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Studying the Tribological Properties of Polymer Composite Materials FIlled with Production Waste

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Abstract. Currently, numerous studies are being conducted in the field of obtaining thermoreactive polymer composite materials and the production of high-responsibility parts based on them in the field of mechanical engineering. The main advantages of such materials are the low cost of production technology and raw materials compared to metals, replaceable when used as parts, wear resistance, and self- lubricating properties. This article examines the content of fillers and the degree of their influence on the properties of ED-20-based thermosetting polymer composite materials. To ensure the self-lubricating properties of the material in the production of wear-resistant composite materials, "pec" was used as a filler, which is the residual waste formed during the thermal processing of gas. It has been established that the content of carbon-containing pecs in the composite material exceeds 5-6%, and they can change the tribological properties of the composite material to a lesser extent. The morphological analysis of peck and the amount of compounds in its composition have been studied. Mechanical activation of fillers ensures their uniform distribution across the structure of the composite material. The composition of the material with the best tribotechnical properties was determined using experimental studies, and the value of the friction coefficient in wear was reduced to 0.14. In addition, fiber fillers were used to ensure sufficient strength along with the hardness of wear-resistant polymer composite materials, and their optimal amount was determined. The article concludes by examining the prospects of thermosetting polymer-based composite materials and highlighting the advantages of their use.

Keywords: thermoreactive polymer, ED-20, peck, filler, composite, tribological properties, morphology, friction, insole.

Introduction

It is a well-known fact that most of the components used in mechanical systems are made up of metals and their composites. It is also well known that demand for high strength low weight of materials is increasing day by in the industries. Various metallic materials with, Cu, Al, steel, Fe etc. are used use for fabrication automobile components, space components, energy sectors, etc. The cost of fabrication and cost materials of these metallic components is increasing day by day, besides these metallic materials possess high density [1]. The researchers and designers are working to find alternative solutions to these problems. Polymer materials, viz, polyethylene (PE), polypropylene (PP), polytetrafluoroethylene (PTFE). etc. and thermoreactive polymer materials are considered to be promising materials for future application of space, automobile, power plant, railway etc. application due to the fact that these material sposes low weight, high corrosion resistance, low coefficient, etc [2]. Known polymer materials are divided into 2 main groups [3]. They are thermoplastics and reactive plastics. Thermosetting materials are considered high heat resistant material 150-180^o C.

Thermoreactive polymers have recently been used for production of many components in railway transportation. These include bush bearings, railway breaking system [4]. These materials are subjected to load in the range of 45- 65 kN, temperature of 55-120^o C, and high corrosive environment are mad of high strength metals and their composites. Due to the fact that most of the parts used in the field of mechanical engineering are made of metals [5]. The demand of high strength, high high mechanical, tribological and performance properties is increasing. This leads to an increase in the cost of them and parts based on them. The role of polymer-based composite materials in solving this problem can be called incomparable. However, the correct selection of binders, fillers and reinforcing materials when creating composite materials requires special knowledge, skills and a lot of experimentation [6].

Presently, the polymer composite materials used in the field of railway transport are imported products, their localization and increasing the operational reliability are considered urgent problems. In particular, the bushings that attach the brake suspensions of railway freight wagons are the most widely used imported products in the repair of wagons [7], [8]. Obtaining bushings with high operational properties using the filling and reinforcing components of these bushings based on local raw materials is one of the urgent problems. The main drawback of the bushings used in the braking system of freight cars was considered to be fast wear and, as a result, a lot of time was spent on its repair [9].

Various researchers have carried out researcher’s studies on improving the tribological properties and physical mechanical properties of polymer composite materials [10].

Mechanical and tribological properties of three types of polymer-based composites were studied [11]. In this research study three polymer-based composites were developed with the help of 2-3 polymer binds. These include polyesters and epoxy resins. Mechanical properties of these polymers were studied under different conditions of load and sliding velocity [12]. These polymers showed that mechanical properties improve with the addition of binders. Friction and wear properties were improved with coefficient of friction value of as low as 0.3 was obtain. When these polymer-based against counter body of steel ball. A wear rate of 0-2 mm^3/Nm was obtained of sliding distance test of 200m. However, the complexity of the matrix mixing technology that makes up this composite limits the production of various details.

