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DESIGN OF MATED PARTS USING POLYMERIC MATERIALS WITH ENHANCED TRIBOTECHNICAL CHARACTERISTICS

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This paper reports a comparative study of the polymeric materials operating in conjugation with steel. In agricultural engineering, a significant role in structural materials belongs to polymer composites. This type of material is characterized by the low price, small technological cost, as well as acceptable processing characteristics. It has been found that it is necessary to form, for each type of mated parts, a set of materials that could maximally meet the operational conditions. To describe the operating conditions in more detail, they need to be generalized for the specific tribological and loading characteristics. Based on this, such load regimes were selected that correspond to the movable mated parts in sowing complexes. For these mated parts, it was necessary, in the course of the tribological study, to choose a material with minimal technological deviations but with enhanced tribotechnical characteristics.

The result of this study has established that under the predefined conditions a polymer-composite material with the high-modulus filler PA-6.6+30 % F demonstrates the best tribophysical characteristics compared to the material PA-6.6. The proposed material, in conjugation with steel 1.1191, has a friction coefficient that is 38...41 % lower, while the temperature in the contact area is 8...12 % less, than that in conjugation with the material PA-6.6. Based on the metallographic analysis of friction surfaces, one can argue that a polymer composite with a high-modulus filler creates favorable conditions for their implementation in the moving units of machines.

The results reported here make it possible to analyze and synthesize composite materials primarily for agricultural engineering, taking into consideration their tribological properties. The findings may be particularly interesting for service departments and enterprises producing parts for sowing complexes

Keywords: polyamide, high-modulus fillers, abrasive resistance, metallography, tribological property, polymer composite, fiberglass

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1. Introduction

The results from operating various machines involved in agricultural production make it possible to assert that their planned resource can prove to be much different from the results of field tests. An important feature of the low reliability of machines and mechanisms is the use of movable mated parts made from metallic materials that possess a low level of tribotechnical characteristics. The proper level of machines' operability is provided by maintenance, primarily lubrication after 35...60 hours of operation. Failure to follow these recommendations causes excessive accumulation of dust, which is an abrasive environment for the further operation of working surfaces of tribo-mated parts and their rapid wear.

To form the mated parts in machines that would preserve a highly effective technical condition and could work during the long operation period, it is necessary to choose the tribologically effective materials for them, with an increased level of tribotechnical characteristics.

Based on the analysis of technical specifications for materials and the scientific and technical literature on their use for heavy-loaded mated parts, the effectiveness of polymer composites has been determined. The most promising, for appropriate working conditions in agriculture and transport engineering, are polymeric materials with various fillers, including fiberglass. Justifying their application for specific operational conditions, technological development, as well as its implementation, is a relevant scientific and technical task. For the rational implementation of these materials into machines' mated parts, they must be investigated in order to identify the tribological properties and tribotechnical characteristics of polymer composites.

2. Literature review and problem statement

The introduction of polymer composites makes it possible to prolong the resource of machines operating under harsh conditions. Widespread are the polyamide materials of various modifications. This type of material is low-cost and available in the required quantity in mechanical engineering. Acceptable results for strength were obtained from studying the composites polyphthalamide and polyamide, reinforced with fiberglass, which is reported in work [1]. However, the study focused on stationary conditions, so the issue of the dynamic tribological conditions was not considered by the authors. Considering the work of polymeric parts under dynamic conditions is necessary to understand their effectiveness for mated parts. The use of structural plastics, which was considered in work [2], makes it possible to form force parts but there are objective difficulties in considering their resource pattern under severe operating conditions in moving mated parts. Paper [3] describes the peculiarities of plastics when used as a material for shafts and gears; however, there remains an issue of selecting this type of material for the dusty modes of operation of mated parts. Operational conditions of agricultural production are harsh for classical metal materials, as indicated in work [4], therefore, as regards the materials for movable mated parts, one needs detailed information about their tribological effectiveness.

