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EFFECT OF PE-LD AND PE-HD AS MODIFIERS OF ELASTOMERS USED IN MOBILE TRACKS ON THEIR TRIBOLOGICAL WEAR

WPLYW PE-LD I PE-HD JAKO MODYFIKATORÓW ELASTOMERÓW STOSOWANYCH W GĄSIENICACH JEZDNYCH NA ICH ZUŻYWANIE TRIBOLOGICZNE

Key words:

polyethylene, abrasive wear, elastomers, mobile track, abrasive soil mass.

Abstract

This paper presents a study of PE-LD and PE-HD as modifiers of elastomers used in mobile tracks on their tribological wear. The experiment was conducted at a “rotating bowl” test stand in three types of soil mass: light, medium, and heavy soil. Based on measurements of mass wear of the tested materials, relative resistance to wear was determined. It was found that an elastomer containing chemically modified polyethylene (PE-HD) was more resistant to wear than an elastomer containing low-density polyethylene (PE-LD). Using a microscope, the condition of the material surfaces following tribological tests was analysed.

Słowa kluczowe:

polietylen, zużycie ściernie, elastomery, gąsienica jezdna, glebowa masa ścierna.

Streszczenie

W pracy przedstawiono badania PE-LD i PE-HD jako modyfikatorów elastomerów stosowanych w gąsienicach jezdnych na ich zużycie tribologiczne. Badania przeprowadzono na stanowisku „wirującej miski” w trzech rodzajach masy glebowej: gleba lekka, średnia oraz ciężka. Na podstawie pomiarów zużycia masy badanych materiałów wyznaczono względną odporność na zużycie. Stwierdzono, że elastomer zawierający polietylen modyfikowany chemicznie (PE-HD) jest bardziej odporny na ścieranie w stosunku do elastomeru o zawartości polietylenu o niskiej gęstości (PE-LD). Za pomocą mikroskopu dokonano analizy stanu powierzchni materiałów po badaniach tribologicznych.

INTRODUCTION

Elastomeric plastics are commonly used to produce mobile continuous track parts for special-purpose vehicles. They are characterised by various properties depending on the chemical composition and environmental parameters. There are many benefits of using them, most importantly increasing the traction capacity of a vehicle, and reducing the unit pressure on the soil. However, so far, what type and condition of abrasive mass affect the process of their wear has not been identified. The significance of the effect of environmental conditions on the values of track elastomer friction coefficient is provided in a study by Bęben [L. 1]. For the same moisture content, in silty clay, the friction coefficient value was 0.9, while, in sand, it was 0.3. This may

indicate a different course of friction under specified soil conditions. The main component of mobile tracks is an elastomer in which polyethylene serves as a filler. Depending on polyethylene density, several types of it can be distinguished. The most common of them include polyethylene with a low density of 0.918–0.930 g/cm³ (PE-LD) and polyethylene with a high density of 0.935–0.965 g/cm³ (PE-HD). Therefore, the significance of the effect of soil properties on the wear rate of elastomer-made mobile parts appears questionable. The complexity of the polymer wear process was addressed *inter alia* in studies [L. 2–13]. The situation is even more complex when they interact with an abrasive soil mass. There are few publications in this field, including [L. 14–16].

This paper analysed the effect of PE-LD and PE-HD as modifiers of elastomers used in mobile tracks on their tribological wear under diverse soil conditions.

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TEST MATERIALS

The test materials included elastomers sampled from two types of mobile tracks indicated as A and B, respectively (Fig. 1). Test specimens were cut out from seamless elastomer tracks.

Parts of the test materials were sampled from a part of the element located outside the reinforcement. According to [L. 17], the main component of elastomers is natural rubber and styrene-butadiene rubber. Natural

rubber is derived from aqueous colloidal dispersions obtained from cultivated rubber-bearing plants. It can be modified by chemical methods (hydrogenation, chlorination), using resins, grafted, and epoxydized. Rubber products with no fillers added exhibit high tensile strength (20 MPa). Styrene-butadiene rubber is manufactured by either emulsion polymerisation or the solution polymerisation method using redox initiators. Highly wear-resistant charcoal and kaolin are used as additives.

