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## **Study of physico-mechanical and tribotechnical properties of polyamide-based composite materials**

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**Abstract:** In this study, the research of physico-mechanical and tribotechnical properties by including molybdenum sulfide, boron nitride, copperized graphite, was highlighted and considered important in the preparation of polyamide-based coating material. Priority was given to the study of the dependence of the physical-mechanical and structural properties on the composition and fraction sizes of copper-plated graphite, which will be included in the polyamide base before the composition of the material is fully formed.

In the course of the study, three components were determined, consisting of thermoanthracite, copper-plated graphite, molybdenum sulfide, and boron nitride, for the binder, which is considered one of the main issues. Among these components, 24% - thermoanthracite, 6% - copper-plated graphite, 3% - MoS<sub>2</sub> and 1% - boron nitride were optimized. Along with the physical and mechanical properties, the service life was the highest in this composition.

It was found that each filler has its characteristic positive properties. However, it is important to note here that the inclusion of copper-plated graphite in the composition improves thermal conductivity and reduces the heating of the working surface of the material, as well as reduces the coefficient of friction and the intensity of wear, improves mechanical and tribotechnical properties. Determining or optimizing the concentration of fillers included together leads to the required level of tribotechnical properties. It has been shown that the self-lubricating ability of the obtained new composition material in oil-free conditions depends on the nature of the fillers included in it and the method of their introduction.

**Keywords:** piston pump, molder, polyamide base, solid filler, chemical composition, press-mold, paste, physical-mechanical property, structure, tribotechnical property.

### **1. INTRODUCTION**

In many fields of modern technology, polymer and antifriction polymer composition materials are used as the most valuable materials and meet different requirements depending on the operating conditions. They use a large number of fillers for the effective operation of these materials in oil-free friction joints. However, despite the great interest in these materials, polyethylene, polyamide, etc. are still used. An extensive study of the properties of materials is required. The obtaining of polymer-based antifriction composition materials and the study of their properties have not yet been resolved [1].

Of course, it would be difficult to research new composite materials without knowing the production technology, physico-chemical and mechanical properties of the existing materials. These materials work well against abrasive wear. However, the poor thermal conductivity and low mechanical strength of these materials limit their field of application, and various binders and fillers are used to improve their tribotechnical properties.

For this purpose, fluoroplast, graphite and molybdenum disulfide are usually applied [4].

### **2. EXPERIMENTAL DETAIL**

The anti-friction properties were studied by the methods indicated in [1,5] with a sliding speed of 0.5-2 m/s and a pressure of 1-5 MPa under stable loading conditions without oil and with oil.

In order to improve the performance of polyamides in different operating conditions, that is, to reduce friction coefficients, various anti-friction components have been added to their composition. The addition of antifriction fillers does not interfere with the processing of polyamides. A composition with a higher amount of filler (90%) is obtained by mixing polyamides in the form of rubs with the filler in an inert environment. It is known that as a result of effective application of highly dispersed fillers, polyamide composite materials with high antifriction properties can be obtained [6]. It should be taken into account that the value of the coefficient of friction changes depending on the value of the



specific pressure and the condition of the friction surface [7]. This change occurs as a result of increased pressure for polyamides. For example, when the specific pressure increases from 60 Pa to 250 Pa in a polyamide-steel pair (velocity 1.17 cm/sec), the coefficient of friction for kapron decreases from 0.124 to 0.095 (dry friction); It decreases from 0.117 to 0.091 in P-68 [6,7].

When fillers are added to the composition of polyamides, their specific impact viscosity and the elasticity of the material decrease. However, it increases resistance to tension, compression, and bending. The use of polyamide as the basis of the composite material increases the resistance of the composite material to shock loads. Machine parts with high mechanical performance, good antifriction and electrical insulation properties can be made from polyamide P-68. Products made of polyamide P-68 maintain anti-corrosion properties in various chemical conditions - alkaline, oil and hydrocarbon environments. Antifriction properties were studied in different loading regimes at a sliding speed of 0.63 m/s, in oil-free and oil-free conditions [3].