Paper [5] considers the models to design composites in the area of textile materials, which were formed on the basis of thermal-elastic pattern; however, one needs additionally to consider the tribophysical properties of the created composites. The use of fibers makes it possible to significantly increase the quality of the basic polymer, as noted in work [6], but it is necessary to examine their content for specific tribological conditions and polymeric materials. This aspect is paid detailed attention to in study [7], which describes a method to form a polymer composite with carbon fibers. The use of a given composite significantly increases the cost of mated parts and sometimes they are not economically feasible, therefore, it is necessary to choose other options for high-modulus materials as fillers to resolve this issue. Paper [8] outlines the tasks of selecting and creating materials with different additives in a polymer base in the implementation of 3D printing; however, it is necessary to further investigate their effectiveness from a tribological point of view. In addition, the addition of carbon fibers to polyamide makes it possible to achieve high strength characteristics, as noted in work [9], although it would increase the thermally conductive layer, which could maximize the polymer transfer of materials in mated parts. Paper [10] states that the reduction of temperature regimes in the mated parts is carried out by lubricants. In turn, materials from the polymeric materials of the polyamide family have significant hydrophilicity, and therefore there is a need for a more detailed study of lubrication modes under these conditions. The supply of lubricants to a tribological contact is possible when using the fundamental foundations of pneumonic, which are described in work [11]. However, these tribological contacts are characterized by higher cost and their design requires research into the operational and tribological properties of specific mated parts.

The authors of work [12], in order to improve the tribological effectiveness of mated parts, add the geomodifier additives; however, its concentration for a specific type of materials and lubrication modes should be systematically investigated. The intensive manifestation of change in the tribotechnical characteristics depending on the quality of the work surface of the selected materials in mated parts is significantly noticeable in heavily loaded assemblies, as indicated in paper [13]. Under these conditions, it is possible to reduce losses on friction due to the introduction of new temperature-resistant polymer composites with the appropriate structural justification. The relevant works state that with the development of robotics with complex moving actions [14] and the use of energy-efficient machines [15], it is necessary to use composite materials in mated parts with low losses for friction. These mated parts are designed only from the point of view of structural concept but it is important and necessary to take into consideration and investigate the tribological efficiency, economic feasibility, and operational reliability. Study [16] shows that the reliable functioning of autonomous machines significantly depends on the quality of the formed movable connections between the parts of their resource patterns and the complexity of control models. Achieving a significant level of reliability requires proper evaluation of their tribological characteristics and selection of materials to prevent the critical wear of mated parts in the operation of machines. Detection of inconsistencies and analysis of the operational properties of polymers must be constantly improved, as indicated in work [17], in order to create conditions for the rational design of disparate mated parts. At the same time, it is necessary to maximally employ the design features of the developed mated parts in the machines' systems and units. Composites with enhanced tensile and strength properties were used in the ABC-PA-carbon fiber system; the results are reported in work [18]. This system has proven itself well during the deformation for stretching under cyclical loads; however, it was not considered under the strict friction modes without lubrication; in the future, it needs to be examined. During the study of tribological processes, it is necessary to rationally select the results according to the criterion of desirability, the methodical apparatus of which is described in work [19], but this is possible only when considering the outlined complex of actual conditions of the friction process. In household appliances, polymers reinforced with fiberglass are most often used, because these materials have sufficient strength, analyzed in paper [20]. However, for the use of plastics for heavily loaded tribo-mated parts, it is important to select plastics and fillers with the necessary temperature characteristics. The use of plastics is currently very common in the manufacture of assemblies and parts of mechatronic modules, described in work [21]. This indicates that each individual node should be considered on the basis of its functionality, tribological or durable, and, for each node of parts, to form a certain type of plastic. The increase in the static strength of plastic for stationary conjugations was realized when using high-modulus materials, reported in [22]; that, however, requires additional research into their dynamic characteristics in movable conjugations. Plastic recycling is also a profitable aspect of such a structural material, as specified in work [23]; but it is desirable to pre-evaluate the destructive processes of plastic, so as not to reduce the characteristics of parts made from recycled plastics. Paper [24] examines the strengthening of thermoplastics using fibrous materials to improve the physical characteristics of the polymer. It should be noted that each characteristic requires individual research on the concentration and content of fibers in the polymer. Several related studies examined the issue of improving the characteristics of tribo- mated parts by using a lubricant environment and tribo-active additives [25], geomodifiers [26], a complex involving lithium and fluoride soaps [27]. The tribological properties of mated parts with these additives are improved by 10...18 % only if there is an oil base, but, under dry friction modes, it is necessary to consider the possibility of adding to the matrix. In tribo-mated parts with reinforced plastics, it is very important to know the mechanical properties, which makes it possible to clarify the permissible loads, studied in work [28]. For moving mated parts, it is additionally necessary to study such properties as they change after the friction process. Paper [29] states that the value of mechanical properties depends significantly on the size and location of the fillers; additionally, it is necessary to study how this location affects the material of the counter-mated parts.

