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EFFECT OF POLYTETRAFLUOROETHYLENE DISPERSION ON STRUCTURE AND PROPERTIES OF ULTRA-HIGH-MOLECULAR-WEIGHT POLYETHYLENE-BASED COMPOSITES

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Abstract: With the purpose of studying the effects of filler dispersion on the structure and properties of composite materials based on ultra-high-molecular-weight polyethylene (UHMWPE), we have used polytetrafluoroethylene (PTFE) with different sizes. The results show that the structure of the composites is more homogeneous; the mechanical properties deteriorate less, and the wear resistance under dry sliding friction with small fillers (Ø 14 μm) is 2 times higher than with large fillers (Ø 100–180 μm). The best weight content of fillers is 10 % PTFE with an increase of the wear resistance of the composites based on UHMWPE by 3.5 times. The limitations of structure, elongation, and tensile strength of the composites are discussed.

Keywords: ultra-high-molecular-weight polyethylene, polytetrafluoroethylene, wear resistance, composite structure, tensile strength, elongation

1 Introduction

Ultra-high-molecular-weight polyethylene (UHMWPE) plays an important role in the group of polymeric materials because of its special properties, such as low friction coefficient, high abrasion resistance, good chemical corrosion resistance, large plastic impact indicators, being used frequently in the machine building, machine parts manufacturing, and machine structures. Composite materials based on UHMWPE allow for increased wear resistance of the frequent-heavy-loading details [1–3]. The basic problem of processing UHMWPE is the low adhesion of molecules between the substrate and the filler in the composite structure [4–5].

Polytetrafluoroethylene (PTFE) is a perfluorinated, straight chain, high-molecular-weight synthetic polymer [6]. In contrast to most inorganic functional filler, PTFE is an organic filler having a unique combination of high heat and chemical resistance together with the lowest friction coefficient of any known internal lubricant, high purity, and dielectric properties. The features and benefits of PTFE include excellent slip, antiblocking, improved stability against polishing, and improved abrasion, scratch, mar and scuff resistances [7].

In [8], the author shows that an addition of 10% PTFE (F–4PN) (Ø100–180 μm) increased the wear resistance under dry sliding friction 1.6 times, but the elongation and tensile strength

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decreased by 40%, and the molecular structure of composites became less homogeneous than that of UHMWPE. In this paper, the author investigated the effect of the size of PTFE fillers with different weight content on the structure and properties of UHMWPE.

2 Materials and method

We used the powder UHMWPE (GUR–2122 provided by company Ticona) with the molecular weight of 4.0 million carbon units and particle size of 5–15 μm, the powder polytetrafluorethylene F–4PN20 (∅ 14 μm) and polytetrafluoroethylene F–4PN (∅ 100–180 μm). The samples of the polymer-polymeric composites were prepared by hot pressing at the pressure of 10 MPa and temperature of 200 °C with the rate of the subsequent cooling of 4 °C/min.

Wear resistance of materials under dry friction was determined on a "shaft-tree" scheme at a load of 68.8 N per sample and the speed of rotation of 100 min^{-1} in accordance with ASTM G99 on the friction machine SMT–1 (slip speed 0.32 m/s). The size of samples was H×W×L = 7×7×10 mm. The diameter of the counterbody made of steel ShKh15 was 62 mm. The area of the friction track was calculated with a help of the software "Rhino Ceros 3.0" by the manual contouring of its optical image (friction track). Tribotechnical characteristics were evaluated by averaging the four samples.

The structural studies were carried out using the scanning electron microscope LEO EVO 50 at the accelerating voltage of 20 kV on the cleavage surfaces of notched specimens mechanically fractured after exposure in liquid nitrogen. The degree of crystallinity was measured with an STD Q600 installation. Mechanical characteristics were determined under tensile tests using the electromechanical testing machine Instron 5582. Testing coupons had a dog-bone shape with the number of specimens of each type not less than 5 (according to Russian state standard – GOST 11262–80).

3 Results and discussion

In this work, we studied the structure and properties of the composites based on UHMWPE with the addition of PTFE particles (5, 10, 20, 40 wt. %). Table 1 shows their the mechanical properties and friction coefficient.