Chinese researchers studied [13] the properties of polymer composite materials using simple cubic modeling. The reliability of the obtained results is based on hundreds of experiments. However, it should be noted that this method loses its accuracy when the amount of dispersed fillers in the composite materials is from 40% to 85%. As a result, the accuracy of the obtained results is reduced [14].

By adding different types of dispersed metal fillers to polymer composite materials, the tribological properties of the composite can be improved. By adding bismuth oxide to PE, PP, epoxy resins, it is possible to improve the resistance of polymer composite materials to erosion due to friction and to use them as protective materials against various radiation rays [15]. However, due to the high density of bismuth, it is difficult to distribute filler particles uniformly throughout the structure, which is the main disadvantage of this method.

In addition, it is possible to ensure the service life and operational reliability of machine parts by applying wear-resistant polymer-based composite materials as protective coatings to the guiding sections [16-17] of machine-building components.

1 Materials and Methods

1.1 Materials and Preparation of Samples

When preparing samples of composite materials attaching brake suspensions to the side frame of railway cars, ED-20 epoxy resin was obtained from Uzbeksitan, dibutyl phthalate and polyethylene polyamine from Russia, and Angren kaolin AKT-10 which produced in the factory “Angren kaolin” in Uzbekistan as a dispersion filler, and glass fiber as screenings were used as a dispersion filler. used a filler and a multifunctional modifier - oil pyrolysis waste was used as a filler. Table 1 presents the functions of the components used in the preparation of samples within the composite, along with their manufacturers.

Table 1. Information about the components of composite materials

№	Ingredients	Function	Standarts	Manufacturer
1	ED-20	Binder	GOST 10587 - 93	Uzbeksitan, JSC "NAVOIYAZOT" - in Navoi
2	DBF	Plasticizer	GOST 12.1.004 - 91	Russia, "Roshal Plasticizers Plant" LLC
3	PEPA	Hardener	TU 6–02–594–70	Russia, "Roshal Plasticizers Plant" LLC
4	Peck	Filler		Uzbeksitan, Guzar, "Shurtanneftegaz" LLC
5	AKT-10	Filler	O‘z DSt 1056:2004	Uzbeksitan, Tashkent “Angren kaolin” LLC
6	Glass fiber	Reinforcing	GOST 319132011	Uzbeksitan, Tashkent "KANOMA" LLC

Composite components were placed in bins. The dry components measured in the distributor in specified proportions are jointly mechanically activated in the “Vibroplanetary Mechanical Activator” for 30 minutes. At the same time, ED-20 epoxy resin was mixed with DBP in a paddle mixer at a temperature of 60 °C until uniform distribution by volume. Then the mixtures prepared on the technological equipment are mixed in a mechanical mixer until 5-6% fiberglass is added and evenly distributed by volume. At the last stage, the required amount of the PEPA hardener component is added to the prepared mixture, and it is pressed in a press for 15 minutes at a temperature of 140°C - 160°C, under a pressure of 10-30 MPa. Then cool the mold in air for 5-15 minutes and remove the samples from it.

Based on the aforementioned technology for obtaining a thermosetting polymer composite material, samples were prepared based on the compositions presented in Table 1 to determine the tribological properties of the materials.

In this study, samples 01, 02, and 03 were selected to compare the properties of the new composite material and to analyze the influence of dispersed and fibrous fillers on the material properties. The first group of the new composites consists of materials without reinforcement, while the second group comprises composite materials reinforced with glass fibers. The influence of reinforcements and their quantity on the tribological properties of the material was investigated. Additionally, the change in the friction coefficient with an increase in the Pek content was analyzed for composites in both groups.