Work [30] notes that polyamide is hydrophilic and it significantly affects the resource of parts, so it is necessary to further investigate how hydrophilicity changes depending on the content of high-modulus fillers in composites. Increasing the fiberglass content leads to an increase in the fluidity and tensile strength of the samples of polymeric materials, which is evident from the results reported in [31]. Under these conditions, it is advisable to investigate mechanical changes in the polymer-composite materials in the mated parts made from steel materials. A study into the characteristics of fatigue at stretching a composite material reinforced with fiberglass is considered in [32]. It is shown that a given material is well suited for reinforcement but its tribological properties need to be investigated in more detail. Building a model and a composite's lifecycle diagram is described in [33], which is useful for nodes exposed to stationary loading. When designing and creating movable mated parts, one additionally needs to consider the tribological pattern of the developed materials. To analyze changes in the mated parts accurately enough, it is necessary to take into consideration available diagnostic information with the minimum possible time to update the database, as reported in paper [34]. The reason for this may be objective difficulties associated with the analysis of the set of diagnostic parameters and their implementation during the operation of nodes. Work [35] examines in more detail the resource diagrams of components in wind installations made from materials formed of fiberglass and epoxy resin. The developed approach, used for parts that worked under aerodynamic loading modes, is effective, but these regimes differ greatly from the dynamic loading modes of parts during friction, which further requires research. Paper [36] examines a procedure to form a mathematical toolkit to predict the strength of composite materials, underlying which is a neural network. Under these conditions, it is necessary to use and expand the possibilities for clarifying the resource model of the developed composite materials. Work [37] states that there is currently an issue of forming composites with dispersed fillers, which make it possible to improve the mechanical characteristics of materials. In this case, there is a problem that fillers possess a complex structure and low compatibility with polymers, which makes it difficult to investigate their characteristics and properties. The formation of composites from a solution, as indicated in study [38], shows a good result of their physical and mechanical properties, which is well-proven in the formation of high-precision parts from this material. Instead, there is a significant disadvantage of this method: the resulting parts have a much higher cost compared to other structural plastics. The use of advanced composite plastics with biological [39] and magnesium [40] fillers is considered, which creates reliable mated parts for operation under a mode of boundary lubrication. An important feature that needs to be investigated for these composites in the future is a dry friction mode when they are mated with metallic parts.

The general advantages of composite materials include their rapid adaptation to operational conditions, affordable basic materials, and a small cost of implementing technology for the manufacture of parts on their basis. Therefore, the effective use of this kind of material for mated parts is possible when studying in detail the mechanisms of their life cycle and their compliance with operating conditions.

3. The aim and objectives of the study

The aim of this study is to experimentally determine the increase in the level of the tribological properties and tribotechnical characteristics of polymer-composite materials with a fiberglass filler.

To accomplish the aim, the following tasks have been set:

– to examine the tribological properties and tribotechnical characteristics of the laboratory samples of mated parts made from the materials of a structural composite with fiberglass fillers and steel under conditions of intensive dust content and abrasive wear;

– to define the characteristics of mated parts made from a structural composite with a fiberglass filler and steel based on the metallographic analysis of their working surfaces.

