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PRACTICE OF USING PARTS MADE OF THE HEAT-RESISTANT POLYMER COMPOSITES IN THE CHEMICAL INDUSTRY AND AGRICULTURAL ENGINEERING

Kabat O. S.[1,2], Kobets A. S.[1], Derkach O. D.[1], Makarenko D. O.[1] and Hnatko O. M.[2]
[1]Ukrainian State University of Chemical Technology, Gagarin Ave, Dnipro, Ukraine
[2]Dnipro State Agrarian and Economic University, Serhiy Yefremov St, Ukraine
E-Mail: flymakd@gmail.com

ABSTRACT

The authors of the article developed polymer composites based on aromatic polyamides, fluoropolymers, and phenolic resins, which have higher physical and mechanical properties than such construction materials as bronze and babbitt. These details, also have similar properties to carbon steels, and in terms of tribological properties, they are significantly superior to them. Polymer composite materials (PCM) were obtained by standard technology, as well as by combining (in situ) the initial components of polymer compositions. The effectiveness of the use of parts from the developed PCM in friction and sealing units of machines and mechanisms of the chemical and agricultural industry has been confirmed. These are the details: sealing of the cantilever shaft of the anchor stirrer; sliding bearings of the soil copying mechanism of the John Deere 1780 seeding machines and the damping mechanism of the cultivator's arrow paw; guide bushings of the movable traverse of the hydraulic press for polymer processing; overlays on the sliding guides of the moving table of the grinding machine (ОШ 143).

Keywords: polymer composites, physical-mechanical and thermophysical properties, friction nodes, sliding bearing, chemical and agricultural engineering, friction and wear, coefficient of friction.

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INTRODUCTION

The modern industry of the developed countries of the world provides a wide range of products in all areas of human life. Its intensive development is due to the high demand for basic consumer products. High-production equipment, which allows for obtaining a significant number of products in a short period, plays an increasingly important role in ensuring demand [1, 2].

To ensure the reliable and durable operation of such equipment, it is necessary to use modern achievements of science and technology. A radical change in the design of the equipment can improve its performance, but this is quite a difficult task. It also requires significant expenditure of human and material resources over a long period. Therefore, this approach is not always rational. Replacing the materials of structural elements with more modern ones allows improving its performance with relatively small capital costs in a short period.

One of the most advanced materials in modern human development is polymers and polymer composite materials (PCM) based on them [3-6]. Their use in modern equipment is steadily increasing, and soon, will supplant such traditional construction materials as metals and alloys based on them. According to the analysis of the BBC Research Report Overview “Engineering Resins, Polymer Alloys, and Blends: Global Markets” from April 2022 until now, the global market for construction polymers and composites based on them will increase from $70.7 billion in 2021 to $94.0 billion by 2026 year. Such an increase in the number of parts made of polymers in modern equipment is due to their sufficient level of physical and mechanical properties, low weight, high level of chemical resistance, the possibility of working in friction nodes without lubrication, etc. The disadvantages of details made of polymers include their low level of heat and thermal resistance. Therefore, the development of (PCM) to produce parts of modern equipment that have a sufficient level of heat and thermal resistance is an urgent task of materials science and mechanical engineering. Comprehensive studies of the characteristics and properties of new PCMs, and the positive experience of their implementation in the tribo-coupling of mechanisms and machines, is a prerequisite for the industrial use of the proposed solutions.

