Methods for implementing the concept of energy and technological compliance of components in the technology of highly filled composites

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Abstract: *Structural and technological aspects of obtaining and processing functional composite materials based on polytetrafluoroethylene are considered. It is shown that, due to the peculiarities of the molecular structure of matrix polymers, within the framework of the traditional technological paradigm, prerequisites are created for the implementation of a structural paradox, which manifests itself in a decrease in the parameters of the stress-strain and tribological characteristics of composites with an increase in the degree of filling. Within the framework of the concept of multilevel modification, methodological approaches to the implementation of the energy and technological compliance of components, which reduce the negative impact of the structural paradox, are considered.*

***Keywords**: POLYTETRAFLUOROETHYLENE, FLUOROCOMPOSITES, STRUCTURAL PARADOX, MULTILEVEL MODIFICATION, ENERGY AND TECHNOLOGICAL COMPLIANCE OF COMPONENTS*

1. Introduction

Composite materials based on polytetrafluoroethylene (PTFE) and other fluorine-containing matrices belong to the class of composites used for the manufacture of elements of metal-polymer systems, operated mainly under the influence of disadvantages – high temperatures, without lubrication supply, aggressive media, etc., to which place high demands on reliability and safety. This type of systems includes sealing and tribological elements of machines, mechanisms and technological equipment used in the chemical industry, heat power, processing industry [1–14].

Features of the operation of structural elements of metal-polymer systems made from fluorine composites, including tribochemical, thermophysical and structural aspects, necessitate the development of methodological approaches to technology that take into account the multifactorial structure formation mechanisms that ensure the creation of a structure with an optimal combination of stress-strain and tribological characteristics. Among the promising approaches in this aspect are the concepts of multilevel modification and energy and technological compliance of components proposed in our studies [7].

The development of methods for implementing these concepts in practical technologies of fluorocomposites, including fluorocomposites with high concentrations of modifying components has some scientific and practical interest.

2. Materials and methods of research

As an object for research, composite materials based on industrial polytetrafluoroethylene of F-4PN, F-4PN90, F-4TM grades were used.

To modify the polymer matrix, we used dispersed fragments of carbon fibers (CF), obtained by grinding carbon tapes produced by OAO Svetlogorsk Khimvolokno, grade LO-1-12N.

To implement the principle of multilevel modification, highly dispersed particles of carbon black (TC) grade P234, ultrafine polytetrafluoroethylene (UPTFE), commercially produced under the Forum trademark, were used.

Experimental samples were formed according to traditional and original technologies using the equipment of a specialized enterprise.

The structural characteristics of the fluorocomposites were studied by IR spectroscopy (Tensor 27, Brucer), optical (Micro 200T-01), atomic force (Nanotop-3), and scanning electron (JSM-50 A) microscopy.

The parameters of the stress-strain and tribological characteristics of the model samples of fluorocomposites were studied according to common methods.

3. Results and Discussion

As noted in [12], "the essence of the multilevel approach proposed in [7] is the formation of the optimal structure of the composite material, which ensures the achievement of a given combination of product indicators from it. At the same time, the methods for creating such a structure are determined by the characteristic features of the molecular structure and mass and can be technologically implemented by introducing functional modifiers of various composition, dispersion and activity into the matrix" [7].

For structural elements with high load-speed parameters, composites with a content of functional modifiers of 10–30 wt. % are used. These composites involve the development of special technologies for the preparation, combination of components, the formation of products and their modification, taking into account the specifics of the operation of a metal-polymer system of a particular design.

An algorithm for the formation of a multilevel optimized structure of composite materials with high performance parameters based on thermoplastic matrices with increased viscosity (PTFE) has been developed (Figure 1). According to the algorithm, based on the methodological approach to controlling the processes of structure formation by directional changes in the parameters of the energy characteristics of the components, it is possible to create prerequisites for the formation of an optimized multilevel structure at the stages of preparation of components, their mix, formation of blanks and manufacture of products.