4. Materials and methods to determine the tribotechnical characteristics of the samples of mated parts made from a polymer composite material

The study used samples made of polymeric materials; steel 1.1191 was taken as a conjugating material (EN 10083, chemical composition (%): Ni (<0.4); Mo (<0.1); Cr (<0.4); S (<0.035); P (<0.03); Mn (0.5–0.8); Si (<0.4); C (0.42–0.5); Fe (remaining)). The polymeric material used as a reference was Polyamide 6.6 (PA-6.6); the examined material Polyamide 6.6+30 % fiberglass (PA-6.6+ 30 % F) was proposed to improve the quality of the conjugation. These materials are commercially available among the materials made of high-molecular compounds in the form of granules with a diameter of 2...3 mm and a length of 1.5...4 mm.

We fabricated the samples from polymeric materials at the laboratory machine PL-32, which makes it possible to cast the polymeric samples of parts under pressure (Fig. 1). The main operations of this method are regulated at an operator's control panel. In the initial stage, we loaded granules of appropriate dimensions to the heating chamber of the machine.

To form the samples and parts from polymeric materials, it is necessary that the starting material should fill the heating chamber, which subsequently provides for a melting point of the material of 488...498 K. Temperature control was performed by temperature sensors; the pressure in the chamber was adjusted according to the indicators of the pressure gauge connected to a hydraulic cylinder. An operator controlled the indicators at the control panel of the foundry machine. Molten polymer material was poured into molds with the required sample sizes. The samples were shaped like a parallelepiped with a length of 53 mm, a width of 29 mm, and a height of 7 mm.

Fig. 1. Foundry machine PL-32

We studied the samples for abrasive resistance and tribotechnical characteristics at a specially prepared set-up (Fig. 2) based on the friction machine SMC-2.

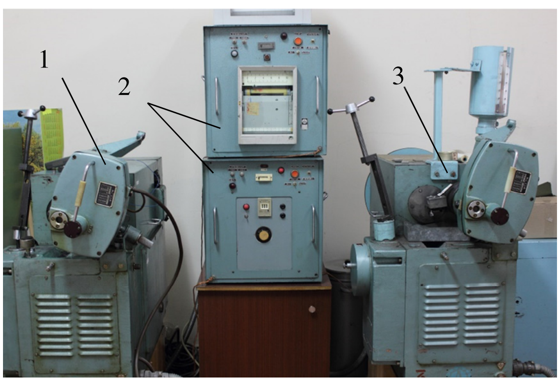


Fig. 2. Set-up for studying friction processes in an abrasive environment and the samples of mated parts without lubrication: 1 – SMC-2 to investigate conditions of dry friction and without lubrication; 2 – control unit over the modes and characteristics of friction during the study; 3 – SMC-2 to study a friction process under dusty conditions

A method of studying the materials' abrasive resistance implied that, under the same conditions, the examined materials' samples are subject to wear. The wear involved the non-fixed abrasive particles of electrocorundum No.16N, which were constantly supplied to the friction zone. Before the study, this abrasive material was dried so that the humidity level did not exceed 0.16 %. General characteristics of the roller are: diameter, 50 mm; width, 15 mm; Shore hardness, 79...84 A; relative elongation, 16...19 %. Before the study, the roller was treated with the sanding paper T2 (grit No. 8P), washed in gasoline, and dried. We studied the wear of polymeric samples at the modified friction machine SMC-2 under the following conditions: load, 44 N; rotation frequency, 1.0 rev/s,

We weighed the examined samples at the laboratory scales TVE-0.21-0.001, II accuracy class, DSTU EN 45501 (Fig. 3).

Fig. 3. Laboratory scales TVE-0.21-0.001

The relative abrasive resistance was calculated by the comparison relative to the reference material. Polyamide 6.6 was taken as a reference sample. The comparative analysis was performed taking into consideration the weight amount of the wear of the examined samples. The relative value of the reference sample is 1.

