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FRICTION PROCESSES OF SELECTED POLYMERS SLIDING ON STEEL AND DURALUMIN IN A LUBRICANT ENVIRONMENT

PROCESY TARCIA WYBRANYCH POLIMERÓW KONSTRUKCYJNYCH PO STALI I DURALUMINIUM W OBECNOŚCI ŚRODKÓW SMARUJĄCYCH

Key words:

friction, wear, polymers, lubricants

Słowa kluczowe:

tarcie, zużywanie, polimery konstrukcyjne, smarowanie

Abstract

The article presents the results of tribological research into engineering polymers (POM, PEEK, PPS) cooperating in sliding motion with 316L steel and EN AW-2017A aluminium alloy in the presence of a liquid (water, hydraulic oil HLP68). This type of friction pair may occur in hydraulic systems (gear pumps, valves, etc.). For comparison, additionally, the results of tribological research

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carried out in dry friction conditions have been shown. In addition, the results of microscopic study of the sliding surfaces of polymeric materials have been presented. Analysis of the test results allows one to describe the processes of friction and wear of the studied sliding pairs.

INTRODUCTION

The problem of friction and wear of polymeric materials is widely described in the literature. Most studies concern research in the conditions of dry friction, because most of the polymer friction nodes **[L. 1, 2]** work in such conditions. A much smaller number of studies are connected with the metal-polymer friction pair in the presence of a liquid **[L. 3, 4, 5]**. Such cooperation occurs most often in technical seals. The tribological research presented in the literature concerns mostly PTFE **[L. 6]**, PE-HD, and elastomers (rubber) **[L. 7]**. In recent times, the question of applying polymeric materials in fluid power units **[L. 8, 9, 10],** such as pumps, valves, or manifolds, has been brought up. This is mainly due to the low density of the polymer materials that can substantially reduce the weight of a product. Moreover, the materials show high chemical resistance, particularly for the fluids used in hydraulic systems. In the case of their application in the hydraulic elements, the polymeric materials should feature good sliding and mechanical properties **[L. 10]**.

METHODOLOGY OF MEASUREMENT

The tribological research into engineering polymers cooperating in sliding motion with metallic materials was carried out on a ”pin-on-disc” test stand (tribometer T-01 M). A view of the examined sliding pair is shown in **Figure 1**. The polymer samples (pin, 8 mm in diameter) used in the test slides on a rotating disc made of 316L stainless steel or EN AW-2017A aluminium alloy (duralumin). For the test, three polymeric materials were selected: polyacetal (POM), polyetheretherketone (PEEK), and polyphenylene sulphide (PPS). Those polymers are some of the most frequently used materials for the making of the sliding elements of machines and practically do not absorb moisture. Moreover, attempts to use polymeric materials in such units as hydraulic gear pumps, valves, or manifolds are made **[L. 9]**.

The aim of the tribological research was to compare the values of the friction coefficient for the examined sliding pairs and to determine the wear process of the polymers. The experiment was performed at a constant value of contact pressure p = 1 MPa, and sliding speed v = 1 m/s, both in dry friction and in mixed friction conditions, i.e. in the presence of water and in the presence of hydraulic oil HLP68. The tested sliding pair was put into a container that was filled with a liquid constituting the environment of the experiment. The liquid level was so selected that, during the test, the sample and the mating element were constantly immersed in it. All measurements took place on the sliding distance s = 2500 m. During the test, the friction forces were recorded and on that basis, and the value of the friction coefficient was determined. All measurements were repeated five times, the final results were averaged, and the standard deviation and the confidence intervals were determined.

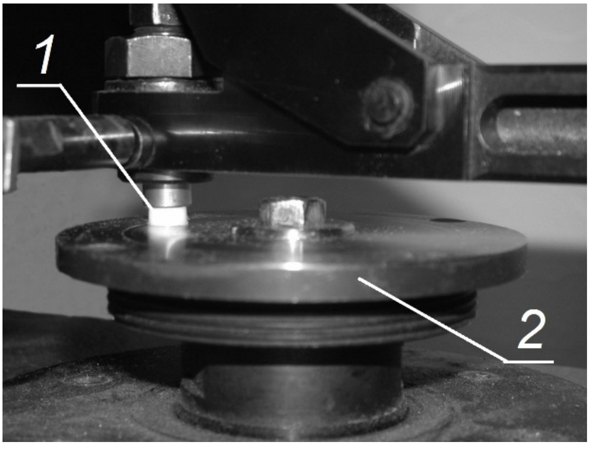


Fig. 1. A view of the investigated couple on the pin-on-disc test stand (1 – polymeric sample, 2 – metallic counterface)