ANALYSIS OF LITERARY DATA AND STATEMENT OF THE PROBLEM

The implementation of PCM in tribo-coupling allows for increasing the resources and durability of the equipment. The main direction of increasing the physical and mechanical characteristics of PCM is the introduction of fillers into their composition. This allows you to adapt their characteristics and properties to specific operating modes. Polymer composite construction materials based on polytetrafluoroethylene (PTFE), polyamides, and phenolic resins have become the most widely used. The main direction of improving the characteristics of these materials is the introduction of fibrous and dispersed fillers into their structure. In [7], the results of the tribotechnical properties of PCM based on PTFE and dispersed copper powder obtained by explosive pressing are given. The proposed technology for obtaining composite material significantly reduces the coefficient of friction and the amount of wear compared to the original material. However, the paper states that the maximum thickness of the part (workpiece) when using the proposed technology should not exceed 15 mm. In addition, the study of the tribotechnical properties of the obtained PCM was carried out in a narrow range of pressure on the sample - up to 0.75 MPa, which limits the scope of their application. It is possible to solve the problem of expanding the range of working pressure and linear speed of sliding, PCM based on PTFE, by introducing fibrous fillers. This method was used in work [8], in which the introduction of carbon fiber (BB), processed in a plasma environment, into PTFE is proposed. The article proves the effectiveness of introducing modified carbon fiber into the structure of finely dispersed PTFE. However, the technology of obtaining such filler involves the use of special expensive equipment, which leads to an increase in the cost of the obtained PCM. One of the methods of solving this problem is the development of a technology for obtaining PCM, based on PTFE and carbon fibers, which has a low cost and at the same time provides the necessary characteristics of the developed materials. This approach is described in work [9], in which the technology of obtaining PCM, based on PTFE and CF, in the environment of a rotating electromagnetic field is proposed. However, the works listed above are aimed at solving the problems of improving the physical and mechanical characteristics and tribotechnical properties of PCM based on PTFE, and the possible areas of use of the obtained materials are declarative.

In [10], the technology of processing phenylone by impact-explosive pressing is proposed. This technology makes it possible to obtain monolithic samples with increased physical and mechanical characteristics, in comparison with the usual processing technology (pressing). However, the disadvantage of the proposed technology is the small height of the workpiece (parts), which can be produced - only up to 10 mm. This problem can be solved by introducing fibrous fillers, which lead to the effect of reinforcing the matrix of aromatic polyamide-phenylene. This method was used in work [11], in which the introduction of nanostructured carbon-fullerene C60 into the structure of phenylene.C2 was proposed. This approach made it possible to increase the strength characteristics of PCM several times. At the same time, the study found that the optimal concentration of the filler is 1.5 wt. %. The disadvantage of this method is the need to use special equipment to ensure uniform distribution of a small amount of filler in the matrix. Moreover, the selected filler has a high cost, which is 50–60 $ / g. As a result, the cost of obtaining finished products increases. One of the directions for solving this problem is the use of fillers that provide the necessary characteristics. At the same time, their concentration in the matrix is much higher. For example, in work [12] it is proposed to use sulfon -T fiber as a filler for phenylone C1. The results of the study confirmed the reduction of wear at the optimal concentration of the filler 10 mass. %. However, the cost of such a filler is quite high, and as a result, it also leads to a significant increase in the price of the obtained PCM. It is possible to solve the task of improving the characteristics and ensuring the necessary properties of PCM by introducing inexpensive and non-deficient fillers. Such an approach was used in work [13], in which it was proposed to introduce silica gel into the matrix of Phenylone C1. The proposed solution makes it possible to increase the *physic*-mechanical and tribological properties of the obtained PCM, ensuring their moderate cost. Usually, investigations of the characteristics and properties of new or modified PCMs are performed under certain fixed modes. While the real modes of operation of moving joints of mechanisms and machines are dynamic. In addition, the task regarding the effectiveness of the introduction of the developed PCM into the equipment nodes and their impact on durability remained unsolved.

Based on the conducted analysis, there are reasons to believe that research devoted to the introduction of developed PCM into tribo-coupling of equipment in the chemical and agricultural industry is relevant.

MATERIALS, TECHNOLOGIES FOR OBTAINING PCM, AND METHODS OF THEIR RESEARCH

Aromatic polyamide (copolymer of polymeta- and polyparaphenyleneisophthalamide), fluoropolymer (polytetrafluoroethylene), and phenolic resin based on diphenylolsulfonformaldehyde oligomer were selected as polymer bases.

Materials based on carbon (technical carbon, raffite) and silicon dioxin (white carbon black, aerosol, silica gel) of various brands and modifications were used as fillers. All these materials are characterized by small sizes from 5 to 20 μm and a developed specific surface area of up to 380 m^2/g.

Samples for experiments and products from the developed PCM were obtained according to the following method:

- obtaining polymer compositions;
- compression pressing (for PCM based on aromatic polyamide and phenolic resin) or sintering (for materials based on PTFE);
- mechanical processing (for finished PCM parts).

Polymer compositions were created according to standard methods and combining (in situ) their initial components [14, 15]. The processing of the obtained polymer compositions into products for materials on different polymer bases differs from each other. Their optimal processing parameters are given in previous studies [16, 17].

