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Research of the structure and properties of antifriction composites with modified polytetrafluoroethylene matrix

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Structures of the powdered polytetrafluoroethylene (PTFE) before and after intensive mechanical activation (mechanical alloying) are investigated by the set of physical research methods. Enhancement of physical and mechanical properties and structuring activity of polytetrafluoroethylene as matrix of composites by means of mechanical activation is shown. Operating modes of mechanical activation equipment are defined, in which the service properties of PTFE are maximized. The effect of mechanical activation technology on restructuring and change of morphology and supramolecular structure of PTFE is detected for the first time. Obtained results and examples of implementation of the developed tribotechnical composites are analyzed.

Key words: polytetrafluoroethylene, matrix, structure, properties, mechanical activation, carbon fiber, composites.

1. INTRODUCTION

To create reliable modern machinery and technological equipment, it is necessary to design and develop highly efficient wear-resistant materials to ensure reli-able operation of friction joints of mechanisms operated in a wide range of loads, speeds and temperatures, and able to work in aggressive environments, as well as in vacuum. Use of polymers as structural materials for tribotechnical usage is due to many factors, including the possibility to form composites with desired proper-ties [1–3].

Review of the literature, patent and commercial sources [2–5] reveals a low potential of traditional technological approaches in obtaining polymeric composite materials (PCM) based on polytetrafluoroethylene (PTFE). However, various advanced technological methods may be performed that allow obtaining composite materials and products from them with the properties required by customers [4–5].

The technology of energy impact on the structure and properties by means of mechanical activation (mechanical effect) presents itself as the most acceptable in the case of PCM with PTFE matrix [6].

Since the chemical, petrochemical, oil and gas, nuclear, aerospace, transportation, ore mining and many other branches of engineering, in order for the equipment to operate efficiently, reliably and safely, require the use of PTFE-based PCM in critical friction joints that determine performance, durability of manufactured equipment and competitiveness of manufactured products, the studies performed and the work results obtained seem to be timely and relevant.

2. EXPERIMENTAL

The object of the research is PTFE of F-4-PN brand (GOST 10007) and PCM with the carbon fiber (CF) based on it.

Activation of PTFE powder was performed on MRP-1M mill with various rotation speed of working mem-bers in the interval of $n = (5–9)\cdot 10^3$ min^{-1} and during experimentally determined time interval of $\tau = (3–8)$ min.

Activated powder was obtained by dry milling in MRP-1M high speed blade mixer.

Test samples were obtained by cold molding technology (molding pressure $P_{mold} = (50.0–70.0)$ MPa), followed by free sintering of tablet blanks in air at 365 ± 5 °C at a speed of heating – cooling of 40 °C/h.

Methodology of the composite properties studying included determining the density ρ (kg/m^3), breaking strength σ_b (MPa), relative elongation δ (%) and wear intensity $I\cdot 10^{-6}$ (mm^3/N$\cdot$m) in accordance with the regulations.

Tests of strength and relative elongation at break were performed on ring samples of *ø50*x*ø40* diameters and 10 mm height using rigid half-discs (GOST 11262) at R–1 disruptive installation (GOST 4651) at the motion speed of sliding member of 0.25 cm/min.

The study of the wear rate was carried out on SMT-1 serial friction machine according to «partial insertion-shaft» scheme.

The magnitude of wear of the samples was determined gravimetrically on an analytical balance within the accuracy of 10^{-5} grams and transferred to the intensity of wear by known methodologies.

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The study of supramolecular structure of activated PTFE and composite structures before and after friction powder were carried out using TESCAN MIRA 3 LMU scanning electron microscope of high resolution.

Processing of experimental data was performed by the methods of mathematical design of experiments and mathematical statistics.

3. RESULTS AND DISCUSSION

One of the most effective and low-cost ways of produce a polymer with new properties is the method of mechanical activation (mechanical alloying) [6].

The studies determined that unlike the structural and morphological structure of activated and non-activated PTFE leads to differences in the properties (table 1).

The authors of this paper determined that the optimal ratios of physical-mechanical and tribotechnical properties an activated PTFE has in mode $n= 9 \cdot 10^3$ min^{-1} and $\tau = 5$ min: breaking strength $\sigma_v = 24.8$ MPa, relative elongation δ = 415 %, wear intensity $I = 610 \cdot 10^{-6}$ mm³/N·m. The non-activated PTFE has $\sigma_b = 9.5$ MPa, $\delta = 96$ %, $I = 1133 \cdot 10^{-6}$ mm³/N·m.

