ISSN 1027-5495. Functional Materials, 31, No.2 (2024), p. 210-214
doi:http://dx.doi.org/10.15407/fm31.02.210

Influence of dispersed filler on the abrasive wear index of ultra-high molecular polyethylene

S.V.Tomin, O.V.Yeromenko, Ye.A.Yeriomina

Dniprovsk State Technical University, 2 Dniprobudivska Str.,
51918 Kamyanske, Ukraine

Received January 23, 2024

The paper describes the influence of the percentage content of crucible graphite and aluminosilicate microspheres on the abrasive wear index of ultra-high molecular weight polyethylene when worn by rigidly fixed abrasive particles. It is shown that the introduction of 10-30 mass.% of crucible graphite or aluminosilicate microspheres into ultra-high molecular weight polyethylene reduces its abrasive wear rate by 20-35%; minimum wear is achieved with a filler amount of 30 mass.%. The result is explained by the high stiffness and strength of the fillers, which leads to an increase in the resistance of composites to mechanical damage to surfaces; this is confirmed by the morphology of the friction surface (roughness decreases 1,35 times).

Key words: ultra-high molecular weight polyethylene, abrasive wear index, abrasive particles, crucible graphite, aluminosilicate microspheres

Вплив дисперсного наповнювача на показник абразивного стирання надвисокомолекулярного поліетилену. *Томін С.В., Єрьоменко О.В., Єрьоміна К.А.*

У роботі наведено результати досліджень впливу відсоткового вмісту тигельного графіту та алюмосилікатних мікросфер на показник абразивного стирання надвисокомолекулярного поліетилену жорстко закріпленими абразивними частками. Показано, що введення 10-30 мас.% тигельного графіту чи алюмосилікатних мікросфер до надвисокомолекулярного поліетилену зменшує його показник абразивного стирання на 20-35 %, сягаючи мінімальних значень при кількості наповнювача 30 мас.%. Покращення даного показника пояснюється високою жорсткістю та міцністю наповнювачів, що призводить до збільшення стійкості композитів до механічного пошкодження поверхонь, як підтверджують результати дослідження морфології поверхні тертя (шорсткість зменшується в 1,35 рази).

1. Introduction

Wear and mechanical damage to the working parts of the equipment is the most common cause of emergency stoppages of production, about 80% of which are related to external abrasive influences. In the operation process, the working bodies of automotive, mining, tillage, textile and seeding equipment are subjected to scratching and cutting effects due to interaction with solid particles (alumina, sand and rocks). As a result, mechanical destruction of the friction surfaces occurs - abrasive wear. One of the technological ways to solve this problem is the use of polymer materials instead of traditional metals and alloys.

Among the large number of polymer materials, ultra-high molecular weight polyethylene (UHMWP) occupies a special place. UHMWP today is an effective replacement for metal products in industrial enterprises around the world due to its high self-lubrication, impact strength, chemical and corrosion resistance, and wear resistance. This high-quality polymer material has been proven to outperform conventional tribotechnical and structural materials in many modern industries [1]. The versatility of UHMWP has made it a popular choice for improving reliability and reducing equipment downtime.

High resistance to corrosion and abrasive wear resistance of UHMWP allow it to be used in agricultural and automotive equipment operating under conditions of high humidity and abrasive particles. In addition, these products are characterized by high damping properties. For agricultural machinery, UHMWP is used in the manufacture of wear-resistant slats, sliding bearings, rollers, gear wheels, protection elements for the bottoms of John Deere, Case/New Holland headers, bearing housings and wipers. The automotive industry is beginning to actively use UHMWPs as light, noise-absorbing and damping materials [2]. Structural elements prone to wear are made from it, for example, cable blocks, support bushings, scrapers, etc. Also, in the automotive industry, UHMWP is used for lining trucks, wagon bodies, and excavator buckets. Replacing serial metal brake pads and gears with products made from UHMWP in many self-propelled combines and harvesting machines can reduce metal consumption by 23 thousand tons and increase service life by 3 times [3, 4].

