ISSN 1027-5495. Functional Materials, 30, No.1 (2023), p. 90-93.
doi:https://doi.org/10.15407/fm30.01.90

Comparative analysis of abrasion wear resistance of ultra-high-molecular-weight polyethylene and basalt plastics on its basis

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Received October 27, 2022

A comparative analysis of the abrasive wear resistance of primary ultra-high-weight-molecular polyethylene of two different brands, OKULEN® OK 2000 (made in Germany) and ASYAPLAST®1000 (made in Turkey) is carried out in the article. It is shown that ultra-high-weight-molecular polyethylene of German production surpasses ASYAPLAST®1000 by almost 26 % in terms of wear resistance. A study of secondary ultra-high-weight-molecular polyethylene produced in Turkey was conducted and it was shown that its wear intensity is almost the same as the primary one, while the cost is 40 % lower. Developed basalt plastics based on ASYAPLAST®1000 ASYAPLAST®1000 secondary ultra-high-weight-molecular polyethylene were studied, and it was established that basalt plastic (40 mass% of fiber content) exceeds the original material by approximately 32 %, and is inferior to the primary OKULEN® OK 2000 by only 5 %.
Keywords: ultra-high-weight-molecular polyethylene, wear, basalt fibers, recycling.

Порівняльний аналіз абразивної зносостійкості надвисокомолекулярного поліетилену та базальтопластиків на його основі. *О.В.Єрьоменко, А.-М.В.Томіна, К.А.Єрьоміна, О.В.Чернявський*

У статті здійснений порівняльний аналіз абразивної зносостійкості первинного надвисокомолекулярного поліетилену двох різних марок OKULEN® OK 2000 (виробник Німеччина) та ASYAPLAST®1000 (виробник Туреччина). Показано, що надвисокомолекулярний поліетилен німецького виробництва за показниками зносостійкості перевершує ASYAPLAST®1000 майже на 26 %. Проведено дослідження вторинного надвисокомолекулярного поліетилену турецького виробництва та показано, що його інтенсивність зношування майже не відрізняється від первинного, у той час як собівартість нижча на 40 %. Досліджено розроблені базальтопластики на основі вторинного надвисокомолекулярного поліетилену марки ASYAPLAST®1000 та встановлено, що за показником абразивної зносостійкості базальтопластик (вміст волокна 40 мас.%) перевершує первинний матеріал приблизно на 32 %, та поступається первинному OKULEN® OK 2000 лише на 5 %.

1. Introduction

The use of ultra-high-molecular-weight polyethylene (UHMWPE) as a material for structural and tribotechnical purposes is steadily increasing in the agricultural industry [1, 2]. This is due to a set of improved technological properties of UHMWPE: high rigidity, increased resistance to various aggressive products, in particular, organic and inorganic acids, alkalis, corrosion, and radiation [3]. Also

Table 1. Functional properties of ultra-high-molecular-weight polyethylene

Indicator	Brand	
	OKULEN® OK 2000	ASYAPLAST®1000
Density, g/cm^3	>0.93	>0.93
Molecular weight, g/mol	~ $9 \cdot 10^6$	~$5 \cdot 10^6$
Yield strength, MPa	17	19
Elastic modulus, MPa	600	700
Shore *D* hardness	61–65	60–62
Friction coefficient	0.10–0.20	0.10–0.20
Maximum operating temperature, K	353	363

UHMWPE surpasses such commonly used polymer materials as polytetrafluoroethylene, polyamide, epoxy resins, etc. in terms of wear resistance.

UHMWPE is used in situations where most metals and thermoplastic polymer materials cannot withstand harsh operating conditions. For example, "POLI PLAST" LLC (Kropivnytskyi) [4] manufactures parts for protecting the bottoms of John Deere, Case/New Holland harvesters, tillage equipment that is bearing housing protection, wipers, etc., which are subject to abrasive wear during the operation of the harvesters, using UHMWPE. UHMWPE products of structural and tribotechnical purpose of the required configuration are usually obtained by mechanical processing of monolithic sheets [5]; it is accompanied by a large amount of waste. As a result, a large amount of waste accumulates at enterprises that manufacture various products using ultra-high-weight-molecular polyethylene.

Nowadays, one of the common practices is the utilization of UHMWPE and, to a lesser extent, the creation of polymer composite materials (PCM) of structural (grids of drainage systems, manhole lids and bodies), general (street furniture, benches for parks, garbage cans) and tribotechnical (gears, sliding bearings) purpose. The secondary use of UHMWPE allows obtaining a number of advantages: environmental aspect, consumer demand and low cost of raw materials.

Taking into account the above, this work is devoted to a comparative analysis of the abrasive wear resistance of UHMWPE and the possibility of using its waste.

2. Objects and research methods

UHMWPE samples for research were provided by "POLI PLAST" LLC whose production uses OKULEN® OK 2000 (made in Germany) and ASYAPLAST®1000 (made in Turkey) brands [6]. The initial characteristics of the materials are given in Table 1.

