Conference Paper

Influence of Carbon Fibers on Structure and Properties of Polytetrafluoroethylene

A.A. Okhlopkova, T.S. Struchkova, A.P. Vasilev, A.G. Alekseev, and L.A. Nikiforov

M. K. Ammosov North-Eastern Federal University, 677000 Yakutsk, Russia

Abstract

In this paper, we studied the effect of carbon fibers on the performance properties of polymer composites based on polytetrafluoroethylene. It was shown that the introduction of PTFE carbon fibers significantly improved tribological and mechanical properties of the composite. The correlation between the performance properties and supramolecular structure was found. Initial lamellar structure of the polymer became less in size without significant changes in morphology when filled. Such process was accompanied by the increase of crystalline regions number and the crystallinity degree of composite. Structural studies have shown that materials with more densely packed and highly crystalline structure have increased mechanical and tribological properties. The developed materials can be used in friction units of machines and devices, where the use of lubricants is not acceptable or restricted.

Keywords: polytetrafluoroethylene, carbon fibers, polymer composite material, mechanical properties, tribological properties, coefficient of friction, degree of crystallinity, supramolecular structures, density

Corresponding Author: T.S. Struchkova; email: sts_23@mail.ru

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1. Introduction

Currently, effective economic development of the Russian Federation is aimed at intensifying the productivity of oil and gas complex, which includes large-scale use of various technological mining equipments. The analysis of equipment operability in the Republic of Sakha (Yakutia) shows that friction units are the most frequent reason of failures. It was found that the sliding bearings were the most vulnerable link in the operation of equipment [1]. Expenses for additional reserve equipment and damage control, as well as a large number of parts, lead to huge losses.

Analysis of the causes of low reliability and durability of parts of friction units demonstrates the need to solve two priority problems – increase of the technical characteristics of materials and their rational use. Modern polymeric composite materials (PCM) are widely used in technical applications in the Arctic. Polytetrafluoroethylene (PTFE) resists to aggressive substances and wide temperature fluctuations. However, low wear resistance limits its application. Various fillers are used to increase PTFE wear resistance [1].

Filler as one of the components plays a leading role in the formation of main characteristics of PCM. Therefore, the mechanical properties of the PCM depend on the content of components [2-4]. One of the promising ways to create tribological materials is the introduction of fibrous fillers into polymer matrix [5]. Fibrous fillers give high bearing capacity, strength, toughness, chemical resistance to PTFE. Study of carbon fiber effect on the properties and formation of composites makes possible to control performance characteristics of composites, i.e. to solve one of the main problems of modern material science.

In this paper, we studied the effect of carbon fiber on PTFE performance characteristics.

2. Methods

PTFE grades PN ("HaloPolimer", Russia) was used as a polymer matrix. PTFE was modified by carbon fiber (CF) ("Belum", Belarus). Tensile strength and elongation at break and modulus were determined according to the State Standard 11262-80, compressive stress at 10% strain were determined according to the State Standard 4651-2014. All mechanical tests were carried out on a universal testing machine AUTOGRAPH-AGS-J (Shimadzu, Japan). Tribological characteristics were investigated according to the State Standard 11629-75 on tribomashine UMT-3 (CETR, USA) according to the scheme of friction "pin-on-disk". Supramolecular structures were observed by a scanning electron microscopy (SEM) on JSM-7800F LV (JEOL, Japan). Assessment of the degree of crystallinity of PTFE and PCM was carried out by X-ray diffraction (XRD) on ARL X'TRA (Thermo Fisher Scientific, Switzerland). PTFE and PCM density were determined by hydrostatic method according to the State Standard 15139-69.

3. Results

The results of the mechanical tests, structural investigations, and density of PCM based on PTFE and CF are shown in Table 1. Mechanical properties of PCM were kept at the level of the original PTFE. The elastic modulus increased by 40% at 5 wt.% of carbon fiber, while strength maintained at the initial level. It is possible because of strong adhesion between the polymer and the carbon fiber [6]. Compressive strength was increased by 50% compared to the original polymer at 5 wt.% of carbon fiber. Increase of carbon fiber content in PCM caused decrease of density.