The effect of fillers such as polyamide-based thermoanthracite, graphite and copper on the antifriction properties of polymer-based composite materials, the nature and comparison of the obtained composite materials with other similar materials are still being studied. As we know, samples of polyamide-based composite materials are made by pressure casting. The increased temperature in the friction zone seriously affects the workability of this material and determines the characteristics of its friction and wear process. It can be concluded that the optimal amount of fillers included in polyamide-based compositions to increase heat transfer and improve anti-friction properties has a positive effect on their friction coefficient. The optimal value of the mass amount and the coefficient of friction was determined depending on the temperature [2].

The addition of copper dust to the composition increases the resistance to light, moisture absorption and mechanical durability of the composition, reduces the coefficient of friction and, as a result, allows to increase the service life of the product. Polyamides are easily oxidized due to temperature effects. In the case of an alloy, intensive oxidation significantly worsens its physical and mechanical properties. To prevent this process, stabilizers - aromatic amines, metals (Cu, Cr, Mn) and other substances are added to polyamides. Physico-mechanical properties of polyamide-based composite material were studied using different fillers in a certain composition.

It was clear from the obtained results that PTGC composite materials have high durability and elastic modulus indicators. It has been shown that the working life of crimping rings made from this composition material increases to 500-550 hours [6].

Depending on the type of conditioner used, its construction, working environment, working conditions, etc. basically, they are made of quite different materials. These materials include polymer materials, rubber and elastomers, metals, solid alloys, composite materials, etc. to show can Their physico-mechanical and tribotechnical properties, as well as the technology of making details from them, are also different. Polyolefins (polyethylene, polypropylene, etc.), polyamides, aromatic polyamides, polycarbonates (diflon), fluoroplasts (PTGC) are preferred to the plastic masses filled in the molding technique.

Currently, polymer composites are widely used in machine-building, considering their physical and mechanical properties. The ratio of the components of the widely used composite materials, which are composed of fluoroplast and graphite as a filler, for the production of piston rings, in mass % was as follows [5,6,7].

Fluoroplast.....70÷90;  
Graphite.....10÷30.

The disadvantage of the applied composite materials is that the working time is less than necessary (200÷250 hours). One of the disadvantages of this composite material is that fluoroplast has fluidity at ordinary temperatures. It requires specially designed sealing devices and its lack of high strength limits its wide application.

The conducted analyzes show that according to its technical nature and the achieved efficiency, the closest composition material [6,7] is mainly polyethylene, and the filler is a mixture of thermoanthracite and graphite with the following components (in wt. %):

Polyethylene.....55÷70; 60÷90;  
Thermoanthracite.....25÷40; 25÷30;  
Graphite.....5; 4.5÷9;  
Copper.....-; 0.5±1.

Obtaining new properties by changing the composition of the above-mentioned sealing materials allows to determine the main goal of the research.

When other filler elements included in the base polymer material selected for the molder are kerosene, gasoline, benzene, mineral organic oil, alcohol, etc. ambient operating temperature should be taken into account. In addition, in metallurgical equipment, fillers are applied for preparation of valves of compressor and pump equipment, side fasteners of cuffs, etc.

Purpose of work. The main goal of the research work is to study the dependence of the antifriction properties of the polyamide-based material on the concentration of fillers such as copper-plated

graphite, molybdenum sulfide and boron nitride and the working temperature.

Research methodology. Currently, copper-plated graphite, which is one of the fillers, is preferred during the research, based on the electrochemical method and the selection of optimal electrolysis modes, the process of coating the graphite scrap with copper in a reducing environment. Taking the graphite material used for covering the surface with copper, the electrode graphite was selected as mentioned earlier and its granularity is taken 50; 200  $\mu\text{m}$ . The selected and fractionated graphite powder was prepared separately for each of the above-mentioned fractions in a special device [7,8]. Before starting the process, the graphite scrub to be used was boiled in water for 15 minutes to free it from the impurities and air pores, and then it was filtered and dried.