It can be seen from Table 1 that the density of UHMWPE–PTFE composites increases, while the hardness does not change significantly. Mechanical properties (tensile strength and value of elongation to failure) gradually reduce with the increase of the PTFE content. The powder size of PTFE particles determines the uniformity of its distribution in the matrix: smaller fillers increase the homogeneity and crystallization and thus form the permolecular structure. The crystallinity decreases with the increase of the weight content of the fillers. Furthermore, Table 1 also shows that mechanical properties of the composites based on UHMWPE are improved with smaller particles than with the larger particles.

Table 1. Mechanical properties and friction coefficient of UHMWPE–PTFE composites with the small (1) and the large (2) size of the filler powder.

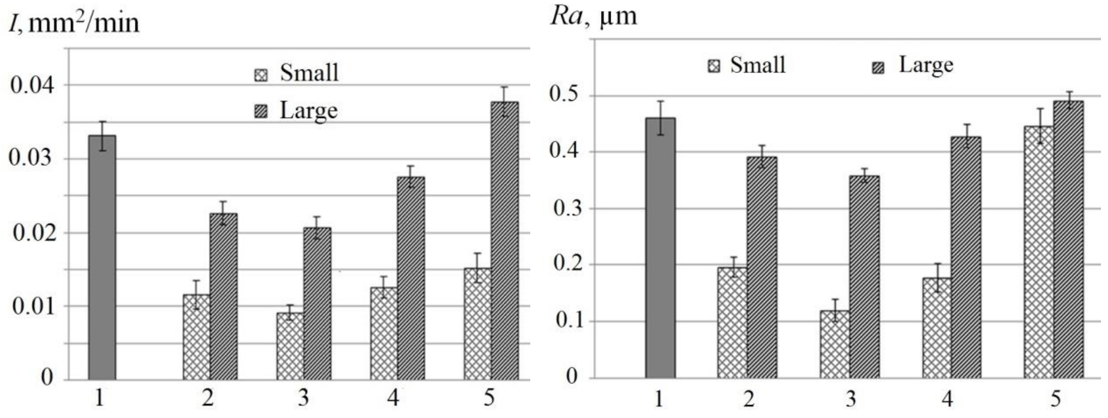
Filler content wt. %	Density g/cm^3	Shore D hardness	Tensile strength σ_u, MPa	Elongation ε,%	Cryst. χ, %	Friction coef. F
0	0.93	59.5 ± 0.6	32.3 ± 0.9	485 ± 23	44.8	0.12
5 (1)	0.97	59.8 ± 0.5	29.2 ± 1.0	465 ± 23	39.5	0.067
10 (1)	1.00	59.6 ± 0.6	27.0 ± 1.2	428 ± 25	35.8	0.067
20 (1)	1.06	59.7 ± 0.6	24.7 ± 1.3	406 ± 24	35.0	0.068
40 (1)	1.22	59.8 ± 0.6	20.2 ± 1.0	217 ± 23	26.0	0.075
5(2)	0.97	59.5 ± 0.5	28.5 ± 1.0	438 ± 25	36.5	0.089
10 (2)	0.99	59.8 ± 0.4	25.1 ± 1.2	384 ± 24	34.3	0.098
20 (2)	1.01	59.6 ± 0.6	22.6 ± 1.3	332 ± 23	32.8	0.098
40 (2)	1.12	59.9 ± 05	18.1 ± 1.0	289 ± 23	20.6	0.099

It can be seen from Fig. 1a that the wear rate of UHMWPE–PTFE composites depends on the weight fraction of the filler and its size: the wear rate decreases more than twice in the composites with the smaller-sized filler. If this takes place, the lowest wear rate is characteristic for the UHMWPE + 10 wt. % PTFE composite (column 3). The surface roughness of wear track of the UHMWPE + 10 wt. % PTFE composite is also the lowest (Fig. 1b). Thus, despite a slight decrease in tensile strength, UHMWPE–PTFE composites show more than 2 times increase in wear resistance under dry sliding friction. The subsequent increase of the PTFE weight fraction above 10 wt. % is not effective from the viewpoint of wear resistance (column 3, 4, 5 – Fig. 1a). Increasing the weight fraction of fillers also decreases the friction coefficient of the composites (Table 1).

