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The role of micro- and nanofillers in abrasive wear of composites based on ultra-high molecular weight polyethylene (UHMWPE)

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The abrasive wear of pure UHMWPE as well as one filled with nano- and micro particles (fibers) were investigated. It was found that abrasive wear resistance of microcomposites (containing AlO(OH) and Al₂O₃ microparticles) can grow up by 16-18 times in comparison with pure UHMWPE depending on the strength and size of the fillers as well as abrasive grit. Nanofillers (AlO(OH) and carbon nanofibers (CNF) as well as SiO₂ and Cu nanoparticles) as opposed to micro fillers can improve abrasive wear resistance of UHMWPE in a significantly less degree (up to 50 %). With the use of optical profilometry, infrared spectroscopy, differential scanning calorimetry and scanning electron microscopy the permolecular structure and friction surface topography of the given antifriction material were analyzed. It is shown that abrasive wear resistance of microcomposites is determined by the nature, weight fraction and micro fillers size as well as abrasive grit ratio. Abrasive wear resistance of nanocomposites weakly depends on the type of filler and is defined by the polymeric matrix (permolecular) structure (crystallinity, structural order) and counter-face abrasive grit. The comparative analysis of the wear mechanisms of UHMWPE based micro- and nanocomposites under abrasive wear (fixed abrasive particles) and dry sliding friction is carried out.

Key words: ultra-high molecular weight polyethylene, micro- and nanocomposites, abrasive wear resistance, permolecular structure, crystallinity.

I. INTRODUCTION

Ultra-high molecular weight polyethylene (UHMWPE) and composites on its basis possess good strain-strength performance, low friction coefficient and high wear resistance, chemical resistance to aggressive media, wide temperature range of stability (especially at low temperatures). These properties make it possible to apply UHMWPE in products being resistant to impact loading, friction and cracking, for example, gears, bushings, couplings, etc. By selection of fillers one can purposefully change the functional properties and expand the scope of using UHMWPE in mechanical, chemical, mining engineering and other industrial applications. Polymeric antifrictional composites based on UHMWPE are effective to be used for transport equipment, mining industry including bearings, sliding surfaces, rollers, ore passes, lining and other friction units exposed to intensive abrasive wear.

Recently, the possibilities of modification UHMWPE by adding micro- and nanosized fillers to achieve the required anti-friction properties mostly at dry sliding friction [1-4] were studied. However, the role of micro- and nanosized fillers under abrasive wear of UHMWPE is not deep enough investigated, and requires assessing the influence of the dispersed fillers size on abrasion wear resistance of composites based on ultrahigh molecular weight matrix [5-8].

The aim of the study is to investigate the impact of the filler dimension (micro- and nano-) on abrasive wear of the polymer as well as to find out mechanisms responsible for changing the tribotechnical characteristics of UHMWPE based composites at abrasive wear.

II. EXPERIMENTAL

The UHMWPE powder GUR-2122 (Ticona, Germany) with the molecular weight of $4.0 \cdot 10^6$ and composite materials on its basis reinforced with micro fillers: AlO(OH) (2-5 μm) and Al₂O₃ (50 μm) and Cu (90-100 nm) nanoparticles, SiO₂ (20-30 nm), CNF (60 nm), AlO(OH) (10 nm) nano fibers were used in the study. Specimens were sintered by hot compression at a pressure of 10 MPa and a temperature of 190 °C with subsequent cooling rate of 3-4 °C/min. Mechanical mixing of UHMWPE polymeric binder powder and fillers was conducted in a planetary ball mill MR/0.5×4 during 20 minutes. Preliminary dispersion of fillers was done in the ultrasonic bath. Mechanical tensile tests of specimens with the gauge length of 25×5×2 mm³ were



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performed with the use of electromechanical testing machine Instron-5582. Size of specimens for wear tests made $7 \times 7 \times 10 \text{ mm}^3$.

Abrasive wear test was carried out with the use of wear testing machine MI-2 intended for rubber wear testing. Experimental parameters under dry abrasive wear were: load - 0.15 MPa and disk sliding velocity – 17.0 m/min. Used abrasive grits were R 240, R 400 and R 1000 with the fixed abrasive particles size of 58.5 μm , 35.0 μm , and 18.3 μm , respectively. Volumetric abrasion wear was estimated by specimen weighing with the following calculation of the weight loss in every 5 minutes. Test methodology is consistent with the requirements of ASTM G99 50324 and DIN. Mechanical and tribotechnical characteristics were assessed by averaging data over five specimens.

Wear surfaces of specimens were investigated by optical profilometer New View 6200 (Zygo). Degree of crystallinity was measured with the help of SDT Q600 installation. Infrared spectra were registered by NIKOLET 5700 spectrometer. Structural studies were conducted by scanning electron microscopy for surface of wear tracks as well as fracture surface of notched specimens being mechanically failure after cooling in liquid nitrogen. Scanning electron microscope LEO EVO 50 was employed at acceleration voltage of 20 kV.

III. DISCUSSION OF RESULTS

The tribotechnical and mechanical properties, permolecular structure and wear surface topography of UHMWPE with AlO (OH) and Al₂O₃ microparticles as disperse fillers were researched in the paper. The weight fraction of the fillers were ranged from 10 to 40 wt. %. Table 1 presents physical and mechanical properties of UHMWPE-based micro composites.

Table 1. Physical and mechanical characteristics of UHMWPE based micro composites

Material	Filler weight fraction, wt. %	Density g/cm ³	Shore D hardness	Ultimate strength, σ_u , MPa	Elongation, ϵ , %
UHMWPE	0	0.936	57.9	33.5	380.4
UHMWPE+AlO(OH)	10	0.991	57.7	27.9	483.3
UHMWPE+AlO(OH)	20	1.046	57.9	29.0	443.4
UHMWPE+AlO(OH)	40	1.276	63.0	18.6	260.5
UHMWPE+Al ₂ O ₃	10	0.997	58.6	22.6	389.8
UHMWPE+Al ₂ O ₃	20	1.065	58.6	17.0	199.8
UHMWPE+Al ₂ O ₃	40	1.276	65.8	15.8	40.7

It is seen from the table 1 that the density of the microcomposites is increased with increasing weight fraction of the fillers, and practically does not depend on the particle size in the range of 2-50 μm . Ultimate strength and elongation of the microcomposites are more sensitive to the filler size, noticeably changing with the increase of its volume fraction in the material filled with larger particles (Al₂O₃).

