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THE INFLUENCE OF HARDNESS OF POLYURETHANE ON ITS ABRASIVE WEAR RESISTANCE

WPŁYW TWARDOŚCI POLIURETANU NA JEGO ODPORNOŚĆ NA ZUŻYWANIE ŚCIERNE

Key words:

PUR – polyurethane, polyurethane foam, Shore hardness, abrasive wear resistance

Słowa kluczowe:

PUR – poliuretan, pianka poliuretanowa, twardość Shore, odporność na zużywanie ścierne

Abstract

This paper presents the experimental determination of the effect of hardness of the polyurethane (PUR) in a form of the elastomer foam used in various parts of machines or appliances subjected to intensive abrasive wear. Such elements, among others, are static and dynamic technical seals, bumpers, shock-absorbing

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parts in joints of machine components, and elements of transport equipment in mining or in aggregate and mineral processing **[L. 1–3]**. Intensive abrasive wear also concerns parts of agricultural and construction machines, road transport, and transport packaging, as well as protective coatings, housing or shields of various machines, and equipment elements **[L. 4, 5]**. An increase in the abrasive wear resistance of directly determines an increase in the durability and operational reliability of machines and equipment **[L. 6]**. The hardness of the elastomeric polyurethane influences its physicomechanical and tribological properties **[L. 7]**. So far, relatively few works have focused on research into the effect of various factors, including the hardness of PUR on the tribological properties of PUR. The aim of this study is to broaden knowledge on the impact of the polyurethane hardness on its resistance to abrasive wear.

INTRODUCTION

Polyurethane generally consists of two components: a polyol and isocyanate. Combining the two ready-for-processing liquid components and other auxiliary materials, such as catalysts, blowing agents, and stabilizers, initiates a chemical reaction that results in the creation of PUR **[L. 8, 9]**. By changing the ingredients and proportions of the mixture, materials of very different properties that suitable for special applications can be produced. Polyurethanes can be made in a form of foams, cast, and thermoplastic elastomers, varnishes, adhesives, fibres, or leather-like materials, used in many areas of life and economy **[L. 10]**. The production technology of polyurethane foams involves the reaction of polyesters or polyethers containing free hydroxyl groups (polyols) with diisocyanates and blowing agents. The mixing of the polyisocyanate and polyol is immediately followed by a chemical reaction that is a basis for the preparation of all types of polyurethane plastics. Depending on the reaction conditions, the type and number of components, products of different properties, for instance of different hardnesses, are obtained. The polymerization of urethane plastics includes two main simultaneous processes: the additional polymerization of the reactive mixture and forming products from the mixture. An important factor determining the proper course of polymerization is the intensive mixing of the ingredients, occurring directly before filling the processing mould cavity, as shown in **Figure 1 [L. 10]**.

The research presented in paper **[L. 7]** shows that the hardness of PUR foam can be defined by changing the polyol-isocyanate ratio, the rotational speed of the mixing head, and the mould temperature.