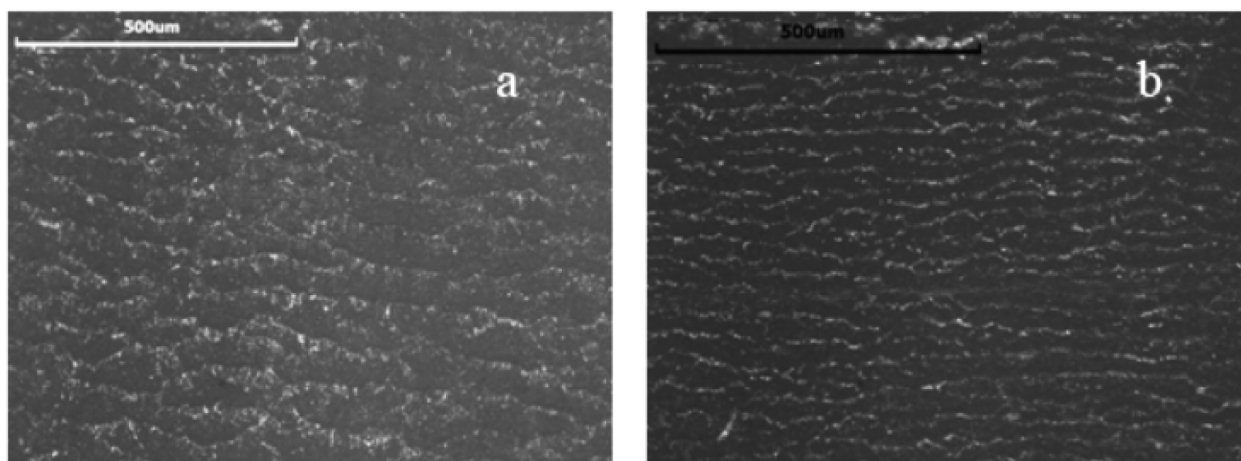


Fig. 1. Elastomer surface before testing: (a) track A; (b) track B

Rys. 1. Powierzchnia elastomeru przed badaniem: a) gąsienicy A; b) gąsienicy B

The presence of chemical compounds in the tested elastomers was identified using infrared spectroscopy (IR) with a SHIMADZU IRTracer – 100 device. An analysis of the results was conducted using the Contaminant Analysis application (Figs. 2 and 3). In the chemical composition of both materials, the presence of the following was found: low-density polyethylene, oxidised polyethylene, ethylene/propylene copolymer with ethylene content of 60%, ethylene-acrylic acid, and Na and Zn ionomers. Polyethylene, due to its structure, is modified by introducing hydrophilic groups to the structure. This is done by high-pressure radical co-polymerisation of ethylene with monomers containing oxygen groups in their structure (e.g., acrylic acid). The most common method is polyethylene oxidation with air or oxygen. Oxidised polyethylene is most important as a raw material in the manufacture of aqueous, ionic, non-ionic, and mixed emulsions. It is also used as an additive in the manufacture of polymers or as a component of biodegradable plastics. The introduction of amide or amine groups to polyethylene increases its resistance to abrasion as well as hardness [L. 18]. The chemical composition of the Track B elastomer differed from the Track A elastomer only in the lack of high-density polyethylene (PE–HD) content.

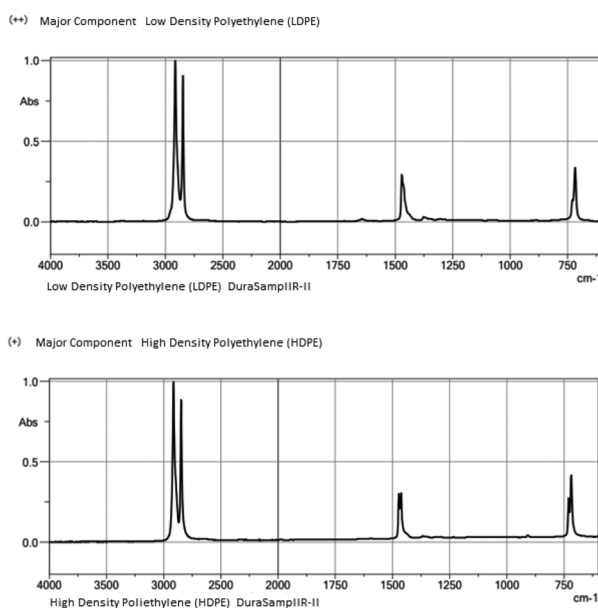


Fig. 2. PE–LD and PE–HD polyethylene content in the chemical composition of the Track A elastomer