To assess the impact of permolecular structure of the matrix on the abrasive wear intensity of the microcomposites on the basis of structurally modified UHMWPE (in the form of mixtures UHMWPE +10 wt.% HDPE-g-SMA and + UHMWPE 10 wt.% HDPE-g-VTMS) the latter were investigated in the study. These composites were previously investigated in [9-11] under dry sliding friction. The composites based on structurally modified matrix were analyzed being filled with 40 wt.% of the micro filler and manifested maximum wear resistance in contrast with unmodified (pure) matrix [12]. Physical and mechanical properties of the composites based on structurally modified UHMWPE matrix are shown in table 2. It follows from the Table 2 that the microcomposites based on the modified matrix have higher strength and low ductility versus microcomposites based on the pure UHMPE.



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Table 2. Physical and mechanical properties of microcomposites based on structurally modified UHMWPE

Material	Weight fraction of filler, wt. %	Density g/cm ³	Shore D hardness	Ultimate strength σ_u , MPa	Elongation ϵ , %
UHMWPE	0	0.936	57.9	33.5	380.4
UHMWPE +HDPE-g-SMA	0	0.933	59.8	30.2	484.7
UHMWPE +HDPE-g-VTMS	0	0.945	59.8	24.0	493.6
UHMWPE+HDPE-g- SMA+AlO(OH)	40	1.300	62.3	18.3	62.6
UHMWPE+HDPE-g-VTM+AlO(OH)	40	1.291	62.2	19.3	60.5
UHMWPE + HDPE-g- SMA +Al ₂ O ₃	40	1.285	60.8	19.5	17.2
UHMWPE + HDPE-g- VTMS +Al ₂ O ₃	40	1.267	64.4	21.0	9.7

Further the abrasive wear of UHMWPE (pure and modified) and composites based on its basis has been investigated. Fig. 1 illustrates the intensity (I) of abrasive wear at the steady-state wearing stage. It is seen that the abrasive wear resistance of UHMWPE increases by 16-18 times at filling UHMWPE by the micro particles (columns 2 and 3). Al₂O₃ particles of larger size are more efficient in comparison with smaller AlO(OH) ones. Abrasive wear resistance of structurally modified matrix is slightly higher than that of the pure UHMWPE (columns 4 and 5). Composites based on this matrix have the abrasive wear resistance similar to one of composites based on pure UHMWPE. In this case Al₂O₃ microparticles also minimize the wear of the composites (columns 8 and 9). Surface roughness measurements (R_a) of specimens at the steady-state stage of abrasive wear are given in Fig. 2. Dependence of R_a at the steady-state stage of abrasive wear of UHMWPE and microcomposites on its basis is similar to the change of wear resistance in the case of adding micron size particles into the polymer. Surface roughness of the wear surface is the lowest for the specimens filled with Al₂O₃ particles (columns 3 and 9).

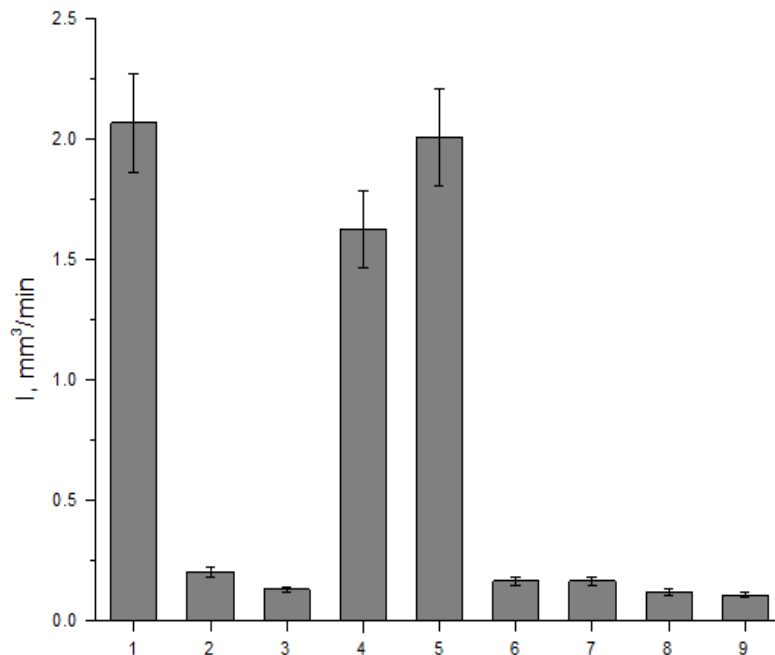


Fig. 1. Wear intensity (I) of pure UHMWPE (1), and the following composites: UHMWPE + 40% AlO(OH) (2) and 40% Al₂O₃ (3), UHMWPE + 10% HDPE-g-SMA (4) and UHMWPE + 10% HDPE-g-VTMS (5), UHMWPE + 10% HDPE-g-SMA + 40% AlO(OH) (6), UHMWPE + 10% HDPE-g-VTMS + 40% AlO(OH) (7), UHMWPE + 10% HDPE-g-SMA + 40% Al₂O₃ (8), UHMWPE + 10% HDPE-g-VTMS + 40% Al₂O₃ (9). R 240.