The density (ρ) of polymers and PCM based on them were determined according to ISO 1183 using the method of hydrostatic weighing on analytical balances VLR-200, with a module for hydrostatic weighing.

The stress at the limit of fluidity (σ_y) and the elastic modulus (E) during compression of the original polymers and PCM based on them were determined according to ISO 604 on a universal tearing machine 2167 P-50.

The hardness (HB) of the materials was determined by the ball indentation method on the 2013 TSHSP hardness tester by ISO 2039-1.

The softening temperature for Vickas TVC was determined on the FWV-633/10 instrument by ISO 1183-1.

Temperature resistance (the temperature *at* the beginning of active destruction) of the research objects was determined using the method of thermogravimetric analysis, by ISO-11358, by methods of scanning temperature and time on a TGA Q50 derivatograph.

The linear thermal expansion α of materials was measured by GOST 15173-70 on the DKV-4 device.

The coefficient of friction (f) and the intensity of linear wear (Ih) during the frictional interaction of the developed polymers and PCM based on them with steel were determined on the 2070 CMT-1 machine in the friction mode without lubrication according to the disc-pad scheme. A steel sample made of the steel 45 with a roughness of Ra = 0.32 μm and a hardness of 45-50 HRC was used. The friction surface temperature (T) was determined using a chrome-alumni thermocouple connected to a MASTECH MS 6514 measuring device.

THE RESULTS OF RESEARCH INTO THE CHARACTERISTICS AND PROPERTIES OF THE DEVELOPED MATERIALS

Heat-resistant PCMs based on aromatic polyamide, fluoropolymer, and phenolic oligomer, which are filled with different amounts of materials based on carbon and silicon dioxide, have been developed. The materials were obtained by standard technology and combining (in situ) the initial components of polymer compositions. Table 1 shows the results of the research into the properties of the developed materials.

The developed PCMs have higher structural materials, such as bronze and babbitt, in terms of physical and mechanical characteristics. It also had properties close to those of carbon steel. Their density values are 3-4 times lower than those of the most common structural materials (metals and their alloys), which significantly reduces the weight of parts. Parts from the developed PCM can work under static and variable loads up to 280 MPa, ensuring reliable and long-lasting operation of the nodes in which they are installed. Taking everything into consideration we should note that the developed PCM in terms of physical-mechanical, thermophysical, and tribological properties exceed the best foreign analogs based on polymers (Noryl, Torlon, etc.).

That is, developed PCM based on aromatic polyamide, fluoropolymer, and phenolic oligomer, filled with finely dispersed materials based on carbon and silicon dioxin, can be recommended for use in structural components of machines and mechanisms. They provide performance at high temperatures and can withstand high loads instead of the most common structural materials (metals and alloys).

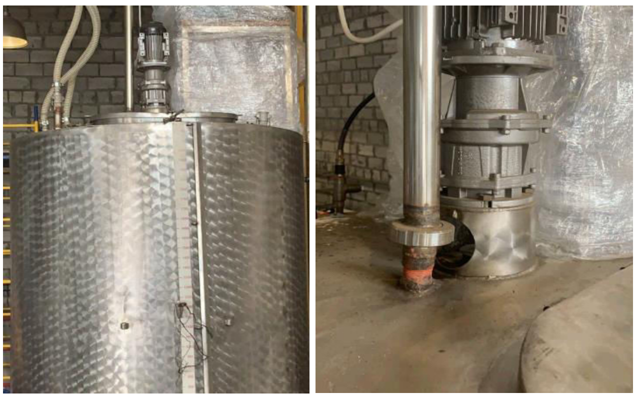
Table-1. Table of physical-mechanical, thermophysical, and tribological studies of the properties of developed polymer composite materials with foreign analogs, steels, and metal alloys [18-21].