Rys. 2. Zawartość polietylenu PE–LD i PE–HD w składzie chemicznym elastomeru z gąsienicy A

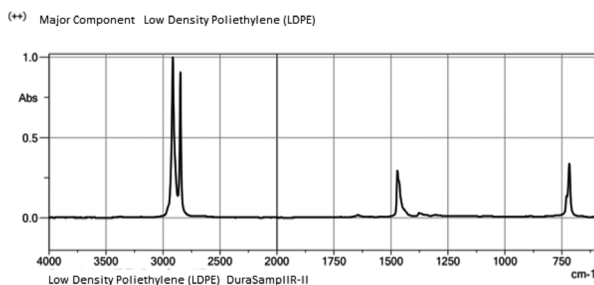


Fig. 3. PE–LD polyethylene content in the chemical composition of the Track B elastomer

Rys. 3. Zawartość polietylenu PE–LD w składzie chemicznym elastomeru z gąsienicy B

Due to the manufacturing method in a gaseous phase under high pressure and at a high temperature, low-density polyethylene (PE-LD) is referred to as high-pressure polyethylene. Polymerisation in the presence of hydroxides and peroxides as catalysts results in a product with the consistency of honey. After passing through a pressure-reducing tank, it takes the form of a ribbon which is granulated after cooling down. Due to the high temperature and high pressure, the resulting high-molecular compound has numerous lateral branches (Fig. 4).



Fig. 4. The structure of low-density polyethylene (LDPE) macromolecules [L. 19]

Rys. 4. Budowa makrocząsteczek polietylenu o niskiej gęstości (LDPE) [L. 19]

It is obtained through free-radical polymerisation at a temperature of 150–260°C with no solvent used, at a pressure of 150–200 MPa, and a reaction initiator, e.g., oxygen or an organic peroxide. The maximum oxygen amount is 0.5% vol. When this limit is exceeded, the polymer structure is adversely affected. Ethylene meets high purity criteria (99.8–99.9%) and contains no impurities, i.e. hydrogen or acetylene. Not only are polymer properties and quality determined by the raw material purity, but also by parameters, particularly temperature.

High-density polyethylene (PE-HD) is obtained at a temperature of 50–70°C in a liquid phase using Ziegler-Natta catalysts. Compared to the high-pressure method, the apparatus is less complicated; however, the application of large amounts of a solvent, an

organometallic catalyst, and its elution from the polymer is very difficult and increases the costs of the process. It is produced under low pressure. Low-pressure ethylene polymerisation uses organometallic catalysts, i.e. titanium tetrachloride (TiCl_4) and triethylaluminium ($\text{Al}(\text{C}_2\text{H}_5)_3$), to form a reaction-catalysing complex.

Complex catalysts are used in the form of suspensions or in aromatic hydrocarbon solutions, e.g., in benzene, as they are blistering, self-igniting in an aqueous environment, or decompose under the influence of oxygen or acids. Operations in which SA complex catalyst is used are carried out under an inert gas, e.g., argon. The reactions occurring in the reactor are exothermic [L. 20].

DESCRIPTION OF TESTS

The testing for wear intensity was conducted under laboratory conditions by the “rotating bowl” method [L. 16]. Rectangular specimens with dimensions of 30 x 25 x 10 mm were subjected to testing. The bowl of the machine was filled with an abrasive soil mass consisting of, respectively, three types of soil marked as light (loamy sand), medium (sandy loam), and heavy (common loam). The tests were conducted in four replications.

