THE PHYSICAL AND AN ENGINEERING APPROACH TO THE
DEVELOPMENT OF NEW WEAR-RESISTANT POLYMER COMPOSITES
BASED ON POLYTETRAFLUOROETHYLENE (PTFE) FILLED WITH
DISPERSE SYNTHETIC AND NATURAL COMPOUNDS

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Abstract
Polyytetrafluoroethylene (PTFE) is the material which is a choice for a variety of applications. For PTFE there is a possibility of effective purposeful regulation of operational characteristics by filling and structural modifying by means of mechanical activation. The use of nanofillers has proven to be an effective means for reducing the wear of PTFE without introducing detrimental effects on its other beneficial properties; microfillers often increase abrasion and friction, and reduce mechanical integrity and chemical resistance. The mechanism of wear is discussed on the basis of the results of experiments and electron microscopy of the friction surfaces.

Key words: polytetrafluoroethylene, polymer composite materials, modification, supramolecular structure, mechanical activation, filling

INTRODUCTION – PROPERTIES OF POLYTETRAFLUOROETHYLENE

Wide application of polymer composite materials (PCM) based on polytetrafluoroethylene (PTFE) in the nodes of friction and compaction of all kinds of machines and equipment is due to specific features of its molecular structure and supramolecular structure (SMS), which provide for the implementation of unique combination of indices of deformation strength, tribotechnical, anticorrosive, thermo–physical and other operational characteristics [1].

PTFE is one of the amorphous-crystalline polymers with crystallites melting point 600 K and vitrification temperature of the amorphous phase 153 K; it has a high degree of crystallinity; the large number of crystallites is observed even after quenching (rapid cooling starting from melting point) [2]. The material has abnormally low friction coefficient (0,01–0,04), but it is disposed to cold flow which can be lowered by fillers introduction. These include high tensile creep loading that appears under 3 MPa of tensile loading at normal temperatures: high thermal-expansion coefficient at normal temperatures that changes abnormally at temperature in the range of structural phase transitions (temperature range from 280 to 310 K); low thermal conductivity (10-50 times less than in metals); low wear resistance under dry friction conditions especially at high sliding velocity [3]. The efficiency of using PTFE-composites reinforced by carbon fibers depends to many factors, which influence the significant increase of physicomechanical characteristics.

The combination of the theoretical research of structural and phase transformations occurring in filling the PTFE-matrix of a composite with fillers and experimental research is the way allowing to formulate a scientifically based approach to the forecasting and targeted regulation of PTFE-composites properties [9].

METHODS OF PTFE-MATRIX MODIFICATION

The various advanced technological methods allow to obtain composite materials and products with the required performance properties. They are the synthesis of polymer matrices of different composition and structure [6, 7]; composition of polymer and oligomer mixture with different levels of interaction [8]; modification of matrices of various origins by aimed restructuring and structural interaction energy impact [9]; matrix modifying by additions of activators of different size, shape and properties [3–9]; formation of nanopfase matrices with significantly different characteristics [4, 5].

Structural – modification of physical and mechanical properties without changing the chemical composition of the polymer and its molecular weight – changing SMS of polymer. For example, mechanical activation, shock and wave processing, radiation exposure, using magnetic and electromagnetic fields [5, 6].

Introduction to polymer substances that can interact with it, including high-molecular (plasticizing, stabilizing, filling). For example, introduction to PTFE various solid components [7]; matrix modifying by additions of activators of different
size, shape and properties [8]; formation of nanopfase matrices with significantly different characteristics [9].

Chemical – influence on polymer of chemical or physical agents, is followed by change of the chemical composition of polymer and (or) its molecular weight, and also introduction at a stage of synthesis of a small amount of substance which enters with the main monomer in copolymerization or a sopolikondensation. In particular, the synthesis of polymer matrices of different composition and structure [1]; composition of polymer and oligomer mixture with different levels of interaction [1] etc. To obtain an efficient PTFE–composite, the above–mentioned factors need to be considered when choosing the composition of a filler, its dispersity, energy state of the surface layer [2] and technology for the activation of ingredients [3, 4], methods of combining components when obtaining a composite material and technological methods for the formation of PTFE products.

The properties of composite materials, in addition to the correct choice of filler, are largely determined by the obtaining technology that determines the nature of interaction at the inter–phase boundary “matrix – filler” and defines the set of properties while forming the material [5]. A positive effect of filling PTFE for improving tribotechnical characteristics is caused by the attenuation of intermolecular bonds in a polymer, formation of the optimum structure of material, involvement of fillers in the process of friction as inhibitors, and increase in workability of the film of friction transfer [6]. Paper [7] demonstrated that the modification of amorphous–crystalline polymers by means of filling leads to changes in the character and morphology of SMS, and this is one of the main reasons for the transformation of properties of a composite. The structurally active fillers which are distinguished by extremely small particle dimensions are the most interesting in terms of the impact on tribotechnical characteristics of PCM [8]. Their use ensures maximal structuring of polymer matrix at the different levels of structural organization and obtaining materials with unique properties.