We determined the friction coefficient based on the torque magnitude of the electric engine at the friction machine in the course of the study. Before starting the study, samples of the materials were pressed against each other for 3 minutes under the study modes to obtain more parallel friction surfaces and adequate results. At the same time, we determined the friction coefficient in the mated samples and parts as the ratio of the torque magnitude of the electric engine to the applied normal load. The temperature in the contact area was determined using a thermocouple with the electronic unit "Hyelec MS6501". The thermocouple was installed in the hole of the sample of the polymeric material. The data were acquired every 5 minutes. The hole was placed 1 mm from the mated working surface of the sample. The depth of the hole was 5...6 mm. During friction, the pressure in the mated samples was 0.45...0.5 MPa, and the sliding speed was 0.781...0.785 m/s.

We studied the working surfaces of friction using the microscope MBI-6 (Fig. 4) with magnification ×400.

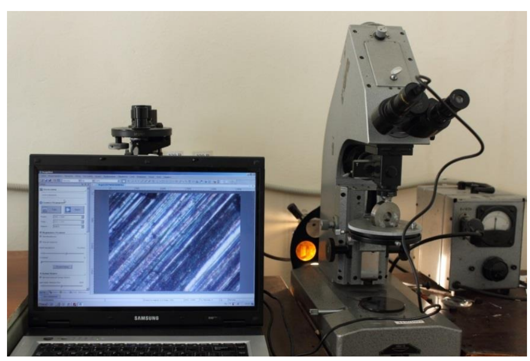


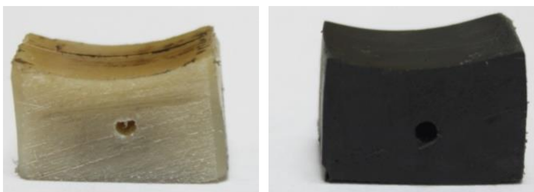
Fig. 4. Microscope MBI-6

Images of the studied friction zones were recorded using an eyepiece camera designed for the microscope; the photographs were electronically stored on a laptop for possible analysis. This set of studies would make it possible to assert the possibility and rationality of the implementation of polymer composites for movable mated parts in machines exposed to abrasive wear.

5. Results of the tribological study of mated parts made from polymeric materials and steel

5. 1. The tribotechnical characteristics and properties of the mated parts' materials

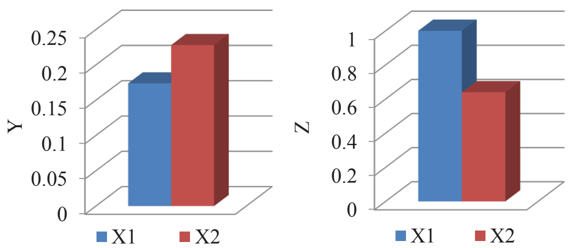
After the course of the study, a significant dust content of the working environment was established, which directly affects the relative abrasive resistance of the polymeric composite materials. The physical appearance of the samples is shown in Fig. 5, which also demonstrates the places where the temperature sensor's controlling element was installed.



a *b*

Fig. 5. Samples after studying their abrasive resistance: *a* – PA-6.6; *b* – PA-6.6+30 % F

Each experiment was performed five times to determine the average values of the corresponding results. The comparative results of relative abrasive resistance are shown in Fig. 6.



a *b*

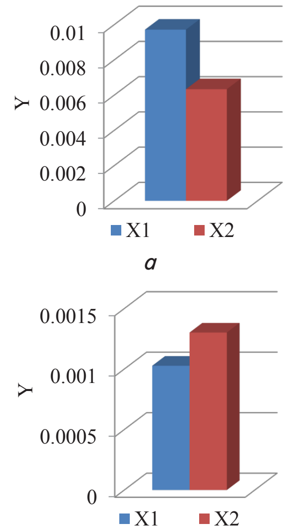
Fig. 6. The average value of results from the tribotechnical study of samples under dusty conditions: *a* – the weight wear of polymer samples, Y – weight wear, g; *b* – the relative abrasive resistance of polymer samples, Z – coefficient of relative abrasive resistance; X1 – PA-6.6; X2 – PA-6.6 +30 % F

One can see that the tested samples demonstrate good results during operation in an abrasive environment; however, the reference sample shows better wear resistance.

The results from our studying the wear of the mated elements of samples in the absence of lubricants, made from the polymer and steel materials, are shown in Fig. 7.