The soils were classified based on their grain size corresponding to PN-EN ISO 14688-2(2006):

- Light soil: silt: 1.80%, clay 31.03%, sand: 67.17%,
- Medium soil: silt: 3.34%, clay: 45.79%, sand: 50.87%,
- Heavy soil: silt: 6.50%, clay: 77.3%, sand: 16.20%.

During the testing, the following friction parameters were adopted: velocity of 1.66 m/s, a friction distance of 10,000 m, and the moisture content of the soil mass of approx. 15%. The mass wear was measured every 2000 m.

The density of each specimen subjected to testing was determined by a laboratory method based on the comparison of the weight and volume of prepared specimens. The hardness of the tested specimens was determined using a Shore durometer according to Scale A. For testing purposes, non-heat-treated 38GSA steel was used as a reference material. The hardness of 38GSA steel was measured using a Vickers HV-10D hardness tester in accordance with PN-EN ISO 6507-1:1999. An indenter load of 98N and the load duration of 10 s were applied. The hardness value was 414 HV.

The chemical composition of the tested steel was as follows: C – 0.35%, Mn – 1.07%, Si – 1.17%, P – 0.028%, Cr – 0.18%, Cu – 0.16%, Al – 0.022%, Mo – 0.16%, Ni – 1.52, and B – 1.25. 38GSA steel has a microstructure of hardening martensite with bainite and a small proportion of troostite.

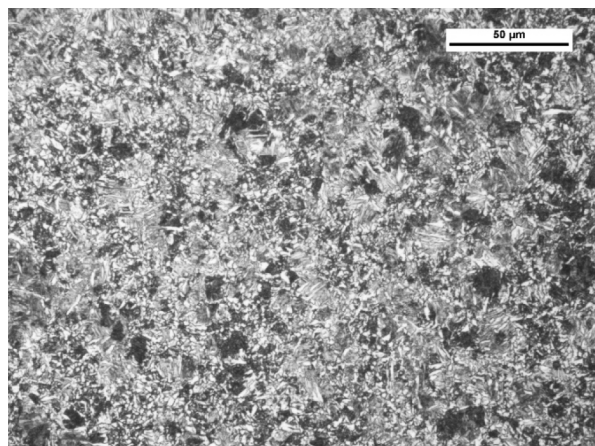


Fig. 5. 38GSA steel microstructure. Etched with 3%HNO₃ (Mi1Fe), light microscopy

Rys. 5. Mikrostruktura stali 38GSA. Trawiono 3%HNO₃ (Mi1Fe), mikroskopia świetlna

The tested materials' resistance to wear was compared based on the abrasion resistance index *K_b* calculated using the following formula [L. 3]:

$$K_b = \frac{\frac{Z_{Vw}}{S_{Tw}}}{\frac{Z_{Vb}}{S_{Tb}}} = \frac{Z_{Ww} \times \rho_b \times S_{Tb}}{Z_{Wb} \times \rho_w \times S_{Tw}},$$

where

- Z_{Vw}* – reference material volume wear,
- Z_{Vb}* – tested material volume wear,
- Z_{Ww}* – reference material mass wear,
- Z_{Wb}* – tested material mass wear,
- S_{Tw}* – reference material friction distance,
- S_{Tb}* – tested material friction distance,
- ρ_w* – reference material density,
- ρ_b* – tested material density.

The surface after the testing was assessed using a Huvitz HRM-300 microscope.

ANALYSIS OF TEST RESULTS

Elastomer materials exhibited hardness and density falling in a similar range of values (Table 1).