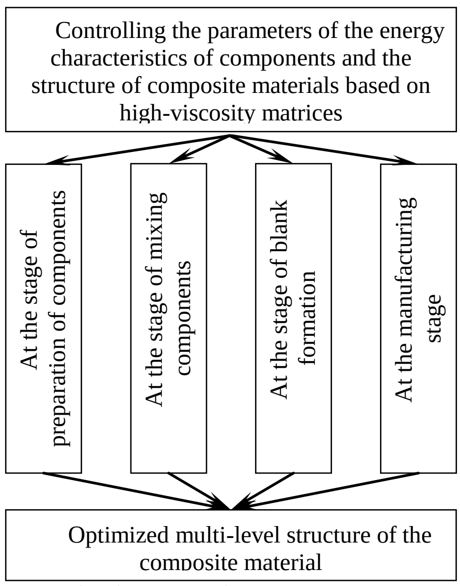

Fig. 1 *Algorithm for formation of a multilevel optimized structure of composite materials based on thermoplastic matrices with high viscosity*

At the same time, prerequisites are created for minimizing the negative impact of the structural paradox, which manifests itself in a significant decrease in the parameters of the stress-strain and tribological characteristics of fluorocomposites formed using the traditional technology of cold pressing followed by sintering (monolithization), with an increase in the content of modifying components above 20–25 wt. %.

As noted in [1–6], PTFE macromolecules are inert in the processes of interfacial interaction with components of different composition, structure, production technology [11], which leads to a significant decrease in the strength characteristics of the matrix due to the manifestation of a “structural paradox” [11]. At the same time, the temperatures of monolithization (sintering) of workpieces in the range of 423–640 K used in the current technological paradigm create conditions for the implementation of the principle of energy and technological compliance of components due to the directed use of graphitization, carbonization, and thermal-oxidative modification of particles. A common technology for obtaining of carbon fibers (CF) as the most effective PTFE modifier is the heat treatment of fibrous semi-finished products from polyamides, polyesters, and other macromolecular compounds [3]. In this case, hydrocarbons are formed with an optimally smooth surface with low adsorption activity. As a multifunctional PTFE modifier, we used dispersed particles of organic polymers (HDPE, PP, PA6, EVA, polysulfone) obtained by dispersion of granular and fibrous semi-finished products.

Model studies on fragments of polysulfone fiber "Fortron" (PS) with nano-sized components of the porous structure showed that heat treatment in the temperature range close to the temperatures of formation of composites based on PTFE leads to a significant increase in the tensile strength parameter σ_{uts} during the formation of nanocomponents in the surface layer (Figure 2).

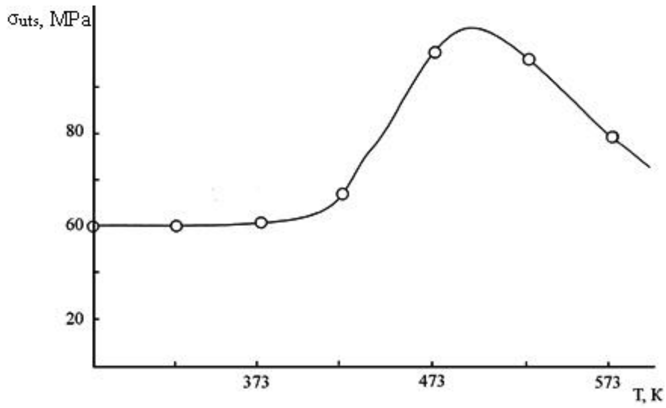

Fig. 2 *Tensile strength of polysulfone nanoporous fiber in terms of heat treatment temperature*

Model studies of PTFE-based composites containing polysulfone fibers have shown that in the process of monolithization of samples under temperature conditions close to the technological conditions for obtaining fluorocomposites, it is possible to achieve strength parameters close to those of samples modified with carbon fibers. In this case, the use of initial nanoporous fragments of polysulfone fiber is preferable compared to the use of products subjected to preliminary heat treatment (Fig. 3, curve 2). Obviously, in the process of monolithization of the composite with the initial PS, conditions are created for the formation of the structure of fiber-like fragments with increased activity in interaction with the matrix due to the special energy state and morphology of the surface layer.

A methodological approach to implementing the energy and technological compliance of components by influencing their technological factors in the process of monolithization was developed in the development of compositions of tribotechnical composite materials based on polytetrafluoroethylene modified with components with a transformable structure and energy parameters in the temperature range of product (blank) monolithization.

