-0.31	0.97	0.79	0.40	0.15	0.51
p = 3 MPa	0.17	0.12	0.38	0.83	1.21	0.57

Table 2. Change in surface roughness Ra after the tribological tests for different parameters of the process calculated by the formula: $\Delta Ra = Ra_{after} - Ra_{before}$

Tabela 2. Zmiana chropowatości Ra powierzchni po badaniach tribologicznych dla poszczególnych parametrów procesu wyliczona ze wzoru: $\Delta Ra = Ra_{po} - Ra_{przed}$

PA6	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Average	Deviation	Average	Deviation
p = 0.5 MPa	-2.85	1.22	-2.04	0.24	-3.01	0.69
p = 1 MPa	0.62	0.93	0.18	0.25	-1.82	0.38
p = 3 MPa	-2.69	0.36	-3.30	0.20	-5.57	0.73
PEEK	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Average	Deviation	Average	Deviation
p = 0.5 MPa	-0.75	0.63	0.42	0.24	-2.38	0.69
p = 1 MPa	1.32	0.87	1.09	0.25	-0.43	0.38
p = 3 MPa	-2.25	0.43	0.07	0.20	-4.99	0.73
PTFE	v = 0.5 m/s		v = 1 m/s		v = 2 m/s	
	Average	Deviation	Average	Deviation	Average	Deviation
p = 0.5 MPa	0.45	0.54	1.36	1.24	-2.02	0.55
p = 1 MPa	-0.90	0.30	0.72	0.58	-1.41	0.25
p = 3 MPa	-1.35	1.17	-1.14	0.40	-3.15	0.68

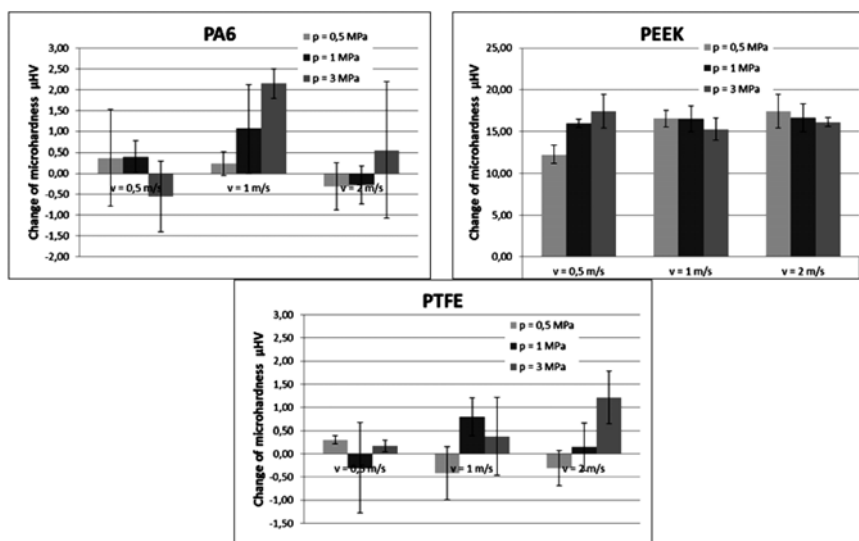


Fig. 2. Change in surface layer microhardness μHV for the studied polymers

Rys. 2. Zmiana mikrotwardości μHV warstwy wierzchniej badanych materiałów polimerowych