Unlike the above-mentioned and used materials in the obtaining of the material from the polyamide base, instead of adding the composition graphite and clean copper copperized graphite is inserted. In the first type, before the complete formation of the composition of the material, the dependence of the physical-mechanical properties of the copper-coated graphite filler, which will include polyamide, on the composition and fraction size was studied (table 1).

Table 1: Characterization of a copper-plated graphite filler composition included in a polyamide base

№	Filler	Fraction of graphite scrap, $\mu\text{m}$	Density, $\text{g}/\text{cm}^3$	Hardness HB, MPa	In compression $\sigma_s$ , MPa
1	copper-plated graphite (60%Cu+40% graphite)	50	4,2	170-280	54
2		200	4,8	150-300	50
3	copper-plated graphite (80%Cu+20% graphite)	50	5,1	180-320	60
4		200	5,7	200-380	56

The material that meets the requirements of the research is preferred to include polyamide thermoanthracite, copper-plated graphite,  $\text{MoS}_2$ , boron nitride. The amount of composites is given in mass % as follows.

Polyamide.....63÷69;  
 Thermoanthracite.....20÷28;  
 Copper-plated graphite.....4÷8;  
 $\text{MoS}_2$ .....2÷4;  
 Boron nitride.....1.0÷1.0.

P-68 material GOST-10589 industrial polyamide and various fillers were used for the preparation of composite material. The proposed composite material is prepared in the following manner: the calculated amount of polyamide ( $d=3\div4\text{mm}$ ,  $l=5\div6$  granules, with particles  $2\div2000\ \mu\text{m}$  in size) is placed in a thermoanthracite press-mould, heated to  $250\text{-}260\ ^\circ\text{C}$  and then mixed.



Fig. 1. Pressing the material filled in the press mold in a hydraulic press

A predetermined amount of copperized graphite,  $\text{MoS}_2$  and boron nitride was added to the molten mass. The well-mixed mass is pressed at a pressure of 80-100 MPa (figure 1), the cooled mixture is crushed on a lathe to a size of 2-3 mm.

In order to ensure uniform distribution of the filler on the basis of polyamide (figure 2), the composite material is reheated  $20\text{-}30\ ^\circ\text{C}$  above the melting temperature, the melted material is mixed and pressed again with a pressure of 80-100 MPa. From the obtained material, a mixture, a sample (pictures 3 and 4) and a finished product were obtained for research (figure 5).

The main parts of the mold are the punch (the upper part of the mold) and the matrix (the lower part of the die). In the upper plane of the press-mold, a chamber-crucible is installed (shown as a broken line in Fig. 2), which the press-mold is loaded into. The material is heated to a viscous fluid state, flows from the pouring hole into the forming mold cavity under the pressure transmitted through the punch of the press. The chemical composition of the received conditioner is shown in table 2.

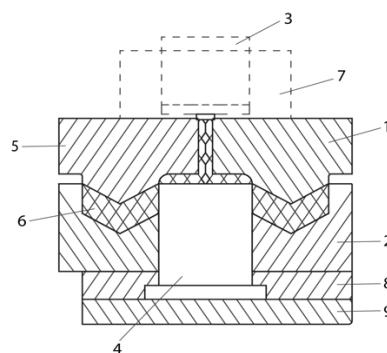


Fig. 2. Schematic view of the press-mold for obtaining the molded part:

1- mold punch; 2-matrix; 3-loader poinson; 4- stuffing; 5-pour hole; 6-detal; 7-kamera tiqel

In order to ensure uniform distribution of the filler on the basis of polyamide (figure 2), the composite

material is reheated 20-30 °C above the melting temperature, the melted material is mixed and pressed again with a pressure of 80-100 MPa. From the obtained material, a mixture, a sample (figures 3 and 4) and a finished product were obtained for research (figure 5). The main parts of the mold are the punch (the upper part of the mold) and the matrix (the lower part of the mold). In the upper plane of the press-mold, a chamber-crucible is installed (shown as a broken line in Fig. 2), which the press-mold is loaded into. The material is heated to a viscous fluid state, flows from the pouring hole into the forming mold cavity under the pressure transmitted through the punch of the press. The chemical composition of the received conditioner is shown in table 2.