To clarify the relationship among the nature of wear (under dry sliding friction) and the structure, wear track surface topography as a function of size and weight fraction of PTFE in UHMWPE-based composites was studied (after the end of testing). Also, the counterface surface and permolecular structure of the UHMWPE–PTFE composites with different size of fillers were examined (Fig. 2, 3).

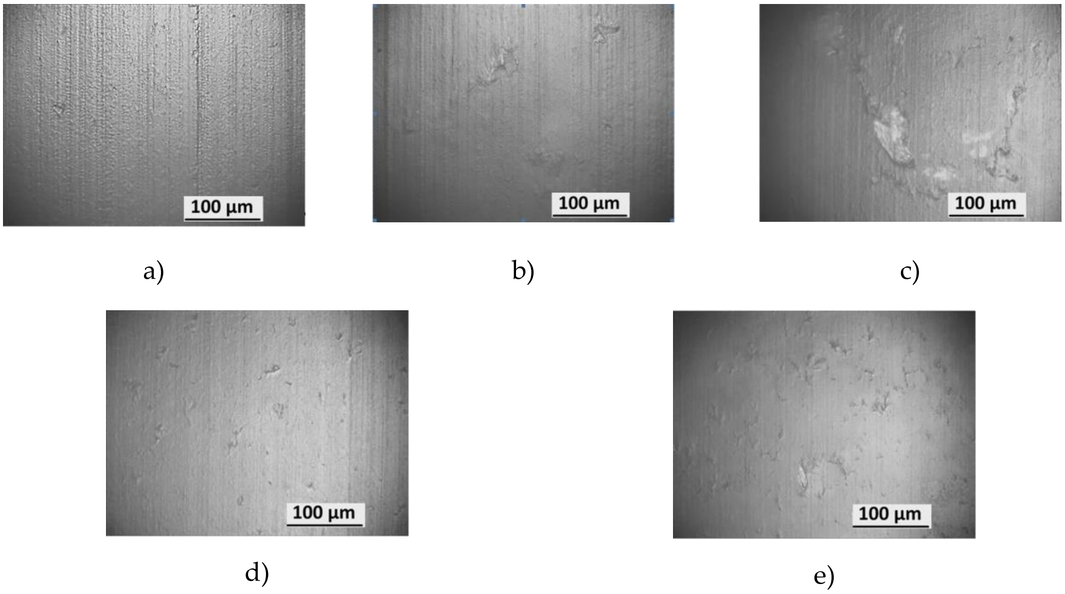
In their dry powder form, PTFE particles are effective lubricants due to their lamellar structures. Such lamellar structures are even able to prevent contact between highly loaded stationary surfaces. In the direction of motion, the lamellae easily shear over each other resulting in low friction. As a result, micro-groves that are the characteristic for the wear track surface of pure UHMWPE and UHMWPE–PTFE composite with large particles, are practically not observed in the composites with smaller particles, indicating that small PTFE particles added to UHMWPE exhibit a good self-lubrication effect under dry sliding friction. In UHMWPE–PTFE composites, the smoothest wear track surface is observed when the weight fraction of the PTFE makes 10 wt. % PTFE (Fig. 2b). This is in a good agreement with the data about the wear rate (Fig. 1a).

As is followed from Fig. 3, the increasing of weight fraction of PTFE gives rise to a gradual change in the permolecular structure pattern: with the increase of PTFE content to 10 wt.%, a refinement of the spherulitic structure elements can be observed (Fig. 3b, 3c). Then the structure becomes less uniform, while the formation of spherulitic structure is suppressed (at 20 wt. % of PTFE – Fig. 3d). It can be seen from the figure that the adhesion between the filler and the matrix is quite satisfactory. The increasing of the PTFE particle size gives rise to the formation of a very non-uniform permolecular structure. In the composites with small PTFE particles, the uniform small-sized spherulitic structure is formed with higher crystallinity compared to that of large polymeric filler particles. On the other hand, the PTFE particles being toughly "pressed" into the UHMWPE matrix play a role of damping inclusions that although increase the wear, do not lead to the decrease of all wear resistance. Therefore, small PTFE particles are preferable when choosing a UHMWPE–PTFE composition for further design of solid nanocomposites on the basis of this polymer.



a) b)