Table 1. Characteristics of elastomeric plastic properties

Tabela 1. Charakterystyka właściwości tworzyw elastomerowych

Material	Density [g/cm ³]	Average hardness Shore DIN53505 Scale A	Mass wear [g]					
			Light soil	Standard deviation	Medium soil	Standard deviation	Heavy soil	Standard deviation
Track A	1.1	69	0.2313	0.0216	0.5628	0.0819	0.4661	0.0113
Track B	1.1	67	0.4797	0.0223	0.7355	0.2722	2.9085	0.3340
38GSA	7.87	380 HV10	1.0114	0.0375	0.9171	0.0461	1.5010	0.1254

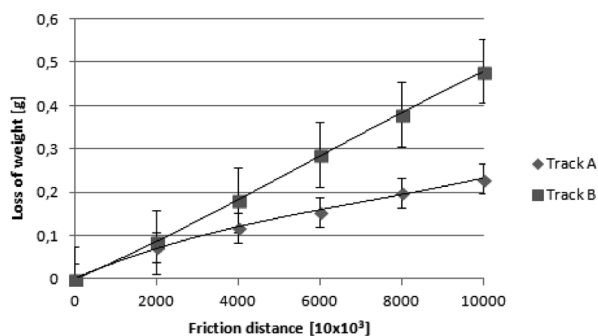


Fig. 6. Average mass wear of the tested materials in the light soil mass

Rys. 6. Średnie zużycie masowe badanych materiałów w masie glebowej lekkiej

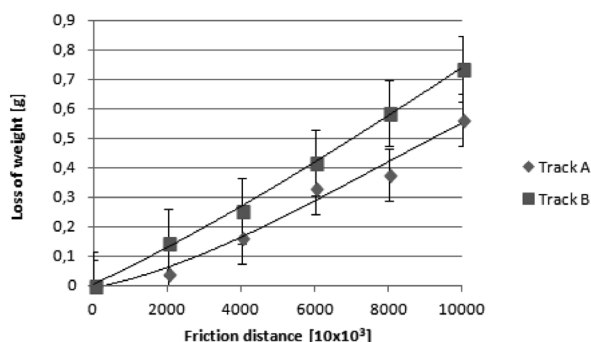


Fig. 7. Average mass wear of the tested materials in the medium soil mass

Rys. 7. Średnie zużycie masowe badanych materiałów w masie glebowej średniej

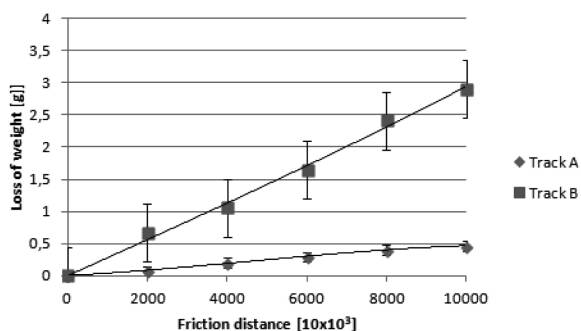


Fig. 8. Average mass wear of the tested materials in the heavy soil mass

Rys. 8. Średnie zużycie masowe badanych materiałów w masie glebowej ciężkiej

The obtained wear values were referred to the wear of steel using the wear index and presented in Table 2. The confidence limits were determined based on T-student distribution at a confidence level of $\alpha = 0.05$.

The obtained results for the abrasive wear index showed that the materials used in the experiment exhibited a lower resistance to abrasive wear than the

38GSA steel. The most similar wear indexes at a level of 76% were noted for Track A in the light soil mass. It contains high-density polyethylene (PE-HD). The lowest wear index (1%) was obtained for Track B, which contained only low-density polyethylene (PL-LD). In the medium and heavy soil, the wear index value fell in the range of approx. 30–55% for Track A, while, for Track B, the index was lower by 37%, irrespective of the abrasive mass type. Figures 6–8 suggest that Track A exhibits lower abrasive wear than that of Track B in all types of abrasive mass. Of all the tested materials, the lowest mass wear was noted for the Track A specimen in the light soil mass, and it was twice as low as the wear in other soil masses.

On the surface of the specimens subjected to testing in the light abrasive mass (Fig. 9), the frequent occurrence of scratches accompanied by impact marks can be observed. This indicates wear caused by loose abrasive particles. The abrasive material affects the surface by rolling and sliding on it and by impacting, which results in scratching and fatigue wear which is manifested by sub-surface and surface cracking that tears off parts of the material.