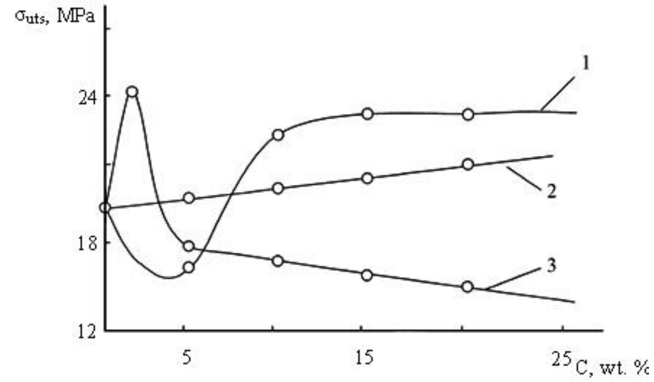

Fig. 3 *Tensile strength of PTFE composite materials in terms of the content in PTFE of carbon-graphite fiber "Viskum" (1) and nanoporous fiber "Fortron" without heat treatment (3) and with heat treatment (2)*

The combination of active nanoscale components ensures the implementation of a synergistic effect of increasing the parameters of the tribological and stress-strain characteristics of the composite material (Fig. 4). Attention is drawn to the significant decrease in the wear intensity parameter of the composite upon the introduction of a complex modifier, including oligomeric and polymeric fluorine-containing components that are part of the UPTFE structure. The presence of the oligomeric component not only contributes to the monolithization of the matrix polymer, but also to the formation of a separating layer on the friction surfaces with high resistance to multiple deformation and alternating transfer.

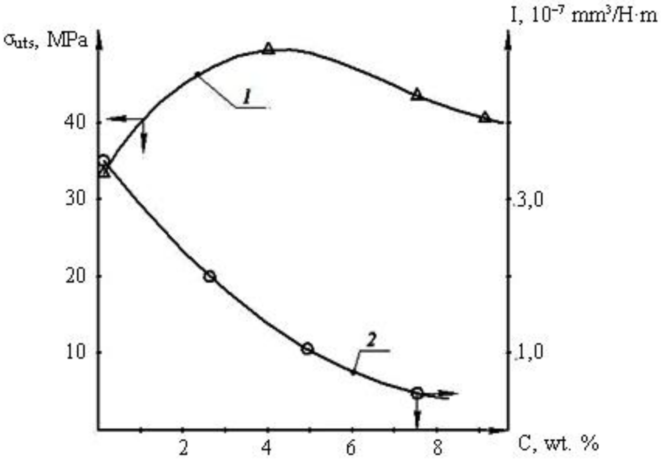

Fig. 4 *Tensile strength σ_{uts} (1) and wear intensity $I\times10^{-7}$ (2) of PTFE composite materials in terms of the content of tetramaleimide (TMI)*

Another methodological approach to implement the principle of energy and technological compliance of components is their activation directly in the process of composite formation at different stages of the technological process (Fig. 5) using mechanochemical effects [11, 12].

To implement the mechanochemical approach in ensuring the energy and technological compliance of the components, methodological principles for the technology of highly filled fluorine composites with high performance parameters have been developed (Fig. 5). The most important component of the proposed principles is the joint activation of the surface layers of the components (PTFE and CF) using mechanical stresses during mixing at the stages of preparation (mechanical activation – MA) and at the stages of monolithization of the workpiece structure under high temperature (triaxial compression – TC) and low temperature (cold monolithization – CM) exposure.

Combination of technologies for mechanochemical activation of components of fluorocomposites with hydrocarbon content from 10 to 40 wt. % at various stages of the implementation of the algorithm shown in Fig. 1 provides the possibility of reducing the negative impact of the structural paradox considered in the studies of A. K. Pugachev and Yu. K. Mashkov [6, 14] (Fig. 6).