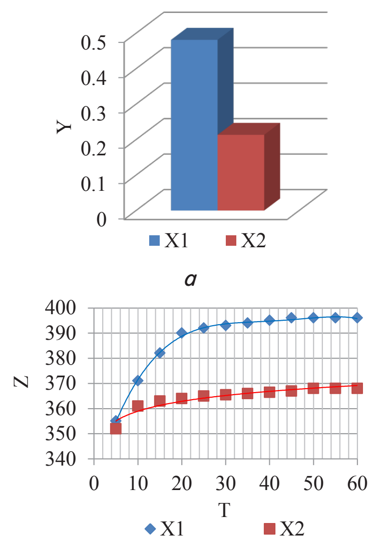
The tribotechnical characteristics of mated parts made from the polymeric and steel materials are shown in Fig. 8. These characteristics are important for assessing the energy characteristics of the constructed mated parts.

The tribotechnical characteristics also indicate that the samples enter the operational mode of the examined mated parts and, therefore, it is possible to observe the normalization and stabilization of temperature in the mated samples, as well as a friction coefficient (Fig. 8, *b*).



b

Fig. 7. The average value of weight wear: Y – weight wear, g; X1 – PA-6.6; X2 – PA-6.6+30 % F; *a* – polymeric samples; *b* – steel samples



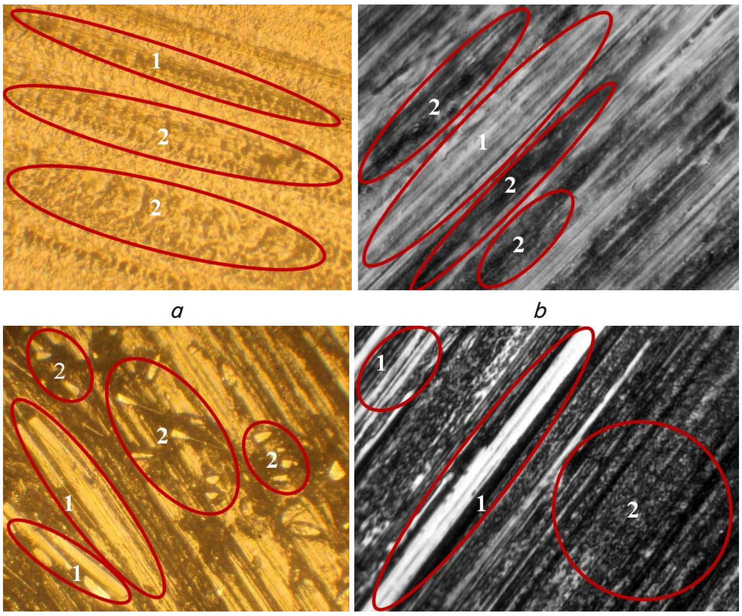
b

Fig. 8. The tribophysical characteristics of mated parts: *a* – friction coefficient in the conjugation between the polymeric materials and steel, Y – the value of friction coefficient in the conjugation; *b* – change in the temperature in the conjugation between the polymeric materials and steel; Z – temperature in the conjugation friction zone, K; T – experiment duration, min; X1 – PA-6.6; X2 – PA-6.6+30 % F

5. 2. Metallographic analysis of the mated parts' materials

Important data in the design of mated parts for machines is the analysis of the quality of their working surfaces in the process of friction. Results from the metallographic study of the reference, examined, and steel samples are shown in Fig. 9.

After analyzing the experiments, it is possible to compile recommendations on the implementation of movable mated parts made from the proposed materials.



a *b*

c *d*

Fig. 9. Metallographic images of the working surfaces of the samples of polymeric and steel materials: *a* – reference sample of the polymeric material; *b* – examined polymeric material; *c, f* – steel samples, ×400

It is known that the tribotechnical characteristics of mated parts significantly affect the resource of machines' assemblies. Based on the indicators of wear under the conditions of high dust content, Fig. 6 demonstrates that the weight wear of samples made from the PA-6.6 material accepts lower values compared to those by PA-6.6+30 % F. This can be explained by the fact that the tribological contact contains solid inclusions of fiberglass, which are better at retaining the micro-abrasive particles. The indicator of the weight wear of samples under dusty conditions is greater than the reference material by 26...30 %, the relative abrasive stability of the examined material is within 62...64 %, which meets the operational modes for mated parts.