Mechanically activated PTFE more actively adheres to the surface of CF (Fig. 2, a, b) than non-activated (Fig. 2, c) in obtaining of PCM. This results in a modification of surface layer CF by activated PTFE, PTFE fragments are distributed on the surface CF with higher homogeneity that enhances their activity in interactions with the PTFE matrix during the formation of the composite. The homogeneous composite structure is formed with fewer voids and with formation of more uniform distribution of the fragments of the filler in the matrix polymer. CF particles are contacted with the activated particles of PTFE and formed the primary adhesive bonds, which reduce the defectiveness of mixture and probability of occurrence of defects during the forming of composite.

Composites filled with CF, created on the basis of such an activated matrix, have significantly higher tribotechnical performance (table 2) than non-activated matrix.

Microphotographs of the friction surface of composites (Fig. 3) show that by increasing the adhesive bond «activated matrix PTFE – filler» wear process is less active than the non-activated composite matrix.

The microphotographs clearly show that in the case of wear of the PTFE composite non-activated (Fig. 3, a) marks of wear are deeper, observed the furrows of temper softening material, etc., which is not observed in wear composite with activated PTFE (Fig. 3, b), and contributes to increasing durability to 50 %.

Table 1 – Effect of mechanical activation PTFE on physical and mechanical and tribotechnical properties

No. of sample	Technology of obtaining	Density ρ, g/cm³	Breaking strength σ_b, MPa	Relative elongation δ, %	Wear intensity $I \cdot 10^{-6}$, mm³/N·m
1	non-activated	2.269	9.5	96	1133
2	τ=5 min., n=5000 min^{-1}	2.211	21.6	416	930
3	τ=8 min., n=5000 min^{-1}	2.175	17.3	280	800
4	τ=5 min., n=7000 min^{-1}	2.205	23.5	423	820
5	τ=8 min., n=7000 min^{-1}	2.211	18.2	358	717
6	τ=3 min., n=9000 min^{-1}	2.203	19.6	290	890
7	τ=5 min., n=9000 min^{-1}	2.214	24.8	415	610
8	τ=8 min., n=9000 min^{-1}	2.213	18.0	340	720

In the structure of PTFE samples after mechanical activation, lentil-like formations are observed in the form of granules with micron dimensions in area and thickness (Fig. 1, b), threadlike strands of fibers with length of 10 to 50 microns and diameter from 10 to 100 nm (Fig. 1, c) and other formations («cobweb», «frost flowers», «lace» and «branch» structures, etc.) (Fig. 1, d–f), which are absent in non-activated PTFE structure (Fig. 1, a).

The influence of external forces on unfilled PTFE in-creases the parameters of its deformation and strength characteristics (breaking strength 2.6 times, relative elongation 4.3 times) while maintaining high tribotechnical performance. This is obviously related to the formation of new reaction centers and an increase in the surface energy of the individual fragments of macromolecules as a result of elastic and plastic deformations at mechanical influence.