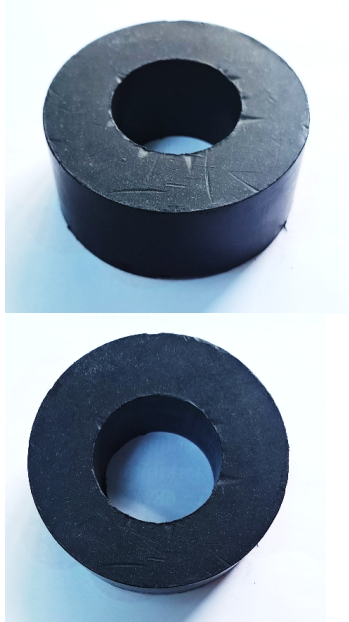


Fig. 3. Primary mixture material

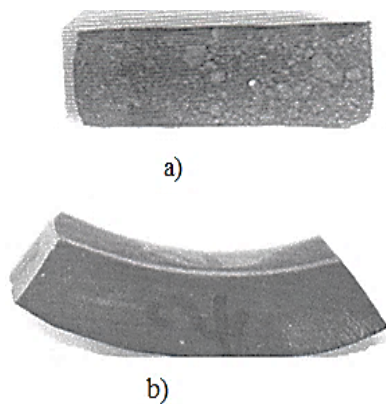


Fig. 4. Research samples obtained in the form of prismatic (a) and pad (b).



Fig. 5. Molding detail

Table 2. Dependence of physico-mechanical properties of composition materials for molding on chemical composition

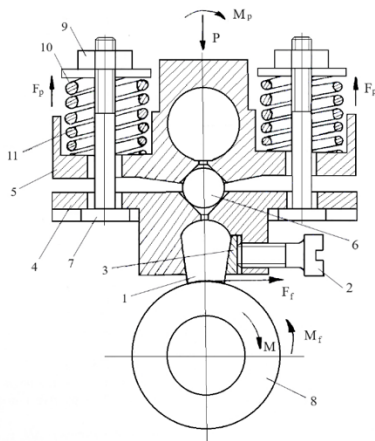
Composites	Chemical composition, mass %		
	1	2	3
Polyamide	63	66	69
Thermoanthracite	28	24	20
Copper-plated graphite (80% Cu+20% graphite)	4	6	8
MoS <sub>2</sub>	4	3	2
Boron nitride	1,0	1,0	1,0

A new layout [9,10] with a design change was used to install the research sample pad on the CMI-2 friction machine (Fig. 6). This arrangement, on the one hand, ensures a free and smooth self-assembly of the pad sample under load, and on the other hand, at sufficiently large frictional forces, it allows creating resistance to the resulting moment and keeping the pad sample. Stainless alloy steel 07X16H6 was used as a contour sample. The hardness of the sample is 36 HRC and the roughness of the surface is Ra=0.63 μm.

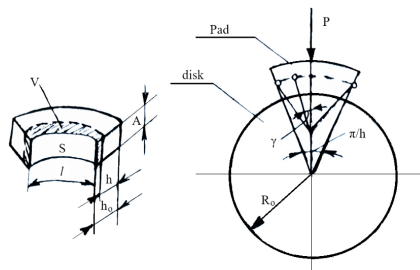
A tight contact of the friction surfaces of the samples along the entire surface is obtained, which is necessary when evaluating the load-carrying capacity of the responsible parts. At the same time, the selected scheme and research conditions for the study of tribotechnical properties allow to bring the experiment closer to real working conditions. The linear dimensions of the pad sample were determined before and after the test. In the process of eating the pad sample, the geometric shape and area of the contact area changes (Fig. 7). The volume of the eaten layer and the contact area of the pad samples are determined by the following formula:

$V = 2AR_0h \cdot \sin(\pi/16)$ ;  $l = 2\gamma R_0$ ;  $S = l \cdot A$   
 Here, V - the volume of the worn layer of the pad sample; S - contact area of the pad sample; A - the thickness of the tested pad sample; R<sub>0</sub> -

radius of contour pattern;  $h$  – the area of the eaten layer;  $l$  is the length of the segment.