Rys. 1. Widok badanej pary ślizgowej na stanowisku pin-on-disc (1 – polimerowa próbka, 2 – metalowy element współpracujący)

The wear value of the polymer samples in the mixed friction conditions, both the linear and the mass, was within the error of the measuring instruments (Z_L <1 µm, Z_m < 0.1 mg). Therefore, the authors omitted the analysis of the wear intensity of the examined polymeric materials, and, in order to determine the wear processes of the investigated polymer materials, a microscopic examination of the sliding surface of the polymers was carried out. The study was performed using a Phenom ProX type electron microscope equipped with an EDS analyser allowing an analysis of the composition of the tested material.

RESULTS OF TRIBOLOGICAL RESEARCH

The results of the tribological investigation showing the value of the friction coefficient for a sliding metal-polymer pair depending on the friction environment are presented in **Table 1**. For easier comparison of the test results, they are also shown in the graphs (**Figures 2** and **3**). The analysis of the results shows that the water environment contributes to an increase in the value of the friction coefficient for the examined sliding pairs. This is observed for PPS and POM cooperating with the steel **(Figure 2)**, as well as for POM and PEEK cooperating with aluminium alloy **(Figure 3)**. This phenomenon was also observed in the previously conducted studies of other polymers **[L. 3, 4, 5, 6]**. One explanation may be the formation of the polymer film transferred onto the surface of the cooperating metal element, which is more difficult in this environment. On the other hand, oil as a lubricant, despite the absence of a polymer layer on the metal element, reduces the friction coefficient compared to the technically dry friction.

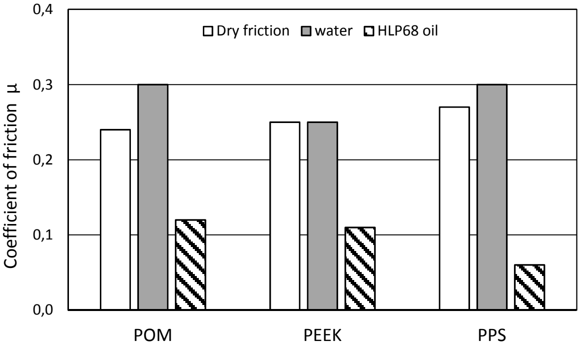


Fig. 2. Friction coefficient for the tested polymer-steel 316L in dry friction conditions, in water and in hydraulic oil HLP68 (p = 1 MPa, v = 1 m/s, T_0 = 24°C)

Rys. 2. Współczynnik tarcia badanych par ślizgowych polimer-stal 316L w warunkach tarcia suchego, w obecności wody oraz oleju hydraulicznego HLP68 (p = 1 MPa, v = 1 m/s, T_0 = 24°C)

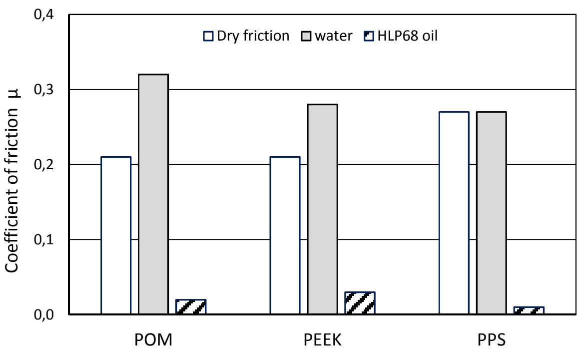


Fig. 3. Friction coefficient for the tested polymer-duralumin pairs in dry friction conditions, in water and in hydraulic oil HLP68 (p = 1 MPa, v = 1 m/s, T_0 = 24°C)

Rys. 3. Współczynnik tarcia badanych par ślizgowych polimer-duraluminium w warunkach tarcia suchego, w obecności wody oraz oleju hydraulicznego HLP68 (p = 1 MPa, v = 1 m/s, T_0 = 24°C)