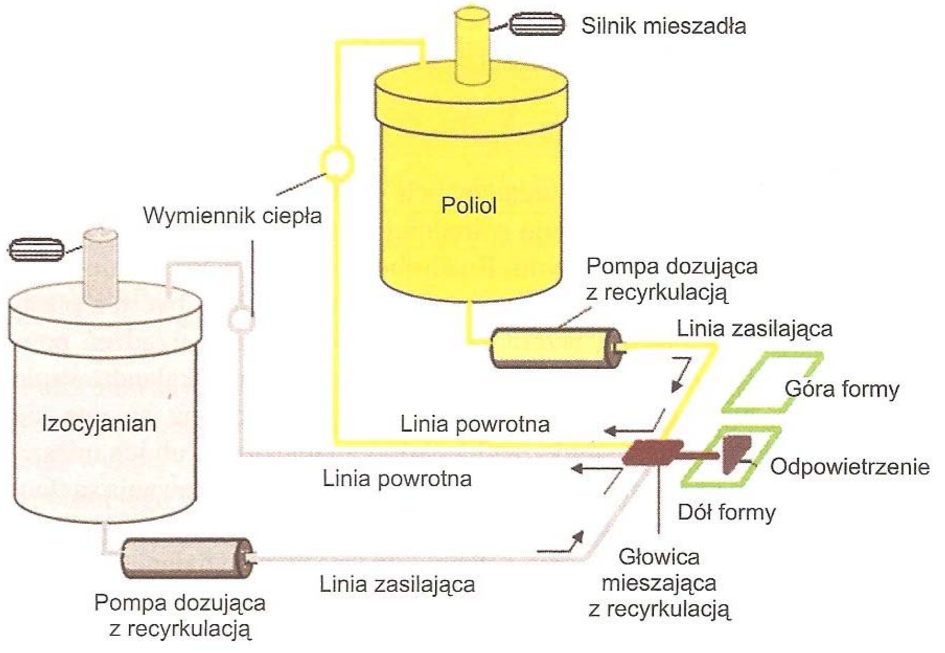

Fig. 1. Scheme for preparing a polyurethane foam [L. 10]
Rys. 1. Schemat wytwarzania pianki poliuretanowej **[L. 10]**

Polyurethane elastomers are rubber-like in their form. They are characterized by excellent mechanical properties, e.g., tensile strength and, at the same time, the relative elongation of up to 600% (**Fig. 2**, **[L. 11]**) and resistance to tearing. PUR is distinguished by outstanding resistance to abrasive wear and compression, which is higher than for any other polymeric material **[L. 12, 13]**, even higher than for the high-resistant rubber or steel **[L. 14]**. Polyurethane elastomers perfectly dampen mechanical vibration; therefore, they are used as flexible machine parts, such as inserts of flexible couplings, buffers, anti-vibration pads, tire treads, as well as elements of technical seals.

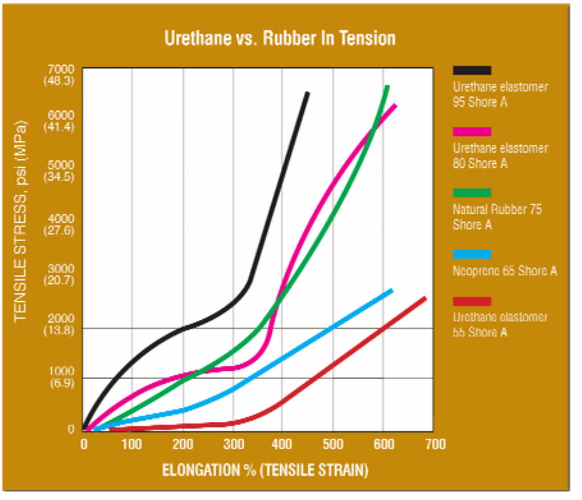

Fig. 2. Tensile stress of PUR featuring different hardnesses as a function of deformation [L. 11]

Rys. 2. Naprężenie rozciągające PUR o różnej twardości w funkcji odkształcenia **[L. 11]**

PURs are further characterized by excellent resistance to mineral oils, grease, gasoline, organic solvents, as well as acids and alkaline solutions. In the presence of oxygen and ozone, PURs do not age, and they are not affected by light radiation (including UV), which prolongs the service life of the polyurethane products **[L. 11]**. Polyurethanes have self-extinguishing properties (they do not burn), electro-insulating properties, are non-staining, and they show approximately six times lower density than steel. PURs maintain their flexibility in the temperature range from –30°C to +120°C, in which they can be used for a long time.

THE AIM OF THE TRIBOLOGICAL STUDY

The aim of the tribological research was to determine the influence of the hardness of polyurethane foams on their resistance to abrasive wear and to explain the mechanism of the PUR foams abrasive wear process, depending on their hardness.