**Fig. 6.** Design for the CMI-2 machine for friction testing of samples: 1- pad sample; 2 – stopping screw; 3 – clamping support; 4-prism; 5 – trunk; 6 – bracket (elbow); 7 – assembly bolt; 8 – ring; 9 – nut; 10 – puck; 11 - springs



**Fig. 7.** Scheme of the sample for the study of tribotechnical characteristics of molding materials

**Research part.** There are such compositions in polymer materials, which are obtained by adding new antifriction additives. Fillers with a layered anisotropic structure (coppered graphite, molybdenum disulfide, boron nitride, etc.) have a special place among these additives. There are different points of view on the lubricating action mechanism of copper-plated graphite, molybdenum sulfide, and boron nitride, which have a layered crystalline structure. Basically, it is considered that the mechanism of action of these substances is explained by the effective force of communication between individual crystal layers and atoms (molecules). In the elementary crystal lattice of copper-plated graphite,  $\text{MoS}_2$  or boron carbide, there are strong bonds between atoms (molecules). However, the communication between individual atomic layers is much weaker. As a result, very little tangential force is spent on sliding the layers relative to each other, in other words, the friction coefficient is small. Undoubtedly, the interaction of solid lubricant with water vapor, air, ability to absorb electric sparks, etc. plays a certain role. In fact, in the friction process determined as a result of

physico-mechanical damage occurring in contact, not the material added to the main material, but the lubricating coating formed from a new lubricating substance participates.

It is known that graphite, which has a layered crystalline structure, consists of an alternating hexagonal hexagonal lattice in which covalent atoms are located. The distance between layers is 0.34 nm, and the distance between atoms in a layer is 0.14 nm. The layers are oriented relative to each other in such a way that three atoms of the hexagon of one layer fall on the vertices of the next hexagon [11,12]. Bonds between atoms within a layer are much stronger than bonds between layers. Due to this, obvious anisotropy is noticeable in graphite. Thus, graphite does not form endless plates (planes) formed from hexagons, but  $\sim 20\text{nm}$  scales are formed in its structure. The layered structure allows graphite to be easily deformed along the plane of the layers.

The presence of copper-plated graphite and its influence on physical-mechanical and operational properties during its deformation have not yet been evaluated. The addition of boron nitride instead of or together with copper-plated graphite and  $\text{MoS}_2$  is very promising. The coefficient of friction of boron nitride with a layered crystal lattice is higher than that of copper-plated graphite and  $\text{MoS}_2$ . Boron nitride is also sensitive to thermal processing in vacuum. Its friction coefficient increases from 0.12 to 0.45 when heated at 200-700 °C under the conditions of  $5 \cdot 10^{-4}$  mm mercury column. It gives a great effect in the production of friction and anti-friction materials. The use of copper-coated graphite, rather than graphite, with these fillers is research that has not been conducted to date. As with many different named materials, the incorporation of non-metallic filler graphite plays a role in shaping the structural properties of polymer-based materials. Graphite is also freely incorporated in many polymer-based materials. However, in many materials, it does not give its effectiveness as much as it should. Despite this, the issue of including graphite in the copper-plated form in the preparation of sealing details can have its effect. Also, depending on the type of material and the field of application, graphite is included in the composition in different mass amounts. However, the fact that high amounts of graphite cannot be added to the slag without harming the mechanical properties of the composition and the cases of structural inhomogeneity after baking make it possible to conduct additional research in the field of composition materials preparation [13,14].

The main innovation in the materials obtained from the specified composition is the use of polyamide as the basis, as well as the inclusion of fillers - copper-plated graphite and boron nitride with  $\text{MoS}_2$ . The inclusion of polyamide in the composition makes the composite material resistant to shock loads.



The inclusion of copper-plated graphite as a filler prevents destruction, as well as increasing resistance to heat transfer, light and moisture changes. The even distribution of surface-coated graphite in the volume allows to increase the amount in the composition. It increases the service life of the sealing by increasing its resistance to being worn.