Table 2. Summary of abrasive wear index

Tabela 2. Zestawienie wskaźnika zużycia ściernego

	Light soil		Medium soil		Heavy soil	
	K_b	confidence limits	K_b	confidence limits	K_b	confidence limits
Track A	0.7623	0.0211	0.3034	0.0802	0.5428	0.0110
Track B	0.3678	0.0218	0.2320	0.3080	0.0869	0.3273
38GSA	1.0000	0.0367	1.0000	0.0451	1.0000	0.1228

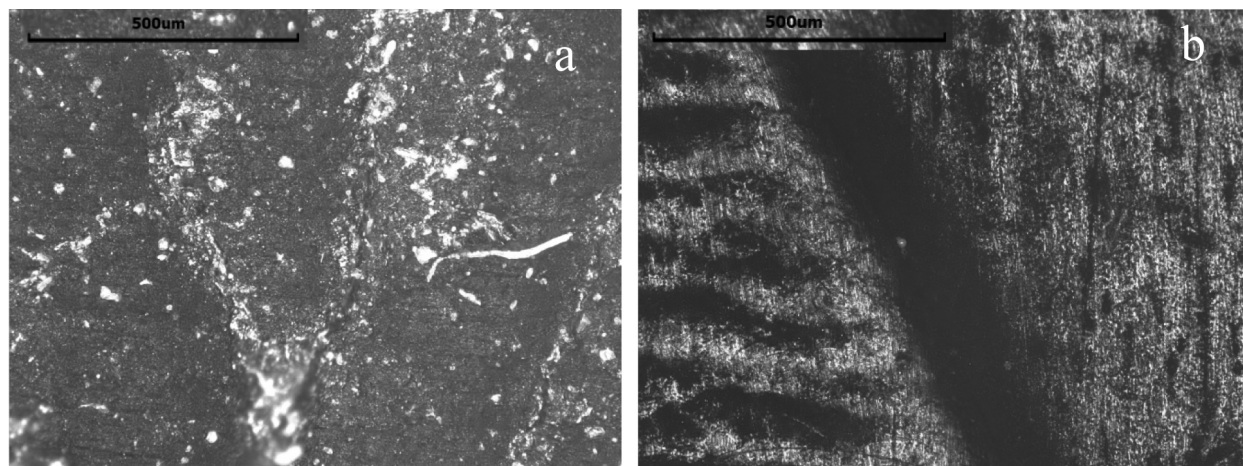


Fig. 9. The surface of a frictionally inter-engaged specimen in the light abrasive soil mass: (a) Track A; (b) Track B

Rys. 9. Powierzchnia próbki współpracującej tarciovo w lekkiej glebowej masie ścierniej: a) gąsienica A; b) gąsienic B

The greater hardness of the material during friction in this type of environment promotes wear resistance. For elastic (soft) materials, the movement of the surface layer of the material may take place. During the wear process in the heavy abrasive soil mass, a strain of the surface layer of elastic materials occurs, which is manifested by the characteristic wave formation on the surface. During the process, the “wave” endings are torn off, which results in a greater material loss compared to a harder material, which is

also demonstrated in the study [L. 15]. This process is more evident for Track B specimens (Fig. 10).

The silts present in the heavy abrasive soil mass, combined with the moisture content, form a binder that fixes abrasive particles, which leads to the “tearing off” of the surface layer of the material (Fig. 11b). Here, a process of wear with consolidated abrasive grains occurs. In such a case, the material is removed under the influence of ridging and scratching (Fig. 11).