METHODOLOGY OF THE TRIBOLOGICAL STUDY

Tests on the resistance of the polyurethane foams of different hardnesses to abrasive wear were carried out on a Tester T-07 stand **[L. 15, 16]**. In **[L. 17]**, the usefulness of Tester T-07 for that type of research into polymer materials was confirmed. A view of the friction couple and the research method diagram is shown in **Figure 3**.

a)

b)

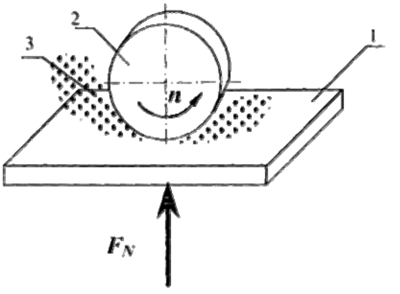

Fig. 3. View of the friction couple (a), scheme of the test of resistance to abrasive wear (b), 1 – sample of the tested material, 2 – rubber roller, 3 – abradant [L. 5, 13]

Rys. 3. Widok pary ciernej – a) oraz schemat metody badania odporności na zużywanie ścierne – b); 1 – próbka z badanego materiału, 2 – rolka gumowa, 3 – ścierniwo **[L. 5, 13]**

This method is compliant with recommendations of the Russian standard GOST 23.208-79, which provides guidelines for testing the abrasive wear resistance of abrasive wear protection materials and coatings. A sample of the tested material (1) during the test is pressed with a force of 44.4 $\boldsymbol{F_N}$ = N to the $\boldsymbol{d}$ = 50 mm diameter rubber roller (2) rotating at a constant rotational speed of $\boldsymbol{n}$ = 60 rev/min. Between the rotating disc and a fixed sample, a loose abrasive (3) is continuously supplied, causing the abrasion of the sample. The abrasive recommended for this method is corundum F90 (according to DIN ISO 8486: 1998). The REFERENCES sample was made of standardized C45 steel featuring the hardness of approx. 200 HB.

Weight wear $\boldsymbol{Z_{wb}}$ both of the test samples and of standard sample $\boldsymbol{Z_{ww}}$ were determined after the same time of testing, during which the rubber roller performed $\boldsymbol{N_b}$ = 600 revolutions, which was assumed for materials featuring the hardness equal to or higher than 400 HV. However, the assumption of the same number of revolutions for the PUR samples, even though, for the materials showing hardness lower than 400 HV, the recommended number of revolutions is $\boldsymbol{N_w}$ = 150 rpm, was due to the exceptional resistance of polyurethane to abrasive wear.

Based on the recorded weight wear values, the coefficient of abrasive wear $\boldsymbol{K_b}$ was derived from formula (1), which is defined as a coefficient of the volumetric wear of the standard sample $\boldsymbol{Z_{Vw}}$ and the volumetric wear of the tested materials Z_{Vb}.

$$K_b = \frac{Zv_w / N_w}{Zv_b / N_b} = \frac{Z_{ww} \cdot \rho_b \cdot N_b}{\rho_w \cdot Z_{wb} \cdot N_w} \tag{1}$$

where $\boldsymbol{Z_{ww}}$ – weight wear of the standard sample (C45 steel) in the test, $\boldsymbol{Z_{wb}}$ – weight wear of the tested material in the test, $\boldsymbol{\rho_w}$ – density of the standard sample material, $\boldsymbol{\rho_b}$ – density of the tested sample material, $\boldsymbol{N_w}$ – the number of revolutions of the standard sample friction path, $\boldsymbol{N_b}$ - the number of revolutions of the tested sample friction path.

STUDIED MATERIALS

Tribological comparative studies of the abrasive wear resistance included polyurethane elastomers (PUR foams) of 75, 80, 83 and 93° Shore A hardness. Different hardness values of the polyurethane foams were obtained by changing the ratio of two main components, namely of polyol and 4,4- methylene phenyl isocyanate. Plates of polyurethane foams were produced by pressureless casting in open metal moulds. Then, from the plates, samples of approx. 30 × 30 mm in size were cut out **(Fig. 4)**, which were subject to the abrasive wear resistance tests on Tester T-07.