As an element of various types of molding structures, it is possible to show the molded surfaces and the details that carry these surfaces. The working capacity of molding structures depends on the material from which they are made: operational conditions, structural, technological, and other factors.

Materials from this group can be used in a light mode, since the strength limit for side fasteners of the selected object is small in specific compression. For the operation of such binders in medium and heavy modes, it is required to increase the density  $\sigma_m$ ,  $\sigma_m^s$ , modulus of elasticity (E), working temperature and hardness. For this purpose, layered anisotropic structured graphite inserted into the base (sonar without copper) allows obtaining a material that works in polymers (polyamide) called molybdenum disulfide and boron nitride. The dependence of the mechanical-physical properties on the content of the received filler materials is shown in table 3, considering the purchase and justification of these fillers as one of the most important studies.

**Table 3: Dependence of mechanical-physical properties on the amount of molding material**

Mechanical-physical properties	1	2	3	Analogue
				PTGC (polyamide, thermoanthracite, graphite, copper)
Density, g/cm <sup>3</sup>	1.46	1.25	1.73	1.3
$\sigma_m$ , MPa	80-90	72-97	100-120	32
$\sigma_m^s$ , MPa	120-150	135-165	150-180	110
Modulus of elasticity, MPa	1200	1050	900	250
Firmness, MPa	74	85	128	62
Working time, hours	620	980	850	550

From the data in Table 3, it can be seen that the proposed composite material has high strength and flexibility, and it was 550 hours in PTGC, while it allowed to increase the working time of the sealing rings to 620-980 hours.

The physical and mechanical properties of the materials shown in Table 3 provide a full opportunity for a comparative study of the properties of the new material. As shown above, the antifriction properties can only be adjusted with different lubricants from this basis.

The advantage of molybdenum disulfide among the specified solid lubricants is that the coating formed on the friction surface reduces wear, eliminates adhesion and adhesion. Its physical and chemical properties have been fully studied by researchers. It is usually used in the form of coppered graphite, boron nitride and MoS<sub>2</sub> powder, or it is injected into a certain depth of the surface as a lubricant by the rotaprint method. As a result of this study, the characteristic properties of the materials obtained as

a result of including MoS<sub>2</sub> and boron nitride in the matrix together with copper-plated graphite were determined.

As a result of the research, 6% of copper-plated graphite, 3% of MoS<sub>2</sub> and 1% of boron nitride included in the composition material were determined. The optimization was carried out according to the linear decay [15] with the help of a special formulation. In the specified optimal composition, the linear wear intensity was 150-200  $\mu\text{m}/\text{km}$ , the working temperature was 150-200 °C, and the friction coefficient was 0.07-0.10. In the specified temperature interval, the softening process did not occur in the composition material. It is shown that the indicated materials do not have a coefficient of friction in the work process under oil-free conditions.

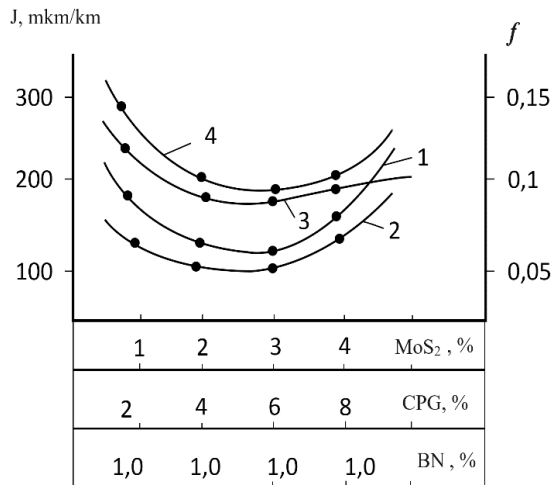
Depending on the increase of 6-8% of copper-plated graphite and 3-4% of MoS<sub>2</sub> as a filler on the basis of polyamide, the lack of necessary level of hardness leads to deformation of the surface during friction. For this reason, the coefficient of friction is high. Since polyamide, which is the basis of the studied material, is a material with the necessary hardness, the inclusion of MoS<sub>2</sub>, boron nitride and copper-plated graphite with a special technology made it possible to obtain both the hardness and the necessary coefficient of friction at favorable prices.