Table 1. The composition of the samples prepared for the experiment

Name	ED-20, %	DBF, %	PEPA, %	Peck, %	AKT-10, %	Glass fiber, %
01- sample (RK)	83,3	8,3	8,3	-	-	-
02- sample (textolite)	Prototip (Fenolformaldegid smolasi + mato va paxta mahsulotlari)					
Sample 03 (AKPMr)	27,0	2,7	2,7	-	67,6	-
Sample 1 (AKPMr-1)	76,9	7,7	7,7	3,8	3,8	-
Sample 2 (AKPMr-2)	71,4	7,1	7,1	7,1	7,1	-
Sample 3 (AKPMr-3)	66,7	6,7	6,7	10,0	10,0	-
Sample 4 (AKPMr-4)	55,6	5,6	5,6	16,7	16,7	-
Sample 5 (AKPMr-5)	45,5	4,5	4,5	22,7	22,7	-
Sample 6 (AYKPMr-1)	74,1	7,4	7,4	3,7	3,7	3,7
Sample 7 (AYKPMr-2)	66,7	6,7	6,7	6,7	6,7	6,7
Sample 8 (AYKPMr-3)	62,5	6,3	6,3	9,4	9,4	6,3
Sample 10 (AYKPMr-4)	52,6	5,3	5,3	15,8	15,8	5,3
Sample 11 (AYKPMr-5)	43,5	4,3	4,3	21,7	21,7	4,3
Note: RC - Reactoplastic component; AKPMr is an anti-friction reagent-plastic composite material. AYKPMr is an anti-friction-wear-resistant reactive plastic composite material.						

2. Results and discussion

The conditions of friction between the metal-polymer pair were studied in the study of the coefficient of friction and wear intensity in composites based on the ED-20 reagent-plastic binder. The experimental testing process was conducted according to the "ball-disk" scheme according to the ASTM G99 standard. The wear of materials was determined using a 3D profile meter using the "Mikron-Tribo" and "MFT5000" tribiometers. The "Micron-tribo" friction machine, designed for testing friction and wear during rotational and forward-return movements using the "ball-disk" method, was tested on samples with diameters of 50 mm and a thickness of 6-10 mm. Our research conducted friction and wear tests of the samples using the rotational method.

$$V = C*L \text{ - wear.}$$

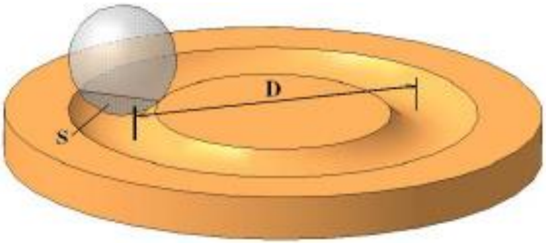

Fig. 1. Test schemes for rotational and forward-reflective friction

D is the diameter of the friction track, S is the cross-sectional area of the track, and L is the length of the track

The wear patterns of samples made of polymer composite materials were investigated using the MFT5000 3D profile.

During the experimental test, when a ball made of St3 steel with a diameter of 5 mm is pressed against the sample with a force of F=5 N, the disk-shaped sample rotates at a speed of n=500 rpm for a time of t = 60 minutes. The standard includes a set of input parameters (load, speed, distance, ball size). In this case, the ball is smaller and the load is lower, while the distance is different.The rotation diameter of the ball on the surface of the sample was set to 40 mm. It was determined that when a sample moves along a circular path with a diameter of 40 mm at a speed of n=500 rpm, the friction distance is 3768 m.

During testing, the magnitude of the friction force is continuously recorded, and the friction coefficient is automatically calculated by recording it graphically on the screen. The test process continues until the ball has fully traversed the specified friction path (L=3768 m).

Next, the linear wear (h) of the composite material was measured using a microscope and the wear intensity of the material was calculated:

$$I_h = h/L$$

where *h* is the surface thickness lost during linear wear, μm.

The track has the shape of a groove, and linear wear, especially its intensity, cannot be calculated in this way. It is better to measure the shape of the track profile and assess the volumetric wear and its intensity. *L* is the path of friction, m.

The morphological analysis of PES, used as a filler in the production of wear-resistant polymer composite materials, was conducted using an emission electron scanning microscope FE-SEM-ZEISS-500, Germany. Morphological analysis (Fig. 2.) revealed that peck particles had a plate-like appearance and this appearance was formed as a result of intense impacts of steel spheres during its activation in a vibro-planetary mechanism. When using plate-like particles as fillers in the production of a polymer composite material, their good compaction and strength compared to non-activated aggregates give the composite material high hardness properties. Hardness is the main property that determines the service life of parts operating under wear and tear conditions.

The quantitative content of organic compounds in the peck composition was determined by adsorption chromatography on an Agilent Technologies 7890 gas chromatograph equipped with a 5975 MSD model mass-selective detector. According to the data obtained, the amount of isoparaffin-naphthenic hydrocarbons in its composition is 7.99%, the sum of aromatic and olefinic hydrocarbons is 91.1%, and the amount of resin is 0.9%.