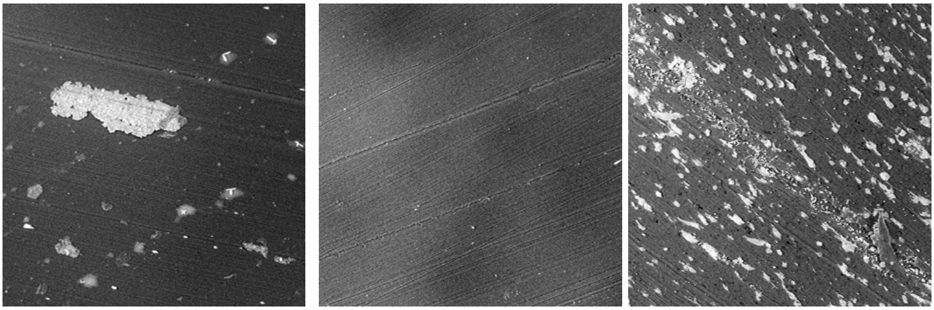
Table 1. Test results of the friction coefficient for different environment
Tabela 1. Wyniki badań współczynnika tarcia par ślizgowych polimer-metal prowadzonych w różnym środowisku

Lp.	Polymeric material	Mating element	Environment	Coefficient of friction	
1	POM	316L steel	dry friction	0.24	±0.024
2	POM		water	0.3	±0.011
3	POM		HLP68	0.12	±0.002
4	PEEK		dry friction	0.25	±0.025
5	PEEK		water	0.25	±0.001
6	PEEK		HLP68	0.11	±0.003
7	PPS		dry friction	0.27	±0.018
8	PPS		water	0.3	±0.008
9	PPS		HLP68	0.06	±0.008
10	POM	Duralumin	dry friction	0.21	±0.006
11	POM		water	0.32	±0.010
12	POM		HLP68	0.02	±0.006
13	PEEK		dry friction	0.21	±0.016
14	PEEK		water	0.28	±0.006
15	PEEK		HLP68	0.03	±0.001
16	PPS		dry friction	0.27	±0.025
17	PPS		water	0.27	±0.012
18	PPS		HLP68	0.01	±0.000

MICROSCOPIC STUDIES

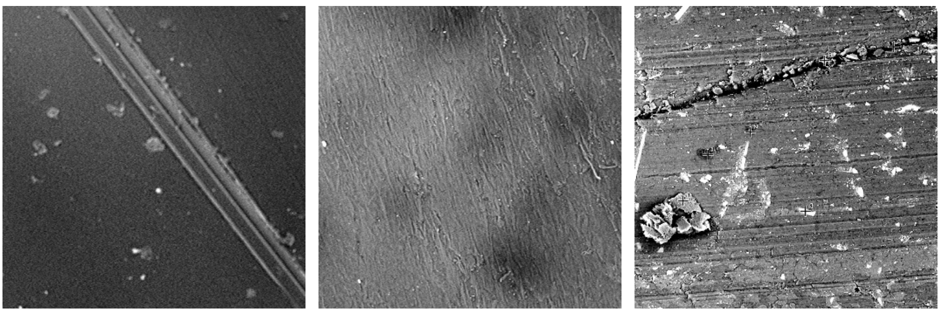
After conducting the tribological research, the sliding surfaces of the polymeric materials were subjected to microscopic examination. Their goal was to describe the wear processes of the studied polymers. Examples of the surface views are shown in **Figures 4–9**.

Based on the observations, it may be noted that, despite the presence of a liquid lubricant, such as water or hydraulic oil, traces of abrasive wear are visible on the surface of the polymers. This demonstrates the occurrence of the direct contact of the polymer with micro inaccuracies of the mating metal surface. The thickness of the lubricant film produced by the liquid is not sufficient to protect the polymer against abrasive wear. This also shows that the carried out tribological tests were held in the mixed friction conditions. The presented microscopic photos also show the differences in the wear of the investigated polymer materials.