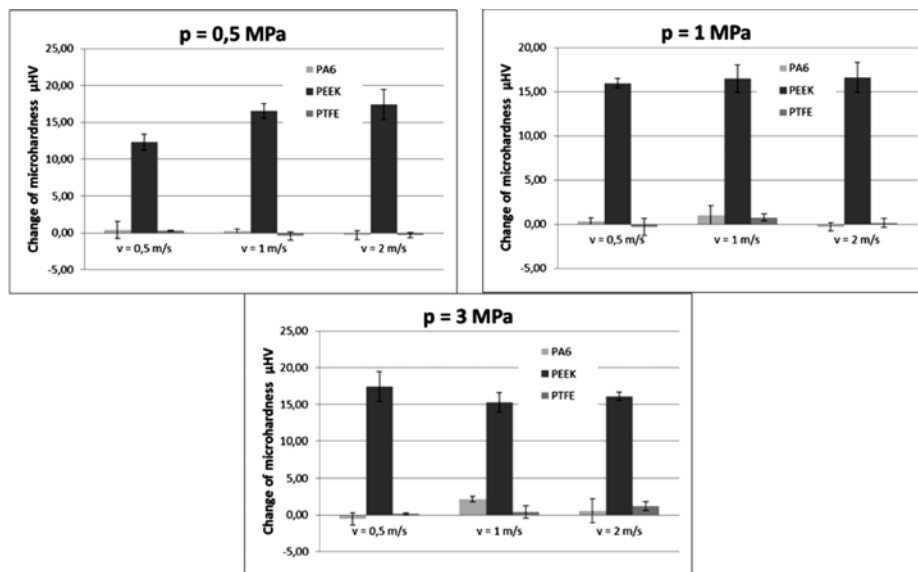


Fig. 3. Change in surface layer microhardness μHV for the set values of the unit pressure
 Rys. 3. Zmiana mikrotwardości μHV warstwy wierzchniej dla zadanych wartości nacisku jednostkowego

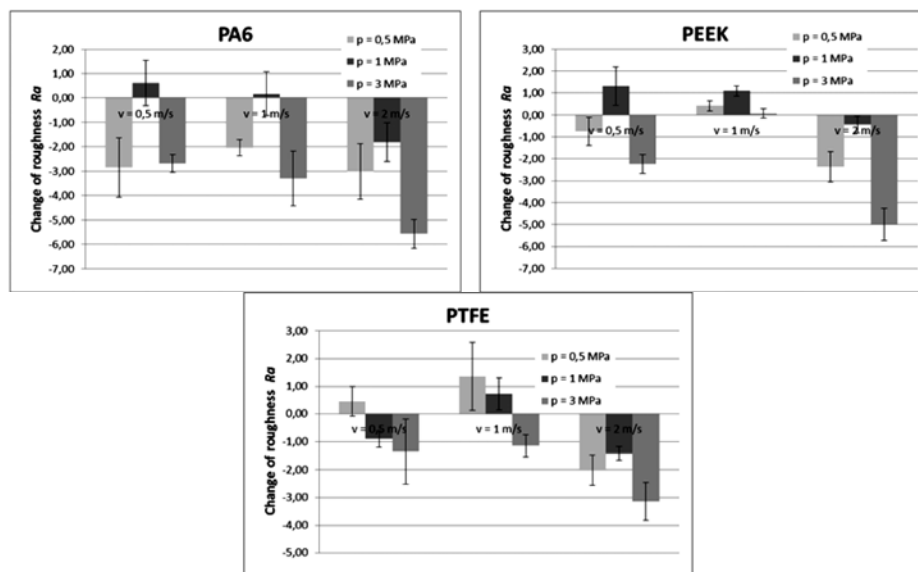


Fig. 4. Change in surface layer roughness R_a for the studied polymers
 Rys. 4. Zmiana chropowatości R_a warstwy wierzchniej badanych materiałów polimerowych