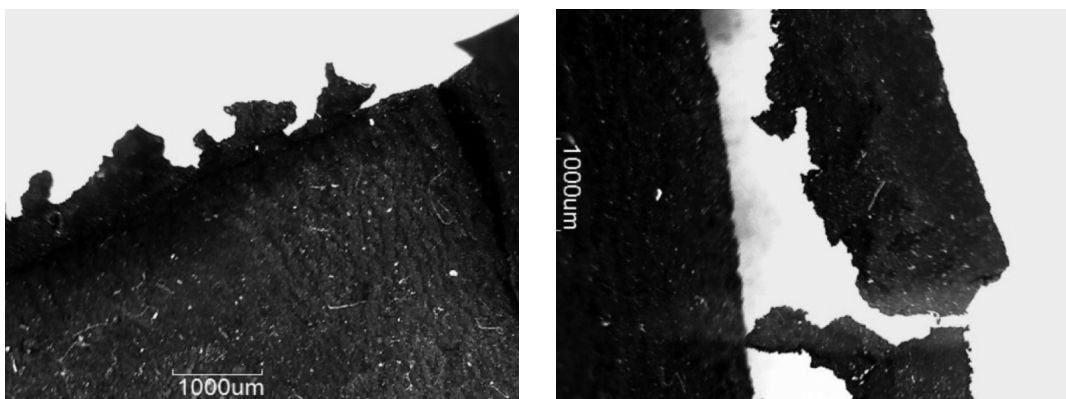


Fig. 10. The surface of specimens and wear products for Track B

Rys. 10. Powierzchnia próbek i produkty zużycia gąsienicy B

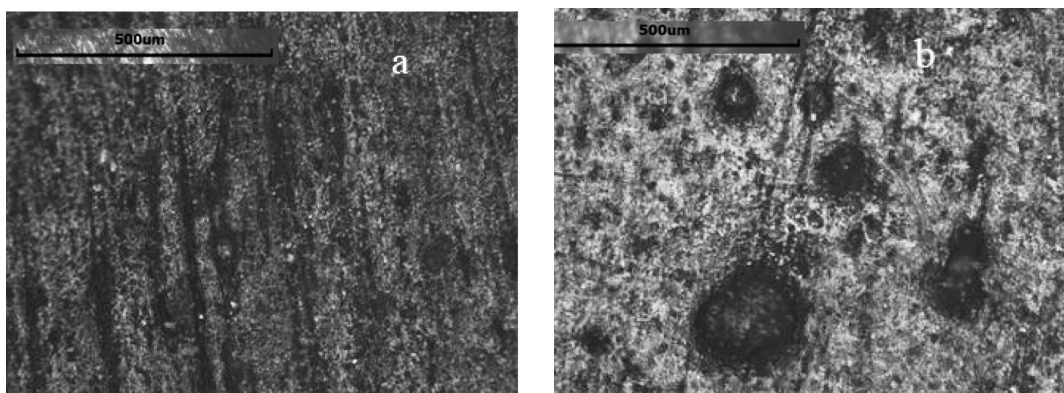


Fig. 11. A view of the specimens' surface following friction in the heavy abrasive mass: (a) Track A; (b) Track B

Rys. 11. Widok powierzchni próbek po tarciu w ciężkiej masie ścierniej: a) gąsienicy A; b) gąsienicy B

During the friction of elastomer materials, various chemical and physical interactions resulting from their multi-phase structure occur related to the wear of particular fillers and the polymer matrix. An increase in local stresses results in the hard filling particles present in the friction zone contributing to an increase in the amount of heat released during friction.

CONCLUSIONS

Under abrasive wear conditions, tribological properties of elastomer materials vary and are determined by abrasive soil mass properties and the chemical composition of the tested materials. Elastomers which contain high-density polyethylene (PE-HD) exhibit higher resistance

to abrasive wear than elastomers containing only low-density polyethylene (PE-LD).

For the tested elastomers, the lowest mass wear value was obtained in the light soil. The wear process in this soil involves the occurrence of scratches and the accompanying impact marks. This indicates wear caused by loose abrasive particles. The mass wear noted for Track A containing high-density polyethylene (PE-HD) was almost two times higher than for the elastomer of Track B.

In the medium abrasive soil mass, the mass wear for the tested elastomers was similar, with the values of 0.5628 g for Track A and 0.7355 g for Track B. As for Track A, it was the higher mass wear for all soil types.

The polyethylene wear values are primarily determined by the course of the surface layer strain, reflected by the characteristic occurrence of waves on the surface. This results in the further process of tearing off the endings of the formed waves, which increases the loss of weight. This process is noticeable in the heavy abrasive mass, because the occurring wear is caused by abrasive grains fixed in the silt and clay. The highest mass wear was noted for Track B with a low-density polyethylene (PE-LD) content of 2.9085 g, which was more than six times higher than the mass wear value for Track A.