Thermodynamic and structural investigations were carried out in order to evaluate the effect of carbon fibers on the supramolecular structure of PTFE and to explain changes in mechanical and tribological properties of PCM. Volume ratio of crystalline phase and crystallinity degree of PCM and original PTFE were defined by powder XRD and differential scanning calorimetry (DSC). The resulting data are presented in Table 2.

Structural studies have shown that the crystallinity degree of PCM determined by XRD increases with increase the content of carbon fibers in PTFE. Volume fraction of crystalline phase in composites calculated from the density increases with increase of filler content. It is known [7] that crystallinity degree increases due to increasing the

Sample	σ_t, MPa	ε, %	E, MPa	σ_c, MPa	ρ, g/sm^3
PTFE	20±1	325±20	440±30	16±1	2.15
PTFE + 1 wt.% CF	19±1	351±20	453±30	19±1	2.15
PTFE + 2 wt.% CF	18±1	340±20	481±30	20±1	2.14
PTFE + 3 wt.% CF	18±1	315±20	581±30	22±1	2.13
PTFE + 4 wt.% CF	19±1	298±20	528±30	23±1	2.12
PTFE + 5 wt.% CF	20±1	297±20	554±30	24±1	2.10

σ_t – tensile strength; ε – elongation at break; E – modulus;
σ_c – compressive strength; ρ – density.

Table 1: Mechanical properties and density of PCM and original PTFE.

Sample	α_{XRD}, %	α_{DSC}, %	$f_c^{\,v}$, %
PTFE	63	42	41
PTFE + 1 wt.% CF	64	40	43
PTFE + 2 wt.% CF	68	41	45
PTFE + 3 wt.% CF	68	40	49
PTFE + 4 wt.% CF	67	39	50
PTFE + 5 wt.% CF	69	37	52

α_{XRD} – crystallinity degree, determined by XRD; α_{DSC} – crystallinity degree, determined by DSC; fcv – volume fraction of crystallinity.

Table 2: Comparison of the volume fraction of crystalline phase and crystallinity degree calculated by XRD and DSC.

proportion of the structurally active surface of filler in PCM. The crystallization process of the polymer matrix occurs on these surface and leads to the reduction of mass wear rate and maintaining of the mechanical properties of materials. DSC showed decrease of crystallinity degree of PCM at filling with CF. It can be explained by decrease of percentage of the PTFE in composites, because thermal effect of crystalline phase can be obtained only from polymer.

Research of supramolecular structure by SEM was conducted to estimate the distribution of the carbon fibers in the polymer matrix. SEM micrographs of PCM containing 1 wt.% and 5 wt.% of carbon fiber are presented in Fig. 1. As can be seen, original PTFE has a lamellar supramolecular structure. Fibers in polymer volume were not uniformly distributed at 1 wt.% of CF. However, increase of CF content to 5 wt.% led to more uniform distribution of fibers in a polymer. It caused significant improvement of compressive strength and maintaining of elongation at break and tensile strength at initial PTFE level. Fibers in the polymer form a spatial framework structure with high crystallinity degree.

Tribological characteristics of the composites are investigated as well. Modification of PTFE by carbon fiber improves the wear resistance of PCM with increase of filler content (Table 3). Wear resistance of materials has increased up to by 71 times at low filling degree (1-2 wt.%). Introduction of the 5 wt.% filler into PTFE led to the further improvement of wear resistance up to by 235 times relative to original PTFE. Perhaps,