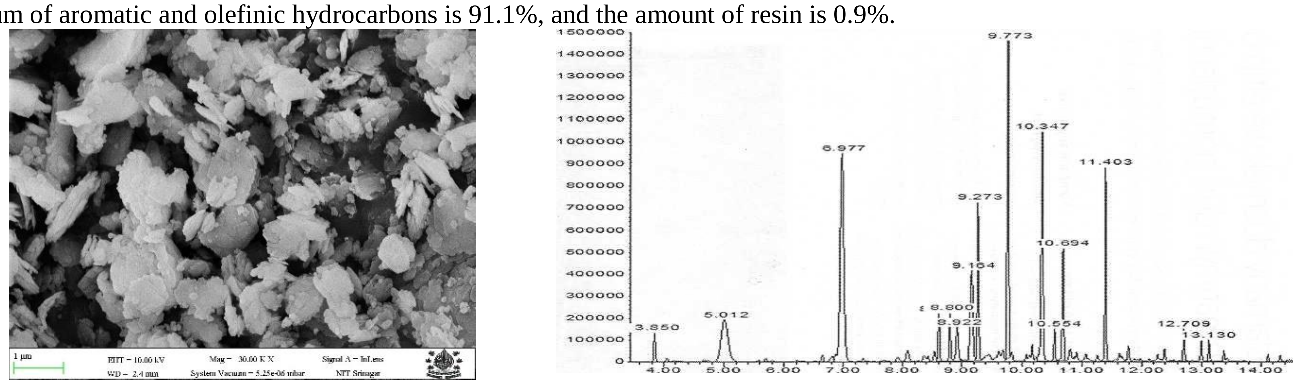

Fig. 2. Morphological (a) and chromatographic analysis of Pek

The amount of fibrous filler in the material was chosen based on research on the change in their friction coefficient. It has been established that increasing the amount of fibrous filler, while increasing the number of fibers located across the surface (Fig. 3), leads to an increase in the coefficient of friction, ensuring electrical conductivity along the surface without the accumulation of tribocharges on the friction surfaces by 6% of the oil content and 5% of the material's operational reliability

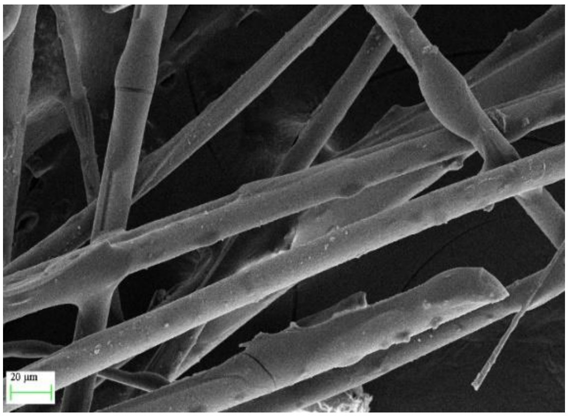

Fig. 3. The structure of the grinding filler (glass fiber) in the composite, (x 1000)

Based on the study of the tribological properties of the materials, optimal compositions of thermoplastic and reactive-plastic composite materials were selected (Table 2) and a 3D profile graph of the wear pattern was analyzed (Fig. 4). As can be seen from the table and profile graph, the reactoplast (AYGPMr-5) heterocomposite material does not lag behind the currently used textolite in terms of its tribological properties. Since the value of the friction coefficient under contact friction in thermoplastic (AYGPMt-3) heterocomposite materials has slightly increased, it is recommended to use these materials as materials resistant to abrasive wear and deformation.