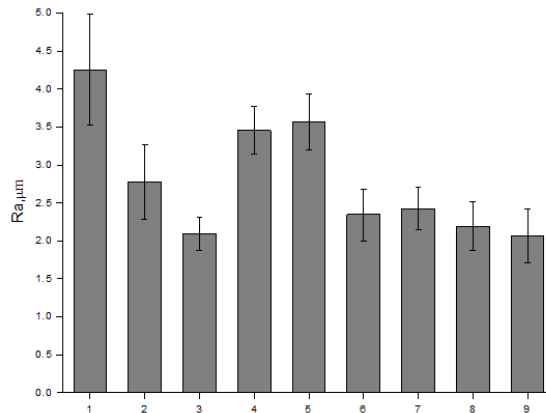


Fig. 2. Dependence of wear surface roughness (R_a) in pure UHMWPE (1) and composites on its basis: UHMWPE + 40% AlO(OH) (2), UHMWPE + 40% Al₂O₃ (3), UHMWPE+10%HDPE-g-SMA (4), UHMWPE +10%HDPE-g-VTMS (5), composites UHMWPE +10% HDPE-g-SMA+40%AlO(OH) (6), UHMWPE +10% HDPE-g-VTMS+40% AlO(OH) (7), UHMWPE +10% HDPE-g-SMA+40% Al₂O₃ (8), UHMWPE +10% HDPE-g-VTMS+40% Al₂O₃ (9). Abrasive grit: R 240.

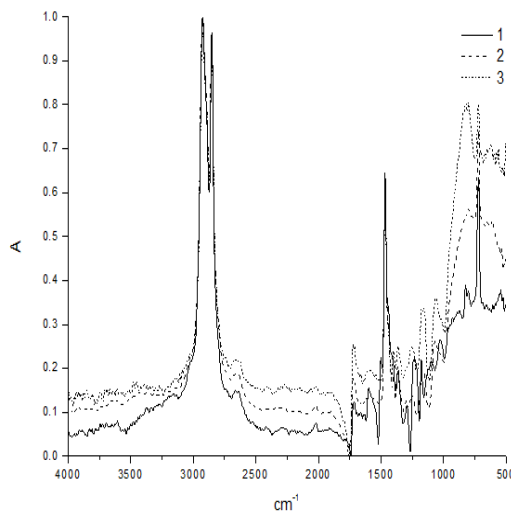


Fig. 3. IR-spectra of pure UHMWPE (1) and the microcomposites: UHMWPE+40% Al₂O₃ (2), UHMWPE +10% HDPE-g-SMA+40% Al₂O₃ (3).

To clarify the mechanism of abrasive wear of UHMWPE based micro composites the per molecular structure and morphology of wear surfaces for all composites under study were investigated. Differential scanning calorimetry has revealed that the crystallinity of these polymeric materials depends on the filler size (Table 3). In doing so, one can not reveal chemical bonds to form between the filler and the matrix (Fig. 3), and IR-spectra of microcomposites are similar to that of pure as well as structurally modified UHMWPE.

It is found that the morphology of the abrasion wear surface of UHMWPE-based specimens and microcomposites on its basis is determined by the size of the filler particles as well as abrasive grit. In Fig. 4 and Fig. 5 the relevant images and distribution of chemical elements such as C, O and Al (gained with the use of the Electron Back Scattering Diffraction mode) on the surface of the composites with the fillers size of 2 and 50 μm are given. In composites with smaller filler particles (Fig. 4) fixed abrasive particles cut the matrix; in doing so within wear scratches the presence of the carbon is mostly revealed (Fig. 4). In composites with larger particles the filler Al₂O₃ interacts with abrasive particles “protecting” the matrix from intensive cutting (Fig. 5). This is confirmed by the quantitative analysis of C, O and Al distribution in structural elements of a wear surface. For the sake of illustrations the element composition within the scratches of wear surfaces of composites with various sizes of fillers at the steady-state stage of abrasive wear (R 240) are given in Table 4.

Table 3. Crystallinity (γ ,%) of UHMWPE based composites

UHMWPE	UHMWPE +40 wt. % AlO(OH) (2-5 μ m)	UHMWPE+40 wt. % Al ₂ O ₃ (50 μ m)	UHMWPE+10% HDPE-g-SMA +40wt.% AlO(OH)	UHMWPE+10% HDPE-g-SMA+40wt.% Al ₂ O ₃
56.6	26.5	21.0	39.0	34.0

Table 4. Distribution of elements in scratches on the wear surface of UHMWPE-based composites

Elyment, wt. %	UHMWPE+40 wt. % AlO(OH) (2-5 μ m)	UHMWPE+40 wt. % Al ₂ O ₃ (50 μ m)	UHMWPE+10 wt.% HDPE-g-SMA +40% AlO(OH)	UHMWPE+10 wt.% HDPE-g-SMA +40% Al ₂ O ₃
C	99.14	33.46	78.4	24.28
O	0.37	21.52	12.78	37.83
Al	0.49	45.02	8.2	37.9