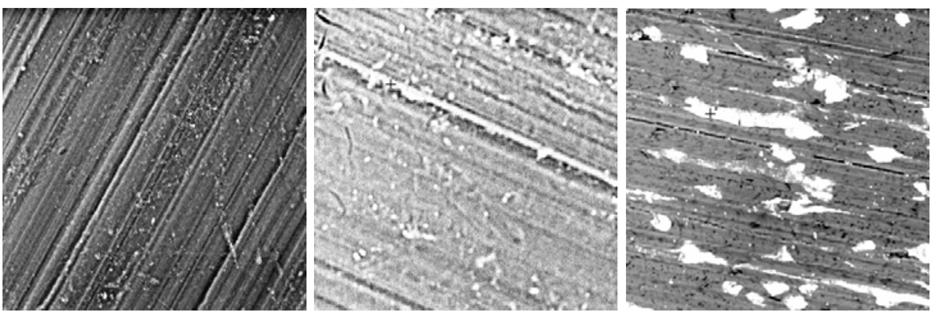
PEEK POM PPS

Fig. 4. Surface of some polymers after sliding on steel 316L in dry friction conditions
Rys. 4. Powierzchnia ślizgowa polimerów po tarciu suchym po stali 316L



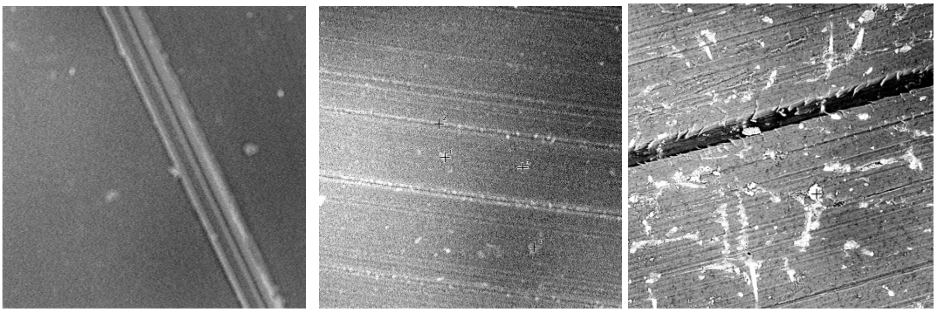
PEEK POM PPS

Fig. 5. Surface of some polymers after sliding on duralumin in dry friction conditions
Rys. 5. Powierzchnia ślizgowa polimerów po tarciu suchym po duraluminium PA6



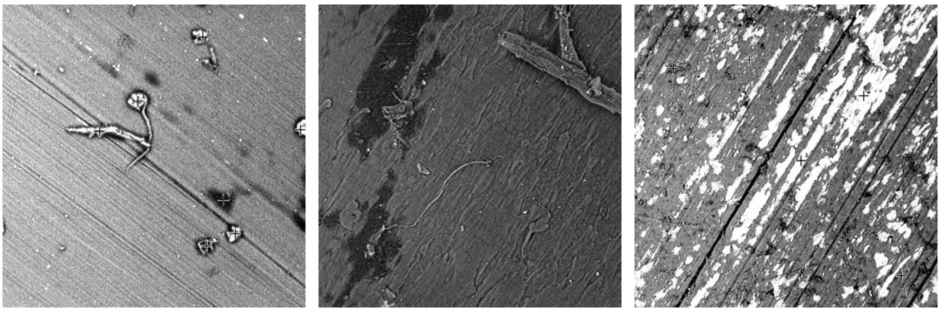
PEEK POM PPS

Fig. 6. Surface of some polymers after sliding on steel 316L in water (mixed friction)
Rys. 6. Powierzchnia ślizgowa polimerów po tarciu po stali 316L w środowisku wody



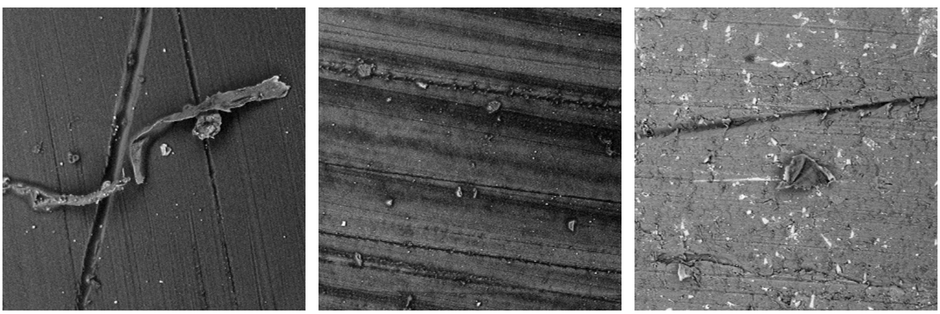
PEEK POM PPS

Fig. 7. Surface of some polymers after sliding on duralumin in water (mixed friction)
Rys. 7. Powierzchnia ślizgowa polimerów po tarciu po duraluminium PA6 w środowisku wody