The stability of operation at low temperatures, a high index of impact strength and wear resistance, made it possible to use UHMWP instead of steel in the manufacture of cutting edges of snow removal machines. The use of such edges increases the durability of roads and their aesthetic appearance, unlike steel edges.

The mining industry uses UHMWP for lining transport chutes, ramps, wagons, bunkers, screens, inclined trays and chutes for bulk materials, etc. Its use reduces the weight of the products and increases wear resistance, which is especially important for operation under the influence of abrasive particles. UHMWP is also used in the production of wear-resistant liners, because its low coefficient of friction helps reduce gutter clogging.

The use of UHMWP products ensures complete elimination of lubricants, increased wear resistance, and reduced coefficient of friction, noise and vibration during operation, the number of planned and preventive maintenance works and downtime of equipment.

However, there are a number of characteristics that prevent the widespread use of UHMWP: high viscosity of the melt, tendency to creep and high coefficient of thermal linear expansion. Disperse (calcium carbonate, boron carbide, graphite, kaolin, anthracite, etc.) fillers (FLs) are introduced into it to reduce the viscosity of the melt. Reducing the melt viscosity could significantly expand the scope of UHMWP applications due to the possibility of using extrusion and injection molding methods. In addition, the use of dispersed FLs increases the wear resistance of UHMWP.

Taking into account the above, this paper is devoted to the development and research of new polymer composite materials (PCMs) with a low index of abrasive wear.

2. Experimental

UHMWP (produced by Jiujiang Zhongke Xinxing New Material Co., Ltd., China) was chosen as a polymer matrix for creating wear-resistant PCMs.

The following materials were chosen as fillers for UHMWP:

- crucible graphite (CG) is natural crystalline graphite obtained by beneficiation of graphite ores. It has the largest particle size among other graphites [7]. The size of the graphite particles was 160 μm.

- aluminosilicate microspheres are white sodium-borosilicate glass powder, the spherical particles of which have cavities inside [8]. The size of individual microspheres ranges from 15 to 125 μm.

PCMs based on UHMWP containing 10–50 mass.% of crucible graphite/aluminosilicate microspheres were prepared by pressing [9]. Abrasive wear index (V_i, mm^3/m) of UHMWP and PCMs based on it (rigidly mounted abrasive particles with a dispersion of 100 μm) was tested on the grinding wheel of a HECKERT machine; its value was determined by the formula:

$$V_i = \frac{\Delta G \cdot 1000}{\rho \cdot L},$$

where ΔG is the mass loss of the material, g;

ρ is the experimental density of the material, g/cm^3;

L is the grinding path length per cycle, m.

The surface roughness R_a (μm) after grinding for UHMWP and PCMs was determined using a 170621 probe profilometer. The morphology of friction surfaces of UHMWP and composites based on it was studied using a BIOLAM-