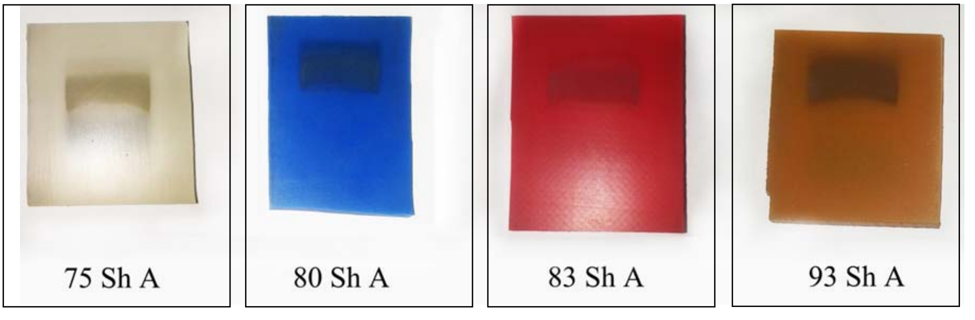

Fig. 4. PUR samples after the resistance to abrasive wear test
Rys. 4. Próbki PUR po badaniach odporności na zużywanie ścierne

RESULTS AND ANALYSIS OF THE TRIBOLOGICAL STUDY

The results of the abrasive wear resistance tests of the different hardness polyurethane foams are illustrated by the bar chart in **Figure 4 [L. 18]**.

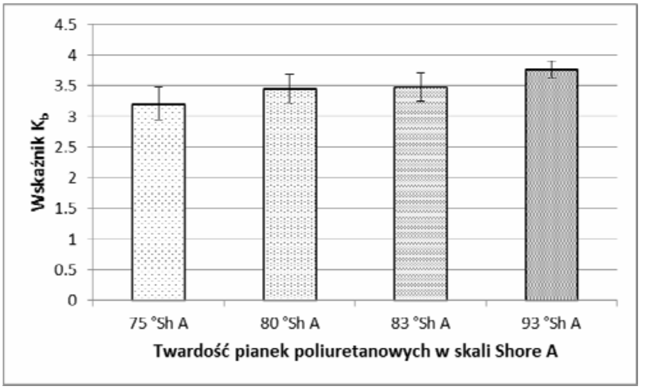

Fig. 5. Index of abrasive wear resistance K_b of polyurethane foams of different hardness
Rys. 5. Wskaźnik odporności na zużywanie ścierne K_b pianek poliuretanowych o różnej twardości

The tribological test results clearly demonstrate that the polyurethane foams feature very good abrasive wear resistance; Kb index of which is more than three times higher in relation to the C45 steel REFERENCES sample, Kb index of which equals 1. Moreover, the test results show that the abrasive wear resistance of the PUR foams increases with an increase in their hardness. The abrasive wear resistance coefficient of the 93° Sh A hardness polyurethane foam is over 16% higher than the one of the polyurethane foam featuring 75° Sh A hardness.

STRUCTURAL STUDY

In order to explain the mechanism of the abrasive wear process of the polyurethanes, a structural study of the friction surface before and after friction was carried out by means of a Phenom ProX manual electron microscope. The results of the microscopic examination of the studied samples are shown in a form of a photomicrograph of their surface in **Figures 6–9**.

a) b)