Indicator	**Properties**						
	Polymer composite materials based on			**Carbon steel**	**Babit, bronze**	**Analogs based on polymers** **марка**	
	aromatic polyamide	**fluoropolymer**	**phenolic oligomer**			**NorylG TX**	**Torlon, DuratonT**
Density, kg/m^3	1375-1575	1950-2000	1500-1900	7700-7900	7000-9000	1050-1210	1350-1450
Stresses at the yield strength in compression σ_y, MPa	260-280	20-35	140-180	210-260	50-120	60-90	160-180
Modulus of elasticity E, MPa	3450-3600	1250-2000	4000-4500	20000	10000	2000-5000	4500-5000
Hardness HB, MPa	200-250	50-67	250-300	190-250	-	-	-
Temperature by Vicka T_{VC}, °C	290-330	210-300	-	Більше 1000	300-440 (melting point)	190-220	270-280
Temperature of the beginning of active destruction, °C	355-380	465-480	340-370	-	-	-	-
Coefficient of thermal linear expansion α, ×10^{-7} 1/°C	310-330	320-500	210-270	100-120	150-220	600-800	250-300
Tribological properties (friction without lubrication, load P=1 MPa, velocity V = 1 m/c):				Does not work with friction without lubrication	Does not work with friction without lubrication		
Coefficient of friction f	0,15-0,25	0,12-0,20	0,45-0,65			-	-
Intensity of linear wear I_h,×10^{-9} m/m	5	2	40			-	-
Temperature on the friction surface T, °C	65-80	40-55	100-140			-	-

RESULTS OF IMPLEMENTATION OF DEVELOPED HEAT-RESISTANT POLYMER COMPOSITES

The parts made from the developed PCM were introduced into the equipment of industrial (TOV "T CORP GROUP", LLC "Khimpostach Dnipro", LLC "Inter Avia Invest") and agricultural (TOV "Kodatike-Agro", NPP Soyuz-Composit) enterprises of Ukraine.

Production studies of parts made of developed PCM based on fluoropolymer were carried out at T CORP GROUP LLC. A bushing made of the developed material is installed in the friction and sealing unit of the cantilever shaft of the anchor stirrer (Figure-1) of the line to produce technical emulsions.



(a) (b)

Figure-1. General view of the anchor stirrer (a) and friction and sealing unit of the anchor stirrer (b).

Based on production tests, the parts made of the developed material worked in friction and sealing nodes of the cantilever shaft of the anchor stirrer (Figure-2) for 22 months, while creating the required level of sealing of the device and working without failures.

Experimental details of the developed PCM based on fluoropolymer for the friction unit and sealing of the cantilever shaft of the mechanical mixer are presented in Figure-2.

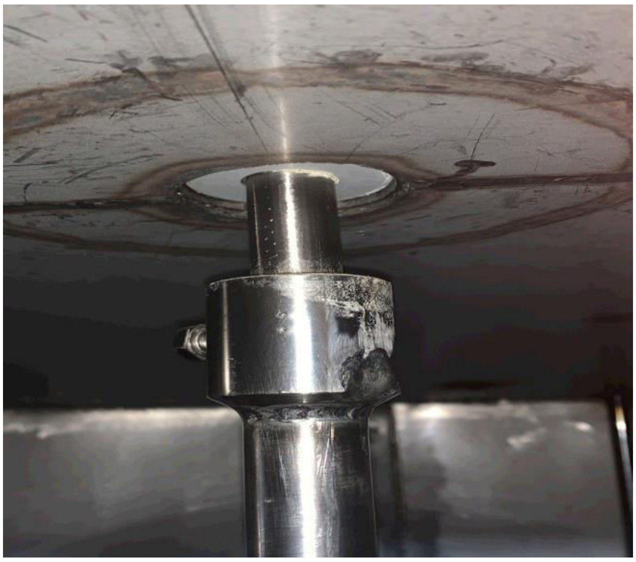


Figure-2. The unit of friction and sealing of the cantilever shaft of a mechanical mixer with an installed experimental sleeve made of PCM based on fluoropolymer and silica gel.

According to the data sheet for the mechanical stirrer, the standard parts (supplied with the stirrer) should be replaced once every 6 months. Due to this fact, the use of parts from the developed PCM allows you to increase the overall durability of the friction and sealing units of the cantilever shaft of the anchor stirrer by 3.7 times. As a result, the following were reduced: the number of planned and preventive repairs, time spent on idle equipment, and costs for the purchase of repair equipment from the equipment supplier. In 2019, the economic effect of the implementation of the developed PCM amounted to 21 thousand hryvnias per year per one unit of equipment. Testing of parts from the developed PCM in the friction nodes of the John Deere 1780 seeding complex was carried out (Figure-3). This unit has 25 sowing sections, which have a system of copying the soil surface of the "parallelogram" type. Each sowing section has 16 movable joints. Therefore, there are 400 friction nodes on the entire sowing complex.