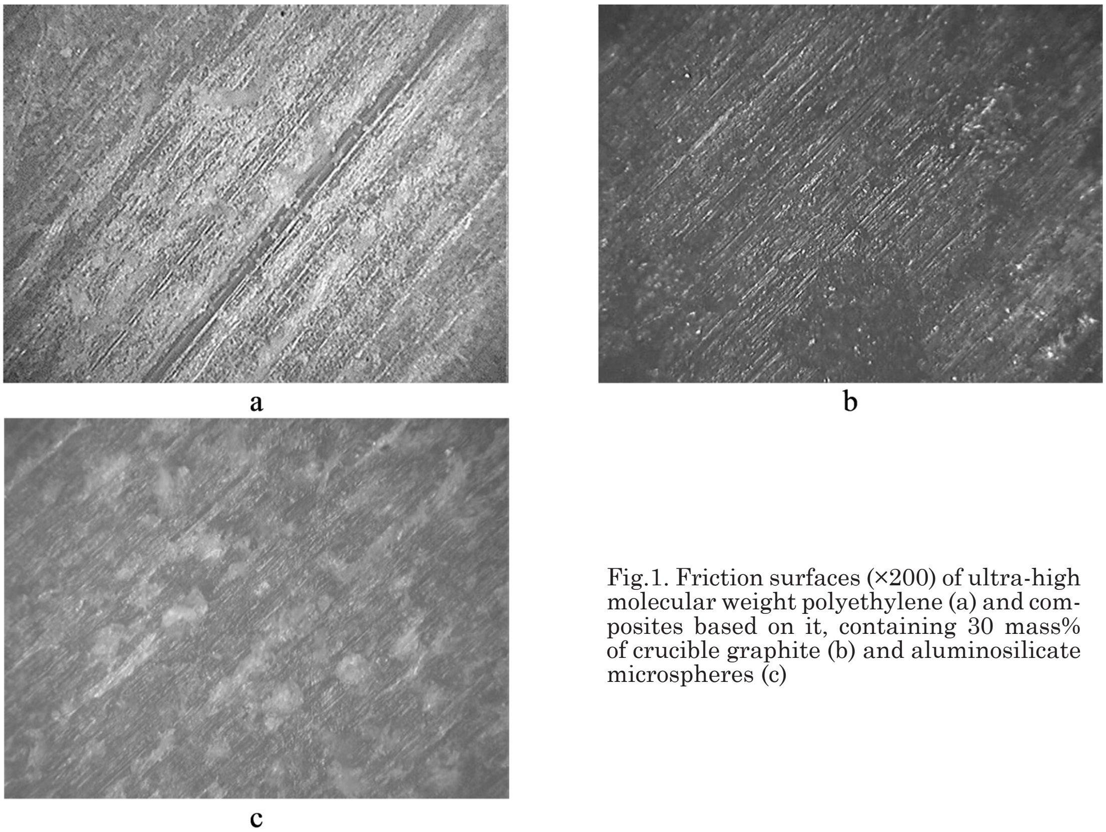

Fig.1. Friction surfaces (×200) of ultra-high molecular weight polyethylene (a) and composites based on it, containing 30 mass% of crucible graphite (b) and aluminosilicate microspheres (c)

M optical microscope equipped with a TREK digital camera (DCMI1300, resolution 1,3M pixels). The hardness of UHMWP and PCMs was measured on the Rockwell scale (HRL) using a 2074 TPR device. An initial load of 98.1 N (10 kgf) and total one of 588.4 N (60 kgf) were applied to the cylindrical sample (Ø=15, h=15 mm). The diameter of the steel indenter during the experiment was 6.33±0.005 mm.

3. Results and discussion

The results of studying the functional characteristics (Table 1) showed, that the introduction of 10-50 mass% of FLs leads to a decrease in the abrasive wear index of UHMWP by 20-35%, reaching the minimum values at 30 mass% of FLs. The improvement of this indicator when filling UHMWP with crucible graphite can be explained by the ordering of the supramolecular structure: an increase in the degree of crystallinity. Kanaga Karuppiah K.S. [10] and Wang L. [11] concluded that there is a relationship between the crystallinity of UHMWP and its tribotechnical performance: the resistance to abrasion increases with increasing crystallinity.

The increase in resistance to deformation was confirmed by comparing the friction surfaces of UHMWP (Fig. 1, a) and graphite plastics (Fig. 1, b, c) using optical microscopy. It was established that the introduction of CG and aluminosilicate microspheres leads to a reduction in the depth of scratches by 35%. Strengthening of PCM occurs due to the fact that FL particles impede the movement of dislocations in the polymer matrix under the action of an applied load (10 N); as a result, the hardness of UHMWPL increases by 17% on the Rockwell scale.