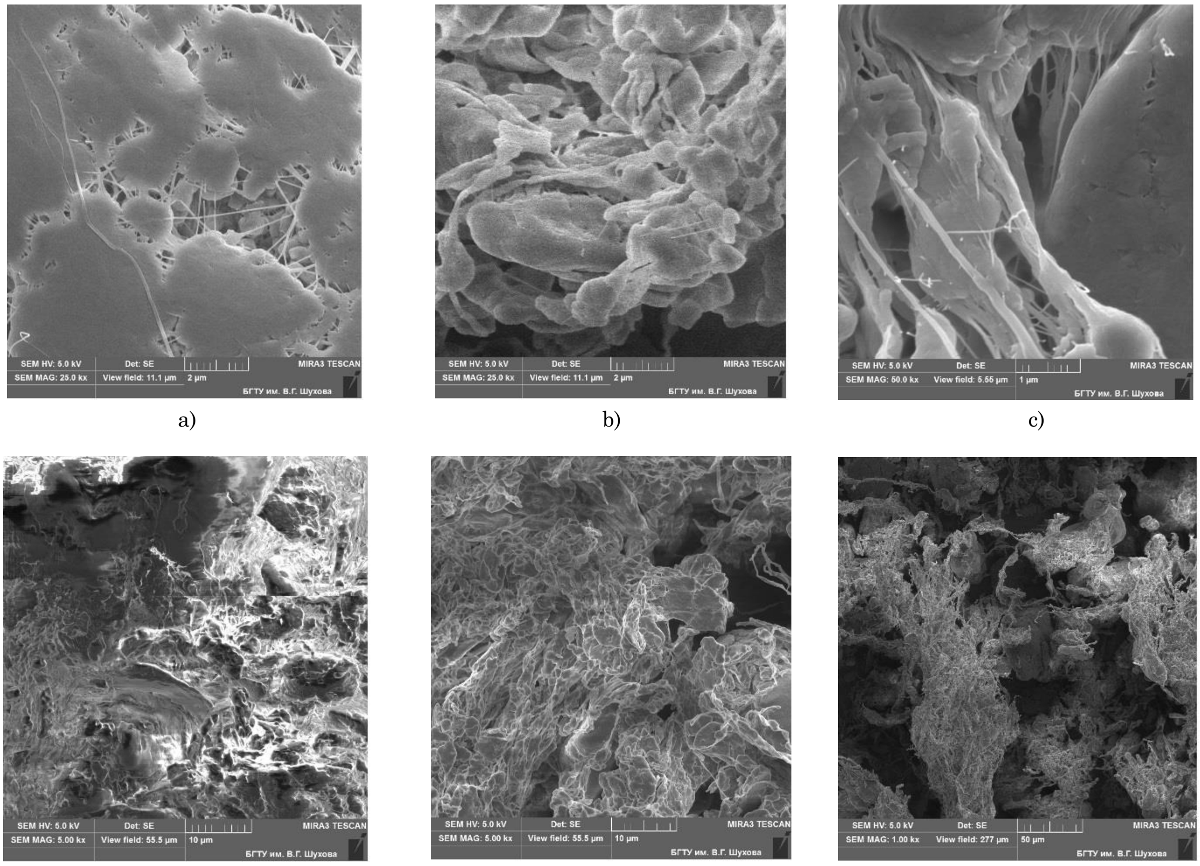
Thus, improving of the wear resistance of the PTFE in mechanical activation associated with a reduced degree of crystallinity and increase in the average interlayer distance in the frictional interaction and structural adaptability modified PTFE in friction and manifestation of synergistic effects of self-organization tribotechnical structures with increased durability.

The use of this composite as a friction units compressors 4GM 2.5 2/3 250, 2RV 3/220, SA 1174, SA 7171 (gland seals and piston rings) contributed to the overall increase of its efficiency by 2.3 times.

4. CONCLUSIONS

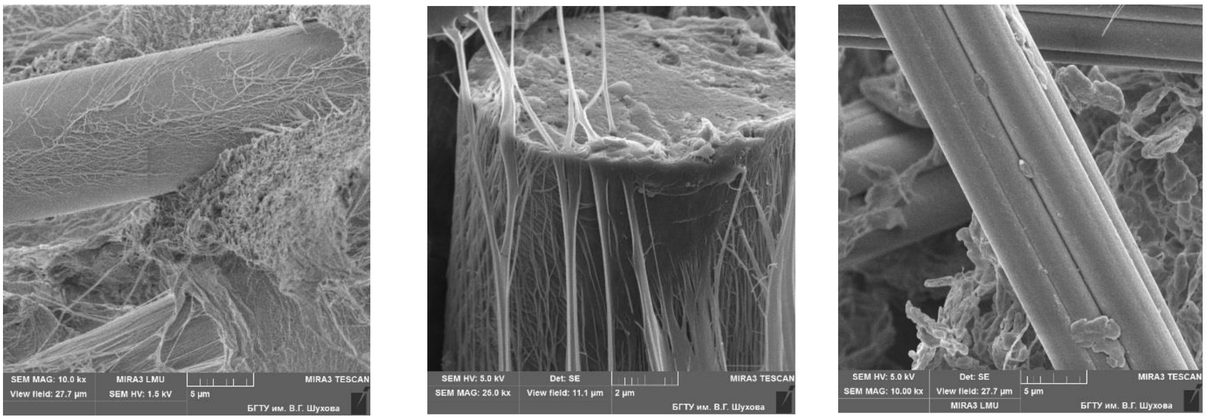
The undertaken studies reveal the possibility to use activated PTFE as a matrix of fluoropolymer composites in order to obtain a composite material with high physical and mechanical properties for friction joints of machinery and equipment for various purposes. As a result of work performed it was obtained modes of process technological equipment, which after processing on it activated PTFE has elevated the performance properties compared to the baseline, and may be used to produce composites based on it with maximum efficiency:

1. Mechanical activation of PTFE matrix leads to the change in its supramolecular structure and increases its reactivity.