It is also important that the selected material has proven effective during operation under conditions of extreme friction. This condition is necessary for materials that are expected to function under conditions of extreme friction. Taking into consideration the data in Fig. 7, the polymeric samples' wear values indicate that PA-6.6+30 % F has a lower wear rate, by 53...54 %, in terms of weight indicator. However, steel samples demonstrate the opposite results, by 21...23 %. The conjugation of the materials "PA-6.6+30 % F – steel 1.1191" shows the result for the relative wear, which is 40...41 % better compared to the conjugation of samples "PA-6.6 – steel 1.1191".

The tribotechnical characteristics of mated samples make it possible to estimate a friction coefficient, as well as operational properties. The material PA-6.6+30 % F, when compared to PA-6.6, has a friction coefficient, which is 38...41 % less, and the temperature in the friction zone is lower by 8...12 %, as evidenced by the results shown in Fig. 8. Since the coefficient of friction and temperature indicators accept the lower values, the destruction of the polymer material "PA-6.6+30 % F" during operation would occur much slower.

6. Discussion of results of studying the tribotechnical characteristics of the samples of mated parts made from polymeric composites with steel

6. 1. Results of studying the tribotechnical characteristics and properties of mated materials

The main characteristic inherent in the materials for movable mated parts is their structural stability under the machines' operating conditions. This is especially important in the design of nodes for agricultural, transporting, and quarry machines. Movable mated parts operate under non-stationary conditions and, due to dust content, may often overheat and fail due to the wear limit. For such movable mated parts and harsh conditions, their lubrication systems in most cases do not change the resource pattern. Extra lubrication points significantly increase the labor intensity of operational work. Therefore, it is advisable to use and develop movable mated parts with an acceptable resource without lubricant points. This is an important task both for materials science and mechanical engineering.

In this research, we have selected low-cost materials, which could be used to reduce the volume of service operations for sowing complexes made in Europe and domestically. All load modes were chosen on the basis of operating conditions with the addition of a 10 % margin, to ensure the resource reserve.

Polyamide 6.6 possesses good structural properties but operates in an unstable manner under significant temperature influences and long-term cyclical loads. In its pure form, this material is hydrophilic, which complicates its use in high-precision mated parts under conditions of significant humidity. Polyamide 6.6 with a 30 % fiberglass content has been proposed as a composite material. Such material is commercially available, and its cost is negligible, therefore, engineering and service enterprises could be easily modernized for the manufacture and repair of movable mated parts for machines.

6. 2. Discussion of results of the metallographic analysis of the mated parts' materials

The progress of friction processes in the mated parts can be clearly observed on metallographic microphotographs of the working surfaces of the mated samples in Fig. 9. Fig. 9, *a*, *b* show results from the metallographic study of the materials "PA-6.6 and steel 1.1191". In a given conjugation, the polymeric material demonstrates clearly expressed areas of destruction, zone 1 (Fig. 9, *a*). Accordingly, these zones generate the wear particles with the polymeric material locally subjected to the process of destruction and deterioration of tribological properties. In addition, in zone 1, there is the chipping of the polymer. Fig. 9, *a* shows transition zones 2, characterizing the zones of the maximum transfer of the polymeric material to the mated steel sample, as well as the onset of destruction. Accordingly, the steel 1.1191 samples (Fig. 9, *b*) also demonstrate zones 1, characterized by the transfer of the polymer. Zone 2 characterizes the tribologically inactive work area.