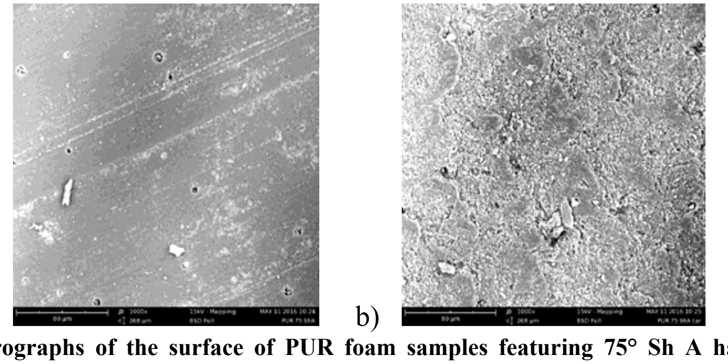

Fig. 6. Micrographs of the surface of PUR foam samples featuring 75° Sh A hardness: prior to testing, b) after the test of resistance to abrasive wear
Rys. 6. Mikrofotografie powierzchni próbek z pianek PUR o twardości 75° Sh A; a) przed badaniem, b) po badaniu odporności na zużywanie ścierne

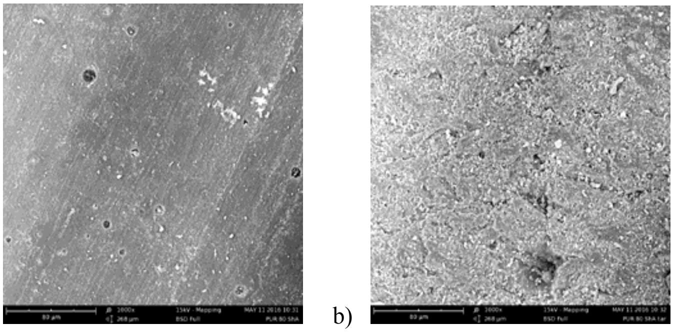

Fig. 7. Micrographs of the surface of PUR foam samples featuring 80° Sh A hardness: prior to testing, b) after the test of resistance to abrasive wear.

Rys. 7. Mikrofotografie powierzchni próbek z pianek PUR o twardości 80° Sh A; a) przed badaniem, b) po badaniu odporności na zużywanie ścierne

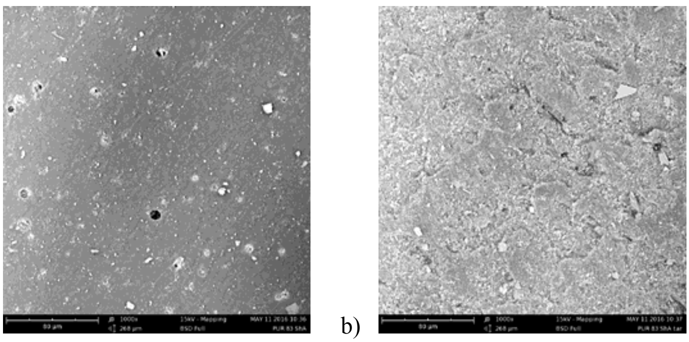

Fig. 8. Micrographs of the surface of PUR foam samples featuring 83° Sh A hardness: prior to testing, b) after the test of resistance to abrasive wear.

Rys. 8. Mikrofotografie powierzchni próbek z pianek PUR o twardości 83° Sh A; przed badaniem, b) po badaniu odporności na zużywanie ścierne

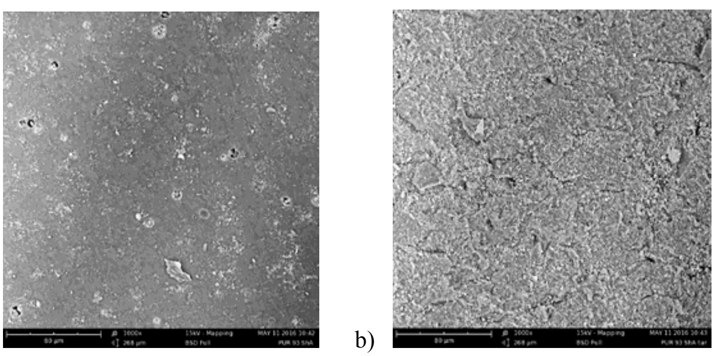

Fig. 9. Micrographs of the surface of PUR foam samples featuring 93° Sh A hardness: prior to testing, b) after the test of resistance to abrasive wear.