The inclusion of copper-coated graphite improves heat transfer and reduces the heating of the working surface of the material, as well as reduces the coefficient of friction and the intensity of wear, improves mechanical and tribotechnical properties. Therefore, determining or optimizing the concentration of fillers leads to the required level of tribotechnical properties.

The presented polyamide material is often applied in its pure state. This material has good chemical resistance. One of the characteristics of this material is that it has a good thermal conductivity index and tribotechnical characteristics improve as the temperature increases. Thus, copper-plated graphite, MoS<sub>2</sub>, boron nitride fillers eliminate the occurrence of defects.

In the process of rubbing on this composition, it creates a thin coating layer on the outer surface that improves the coefficient of friction. The homogeneity of the microstructure relative to PTGC is still maintained on the non-friction sonar surface. At this time, during friction, the temperature in the working zone is 100-150 °C.

In these compositions and regimes, the linear wear during friction was 100-150  $\mu\text{m}/\text{km}$  and the coefficient of friction was low. The inclusion of fillers in a high content disrupts the homogeneity in the structure, and the coefficient of friction and linear wear begin to increase compared to the optimal norm

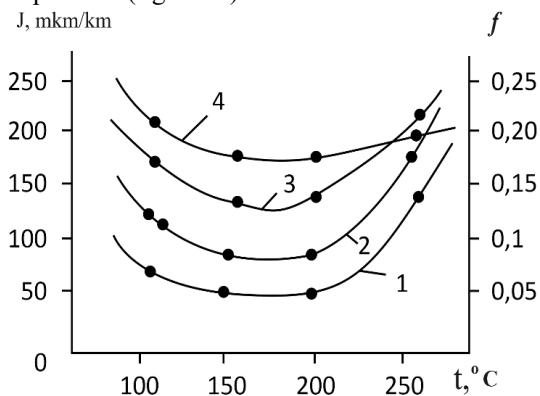


**Fig. 8.** The graph of the dependence of linear erosion on the concentration of the filler: 1, 3-friction coefficient; 2, 4-linear wear; 1, 2-studied; 3, 4-PTGC (comparable)

It can be concluded from the research that fillers (coppered graphite, MoS<sub>2</sub> and boron nitride) introduced in certain optimal amounts to increase heat transfer and improve antifriction properties have a positive effect on the friction coefficient of the material (Figure 8).

It has been shown that the self-lubricating ability of the composite material under oil-free conditions depends on the nature of the fillers included in it.

At the same time, with the help of the conducted research, the amount of filler and base material in the composition material was determined depending on the linear wear, and the value of the friction coefficient was specified depending on the working temperature (figures 9).



**Fig. 9.** The graph of the dependence of the coefficient of friction and linear wear on the working temperature of the material: 1, 3-friction coefficient; 2, 4-linear wear; 1, 2-studied; 3, 4-PTGC (comparable)