It should be noted that an increase in the number of test cycles (see Fig. 2) leads to a decrease in the abrasive wear rate of both UHMWP and composites based on it. This can be explained by the fact that the micropits and micropores of the grinding wheel are filled with finely dispersed wear products formed in the friction process; as a result, its surface “deteriorates”.

Note that best set of functional properties was obtained for PCMs containing 30 mass% of FLs. A further increase in the FL content in UHMWP leads to a decrease in abrasive wear index and hardness, which is likely due to an increase in defectiveness in the bulk of the

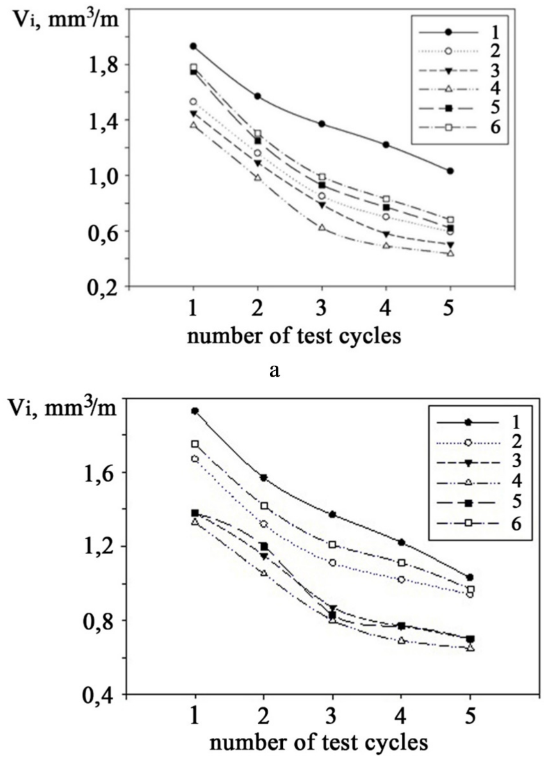

Fig. 2. Dependence of the index of abrasive wear (V_i, mm^3/m) on the number of test cycles for ultra-high molecular weight polyethylene (1) and composites based on it, containing 10 (2), 20 (3), 30 (4), 40 (5), 50 (6) of CG (a) and aluminosilicate microspheres (b)

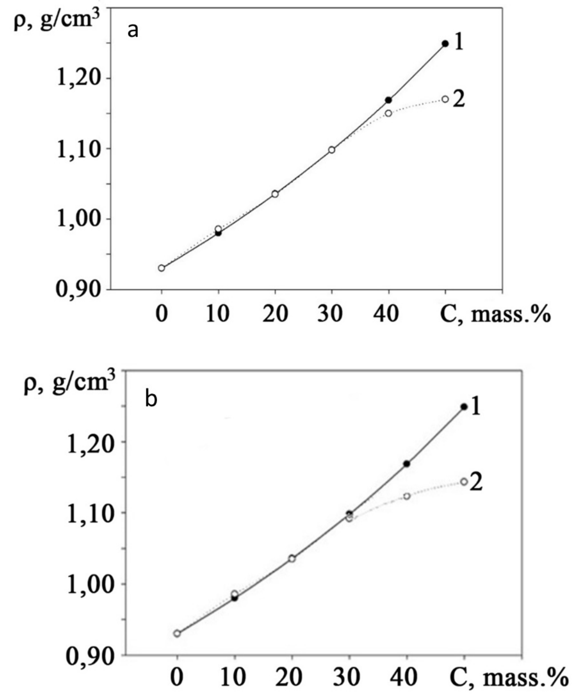

Fig. 3. Calculated (1) and experimental (2) density (ρ, g/cm^3) of ultra-high molecular weight polyethylene depending on the content (C, mass%) of crucible graphite (a) and aluminosilicate microspheres (b)

polymer material. The presence of defects can be explained by insufficient adhesion between UHMWP and FLs. This conclusion is confirmed by a comparison of the calculated and experimental density (Fig. 3).