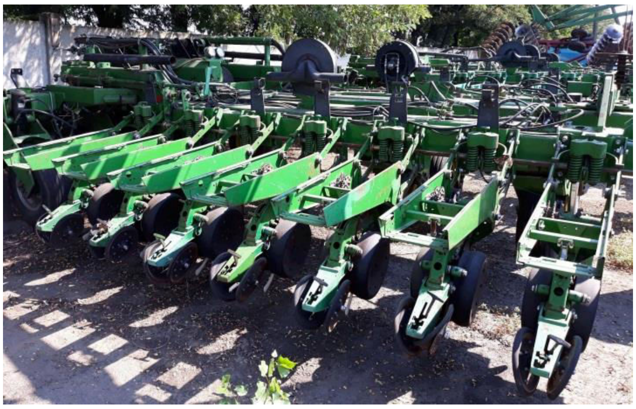


Figure-3. John Deere 1780 sowing complex (in storage during downtime).

In these hinges, parts made of polymer composite material UPA 6-30 (TU 6-12-31-654-89) are used as bushings of sliding bearings. The average service life of these units of the sowing complex is 10,000 hectares. Under the conditions of the KODATSKE-AGRO LLC agricultural company, the specified seeding complex achieved this development within two years. According to this fact, every two years, its planned repair takes place, which involves the maintenance of friction nodes, during which all polymer parts are replaced with new ones. The estimate of this repair for 2019 was from 90 to 100 thousand hryvnias.

Therefore, increasing the reliability and durability of the friction units of the sowing complex is an urgent task, the solution of which will save money on planned repairs. PCM based on aromatic polyamide is proposed as a material for the production of parts of friction nodes of sections of the sowing complex. According to laboratory studies, these materials are significantly superior to the UPA-6-30 material in terms of physico-mechanical, thermophysical, and tribotechnical properties, but cost 20% more [13].

Polymer parts from the analog (UPA-6-30) and the developed PCM based on aromatic polyamide are made from blanks using turning. In fig. 4 shows the general view of "mushroom" type details.

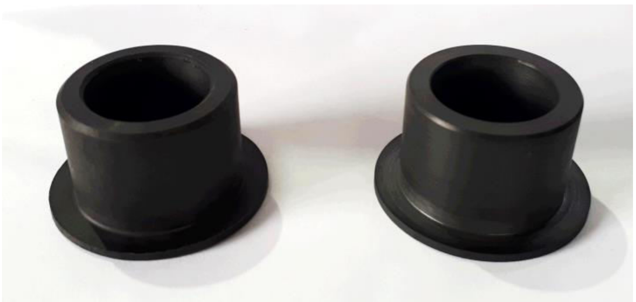
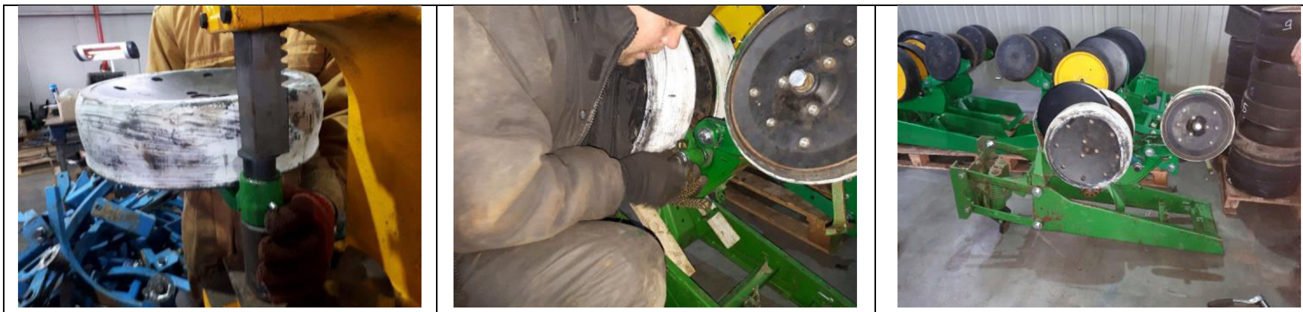


Figure-4. Bushings of the sliding bearings of the sections of the John Deere 1780 sowing complex of the "mushroom" type from the developed polymer material based on aromatic polyamide.

