The PTFE-nanocomposites mechanical properties for transport systems dynamic sealing devices elements

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Abstract. The mechanical properties study results of polymer nanocomposites based on polytetrafluoroethylene with modifiers in the form of micro- and nanoscale cryptocrystalline graphite and silicon dioxide powders are determined. The nanocomposites mechanical properties determined values provide high sealing degree of transport systems dynamic sealing devices elements. When the temperature changes from cryogenic to high positive then the elastic modulus, tensile strength decrease significantly and nonlinearly, the latter limits the composite usage in heavily loaded tribosystems operating at elevated temperatures.

1. Introduction
The sealing devices reliability largely determines transport systems and machine building equipment operation durability and stability. Specific friction units features, especially in the transport system undercarriage elements operating under significant dynamic loaded conditions, require continuous improvement both as sealing devices design as materials used. Increased reliability and machine life ensuring raise the problem of structural materials development with higher physical and mechanical properties performance, retained for long operation period in a loading variable conditions at different temperatures.

The materials based on polytetrafluoroethylene (PTFE) are the most suitable for extreme conditions in a wide range of positive and negative temperatures among antifriction usage polymeric composite materials (PCM) [1, 2].

Composite materials with fillers-modifiers nanoparticles have properties that differ significantly from the material with micro-sized particles properties due to the higher surface energy and nano-sized filler particles activity [3, 4]. The combined micro-and nano-sized fillers usage effectiveness for PTFE-based PCM properties complex improvement is shown in works [5].

2. The problem setting
There is the same type of structural phase change in the samples and machine parts volumes for uniaxial and other forms of static and dynamic load and deformation as well as frictional interaction in the solids surface layers that lead to mating surfaces micro defects and destruction (wear) gradual accumulation [6]. During operating construction materials have different types of stress and significant deformation leading to defects and structural phase transitions occurrence and accumulation accompanied with change in the physical and mechanical properties. Therefore, one of new PCM development main tasks is to improve the mechanical and tribological properties performance to increase the polymer components reliability and durability at work in friction units. We solve the
problem of studying the fillers concentration and the ambient temperature influence on the PTFE-based PCM mechanical properties.

3. Methods of research
The study subject is PTFE based nanocomposites (Ftoroplast-4PN GOST 10007-80) widely used in metal polymer machinery friction units [1, 2]. According to the preliminary studies results [5, 7] to modify the structure and to improve PTFE properties we used complex content of the polymer with nanodisperse silicon dioxide SiO2 grade BS-120 powder (GOST 18307-78) in the concentration range from 1.0 to 3.0 wt. % and micro-sized powder cryptocrystalline graphite (CCG) at 8.0 wt. %. Samples for studies were prepared on the cold pressing and free sintering conventional technology.

The PCM mechanical properties study: tensile strength $\sigma_r$ and elasticity modulus $E$ in tension was carried out according to GOST 11262-80 on tensile testing machine “Zwick / Roell” completed with a heat chamber. PCM samples were made from flat slabs of rectangular cross section by stamping in cutting dies. Research methods included the testing of at least four samples for each PCM composition at tensile strain speed 50 mm/min. The study was conducted in the temperature range from 20°C to 180°C. The test results automated processing provided to obtain data with an error of not more than 5.0%.

4. The experimental results
The concentration dependence of the tensile strength and elasticity modulus is shown in Fig.1.

![Figure 1](image1.png)

**Figure 1.** Concentration dependence of tensile strength $\sigma_r$ and elasticity modulus $E$ in tension for PTFE-based composite with 8 wt.% CCG and 3 wt.% BS.

Temperature dependence of the elasticity modulus in tension and tensile strength is shown in Fig. 2.

![Figure 2](image2.png)

**Figure 2.** The temperature dependence of the Young’s modulus $E$ and the tensile strength $\sigma_r$ for PTFE-based composite with 8 wt.% CCG and 3 wt.% BS.
Increasing nano-sized filler concentration results in decrease in tensile strength to 28% and increase in the elasticity modulus by 12% (Fig. 1). In terms of elastic modulus at room temperature the studied PCM should be classified as moderately soft materials (E ~ 20…500 MPa) [8, 9] used in sealing technology with average values of contact pressures and moderate speeds [8]. The combination of moderate hardness with a tensile strength close to the unfilled PTFE value corresponds to materials used in metal polymer tribosystems and allows using them in the reliable sealing elements development that provide high degree of tribo matching tightness when dynamic loads change.

Increasing the temperature from 20°C to 180°C leads to significant non-linear reduction in elasticity modulus and tensile strength – to 4.4 and 2.7 times respectively (Fig.2). Reduced mechanical properties characteristics both as PTFE as PCM on its basis are consistent with the data [10].

The relatively low elastic modulus values contribute to the sealing devices tightness degree rise, it makes it advisable to use PTFE-nanocomposites for making sealing elements of such devices. At the same time the strength characteristics limit the use of these materials in high-tribosystems composites, operating at elevated temperatures.

Reducing the PTFE-nanocomposites mechanical properties characteristics with temperature increasing may be associated with changes in molecular mobility in the investigated composites polymer matrix due to the filler energy impact. As a consequence, the phase transition change of the PTFE elementary triclinic cell type into the hexagonal in the temperature range from 20°C to 45°C is accompanied with the structure reorganization determining the PCM mechanical properties. With further temperature increase above 80°C there is transition slow physic relaxation process connected with the ordered micro areas mobility consisting of a large number of segments (‘defrosting’ relaxation transition of polymer matrix molecular chains micro Brown movement). To identify the filler influence on the polymer amorphous phase supramolecular structure it is necessary to study molecular mobility in the matrix and the considered nanocomposites viscoelastic properties.

5. Conclusion
The study results analysis leads to the following conclusions.

1. Increase in nano-sized modifier concentration in the complex filler content increases the elasticity modulus and decreases the composite tensile strength to 12% and 28% respectively.

2. Raising the ambient temperature from +20°C to +180°C has a significant impact on the PTFE based polymer nanocomposites mechanical properties performance and leads to monotonous and non-linear decrease in the elasticity modulus and tensile strength of the PTFE-nanocomposites in tensile into 4.4 and 2.7 times respectively.

3. The developed PTFE- nanocomposites mechanical properties characteristics make them to be used for the transport systems dynamic sealing devices elements manufacture.

References

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