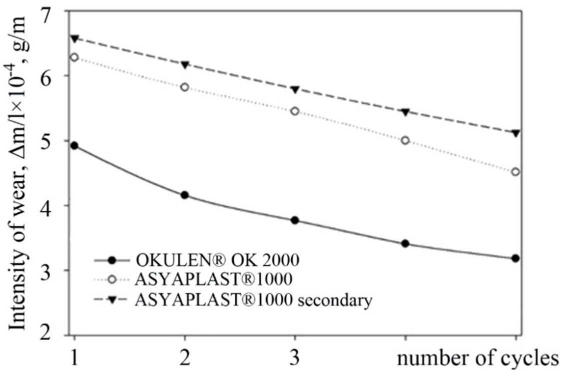

Fig. 1. Dependence of wear intensity of ultra-high-molecular-weight polyethylene on the number of test cycles.

The study of the abrasive wear resistance of samples was carried out using rigidly attached abrasive particles (dispersity of the abrasive paper was 40–60 μm) on a HECKERT test machine. Before the start of the experiment, each sample underwent preliminary grinding (running-in) in the working mode until full contact with the sanding pad was achieved. The amount of mass wear (Δm) of materials was determined using analytical VLR-200 scales with an accuracy of 0.00001 g. The load on the sample during the experiment was 0.1 MPa; the friction path was 40 m. The wear intensity as the ratio of the mass loss of the test sample (Δm, g) to the friction path during one cycle (l = 40 m) was determined with an accuracy of 0.00001 g. The morphology of the friction surfaces of UHMWPE was studied using a BIOLAM-M experimental binocular microscope.

3. Results

Fig. 1 shows the dependence of the wear intensity of UHMWPE samples of OKULEN® OK 2000 (●) and

Table 2. Basalt fiber properties

Indicator	Value
Density, g/cm^3	2.70
The average diameter of the elementary fiber, μm	13.6
Operating temperature, K	23–923
Chemical resistance (loss of mass, % after three hours of boiling) in:	
— H_2O	1.6
— 2NaOH	2.75
— 2NHCl	2.2
Thermal conductivity coefficient, W/m·K:	
— at 398 K	0.064
— at 573 K	0.096

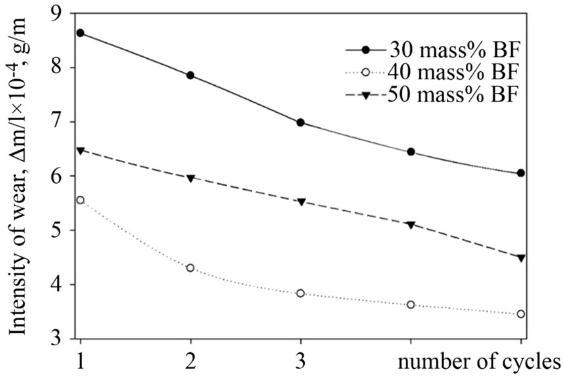

Fig. 2. Intensity of wear of basalt plastics based on recycled ultra-high molecular weight polyethylene.

ASYAPLAST®1000 (O), as well as the recycled secondary ASYAPLAST®1000 (▼), on the number of test cycles.

From the data shown in Fig. 1, it can be seen that German-made UHMWPE exceeds ASYAPLAST®1000 by almost 26 % in terms of wear resistance.

We also studied the secondary ASYAPLAST®1000 UHMWPE, taking into account the fact that the use of recycled UHMWPE will allow reducing the amount of recycled production waste, which will improve the environmental situation and increase economic efficiency (the cost of recycled UHMWPE is approximately 40 % lower than the cost of the primary one).

As it can be seen from the data presented in Fig. 1, the intensity of wear of recycled UHMWPE (made in Turkey) practically does not differ from the primary one, while the cost of the recycled material is much lower.

It is interesting to note that the largest mass loss of all test samples occurs during the passage of the first 40 m. Then the mass loss decreases when the sample passes the next 40 m. This is due to the fact that in the process of friction, finely dispersed wear products fill the micro depressions of the grinding wheel, and as a result, the samples are less scratched and cut.

Recycled polyethylene was reinforced with discrete fiber in order to improve abrasion resistance. The analysis of data from [7, 8] has shown that basalt fibers (BF) are promising fillers for creating PCMs with high functional properties. Thus, these PCMs are significantly superior to traditional materials and alloys for structural and tribotechnical purposes in terms of their mechanical, thermophysical and tribological properties.

The advantages of parts made of basalt plastics (BP) include: high resistance to corrosion; chemical inertness (withstand long-term operation under the influence of natural factors: moisture, solutions of salts, alkalis, and acids); high specific mechanical characteristics; high impact strength and viscosity, damping properties. Taking into account the above, discrete basalt fiber (BF) was chosen as a filler (manufactured by PJSC "Research Institute of Fiberglass and Fibers" (NISKV), Ukraine), the technical characteristics of which are given in Table 2.