PEEK POM PPS

Fig. 8. Surface of some polymers after sliding on steel 316L in oil HLP68 (mixed friction)
Rys. 8. Powierzchnia ślizgowa polimerów po tarciu po stali 316L w środowisku oleju HLP68



PEEK POM PPS

Fig. 9. Surface of some polymers after sliding on duralumin in oil HLP68 (mixed friction)
Rys. 9. Powierzchnia ślizgowa polimerów po tarciu po duraluminium PA6 w środowisku oleju HLP68

In dry friction, smoothing of the polymer elements' surface occurs **(Figs. 4, 5)**. It is demonstrated by a lower number of fissures' edges and microcracks as well as their smoothing, which are formed by the wear. In the case of PEEK, deep furrows, scratches, and wear products of the polymeric material are visible on the sliding surface **(Figs. 8, 9)**. They can be seen on the surface of the polymer even after the process of friction in the conditions of mixed friction, indicating contact of surface asperities of the metal element with the polymeric material. After the study in the water environment, scratches are visible on the sliding surface of all the investigated polymer materials; however, in the case of POM and PPS, they are not as clear and deep as for the PEEK. This is because it is difficult to create a polymeric coating on the surface of the metal in the presence of water **[L. 3, 4, 5]**.

Additionally, on the surface of the PPS, wear products of the metal element (steel and aluminium) **(Figures 4–9)** can be observed, which exist independent of the environment in which the test was carried out. It proves that, during the friction of PPS against metals, wear of a harder metal element is also present.

The presence of oil during friction facilitates sliding of the polymer on the metal surface, thus contributing to a less intensive wear process of the polymer **(Figures 8, 9)**. In this case, the depth of the grooves and their number is lower compared to the case of friction in the presence of water. This shows that the use of elements of friction pairs made of polymer materials in the equipment working in water, despite the corrosion resistance, can lead to an increase in their wear in comparison to the dry friction or in the presence of oil. This requires, however, further tribological research on the effect of the surface roughness of the mating elements and of temperature and sliding velocity on wear intensity of polymeric materials used for the moving parts of hydraulic equipment.

SUMMARY

The article presents the results of studies of selected polymeric materials (PEEK, POM, and PPS). These materials may be used in hydraulic systems, where water or hydraulic oil is the working medium. Therefore, such liquids were chosen for the tribological research. Additionally, for comparative purposes, tribological tests in dry friction conditions were carried out. The materials that were cooperating in sliding motion with the polymers were 316L stainless steel and aluminium alloy (Duralumin EN AW-2017A), which can work in the aquatic environment.

The obtained results show the following:

- The value of the friction coefficient of the examined sliding pairs in water is greater than in dry friction. The explanation of it may be the difficulty in creating of the polymeric coating on the surface cooperating in sliding motion with metallic material. Such a phenomenon occurs during friction of the polymer-metal sliding pairs **[L. 3, 4, 5]**.
- The lowest values of the friction coefficient were observed during the cooperation of the tested materials in the environment of hydraulic oil.

- The sliding cooperation of polymeric materials with metallic materials was held in the mixed friction conditions where direct contact of hard micro-roughness of the metal surface with the polymer surface was recorded. Evidence of this was observed on the sliding surface where scratches of the polymers were created as a result of abrasive wear.

The research presented in the paper was of a preliminary character. A more precise explanation of the obtained results needs further study of the polymer-metal tribological pairs at different values of the operating parameters, such as pressure unit, sliding velocity, etc. In addition, it would be required to conduct additional studies concerning the wettability of the surface of the examined polymers with liquids used in hydraulics as a working media.

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Streszczenie

W artykule przedstawiono wyniki badań tribologicznych polimerów konstrukcyjnych (POM, PEEK, PPS) współpracujących ślizgowo ze stalą 316L, a także stopem aluminium EN AW-2017A w obecności cieczy (woda,

olej hydrauliczny HLP68). Tego typu pary trące mogą występować w urządzeniach hydraulicznych (pompy zębate, zawory itp.). W celu porównania przedstawiono dodatkowo wyniki badań tribologicznych przeprowadzonych w warunkach tarcia technicznie suchego. Ponadto zaprezentowano wyniki badań mikroskopowych powierzchni ślizgowych materiałów polimerowych. Przeprowadzona analiza wyników badań umożliwiła opisanie procesów tarcia i zużywania badanych par ślizgowych.