It should be noted that the industrial implementation of the technologies is associated with significant energy, material, and labor expenses and requires the managerial study of the price-quality relationship. The filled polymers technology, first of all, is the process of mixing the initial components. It determines the ultimate macro- and microstructure of composite materials, their physicomechanical and tribotechnical characteristics. The physicomechanical and tribotechnical characteristics of filled polymers relate not only to the interaction between components, but also to the change in structure and properties of PCM associated with phase and structural transformations.

**METHODS OF RESEARCH**

The methodology of studying the composite properties included determining the density \( \rho \) (g/cm\(^3\)), breaking strength \( \sigma_0 \) (MPa), relative elongation \( \delta \) (%), and wear intensity \( I \cdot 10^{-7} \) (mm\(^3\)/N·m) in accordance with the regulations. The tests of strength and relative elongation at break were performed on ring samples of 50x40 cm diameter and 10 mm in height using rigid half-discs (ISO 527-1/2 and ASTM D638) on an R-1 disruptive installation (ASTM D695 - 15) at the motion speed of sliding member of 0.25 cm/min. The density \( \rho \) (g/cm\(^3\)) of the samples was determined by hydrostatic weighing (ASTM D1505 - 10). The study of the wear rate was carried out on an SMT-1 serial friction machine according to the “partial insertion-shaft” scheme.

**RESULTS AND DISCUSSION**

The increase of PTFE wear resistance in the mechanical activation is associated with the decrease of crystalline degree and the increase of average interlayer distance during the frictional interaction and the structural adjustability of the modified PTFE under conditions of friction and demonstration of synergistic effects of self-organization tribostuctures with high wear resistance.

Using the methods of electron microscopy, it was established that the PTFE supramolecular structure under the mechanical activation has been significantly changed from a disordered lamellar structure to a spherulitic structure with higher ordering (Fig. 1). In the structure of PTFE samples after the mechanical activation, strands of fibers with a length of 10 to 50 microns and a diameter from 10 to 100 nm (Fig. 1, b) and “frost flowers” (Fig. 1, c) are observed which are absent in the non–activated PTFE structure (Fig. 1, a).
The difference between the particle morphology of fractions is due to the fact that the products obtained at different thermobaric effects have different ratios of molecular components, and each of them is intended for the construction of certain morphological formations.

In the IR spectra of these formations, the bands that characterize the vibrations of individual fragments and whole chain even under intense energy impact are preserved. This allows assuming that the external mechanical influence does not result in noticeable destruction of polytetrafluoroethylene molecular chain, but in some cases, certain changes occur at the molecular level, which leads to enhanced physical, mechanical and service properties of the polymer and reveals the possibility to use activated PTFE as a matrix of fluoropolymer composites of various applications.

Thus, due to the high physicomechanical and wear resistance indices, mechanically activated PTFE and its compositions may be used for manufacturing antifriction parts of machinery and equipment moving joints.

The research of mechanism and the nature of moisture absorption by CFRP and the evaluation of property loss of the composition were carried out. The research results showed (Fig. 2) that surface microdefects (Fig. 2, a) could appear in CFRP during the product manufacturing, which can develop into destroying cracks (Fig. 2, b).

Simultaneously with the activation process of the fillers, takes place the chemical mechanical destruction of macromolecules polytetrafluoroethylene with the formation of radical fragments. Availability, on the one hand, the active surface of fillers and with another - free radical of the polymer macromolecule can initiate the reaction of vaccination of polymer to the filler [9]. Although such reactions with the formation of chemical bonds between polymer and filler surface are passing only on the active centers and have the probable character, however their contribution to the creation of the strengthened composite material quite substantial.

Methods of electron microscopy (Fig. 3) was established the formation on the surface of the fragments of CF more stable intermediate layer of polytetrafluoroethylene (Fig. 3, b), than without.
their activation (Fig. 3, a), that «cures» the defects of the fillers and promotes the formation of a stable spacious cluster of filler in the volume of matrix composition. Thus, mechanical activation method of obtaining composite greatly transforms weekend particle of the fragments of CF transforming them into a structure that are covered with a thin, nanoscale layer of PTFE.

These formations are active nanofillers of PTFE, which significantly (by 20-45 %) increase its physical-mechanical and performance properties.

CONCLUSION
Uniqueness of PTFE properties, insufficient study of its physical structure and properties, insufficient informational content of researches of the interphase phenomena and structure-forming processes in case of mechanochemical activation and in the presence of fillers, insufficient study of influence of structure, structure and properties and manufacturing techniques on tribotechnical characteristics of materials on the basis of PTFE do them urgent about objects of further researches.

References