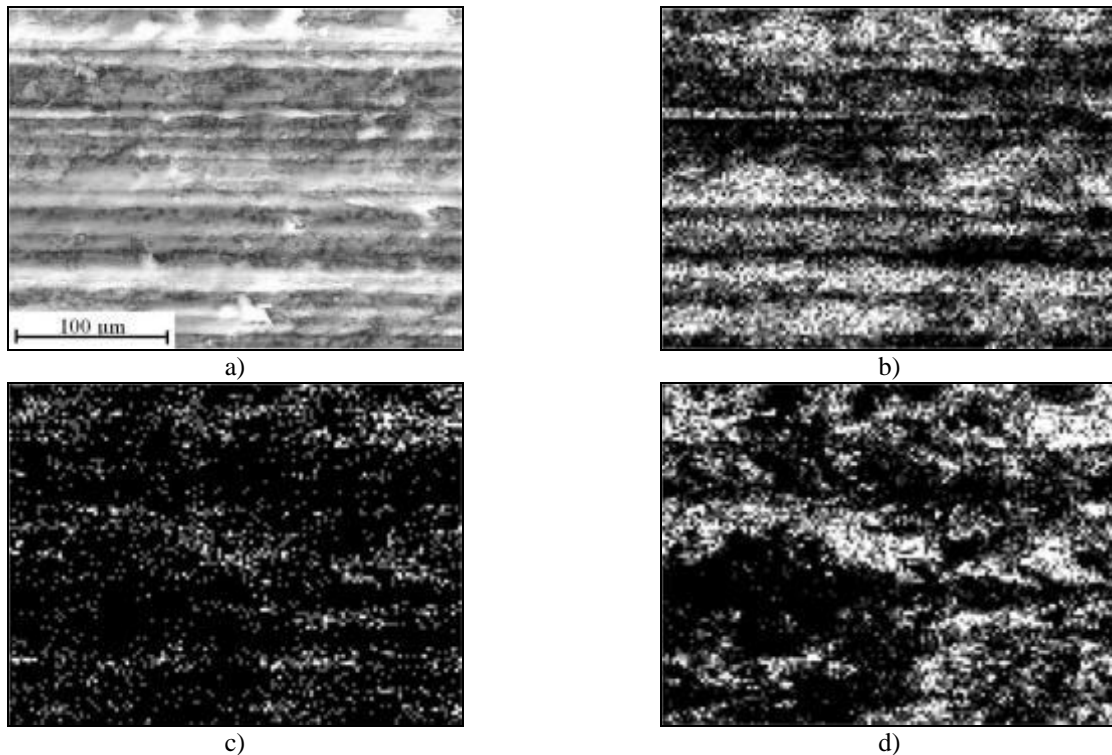
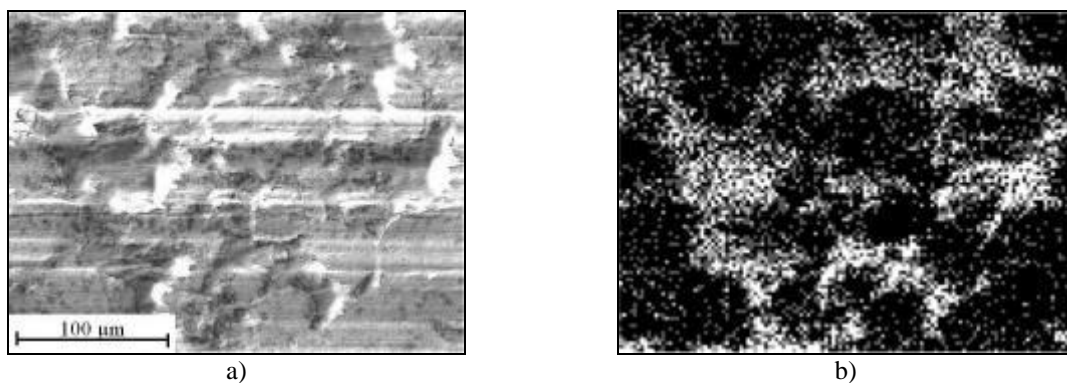


Fig. 4. SEM micrographs of wear surfaces in the direct (a) and inverse scattered electrons (EBSD mode) of the composite UHMWPE+10% HDPE-g-SMA+40%AlO(OH) (b-d). Distribution of C (b), O (c) and Al (d) on a wear surface. R 240.



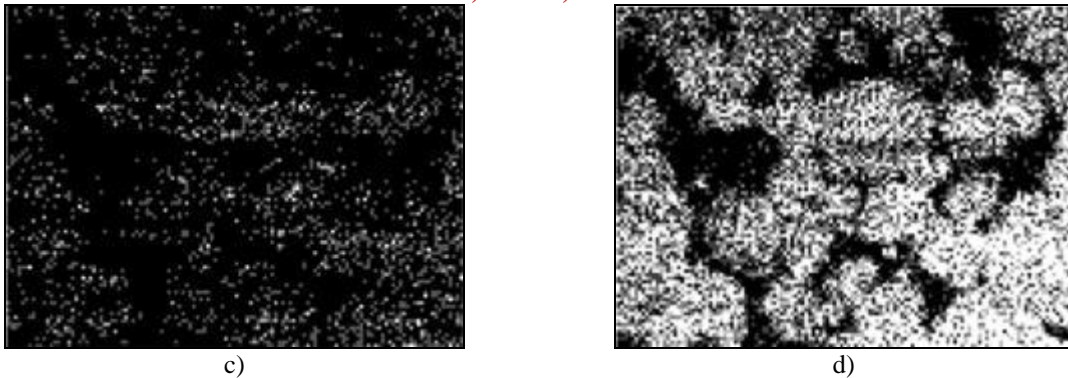


Fig. 5. SEM micrographs of wear surfaces in the direct (a) and inverse scattered electrons (EBSD mode) in the composite UHMWPE +10% HDPE-g-SMA+40% Al₂O₃ (b-d). Distribution of C (b), O (c) and Al (d) on the wear surface. R 240.

It is seen from Table 4 that in surface scratches of the micro composite filled with large particles Al₂O₃. the C and Al elements are prevailed.

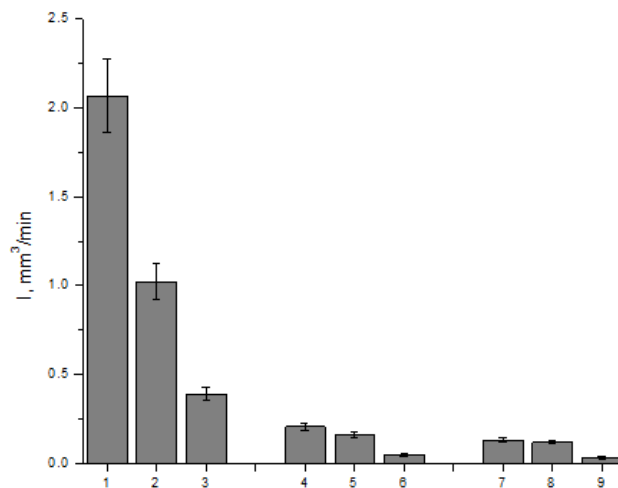


Fig. 6. Dependence of wear intensity (I) for pure UHMWPE (1-3) and composites: UHMWPE + 40% AlO(OH) (4-6) and 40% Al₂O₃ (7-9) on abrasive grit: 1,4,7 – R 240; 2,5,8 – R 400; 3,6,9 – R 1000.