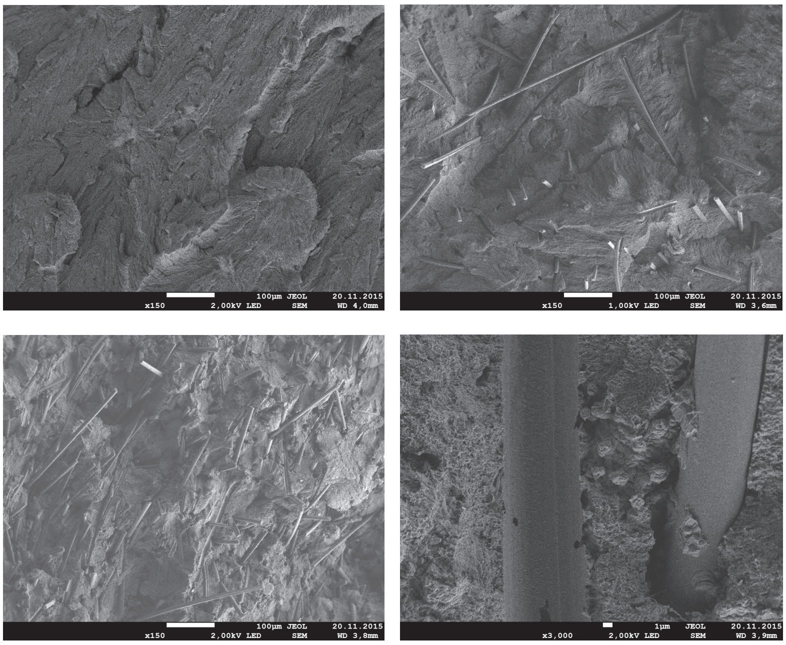

Figure 1: Micrographs of supramolecular structure: a) initial PTFE (× 150); b) PTFE + 1wt.% CF (× 150); c) PTFE + 5 wt.% CF (× 150); d) PTFE + CF (× 3000).

Sample	I, kg/h×10^{-6}	*f*
PTFE	≥120	0.22
PTFE + 1 wt.% CF	2.86	0.16
PTFE + 2 wt.% CF	1.69	0.17
PTFE + 3 wt.% CF	0.67	0.21
PTFE + 4 wt.% CF	0.62	0.21
PTFE + 5 wt.% CF	0.51	0.22
I – mass wear rate; *f* – friction coefficient.		

Table 3: Tribological characteristics of PCM and original PTFE.

the surface layers of the polymer are worn, and uncovered fibers play the role of a protective screen for the polymer.

Friction coefficient is a key in estimating the durability of material and depends on the roughness. Contact occurs in discrete areas, which are elementary contact pad resulting elastic or plastic deformation [8]. It is shown that at low carbon fiber content (1-2 wt.%) friction coefficient of PCM decreases, and wear resistance is increased by 71 times in comparison with initial polymer. Reduced friction coefficient compared to the original PTFE can be explained by the formation of transfer film performing the function of lubricant [9].

When increasing the fiber content up to 5 wt.%, the friction coefficient of materials remains at the original polymer level. Probably, the fibers locate on the friction surface and reduce contact area, thus decreasing molecular component of mechanical friction. It can explain reducing of friction coefficient.

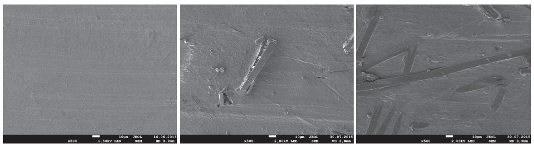

Figure 2: Micrographs of friction surface (×500): a) the original PTFE; b) PTFE + 1 wt.% CF; c) PTFE + 5 wt.% CF.

Friction surface was investigated by SEM in order to explain the changes in properties of PCM compared to PTFE. The carbon fibers are arranged randomly on the friction surface (Fig. 2). It is seen that fibers play the role of contact spots, which can reduce the deformation component of friction, thus improving wear resistance with an optimum at 5 wt.% of CF.

4. Conclusion

The following conclusions can be made based on the studies of polymer composite materials. The friction coefficient of PCM significantly reduces at low degrees of PTFE filling. 5 wt% of carbon fibers significantly improve wear resistance of PTFE, while maintain the coefficient of friction. Fibers in the polymer form a spatial framework structure with a high crystallinity degree. Developed composites can be used as sliding bearings and sealing materials. The resulting materials have high performance and are promising in mechanical engineering and instrument making.

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