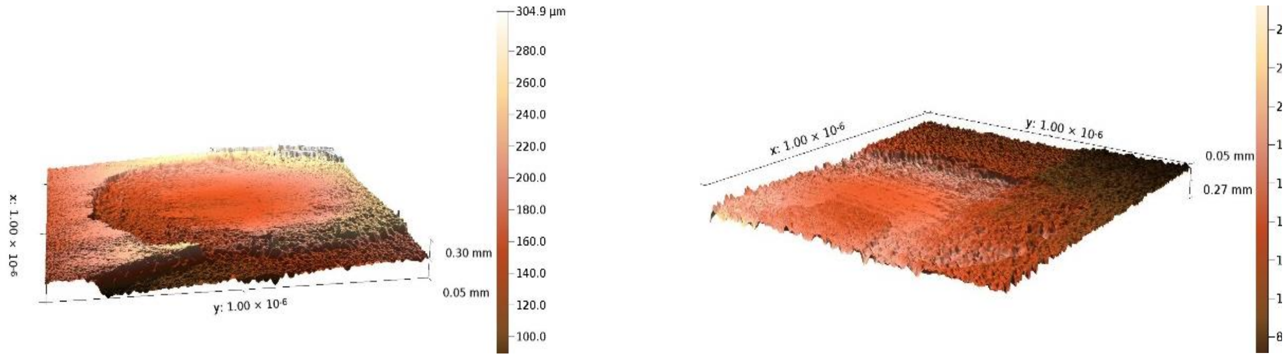

Fig. 4. Profiles of textolite (a) and GKPM (b), determined using a universal tribometer MFT-5000

Currently, railway freight wagons are manufactured based on PT brand textalites with sleeves connecting the brake suspension to the side frame. PT texallite, being an imported raw material, is considered very expensive and rare.

To this end, the wear resistance properties of samples made of heterocomposite polymer materials were compared with textile materials of the standard PT brand, which are currently used to attach the brake suspension of railway freight cars to the side frame, and the samples were tested on metal-polymer systems using a universal tribometer MFT-5000 according to the parameters of real operating conditions.

It is known that the amount of wear caused by friction between the bodies changes directly proportional to the coefficient of mutual friction between them. If the coefficient of friction is small, the material will be resistant to wear. The results obtained show that sample AGPMr-5 has the lowest coefficient of friction (Table 2). However, the absence of a glass fiber filler in its composition does not ensure its resistance to shock loads. This property of the material is ensured by adding 5% glass fiber to its composition (AYGPMr-5).

Table 2. The tribological properties of the samples

Name	Friction path L, m	Linear wear h, μm	Wear intensity I_h , 10^{-8}	Friction coefficient, f
RK	3768	170	4,51	0,42
textolite	3768	140	3,72	0,22
AGPMr	3768	155	4,11	0,35
AGPMr-1	3768	160	4,25	0,4
AGPMr-2	3768	150	3,98	0,32
AGPMr-3	3768	120	3,18	0,26
AGPMr-4	3768	110	2,92	0,16
AGPMr-5	3768	108	2,87	0,14
AYGPMr-1	3768	140	3,72	0,44
AYGPMr-2	3768	135	3,58	0,36
AYGPMr-3	3768	115	3,05	0,28
AYGPMr-4	3768	112	2,97	0,18
AYGPMr-5	3768	110	2,92	0,16

Thus, the tribological properties of heterocomposite materials are not inferior to the tribological properties of PT materials. Consequently, for manufacturing bushings that connect brake suspensions to the side frame of railway rolling stock, it is possible to use a new heterocomposite material. This material can contain 35-45% of ED-20 epoxy resin, 2-5% of dibutyl phthalate, 2-5% of polyethylene polyamine, 20-25% of petroleum waste (pitch), 20-25% of AKT-10 Angren kaolin, and 5-10% of reinforcing glass fibers, all by total mass.

Conclusion

The results of studies conducted on samples obtained by casting in laboratory conditions with a diameter of 5 cm and a thickness of 4-6 mm based on a thermosetting polymer binder (ED-20) revealed the following:

1. It has been established that as a chemical modifier with mechanically activated dispersed fillers, the surface surfaces of oil-bearing heterocomposites are activated, and a strong interstructural bond is formed due to a decrease in the moistening angle of the surface tension of the modifier in the heterogeneous system.

2. Optimal compositions of deformation, abrasion, and wear-resistant heterogeneous polymeric materials based on reactoplastic binders AIGPMr-5 have been proposed, and it has been established that the content of 6% oil pecs in their composition performs a multifunctional function in structure formation, while the content of 5% fiber filler increases tensile strength by 1.8-2 times and deformation resistance by 1.3-1.4 times, ensuring operational reliability.

3. The operational reliability of sleeves made of materials containing AYGPMr-5, obtained by mechanochemical modification using a vibration planetary activator, is ensured by a low coefficient of friction, i.e., equal to 0.16.

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