Polymer composite materials based on ultra-high molecular weight polyethylene and modified montmorillonite

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Abstract. The research paper presents the results of studies of the influence of organically modified montmorillonite (OMMT), grade 101/102, on the mechanical and tribological characteristics of the ultra-high molecular weight polyethylene (UHMWPE). The filler was introduced into the polymer matrix in 0.5, 1 and 2 wt. % content. Samples for testing were obtained by hot pressing. It was found that adding 0.5 wt. % OMMT in ultra-high molecular weight polyethylene leads to improving the tensile strength by 23 % and elasticity modulus by 14 % relative to the unfilled polymer. It has been shown that the mass wear rate of the material under dry sliding friction was reduced by 1.5 times and linear wear by 2.8 times compared with initial ultra-high molecular weight polyethylene.

1. Introduction
As it has currently been observed nowadays, use of polymer composite materials (PCM) has become widespread including manufacturing of vehicle parts and technical equipment, due to the need to replace traditional expensive materials [1]. One of the promising polymers for PCM is ultra-high molecular polyethylene with its unique properties. Ultra-high molecular polyethylene (UHMWPE) has low friction coefficient high strength, resistance to cracking, that makes it possible to be used as base polymer to create PCM for operations in extreme conditions, including space systems [2-4].

The use of layered silicates as fillers of UHMWPE leads to a significant increase in the Young's module of elasticity, strength, flexibility, hardness and PCM barrier properties even with a small degree of filling [5]. One of the most commonly used layered silicates is montmorillonite (MMT), obtained from bentonite clays [6].

Research paper [7] discusses that the use of MMT with good dispersion in the polymer matrix provides significant improvement in the complex properties of the resulting composites. Nevertheless, the process of combining the components of the composite remains a complex technological task due to the organophobic nature of montmorillonite [8, 9]. In order to ensure the dispersion of clay and the intercalation of polymer macromolecules into the space between silicate plates, MMT powders are treated with surfactants as quaternary ammonium salts (QAS) [10]. Such organomodified clay (organoclay) is well dispersed in the polymer matrix and improves the interaction with polymer macromolecules in comparison with ordinary clay [11].

The purpose of this work is to study the effect of organomodified montmorillonite on the mechanical and tribological properties of UHMWPE.
2. Models and Methods
For the research we used UHMWPE GUR 4022 (Celanese Corporation, China) with molecular weight of $5.3 \times 10^6$ Da, average particle size of 145 μm and density of 0.93 g/cm³. OMMT brand Monamet 101/102 (Metaclay, Russia) was used as a filler; the surface of the particles was modified with QAS mixture.
Polymer composite materials were prepared by hot pressing under 10 MPa and 175-180 °C temperature for 20 min.
Physical and mechanical properties of PCM have been studied on a tensile machine Autograph Shumadzu AGS-J (Japan) using ASTM D3039/D3039M – 14. The moving speed of the grippers was 50 mm/min.
The tribotechnical characteristics were determined on a CETR UMT-3 (United States) multipurpose high-temperature tribometer. Tests were performed in accordance with the “finger–disk” friction mode. A cylindrical PCM sample with a 10-mm diameter was exposed to a specific load of 150 Н at a sliding rate of 0.5 m/s.
Supramolecular structure of PCM was characterized by scanning electron microscopy (SEM) with JEOL JSM-7800FX (Japan).

3. Results and Discussion
Figure 1 represents the results of studies of the physical and mechanical characteristics of PCM based on UHMWPE and organomodified montmorillonite (OMMT).
Analysis of the physical and mechanical studies showed that the introduction of OMMT in UHMWPE leads to increase both tensile strength by 23% and modulus of tensile elasticity by 14% compared with the original polymer matrix. In this case, the relative extension at 0.5 wt. % and 1 wt. % filling PCM remains at the level of the original UHMWPE. The observed results can be explained by the enhancement effect of the polymer matrix due to the interaction with the modified surface of the organic clay.

As it can be seen from Figure 2, the introduction of organoclay into the polymer matrix leads to decrease in the rate of mass wear rate by 1.5 times, and linear wear - by 2.8 times compared with the original UHMWPE. At the same time, increase in strength and wear resistance is achieved even with a small degree of filling, namely, at 0.5 wt. % content OMMT. In addition, structural studies have shown that the use of organoclays as filler of UHMWPE contributes to uniform distribution of its particles in the volume of the polymer matrix (Figure 3), which in turn does not require additional process steps in the PCM processing.

Figure 3 shows micrographs of supramolecular UHMWPE and composites based on it.

As it can be seen from Figure 3, the supramolecular structure of the original UHMWPE is characterized as lamellar. With the introduction of 0.5 wt. % of organoclay in UHMWPE, the transformation of its supramolecular structure from lamellar to spherulitic is observed with the OMMT particles being crystallization centers. Increase in the concentration of OMMT in UHMWPE leads to decrease in the size of structural elements, suppression of the formation of spherulitic structures (1 and 2 wt.%), and the formation of areas with loose structure [12, 13].
Figure 3. Microphotographs of supramolecular structure at x300:
  a) initial UHMWPE; b) UHMWPE+0.5 wt. %; 
c) UHMWPE+1 wt. %; d) UHMWPE+2 wt. %.

This nature of the change in the structure of the PCM is consistent with the results of the research on the mechanical and tribological characteristics of PCM: at these concentrations of filler, a slight decrease in mechanical parameters was noted.

4. Conclusion
On the basis of the conducted studies, it was shown that the use of organomodified montmorillonite as filler for UHMWPE contributes to increase in the strength by 23%, wear resistance by 1.5 times while maintaining stable and low values of the materials' friction coefficient. Structural studies have shown that the introduction of organoclay into polyethylene contributes to the formation of the spherulite structure of composites, where the filler particles act as crystallization centers. Materials with such structure are characterized by increased strength and wear resistance compared with the initial polymer.

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