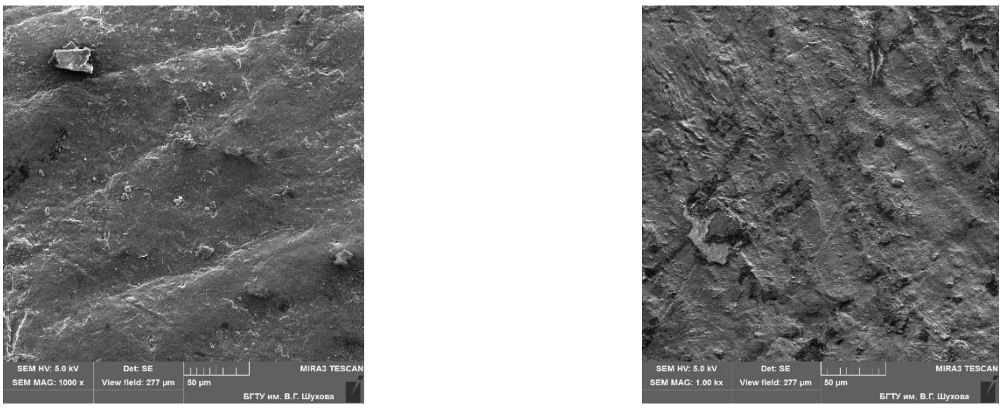
a) b) c) d) e) f)

Fig. 1. Structure of PTFE before (a) and after (b-f) mechanical activation



a) b) c)

Fig. 2. Microphotographs of PTFE composite structures with CF with activated (a, b) and non-activated (c) matrix



a) b)

Fig. 3. Microphotographs of the friction surface of PTFE composites with non-activated (a) and activated (b) matrix

Table 2 – Properties of PTFE composites depending on the use of activated and non-activated matrix

Composite	Properties							
	Density ρ, g/cm^3		Breaking strength σ_b, MPa		Relative elongation δ, %		Wear intensity $I \cdot 10^{-6}$, mm^3/N·m	
	non-activated	activated	non-activated	activated	non-activated	activated	non-activated	activated
F4CF10	2.01	2.02	17.5	17.9	90	98	25–60	21–51
F4CF15	1.98	1.99	18.3	19.1	105	115	20–50	17–42
F4CF20	1.96	1.98	20.4	22.1	120	145	19–45	16–38
F4CF25	1.95	1.96	16.9	18.4	115	125	18–40	15–34

2. The best performance has activated PTFE in activation mode $n = 9 \cdot 10^3$ min^{-1} and $\tau = 5$ min: breaking strength $\sigma_b = 24.8$ MPa, relative elongation $\delta = 415$ %, wear intensity $I = 610 \cdot 10^{-6}$ mm^3/N·m. The non-activated PTFE has $\sigma_b = 9.5$ MPa, $\delta = 96$ %, $I = 1133 \cdot 10^{-6}$ mm^3/N·m.

3. PCM based on activated PTFE has physical and mechanical characteristics of 3–5 times higher than non-activated, durability 1.5 times higher.

Исследование структуры и свойств антифрикционных композитов с модифицированной политетрафторэтиленовой матрицей

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Совокупностью физических методов исследований изучено строение порошкообразного политетрафторэтилена (ПТФЭ) до и после интенсивной механической активации (механического легирования). Показано повышение физико-механических свойств и структурирующей активности политетрафторэтилена как матрицы композитов за счет механической активации. Определены режимы работы механоактивационного оборудования, при которых служебные свойства ПТФЭ максимальны. Впервые выявлено влияние технологии механической активации на структурную перестройку и изменение морфологии и надмолекулярной структуры ПТФЭ.

Ключевые слова: политетрафторэтилен, матрица, структура, свойства, механическая активация, углеродное волокно, композиты.

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Дослідження структури та властивостей антифрикційних композитів з модифікованою політетрафторетиленовою матрицею

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Сукупністю фізичних методів досліджень вивчено будову порошкоподібного політетрафторетилену (ПТФЕ) до і після інтенсивної механічної активації (механічного легування). Показано підвищення фізико-механічних властивостей та структуруючої активності політетрафторетилену як матриці композитів за рахунок механічної активації. Визначено режими роботи механоактиваційного обладнання, при яких службові властивості ПТФЕ максимальні. Вперше виявлено вплив технології механічної активації на структурну перебудову та зміну морфології і надмолекулярної структури ПТФЕ.

Ключові слова: політетрафторетилен, матриця, структура, властивості, механічна активація, вуглецеве волокно, композити.

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