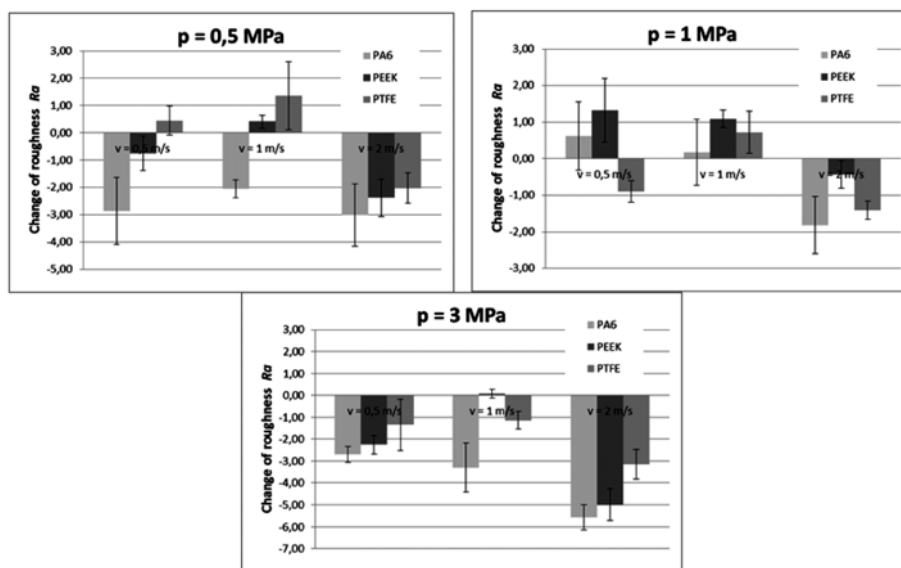


Fig. 5. Change in surface layer roughness R_a for the set values of the unit pressure

Rys. 5. Zmiana chropowatości R_a warstwy wierzchniej dla zadanych wartości nacisku jednostkowego

SUMMARY AND CONCLUSIONS

The tribological research has definitely shown the obvious impact of the friction parameters on the quality of the surface layer of the studied polymeric materials both at low temperatures as well as at room temperature [L. 4]. The highest microhardness change that was observed during the research concerned PEEK and amounted to approximately 500% at $p = 0.5 \text{ MPa}$ and 700% at $p = 1 \text{ MPa}$. This significant increase in the microhardness shows strengthening of the surface layer and, at the same time, a change in the material properties at the surface of the sample. For the highest load, the upward trend is not noticeable. The material also showed the highest repeatability of results. In the case of the other two materials, a large discrepancy in the results could be caused by the initial surface roughness that affects the accuracy of the microhardness measurement performed by means of the Vicker's method.

An interesting observation is a lack of dependence between the changes in microhardness the changes in the friction parameters at low temperatures for the PTFE. Such behaviour can be explained by the lamellar structure of the material. The polymer chains, due to wear, are removed from the surface layer in a form of the flakes of material. The process was repeated frequently enough for the material's surface layer not to be consolidated.

It is presumed that the microhardness increase after the friction process can be justified by the ordering of the polymeric materials' surface structure, resulting from the interaction in the friction zone boosted by the temperature increase in that zone. The thesis, however, requires confirmation in further research.

In the case of the material's roughness study, one can observe a considerable discrepancy in the obtained results. A part of the research showed an increase in roughness, and a part of the research showed a decrease in the roughness value. The roughness decrease was observed in each of the studied materials at the highest set unit pressure. The force applied on the sample's surface resulted in the smoothing of its surface determined by the plastic strain and the plastic flow of the polymer.

A part of the studied surfaces, and mainly PA6, after the experiment, showed a higher surface roughness. The fact was an interesting observation that requires deeper and closer investigation. It is presumed that the presence of foreign matter or a number of wear products may have caused the abrasive wear of the material by generating scratches or grooves on the polymer's surface, thus increasing its roughness.

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Streszczenie

Stan warstwy wierzchniej materiałów polimerowych współpracujących ślizgowo ze stalą ma znaczący wpływ na właściwości tribologiczne w niskiej temperaturze. W niniejszej pracy podjęto próbę określenia wpływu parametrów procesu tarcia na zmiany zachodzące w warstwie wierzchniej materiału polimerowego. Do badań przyjęto następujące materiały polimerowe: PA6, PEEK oraz PTFE współpracujące ślizgowo z typową stalą konstrukcyjną C-45. Polimerowe próbki najpierw zostały poddane badaniom tribologicznym w zakresie temperatury $T = (-50 \div 0)^\circ\text{C}$, następnie poddano ocenie trące powierzchnie polimerowe określając zmianę chropowatości oraz mikrotwardości powierzchni. Podczas eksperymentu zmiennymi parametrami była prędkość ślizgowa ($v = 0,5 \div 2$ m/s) oraz nacisk jednostkowy ($p = 0,5 \div 3$ MPa). Wykazano zmiany warstwy wierzchniej po badaniach tribologicznych w niskiej temperaturze. Zauważano umocnienie oraz wygładzenie powierzchni trącej w zależności od przyjętych parametrów procesu.