Thus, obtained dependences of physical-mechanical properties and wear resistance under the abrasive wear of UHMWPE filled with micro particles with different weight fraction and size indicate that there is an optimum composition and ratio between filler size and abrasive grit that provide the highest abrasive wear resistance of UHMWPE based microcomposites. Abrasive wear resistance for the above mentioned composites at use of various abrasive grit (R 240, R 400, R 1000) was investigated in the study. It was revealed that wear intensity of composites falls down with the fixed abrasive grain size reduction (Fig. 6). In doing so, the dependence of the abrasive wear intensity on abrasive grain size is similar to dependence of friction surface roughness on the size of abrasive particles. Comparable dispersion of the fillers Al₂O₃ and abrasive powders (R 240 and R 400) show the same roughness of the wear surface for the UHMWPE based micro composites. At use of small size of fixed abrasive particles (R 1000) wear intensity and surface roughness of composite specimens are nearly equal to one of the pure UHMWPE and correspond to the dry sliding friction mode [10].

Mechanical and tribotechnical properties as well as per molecular structure and friction surfaces of UHMWPE specimens with nano fillers such as nano particles Cu, SiO₂ and CNF, AlO(OH) nano fibers have been also studied. The optimum weight fraction of nano fillers under condition of the dry sliding friction in the amount of 0.5 wt. % was determined by the authors in [9-11]. Table 5 presents the mechanical properties of nanocomposites based on pure and structurally modified UHMWPE by various nano fillers.



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Table 5. Physical and mechanical properties of nanocomposites based on pure and structurally modified UHMWPE

Material	$\chi, \%$	Density g/cm^3	Shore <i>D</i> hardness,	Ultimate strength, σ_u, MPa	Elongation $\epsilon, \%$
UHMWPE	56.5	0.936	57.9±0.6	33.5±1.8	380.4±23.6
UHMWPE+SiO ₂	53.3	0.933	58.9±0.3	32.6±1.5	477.4±38.6
UHMWPE+ AIO(OH)	55.8	0.921	59.0±0.4	27.3±1.9	370.7±53.8
UHMWPE+Cu	53.5	0.947	58.3±0.2	22.1±3.1	467.3±25.5
UHMWPE+CNF	50.1	0.928	58.8±0.4	22.6±2.7	399.4±32.9
UHMWPE+HDPE-g-SMA	58.6	0.933	59.9±0.5	28.2±3.6	484.8±30.3
UHMWPE +HDPE-g-SMA +SiO ₂	58.0	0.935	57.6±1.0	31.6±1.5	497.5±20.2
UHMWPE+HDPE-g-SMA+ AIO(OH)	56.0	0.939	57.4±0.8	31.3±2.3	476.3±35.8
UHMWPE +HDPE-g-SMA+Cu	55.5	0.946	59.6±1.0	27.9±1.7	497.8±20.9
UHMWPE +HDPE-g-SMA+CNF	54.4	0.935	56.9±0.7	31.5±1.2	466.3±25.8
UHMWPE+HDPE-g-VTMS	53.5	0.945	59.8±0.8	24.0±2.8	493.6±36.6
UHMWPE +HDPE-g-VTMS+SiO ₂	52.5	0.934	56.8±1.0	31.3±2.9	442.1±47.2
UHMWPE+HDPE-g-VTMS+ AIO(OH)	51.0	0.945	57.8±0.5	29.4±4.2	430.3±35.9
UHMWPE +HDPE-g-VTMS+Cu	50.3	0.943	57.8±1.3	26.4±3.2	451.7.±46.3
UHMWPE+HDPE-g-VTMS+CNF	50.9	0.937	58.4±0.8	22.7±1.8	374.3±29.1

As one can see from the table 5 the density of nanocomposites varies slightly when adding nanofillers for the both cases: pure UHMWPE and structurally modified one (with adding graft HDPE). The observed variations may be associated with some heterogeneity in distribution of nanofiller particles, but it is not the consequence of pores presence. It is shown in [10] that the porosity of nanocomposites based on UHMWPE does not change noticeably when adding nanoparticles and nanofibers within the range of 0.1 -0.5 wt. %. It should be noted that at the use of the modification methods (adding of two kinds of grafted copolymers as well as nanofillers), changing the strength and ductility characteristics is the natural way. In general, it can say that as a result of the structural modification the ultimate strength of UHMWPE based composites filled by nanoparticles and nanofibers decreases, while plasticity, in most cases, increases. A more significant increase of plasticity is observed in structurally modified nanocomposites that is associated with adding of the grafted high density polyethylene.

Analysis of the kinetic curves of abrasive wear of nanocomposites based on pure and structurally modified UHMPE testified that abrasive wear of nanocomposites depends, above all, on the size of fixed abrasive particles. This is clearly illustrated in Fig. 7, where the diagram of the abrasive wear intensity (I , mm^3/min) of nanocomposites is given for three sizes of abrasive grain ($R 240$, $R 400$, $R 1000$). It is seen that the weight loss under abrasive wear of the specimen is pronouncedly reduced when UHMWPE is filled by nanoparticles and nanofibers only under testing using the largest of the above named abrasives, namely $R 240$. When reducing the size of fixed abrasive particles the wear resistance of UHMWPE and nanocomposites on its basis is increased but the difference in their values for all investigated specimens is noticeable less. At the abrasive grit of $R 1000$ wear intensity is almost identical for all composites $I \sim 0.4 \text{ mm}^3/\text{min}$. In doing so, nanoparticles and nanofibers in a similar way affect the wear resistance.