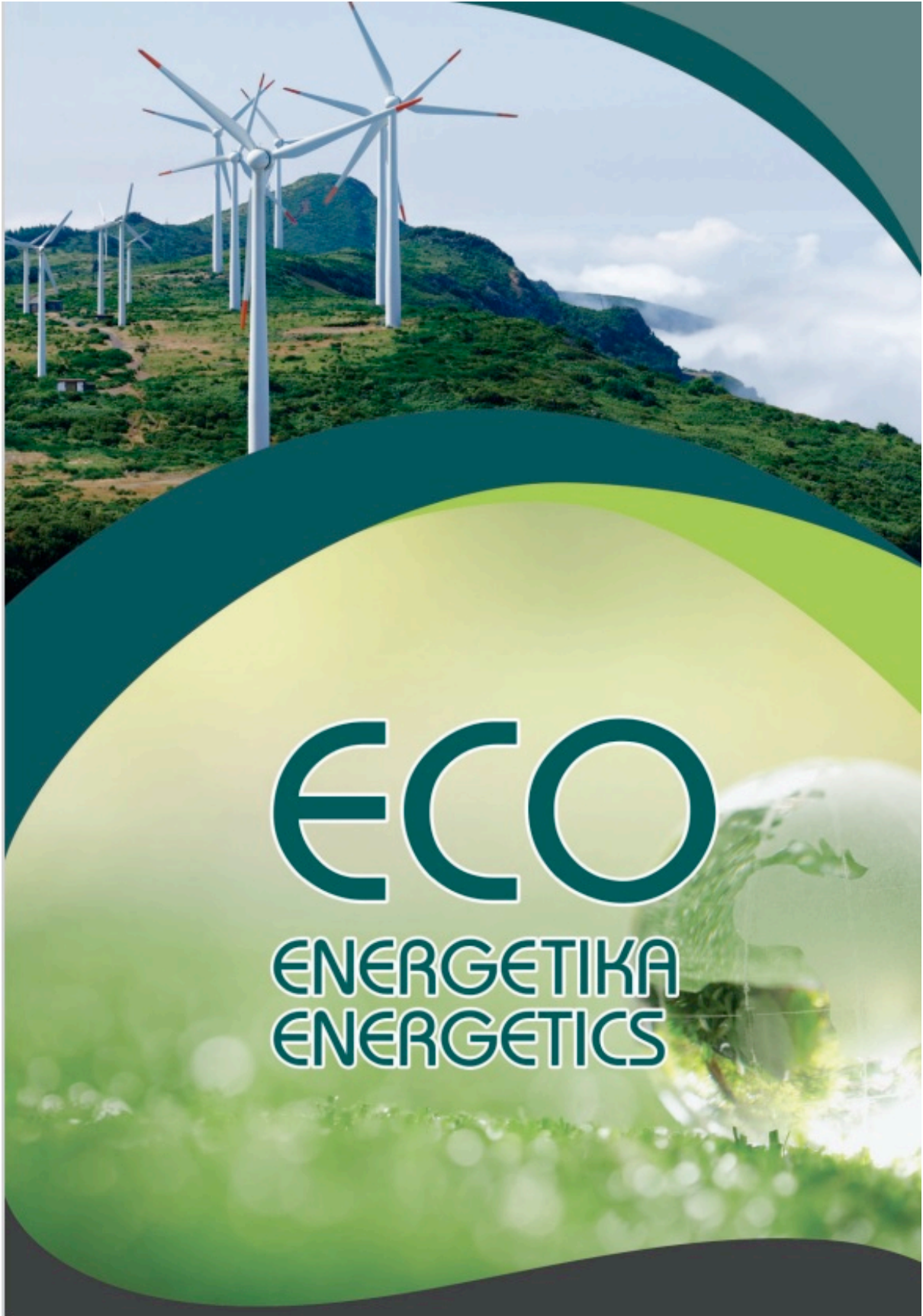
### 3. CONSOLUSION

1. It has been found that in the production of various details, including fasteners, in machine building, taking into account the physico-mechanical and tribotechnical properties, the use of antifriction materials with new fillers has been widely used.
2. It was determined that the study of the nature of the various fillers and methods of introduction used in the production of polyamide coating material shows its effect on the obtained properties. Similarly, the introduction of copper-plated graphite and anisotropic boron nitride fillers into known materials has achieved new results.
3. As a result of the research, it became clear that the copper-plated graphite MoS<sub>2</sub> and boron nitride fillers included in the polyamide base eliminate all the deficiencies on the surface and inside of the antifriction material.
4. When filler composition materials - thermoanthracite, copper-plated graphite, MoS<sub>2</sub> and boron nitride are included in the composition of polyamide, it is possible to reduce its coefficient of friction by 1.5-2 times, and the intensity of corrosion by 1.3-3.2 times. It was determined that the working life of the sealing rings obtained from this composition material increased to 620-980 hours and 1.8 times the advantage was gained.

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