Rys. 9. Mikrofotografie powierzchni próbek z pianek PUR o twardości 93° Sh A; przed badaniem, b) po badaniu odporności na zużywanie ścierne

The analysis of the microphotographs shows that the friction surface of the tested PUR samples has clear signs typical of abrasive wear, but no signs of elastic deformation. In the PUR samples of lower hardness **(Fig. 6)**, areas of intensive wear of the material as well as areas with no wear signs can be observed. The higher hardness PUR samples' surface **(Figures 8, 9)**, however, shows smaller damage due to wear, even though numerous cracks of the material are visible. Those cracks may result from the cyclic (fatigue) material deformation during the friction process. The structural study does not allow us to fully explain the reasons for the increased resistance to abrasive wear of the harder types of the studied polyurethanes. The reasons for such behaviour of the tested materials during friction under conditions of intense abrasion seem to be an effect of the differences arising from their chemical composition and molecular structure of particular PUR types, which, however, requires further study.

SUMMARY AND CONCLUSIONS

The tribological laboratory research into the commercial types of polyurethane has shown a relation between abrasion resistance index K_b and the hardness of the test samples. With an increase in the hardness of the tested PUR foams, the value of K_b index increases. The research results prove that the tested polyurethane foams feature very high resistance to abrasive wear in comparison to other polymeric materials used in the construction of machines. The study of the friction surface structure before and after friction do not explain the causes of the increased resistance to abrasive wear of the harder types of the studied polyurethanes, which probably results from the chemical composition and the structure of particular PUR types.

Based on the analysis of the research results, the following conclusions can be drawn:

1. The results showed an increased rate of tribological abrasive wear resistance K_b of the polyurethane that depended on an increase in its hardness.
2. The elastomeric polyurethane foams, compared to other polymeric materials, as well as to the abrasion-resistant metals, feature considerably higher, even more than three times, resistance to abrasive wear.
3. The use of polyurethane in the components of machines, appliances or the coating of parts exposed to intensive abrasive wear can contribute to an increase in their stability and operational reliability.
4. The structural study on the friction surface of the polyurethanes has not explained the causes of the increased resistance to abrasive wear of the harder types of the studied polyurethanes, since this may be due to different chemical compositions and molecular structures of particular PUR types.

5. The research into the physical modification of the elastomeric polyurethanes and a polyurethane coatings applied to the bases made of various materials should be continued, both in order to explain the processes of their wear, as well as possible future technological applications.

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Streszczenie

W artykule przedstawiono doświadczalne określenie wpływu twardości poliuretanu (PUR) o postaci pianki elastomerowej stosowanej na różne elementy maszyn i urządzeń narażonych na intensywne zużywanie ścierne. Takimi elementami m.in. są: uszczelnienia techniczne spoczynkowe i ruchowe, odboje, części amortyzujące w połączeniach podzespołów maszyn, elementy urządzeń transportowych w przemyśle wydobywczym i przetwórczym kruszyw oraz minerałów. Na intensywne zużywanie ścierne narażone są też części maszyn rolniczych, budowlanych, środków transportu kołowego i opakowań transportowych, jak również powłoki ochronne na różnych elementach, czy też osłony i obudowy wielu innych maszyn i urządzeń. Zwiększenie odporności na zużywanie ścienne tych części bezpośrednio przekłada się na wzrost trwałości i niezawodności eksploatacyjnej maszyn i urządzeń. Twardość PUR o postaci elastomeru ma wpływ na jego własności fizykomechaniczne i właściwości użytkowe, w tym także tribologiczne. Dotychczas stosunkowo niewiele prac dotyczyło badań różnych czynników, w tym twardości PUR, mających wpływ na właściwości tribologiczne PUR. W niniejszej pracy wykazano, że wzrost twardości elastomerowych pianek PUR powoduje zwiększenie ich odporności na zużywanie ścierne.