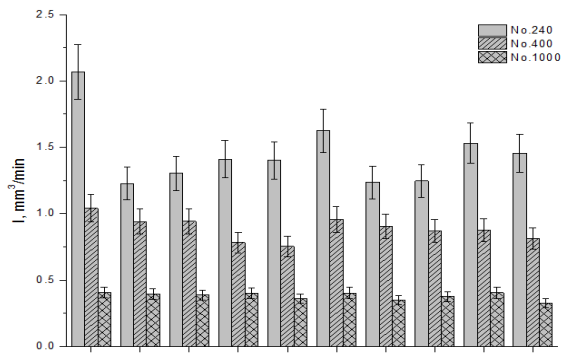


Fig. 7. Intensity of abrasive wear (I) of pure UHMWPE (1), nanocomposites UHMWPE +0.5 wt. % SiO₂ (2), UHMWPE+0.5 wt. %AlO(OH) (3), UHMWPE+0.5 wt. %Cu (4), UHMWPE+0.5 wt. %CNF (5), UHMWPE+10 wt. %HDPE-g-SMA (6), UHMWPE+10 wt. %HDPE-g-SMA+0.5 wt. % AlO(OH) (7), UHMWPE+10 wt. % HDPE-g-SMA+0.5 wt. %SiO₂ (8), UHMWPE+10 wt. % HDPE-g- SMA+0.5 wt. %Cu (9), UHMWPE +10 wt. % HDPE-g-SMA+0.5 wt. %CNF (10). R 240, 400, 1000.

The effect observed may have the following explanation. In the process of abrasion the wear products (debris) fill the space between fixed particles of the abrasive paper. The less is abrasive grain size, the faster this process develops. As a result, the abrasive paperability to wear (cut) specimen surface is reduced, and the difference in per molecular structure formed practically exerts no effect on the value of volumetric wear. However, based on the analysis of the data shown in Fig. 7 at wearing by the largest abrasive grit R 240 it might be postulated that: 1) filling of UHMPE by nanoparticles can reduce the intensity of abrasive wearing up to 1.5 times; 2) the addition of only grafted HDPE can provide minimum (about 20%) improvement of abrasive wear resistance compared to pure UHMWPE; 3) abrasive wear resistance of nanocomposites based on UHMWPE with added grafted HDPE are equal to one of composites based on pure UHMWPE. Thus the filling of UHMWPE by nanoparticles can exert a positive effect from a point of view of greater resistance to abrasive wear that practically does not depend on the fact of structural modifications introduced by adding of the grafted HDPE. Further the morphology and wear track roughness for all studied nanocomposites were investigated under abrasive wearing. Diagrams to show the roughness (R_a , μm) of the wear surface of nanocomposites at use of fixed abrasives particles of R 240, 400 and 1000 are demonstrated in Fig. 8. These data indicate that the dependence of the roughness on the fixed abrasive particles size completely correlates with similar dependence on abrasive wear intensity. For abrasive grain size R 1000 regardless of the type of nanofiller the roughness of the friction surface for all composites is minimum and almost identical: $R_a = 0.7-0.8 \mu\text{m}$. It also confirms the assumption that at low abrasive grit during the tests the specimen surface interacts with the abrasive through a layer of solid polymer "lubrication" that partially diminish cutting action of the former. As a result of the roughness value is less than characteristic size of abrasive particles more than by 20 times.

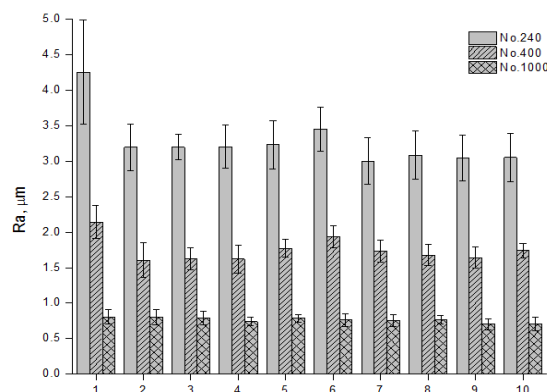


Fig. 8. Dependence of roughness of abrasive wear surface (R_a) for pure UHMWPE (1), nanocomposites UHMWPE +0.5 wt. % SiO₂ (2), UHMWPE+0.5 wt. %AlO(OH) (3), UHMWPE+0.5 wt. %Cu (4), UHMWPE+0.5 wt. %CNF (5), UHMWPE+10 wt. %HDPE-g-SMA (6), UHMWPE+10 wt. %HDPE-g-SMA+0.5 wt. % AlO(OH) (7), UHMWPE+10 wt. % HDPE-g-SMA+0.5 wt. %SiO₂ (8), UHMWPE+10 wt. % HDPE-g- SMA+0.5 wt. %Cu (9), UHMWPE +10 wt. % HDPE-g-SMA+0.5 wt. %CNF (10). R 240, 400, 1000.

SEM-micrographs of abrasive wear surfaces are presented in Fig. 9. The morphology of the abrasive wear surface of pure UHMWPE, nanocomposites and their mixtures with HDPE-g-SMA is similar, and is determined mainly by the size of fixed abrasive particles (Fig. 9, a-d and e-h). It should be noticed that the structural modification of polymer matrix by adding grafted HDPE (HDPE-g-SMA and HDPE-g-VTMS) does not change significantly the surface morphology at abrasive wear (Fig. 9, c), though it evidently contains signs of backtransfer of wear products onto the specimen friction surface. The similar effect is peculiar for a friction surface of the pure UHMWPE specimen (Fig. 9, a). For nanocomposite specimens having slightly higher wear resistance the morphology of friction track is characterized mainly by cutting scratches oriented towards the direction of counter face sliding (Fig. 9, b, d). In the case of smaller abrasive particles the friction surface morphology is similar (Fig. 9, e-h).