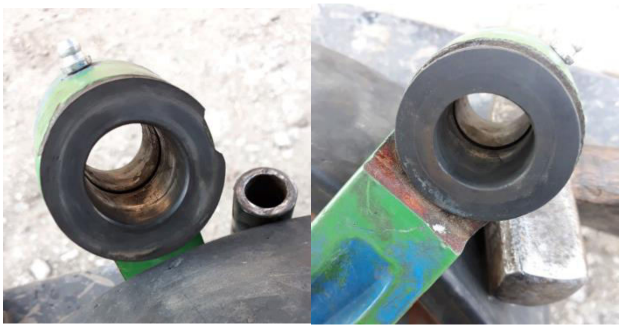
The resulting parts were pressed into the clamps of the levers of the sections of the John Deere 1780 seeding complex (Figure-5 a) and assembled according to the same technology (Figures 5, b, c).



(a) (b) (c)

Figure-5. Pressing the bearing with PCM into the lever of the copying mechanism of the John Deere 1780 sowing complex (a), installation of levers on the sowing section (b), and sowing section in assembly (c).

Replacing parts from UPA 6-30 with the developed PCM made it possible to increase the durability of the friction units of the seeding complex. When it is disassembled during the current repair (after 2 years of operation), chips and scratches are observed on the parts of the UPA 6-30, which are a consequence of the beginning of their emergency wear, which can lead to the destruction and jamming of the friction nodes (Figure-6). Therefore, they were replaced with new ones. The parts from the proposed material do not have such damage and remain working in friction nodes.



(a) (b)

Figure-6. The state of the experimental parts after cultivation of 10,000 ha of the John Deere 1780 sowing complex the part is made of UPA-6-30 (a) and of developed PCM based on aromatic polyamide (b).

The next disassembly of the sowing complex took place one year later, and it was established that the parts from the developed PCM did not have significant damage on the surface. At the same time, the inner diameter of the sleeve has almost reached the maximum allowable size, so, these parts need to be replaced. According to the conducted production experiments, it was established that parts based on aromatic polyamide retain their performance for one year longer, compared to parts made from UPA 6-30. This makes it possible to increase the working time before major repairs from 10,000 ha to 15,000 ha (on average once every 3 years). If the average service life of the sowing complex is 12 years, the developed materials will allow the elimination of 2 capital repairs, which will significantly reduce operating costs.

The economic effect of the introduction of parts, made of developed materials based on aromatic polyamide, into the friction nodes of the sections of the John Deere 1780 sowing complex for 2019 is UAH 150,000 (considering the average operation of the unit of 12 years).

At the Soyuz-Composite LLC enterprise, research was carried out on the slide bearings of the damping mechanism of the arrow paw of the cultivator from the developed PCM based on aromatic polyamide (Fig. 7).

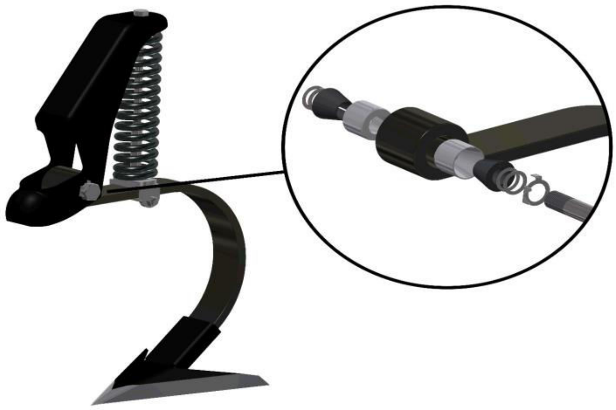
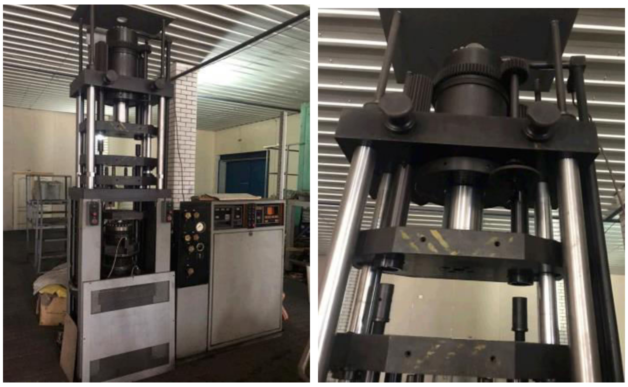


Figure-7. Cultivator paw arrow and bearing assembly with experimental design of damping mechanism assembly.