The preparation of basalt plastics based on the recycled UHMWPE containing 30–50 mass% of BF was carried out according to the method described in the work [9]. The results of the research are presented in Fig. 2.

As it can be seen from Fig. 2, the introduction of BF does not change the general appearance of the dependence of wear intensity on the number of cycles. At the same time, basalt plastic containing 40 mass% of BF is characterized by the lowest intensity of wear. In general, it should be noted that the introduction of such an amount of BF to recycled UHMWPE leads to an increase in the wear resistance of the latter by approximately 43 %, which is due to the high hardness of the filler; this is characteristic of most composites containing solid filler [10].

Studies of the friction surfaces of recycled UHMWPE (see Fig. 3) and composites based on it under conditions of abrasive wear showed that the particles of the fixed abrasive cut the polymer binder, but the plowing furrows in basalt plastic are less

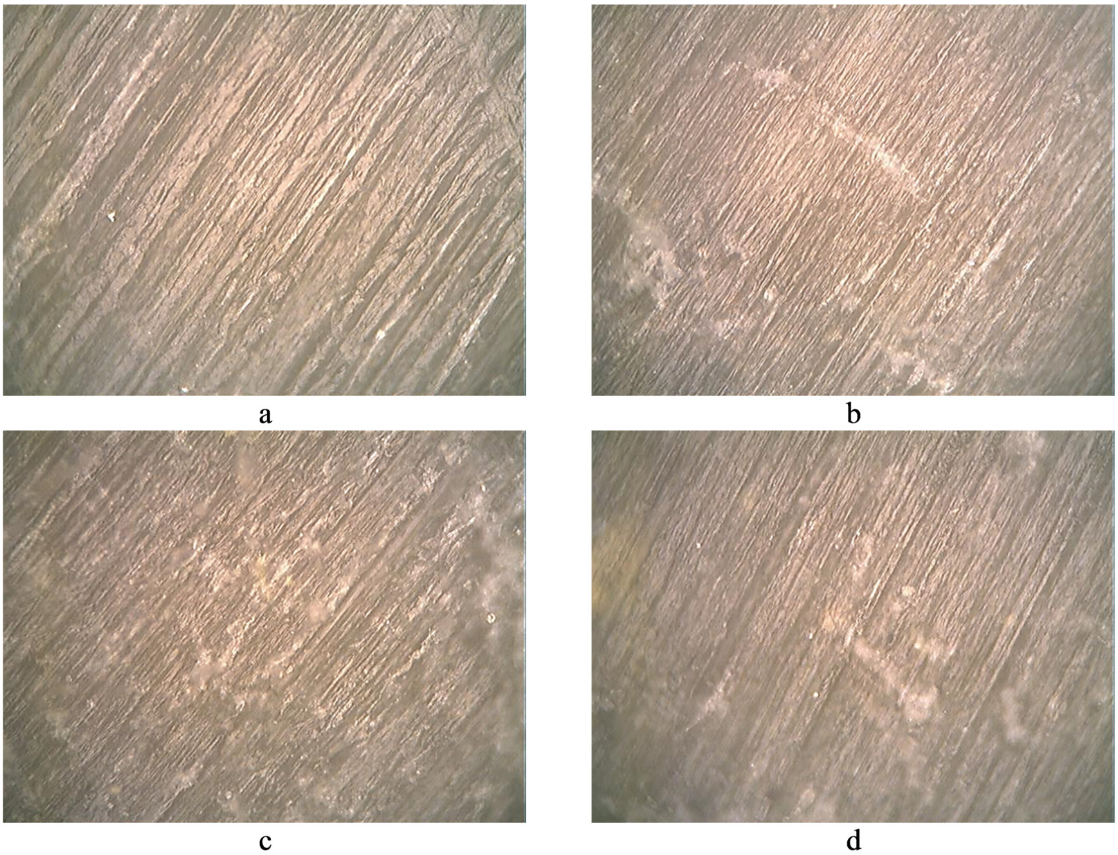

Fig. 3. Friction surfaces (×200) of recycled ultra-high molecular weight polyethylene (a) and basalt plastics based on it, containing: b — 20, c — 30, d — 40 mass% of fiber.

deep compared to unfilled recycled ultra-high molecular weight polyethylene.

It is interesting to note that the designed basalt plastics are similar to the primary ultra-high molecular weight polyethylene of German production in terms of wear resistance.

4. Conclusions

It was established that the developed basalt plastic made of the recycled UHMWPE exceeds the primary one by approximately 32 % in terms of abrasive wear resistance, and is inferior to the German one by less than 5 %. The use of this composite by the enterprise in the future will allow us to obtain a significant environmental effect due to the recycling of UHMWPE, which will also improve the technical and economic performance of the products. Therefore, basalt plastic with an effective (40 mass%) content of BF can be used for the manufacture of various products of "POLI PLAST" LLC which are used in agricultural machinery: protection of the bottoms of Case/New Holland, John Deere and MAANS harvesters, wipers and bearing liners, etc.

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