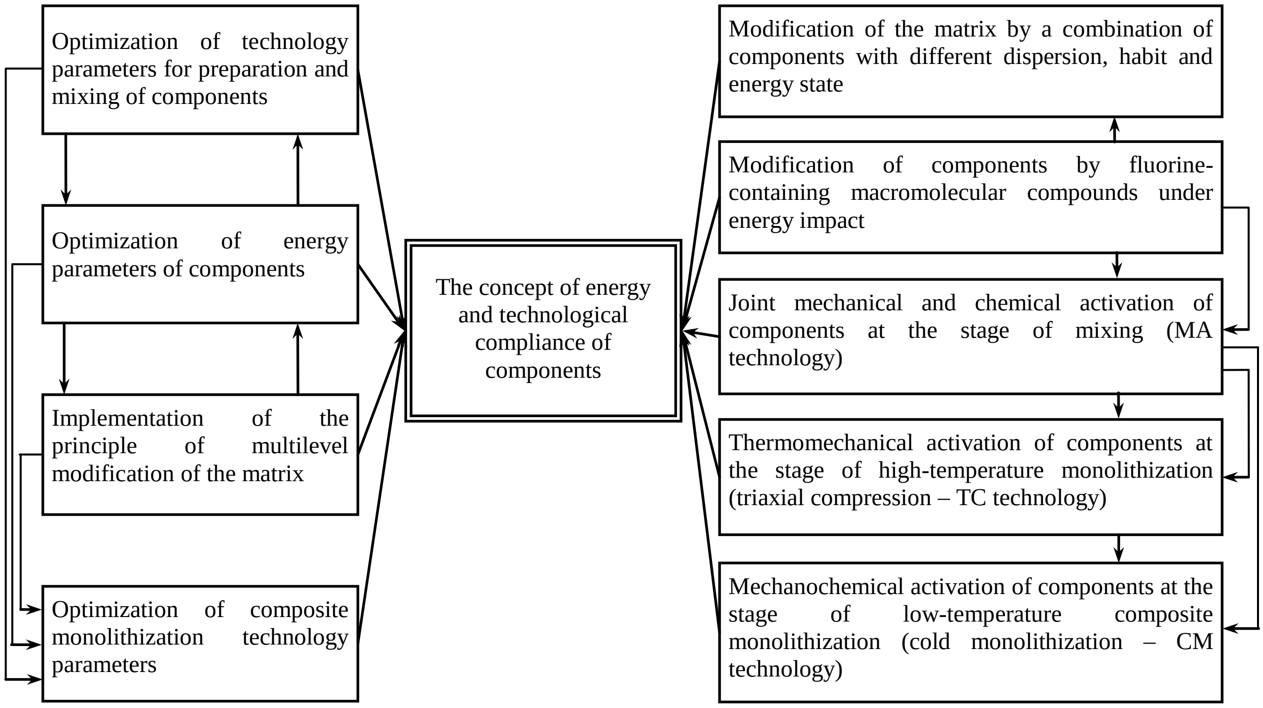

Fig. 5 *Methodological principles of the technology of highly filled fluorocomposites with high performance parameters*

A complex of studies of the features of the structure parameters of fluorocomposites with different content of modifiers at different levels of organization, summarized in [11], made it possible to develop compositions of fluorocomposites with parameters of stress-strain and tribological characteristics that exceed the well-known domestic and foreign analogues "Fluvis", "Flubon", F4K20 and others, and effective technologies for their production and processing into products for metal-polymer tribological and sealing systems, including those operated under extreme conditions.

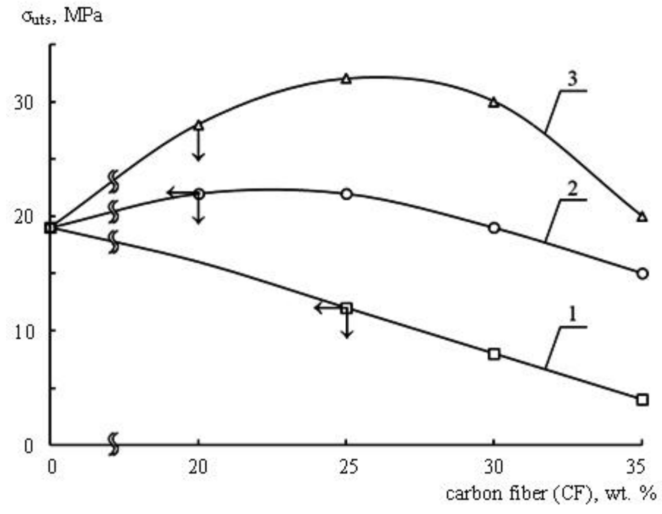

***Fig. 6** Tensile strength σ_{uts} of PTFE composite materials in terms of the content of carbon fiber (CF) during mechanical combination of components (1), with mechanochemical activation of components (MA technology) and monolithization in a free state (CM technology) (2) and under conditions of triaxial compression (TC technology) (3) [11]*

4. Conclusion

The developed technologies based on the activation of components during joint thermal, thermomechanical (TC technology), mechanochemical (MA and CM technologies) processing make it possible not only to achieve a synergistic combination of high performance parameters, but also to expand the brand range of fluorocomposites, including highly filled ones, containing up to 40–45 wt. % of hydrocarbons with high thermophysical and load parameters. The novelty of the developed methodological approach for implementing the principle of energy and technological compliance of components at various stages of the technological process of functional composites and the priority of domestic developments in the field of materials science and technology of fluorocomposites are confirmed by a series of patents of the Russian Federation, the Republic of Uzbekistan, the Republic of Belarus.

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