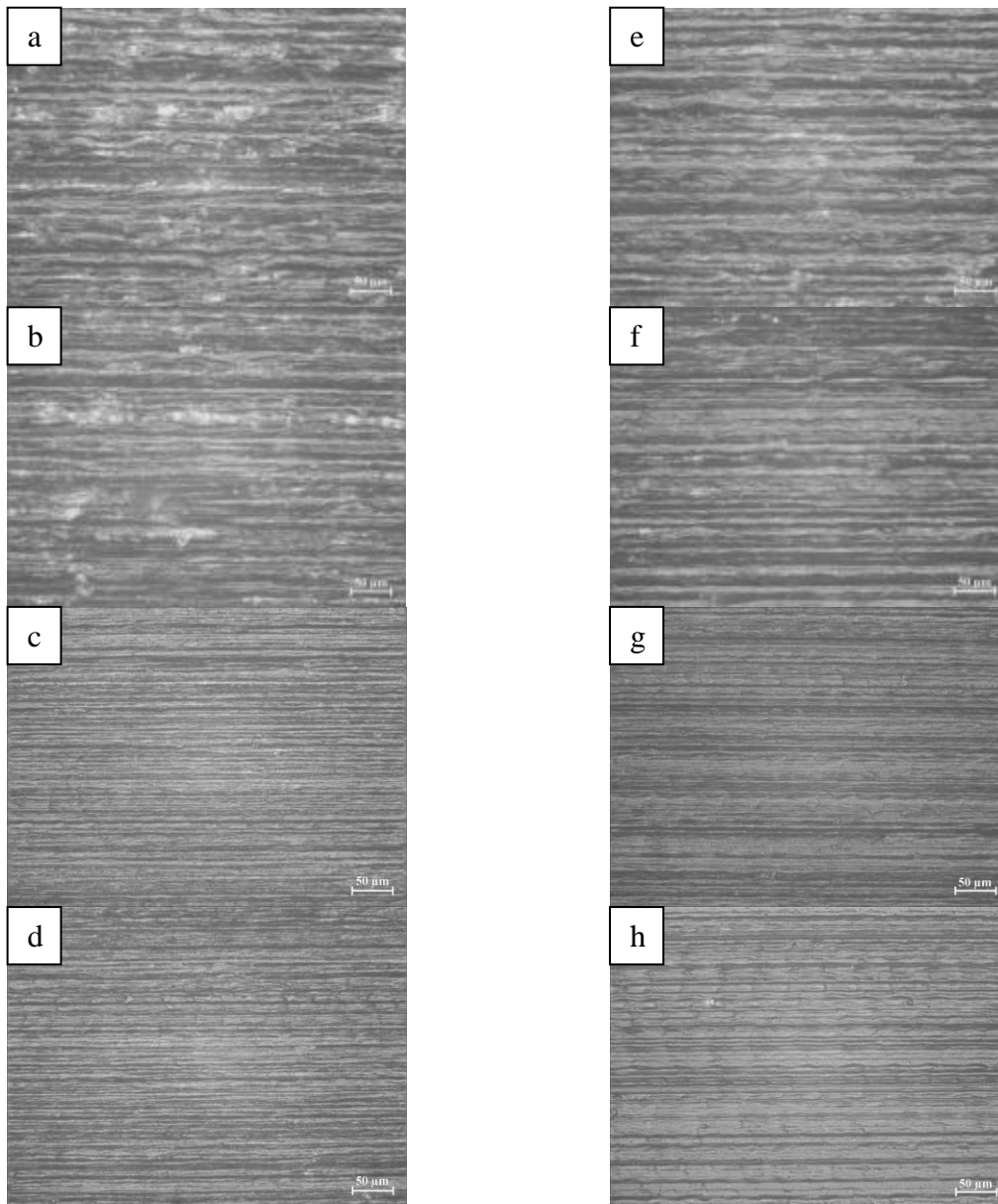


Fig. 9. Micrographs of abrasive wear surfaces for pure UHMWPE (a,e) and nanocomposites: UHMWPE+0.5 wt. % AlO(OH) (b,f), UHMWPE+10 wt. % HDPE-g-SMA (c,g) and nanocomposites based on UHMWPE+10 wt. % HDPE-g-SMA+0.5 wt. % AlO(OH) (d,h) at different abrasive grit: R 240 (a-d) u R 1000 (e-h).

However, the wear resistance of practically all types of studied specimens (in contrast with microcomposites) is changed within small limits that is to our mind is related to the formation of the same type of per molecular structure (spherulitic one) (Fig. 10) at the crystallization of UHMWPE and all examined UHMWPE based nanocomposites. Thus, it becomes clear that adding of the grafted copolymer exerts minimal influence and slightly changes wear resistance of the specimen.