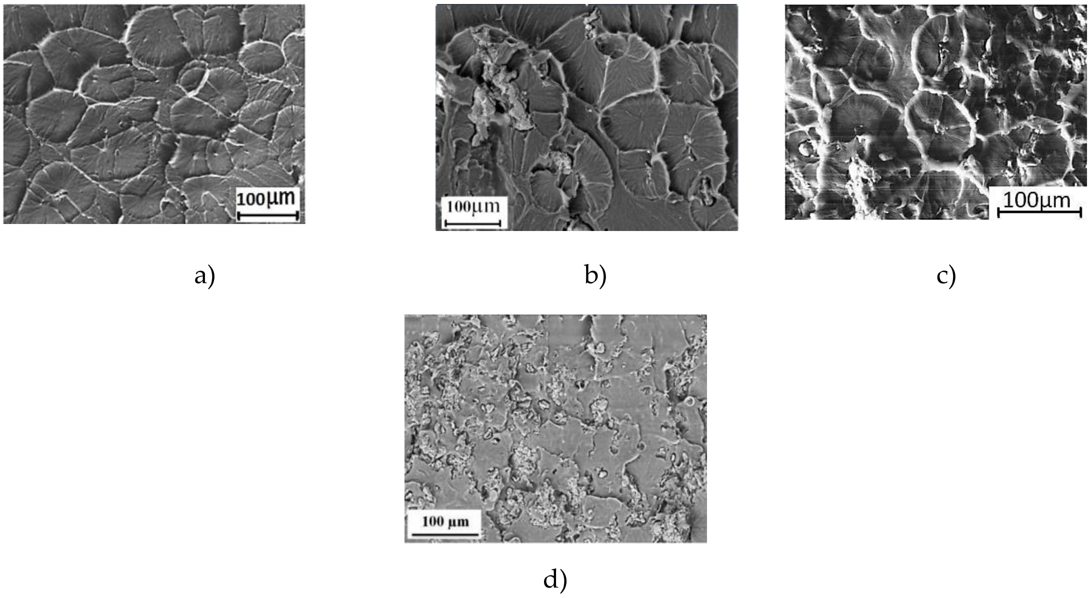
Fig. 1. Wear rate (I) (a) and surface roughness of the wear tracks (Ra) (b) of UHMWPE and UHMWPE–PTFE composites: pure UHMWPE (1) UHMWPE + 5 wt.% PTFE (2) UHMWPE + 10 wt.% PTFE (3) UHMWPE + 20 wt.% PTFE (4) and UHMWPE + 40 wt.% PTFE (5) under dry sliding friction



a) b) c)

d) e)

Fig. 2. Micrographs of wear track surfaces of UHMWPE (a), UHMWPE + 10 wt.% PTFE (large) (b), UHMWPE + 20 wt.% PTFE (large) (c), UHMWPE + 10 wt.% PTFE (small) (d) and UHMWPE + 20 wt.% PTFE (small) (e) under dry sliding friction



a) b) c)

d)

Fig. 3. Micrographs of permolecular structure of UHMWPE (a), UHMWPE + 10 wt.% PTFE (large) (b), UHMWPE + 10 wt.% PTFE (small) (c), UHMWPE + 20 wt.% PTFE (small) (d)

Thus, reducing the size of fillers suiting the size of UHMWPE particles helps to improve the structure and mechanical properties of the composites based on UHMWPE. However, as the melting temperature of PTFE is higher than the processing temperature of composites (330–200 °C), the structure of composites is not very homogeneous.

4 Conclusion

The dispersion of fillers greatly affects the structure and properties of Ultra-high-molecular-weight Polyethylene – Polytetrafluoroethylene composites in two ways: (i) when adding FTFE with small-sized particles (∅ 14 μm), the structure of the composites is more homogeneous, and the mechanical properties deteriorate less than in case of adding filler with larger size (∅ 100–180 μm); (ii) the wear resistance of composites with smaller fillers is 2 times higher than that of composites with larger fillers and 3.5 times higher than that of pure UHMWPE. The best weight fraction of PTFE is 10 wt.%.

Nomenclature: I – wear intensity, mm^2/min; σu – ultimate strength, MPa; ε – elongation, %; Ra – the wear track roughness, μm.

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