REFERENCES

1. Bęben A.: *Maszyny i urządzenia do wydobywania kopalin pospolitych bez użycia materiałów wybuchowych*. Wydawnictwo AGH, Kraków, 2008.
2. Wieleba W.: The mechanism of tribological wear of thermoplastic materials. *Archives of Civil and Mechanical Engineering*, Vol. 7, 2007, No. 4, pp. 185–199.
3. Capanidis D., Tański A.: Badania odporności na zużycie ścierne wybranych polimerów inżynierskich. *Tribologia*, 4, 2012, pp. 25–32.
4. Capanidis D., Kowalewski P., Krauze M.: Study of resistance to abrasive wear of multicomponent polyoxymethylene composites. *Tribologia*, 265, 2016 (1): pp. 7–19.
5. Hooke C.J., Kukureka S.N., Liao P., Chen Y.K.: The friction and wear of polymers in non-conformal contacts. *Wear*, 200 (1–2), 1996, pp. 83–94.
6. Friedrich K.: *Polymer composites for tribological applications*. Advanced Industrial and Engineering Polymer research, 2018, 1, pp. 3–39.
7. Myshkin N.K., Petrokovets M.I., Kovalev A.V.: Tribology of polymers: Adhesion, friction, wear, and mass-transfer. *Tribology International*, 2005, 38, pp. 910–921.
8. Lancaster K.L.: Relationships between the Wear of Polymers and their Mechanical Properties. 183, 1968, 16, pp. 98–106.
9. Laux K.A., Jean-Fulcrand A., Sue H.J., Bremner T., Wong J.S.S.: The influence of surface properties on slipping contact temperature and friction polyetheretherketone (PEEK). 2016, 103, pp. 397–404.
10. Yamamoto Y., Takashima T.: Friction and wear of water lubricated PEEK and PPS slipping contacts. *Wear* 253 (7–8), 2002, pp. 820–826.
11. Quaglioni V., Dubini P.: Friction of polymers slipping on smooth surface. *Advances In Tribology*, 8, 2011.
12. Werner P., Altstadt V., Jaskulka R., Jacobs O., Sandler J.K.W., Shaffler M.S.P., Windle A.H.: Tribological behaviour of carbon-nanofibre-reinforced poly(ether ketone). *Wear* 257 (9–10), 2004, pp. 1006–1014.
13. Wieleba W.: *Bezobsługowe łożyska ślizgowe z polimerów termoplastycznych*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław, 2013.
14. Napiórkowski J., Ligier K.: Investigation of wear resistance of polyurethanes in abrasive soil mass. *International Symposium on Material Science and Engineering (ISMSE 2018)*; 19–21 January, Seoul, South Korea, 2018 / edited by: Kaloop Mosbeh, HuJongwan Melville: American Institute of Physics.
15. Napiórkowski J., Ligier K.: Tribological properties of polyurethanes in abrasive soil mass. *Tribologia*, 2017, 6, pp. 65–70.
16. Kalácska G., Zsidai L., Keresztes R., Eberst O., Pop S.: Abrasive wear of polymers/steel gear pairs in different soil types. *The International Conference of The Carpathian Euro-Region Specialists In Industrial System 7th Edition*, 2008.
17. Zhang L., Chen Y., Ji H.: The application of a new composite elastomer material in rubber tracks. *Advanced Materials Research*, vol. 881–883, 2014, pp. 834–840.
18. Zawadiak J., Marek A., Stec Z., Orlińska B.: Utleniony polietylen. Metody otrzymywania i zastosowanie. Oxidized polyethylene. Methods for production and applications. *Przemysł Chemiczny*, 88, 2009, 9, pp. 1006–1010.
19. Dobrosz K., Matysiak A.: *Tworzywa sztuczne*. Wydawnictwo Szkolne i Pedagogiczne, Warszawa, 1994.
20. Jakubiak Z.: *Wytwarzanie polimerów*. Instytut Technologii Eksploatacji – Państwowy Instytut Badawczy, Radom, 2006.