From the data shown in Fig. 3, it can be seen that with a content of crucible graphite or aluminosilicate microspheres of 10-30 mass%, the experimental and calculated density of PCMs are the same. Based on this, we can conclude that due to the strong interaction between the components at the “UHMWP-FLs” interface, the supramolecular structure of the obtained PCMs is more homogeneous and ordered.

With a further increase in the FLs content up to 40-50 mass%, the dependence changes: the experimental density is lower than the calculated one, that is, the PCMs structure is looser, and the composite contains defects. The formation of defects is explained by the high viscosity of the UHMWPL melt and the low mobility of macromolecules in the liquid state;, thus, it is difficult for it to be evenly distributed over the PL surface at its high concentration.

Table 1 – Functional characteristics of ultra-high molecular weight polyethylene and composites based on it

Index	Content of crucible graphite/aluminosilicate microspheres, mass%					
	0	10	20	30	40	50
Index of abrasive wear*, V_i, mm^3/m	1.36	0.97/0.96	0.91/0.92	0.85/0.87	1.07/0.89	1.12/1.18
Roughness *, R_a, μm	2.57	1.97/2.01	1.75/1.86	1.63/1.71	2.12/1.77	2.35/1.96
Hardness on the Rockwell scale (HRL), hardness units	83	90/90	95/93	97/96	93/95	86/89

* Average value of 5 test cycles

As a result, areas of graphite or aluminosilicate microspheres "not impregnated" with the crucible polymer are formed [12, 13]. [12, 13].

4. Conclusion

The analysis of the obtained results showed that the use of crucible graphite and aluminosilicate microspheres as fillers for UHMWP is a promising way to improve its tribotechnical properties: a 35% decrease in abrasive wear and roughness is observed. It was established that the most effective content of the filler for UHMWP is 30 mass% of crucible graphite or aluminosilicate microspheres. The developed PCMs with high abrasive wear resistance can be used in various fields, for example, in industrial pumping equipment, protective linings of pipelines, teeth and tracks of special equipment, etc.

References

1. https://polyplast.tech/uslugi/uhmwpe
2. Suveda Aarya, Pawan Kumar, Mamta Bhatia, Sanjeev Kumar, Jyotsna Sharma, Siddhartha, *J. Advances in Polymer Technology*, **1-8** (2021).
3. Peng Chunzheng, *J. Surface and Interface Analysis*, **50**, 5 (2018).
4. Baena J., Wu J., Peng, Z., *J. Lubricants*, **3**, 2 (2015).
5. Guo B., Lijuan Wang, P. Yin, Bengang Li, Panxin Li, *J. Materials Science*, **33** (2015).
6. Sullenberger K., Wagman R., *J. IAPD Mag.: The Voice of Plastics Distribution*. (2001).
7. https://bonustrade.com.ua/ua/p1218905088-grafit-tigelnyj.html https://www.endoterm.com.ua/product/mikrosfera.php
8. O.V. Yeromenko, A.-M.V. Tomina, Ye.A. Yeriomina, O.V. Chernyavskyi, *Funct.Mater.*, **30**, 90, (2023).
9. Kanaga Karuppiah K.S., Bruck A.L., Sundararajan S., Wang J., Lin Z., Xu Z.-H., Li X. *J. Acta Biomater*, **4**, 5 (2008).
10. Wang L., Gao S., Wang J., Wang W., Zhang L., Tian M.. *J. Adhesion,* **94**, 1 (2018).
11. M.A. Grashchenkova, A.-M.V. Tomina, O.I. Burya, S.V. Krasnovyd, A.A. Konchits, B.D. Shanina, *J. Nanosistemi, Nanomateriali, Nanotehnologii,* **21**, 1 (2023).
12. A.-M.V. Tomina, O.V. Yeromenko, *Funct.Mater.*, **30**, 403 (2023).