This made it possible to increase the reliability and productivity of the cultivator at a high level of loads due to deep cultivation and the use of the tool on "heavy" soils. The increase in these parameters occurred due to the elimination of the phenomenon of slander on the surface of the metal bushings of the movable connections of the cultivator. This, in turn, made it possible to reduce the gaps in the *tribe* couplings of the tool, which led to their radial beating and premature wear. The use of plain bearings from the developed PCM based on aromatic polyamide made it possible to increase the durability of the damping mechanism of the cultivator's time stand by 4-5 times compared to the standard (basic) model.

Production tests of the reliability and durability of the guide bushings of the movable traverse of a hydraulic press designed for processing polymeric materials were conducted at Khimpostach Dnipro LLC (Figure-8).

In their original form, guide bushings are made of bronze grade БрАЖ 9-4 and require constant lubrication with grease lubricants. Insufficient lubrication significantly increases the likelihood of jamming of the guide bushing-column friction unit, which leads to press failure due to the stoppage of its moving traverse. Bushings for this friction unit were developed from a polymer composite material based on aromatic polyamide. This material ensures performance at pressures up to 1.5 MPa and sliding speeds of 1.5 m/s, in the friction mode without lubrication. It should be noted that the jamming of assemblies with these materials is less likely than when using bronze since they have a better level of tribological properties when friction on steel.



(a) (b)

Figure-8. General view of the hydraulic press (a), press crosshead movement unit (b).

When replacing bronze bushings with the proposed polymer composite material, it turned out that they were working during the test period from 2018 to 2019. The developed PCM parts do not require constant lubrication (single lubrication was performed when these bushings were installed), unlike bronze parts that need to be lubricated at each scheduled maintenance of the press. This saves lubricants and time for lubrication, ensuring a high level of reliability and durability of friction units in the moving traverse of the hydraulic press.

At the enterprise, Inter Avia Invest LLC, production tests were carried out on the operation of fluoropolymer-based polymer composite materials on the sliding guides of the moving table of a grinding machine (OSH 143). Serial bushings are made of antifriction bronze and require constant lubrication with grease, which contaminates the friction surfaces and leads to the adhesion of solid abrasive particles from the grinding wheel, followed by intense abrasive wear of the friction unit. The developed sliding guide linings are made of a fluoropolymer-based polymer composite material that can operate without lubrication and provides a high level of reliability and durability. The use of these linings has made abrasive wear of the sliding guides virtually impossible since small abrasive particles practically do not stick to the sliding guides of the moving table of the grinding machine and can be removed from them quite easily.

The use of the developed PCM linings instead of bronze ones during 2018-2020 significantly reduced the wear of the sliding guides of the grinding machine's moving table. This eliminated the need for their repair, which is carried out once a year according to routine preventive maintenance. In other words, the company managed to save money spent on two routine maintenance (for the period from 2018 to 2020) and reduce equipment downtime during these repairs.

CONCLUSIONS

The developed PCMs based on aromatic polyamide, fluoropolymer, and phenolic resin have higher physical and mechanical properties than such structural materials as bronze and babites, have similar properties to carbon steels, and exceed them in tribological properties.

Industrial studies of parts made of the developed PCMs were conducted at the enterprises of «T CORP GROUP» LLC, «Kodatike-Agro» LLC, SPE «Soyuz-Composit», «Khimpostach Dnipro» LLC, and «Inter Avia Invest» LLC. The economic feasibility of using the developed PCM parts in the friction and sealing units of the cantilever shaft of the machine with a low-speed mechanical stirrer, in the friction units of the soil copying mechanism of the John Deere 1780 sowing complex, in the damping mechanism of the cultivator stand, in the guide of the moving traverse of the hydraulic press for processing polymeric materials and in the sliding guide of the moving table of the grinding machine (ОШ 143) was confirmed.

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