In the mated materials "PA-6.6+30 % F – steel 1.1191", given the low operating temperatures, the destruction of the polymer manifests itself to a slight degree, but one clearly observes zones with the tangential 1 and regular arrangement of fiberglass. These additives predetermine the increased strength and thermal conductivity of the composite. Fig. 9, *d*, illustrating a mated steel sample with the material PA-6.6+30 % F, shows highlighted zone 1, which characterizes the local supporting track of friction. In this case, the maximum transfer of the polymer occurs only along it. During the prolonged service life, the number of tracks may increase but the polymer would mainly be transferred to their plane. Zone 2 outlines the area of the tribological zone of low activity. It is possible to recommend the material "PA-6.6+30 % F" for making mated parts with steel 1.1191, as well as composite materials for the manufacture of components for movable mated parts in agricultural, transporting, and quarry machines. An important limitation to consider in the design of mated samples from the proposed materials is the temperature regime, which should not exceed 350–480 K. This relates to that the material within these limits gradually loses its heat resistance during operation. For subsequent studies in this area, it is necessary to improve the polymeric-composite material so that it works better in an abrasive-dusty environment, by varying the fiberglass content in the polymer matrix.

7. Conclusions

1. The resulting material PA-6.6+30 % F, when compared to the reference material PA-6.6, has lower friction coefficient values, by 38...41 %, and the temperature in the conjugation with steel 1.1191 decreased by 8...12 %. In turn, the mated parts made from the material "PA-6.6+30 % F – steel 1.1191" demonstrate the results that are 40...41 % better in terms of relative wear, compared to the mated parts from "PA-6.6 – steel 1.1191". Our results indicate greater efficiency of the use of the proposed polymeric composite.

2. The metallographic analysis has revealed improvements in the characteristics of the friction surfaces of mated parts made from the material "PA-6.6+30 % F – steel 1.1191". This is evidenced by the reduced number of destruction zones, as well as the presence of local friction tracks. It has been established that the transfer of a polymeric material also occurs locally to their work surfaces. In this conjugation, there exist the inactive tribological zones on steel 1.1191, which is a reserve for the further formation of supporting tracks during the operation of mated parts made from the specified materials.

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CONTROLLER OF FLUORINE-DOPED TIN OXIDE THIN FILMS DEPOSITION VIA CYCLES AND ANNEALING TEMPERATURES BY SPIN COATING TECHNIQUES

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Fluorine-doped tin oxide (FTO) thin films have been deposited by the modified spin coating method at 3000 rpm using tin (II) chloride dehydrate ($SnCl_2{\cdot}2H_2O$) as a precursor, ammonium fluoride (NH4F) as a dopant and ethanol as a solvent. The aim of this research is to find out the quality of the thin film based on the number of cycles (3, 4, 5, and 6 cycles) and annealing temperature (300, 400 and 500 °C). The variation of annealing temperature and number of cycles can affect the crystal structure of the FTO thin film, crystal size and grain size. Increasing the number of cycles and annealing temperature can lead to larger crystallite size and lower dislocation density, so that electrons between the grains can move easily. The large grain can reduce the grain boundary, increasing the electron mobility and decreasing the resistivity. XRD analysis shows that the structure of SnO_2 polycrystalline with the most dominant crystal plane (110) is formed in this research when compared to the intensity of other structures. The resistivity value decreases with increasing the annealing temperature and number of cycles. In addition, transparency value also decreases along with increasing the annealing temperature and number of cycles. The optimum results of resistivity and transparency values obtained in this research are $1.69{\times}210^{-2}$ Ω·cm and 69.232 % at 500 °C and 5 cycles. These results can be used as a reference for further study to optimize the production of fluorine-doped tin oxide (FTO) thin film with spin coating. Therefore, many factors that affect the production of fluorine-doped tin oxide (FTO) thin film, either dissolving stage or deposition process on the substrate surface still need to be studied deeply to obtain the optimum result

Keywords: spin coating, number of cycles, annealing temperature, resistivity, transmittance

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1. Introduction

A dye-sensitized solar cell (DSSC) is a technology that converts sunlight energy (visible light) into electrical energy. One of the components that support the DSSC working process is a transparent conductive oxide (TCO). Transparent conducting oxide is a thin layer of metal oxide that has high electrical conductivity and optical transparency [1]. Besides supporting the DSSC working process, this TCO can also be applied in the daily activity such as sensors, solar