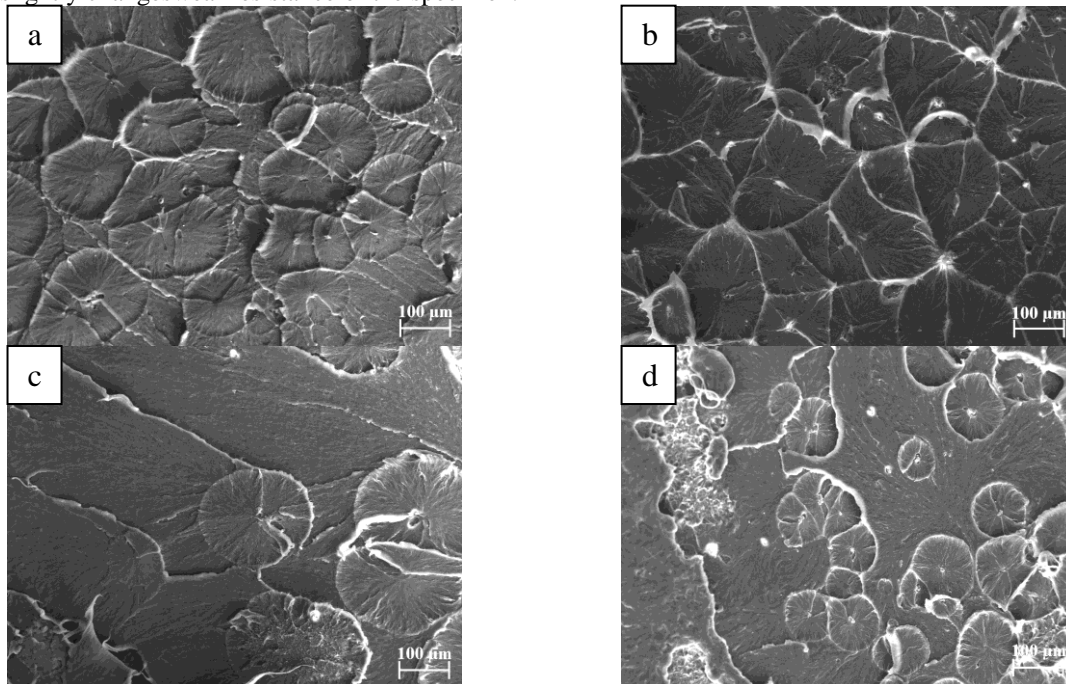


Fig. 10. SEM images of per molecular structure of UHMWPE (a) and nanocomposites: UHMWPE+0.5 wt. % AlO(OH) (b), UHMWPE+10 wt. % HDPE-g-SMA (c) and UHMWPE+10 wt. % HDPE-g-SMA+0.5 wt. % AlO(OH) (d).

The analysis performed by method of differential scanning calorimetry has revealed that at filling UHMWPE by nanoparticles and nanofibers the degree of crystallinity is reduced down to 6.3% (table 5). It is also seen that there is no formation of chemical bonds between nanofillers and polymeric matrix [11]. Moreover, according to data of IR-spectroscopy one cannot observe nucleation of new chemical bonds into UHMWPE being structurally modified by adding grafted polyethylene [9,10].

Thus, the lack of formation of new chemical bonds, a slight modification in degree of crystallinity, the absence of porosity, similarity in the friction surface topography, a weak dependence of abrasive wear resistance of nano-filler type (in contrast with microcomposites) suggests that the nanofillers affect the abrasive wear predominantly through the formation of per molecular structures and its subsequent destruction under cutting by fixed abrasive particles. As a result, nanofillers, partially changing the per molecular structure under hot compression can affect resistance to abrasive wear.

The comparative analysis of the role of nanofillers to ensure the wear resistance of UHMWPE based nanocomposites under abrasive wear and at dry sliding friction was carried out. Surface morphology and wear intensity of UHMWPE as well as nanocomposites on its basis at dry sliding friction (without abrasive) were investigated in [11] where it was shown that wear resistance of UHMWPE filled with nanoparticles and nanofibers is increased by 4-6 times. In so doing wear intensity of the nanocomposites correlates with roughness (R_a) of wear track surface at the steady-state stage. For the sake of comparison the values of wear track surface roughness of pure UHMWPE and nanocomposites are given in Fig. 11.



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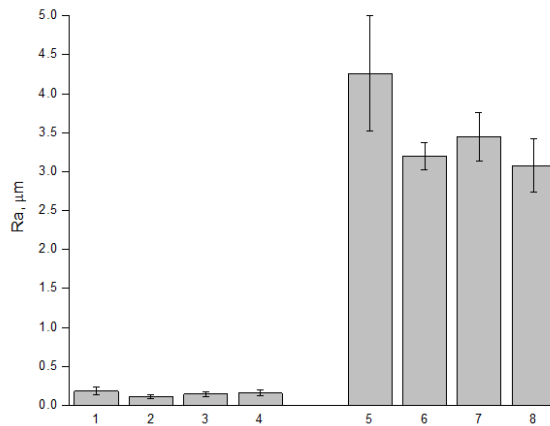


Fig. 11. Roughness of a wear surface (R_a) for UHMWPE based nanocomposites without abrasive (1-4) and with abrasive grit R 240 (5-8): 1,5 - pure UHMWPE; 2,6 - UHMWPE+0.5 wt. % AlO(OH); 3,7 - UHMWPE+10 wt. % HDPE-g-SMA; 4,8 - UHMWPE+10 wt. % HDPE-g-SMA+0.5 wt. % AlO(OH).

It is seen that the role of nanofillers in wear resistance of UHMWPE based composites at dry sliding friction and under abrasive wear is fundamentally different. In the first case solid particles of nanofiller under the friction tend to "oscillate" in a destructured surface layer of the polymer matrix, and serving as a solid lubricant provide higher wear resistance of composite. In the second case, the polymeric matrix is cut by fixed abrasive particles without interaction with nanofiller (due to the different sizes of nanoparticles and abrasive grains). Therefore wear resistance of UHMWPE based nanocomposites under abrasive wear is determined by the size of abrasive grains and strength of the per molecular structure formed (degree of crystallinity, shape and size of spherulites).

IV. CONCLUSION

Study of physical, mechanical and tribotechnical characteristics as well as structure of composites based on UHMWPE modified by adding fillers of various sizes have shown the following:

- abrasive wear resistance of UHMWPE based microcomposites is increased by 16-18 times at filling UHMWPE with micro particles AlO(OH) and Al₂O₃;
- The key role in abrasive wear resistance of UHMWPE-based microcomposites plays the ratio between sizes of micro filler particle and abrasive grains. Comparable size of micro fillers and fixed abrasive particles show the maximum wear resistance of UHMWPE-based microcomposites.
- abrasive wear resistance of UHMWPE based nanocomposites is slightly increased in comparison with the wear resistance of the same composites at dry sliding friction;
- the positive role of nanofillers as a solid lubricant under abrasive wear to enhance the wear resistance of polymeric composites is restrained by dimension disproportion of nano fillers and abrasive grain grit;
- Structural modification of the pure UHMWPE matrix by adding grafted high density polyethylene does not significantly affect the abrasive wear resistance of composites due to formation of the equivalent type of per molecular structure.

SYMBOLS

σ_u – ultimate strength, MPa; D – Shore hardness; ε – elongation at failure, %; A – optical density, I – wear intensity, mm³/min; χ – crystallinity, %; R_a – roughness of wear track, μm .

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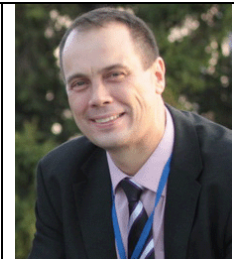
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