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Research of the tribological properties of filled epoxypolymer composites for improving the performance characteristics of friction units of vehicles

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Abstract

The tribological properties of filled epoxy polymer composites were studied in order to improve the operational characteristics of friction nods of means of transport. The polymer matrix of the composite is formed on the basis of ED-20 epoxy oligomer (q = 100 wt. parts) with the addition of orthophthalic dicyclopentadiene unsaturated pre-accelerated polyester resin ENYDYNE H 68372 TAE (q = 10 wt. parts per 100 wt. parts of epoxy resin), at the same time, cold hardening hardener polyethylene polyamine (PEPA) (q = 10 wt. parts), initiator for polyester resins Butanox-M50 (q = 1.5 wt. parts) was used. The modifier methylene diphenyl diisocyanate (q = 0.25 wt. parts) and fillers: hexagonal h-NB 8–10 µm (q = 60 wt. parts) and mica 20–40 µm were added to the composition of the epoxy-polyester composite (q = 20 wt. parts). The tribological properties of the composites were studied using a 2070 CMT-1 friction machine after exposure for 150 days in aggressive river water (Dnipro River) and alkaline environments (50 % NaOH solution).

Keywords: *aggressive environment, anti-friction material, coefficient of friction, epoxy-polyester composite, tribological properties, wear intensity.*

Introduction

Today, for the cargo transportation, in particular, products of the oil and gas industry, means of water transport with the use of specially designed vessels are widely used. At the same time, reliability, maintainability and longevity of all elements of vehicles are important, which ensures technical and economic characteristics of cargo delivery to the consumer [1–2]. Tribological parts, in particular the material from which they are made, play a key role in the failure-free and reliable operation of vehicles [2–3]. One of the methods of increasing the efficiency of friction nodes is the use of polymer materials and coverings based on them [3–5]. However, the constant operation of parts and mechanisms under the influence of an aggressive environment, variable temperatures and loads puts high demands on the material from which they are made and requires constant improvement in order to increase efficiency [4–6]. Therefore, the creation of polymer composite materials with improved complex physical-mechanical, thermophysical and tribological properties is relevant and promising [4–7].

Currently, reactive plastic polymers based on epoxy and polyester resins are widely used [4–7]. The authors [5–9] proved, that ease of manufacture, controlled influence on properties in a wide range, resistance to aggressive environments, and efficiency make it possible to use polymer composite materials based on epoxy resins in many parts and mechanisms of means of transport, in particular, friction pairs. The researches results of the tribological properties of epoxy resin modified with molybdenum disulfide and carbon nanotubes are given in the study [8]. The authors noted an increase in the hardness and modulus of elasticity of the composites, which could be used as materials in environments with high temperatures and high pressure, where lubricant materials and lubricants are not effective. There are known studies of the effect of carbon nanofibers with graphene nanoplates on the antifriction properties of epoxy composites [9]. At the same time, the use of nanotubes and graphenes significantly affects the cost of the part. Therefore, it is relevant and promising to create an anti-friction material that will be characterized by increased operational characteristics, availability of ingredients and a relatively low cost.

The purpose of the work is to study the tribological properties of filled epoxy polymer composites to improve the operational characteristics of friction nodes of vehicles due to their use.

Materials and methods of research

The following components were used in the formation of matrices of composite material (CM).:

Epoxy oligomer ED-20 (q = 100 wt. parts).

Orthophthalic dicyclopentadiene unsaturated pre-accelerated polyester resin ENYDYNE H 68372 TAE – q = 10 wt. parts (the content is indicated per 100 wt. parts of epoxy resin), which contains an inhibitor to prevent instant polymerization (gelation time τ = 20–24 min).

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Cold hardening hardener polyethylene polyamine (PEPA) q = 10 wt. parts (the content is indicated per 100 wt. parts of epoxy resin).

Initiator for polyester resins Butanox-M50 – q = 1.5 wt. parts, which is methyl ethyl ketone peroxide (MEKP), and contains a low amount of water and a minimal amount of polar compounds, compared to ethylene glycol.

5. Modifier methylene diphenyl diisocyanate, commonly known as pure MDI (4,4-MDI) – q = 0.25 wt. parts. Methylene diphenyl diisocyanate is an aromatic diisocyanate used for three-dimensional crosslinking of polymers in the manufacture of polyurethane. Chemical formula: $CH_2(C_6H_4NCO)_2$, molar mass 250 g/mol, density 1.18 g/cm^3.

Filler 1: hexagonal h-NB 8–10 μm – q = 60 wt. parts.

Filler 2: mica 20...40 μm – q = 20 wt. parts (fractionated micromica of the "Standard" series (TU 5725-005-40705684−2001) grade MC-20-80 with a dispersion of 20–40 μm. Mineral composition: mica-muscovite $KAl_2[(OH, F)_2AlSi_3O_{10}]$. Chemical composition according to TU 5725-005-40705684–2001: silicon oxide (SiO_2) – 44–50%, aluminum oxide (Al_2O_3) – 27–35 %, iron oxide (Fe_2O_3) – less than 5 %, magnesium oxide (MgO) – less than 2 %, potassium oxide (K_2O) – more than 8 %, water-soluble salts – less than 0.2 %).

Before the introduction of hardeners, the composition was modified by ultraviolet irradiation for 5 minutes.

The materials were approved according to the experimentally established regime: the formation of samples and their aging during the time $t = 12.0 \pm 0.1$ h. at a temperature of $T = 293 \pm 2$ K, heating at a rate of $\upsilon = 3$ K/min to a temperature of $T = 393 \pm 2$ K, keeping the samples at this temperature for a time of $t = 2.0 \pm 0.05$ h., slow cooling to the temperature $T = 293 \pm 2$ K. In order to stabilize the structural processes in the matrix, the samples were kept for $t = 24$ h. in air at a temperature of $T = 293 \pm 2$ K.

The tribological properties of the materials were studied on the testing machine 2070 CMT-1 according to the "disk-pad" scheme and the method in accordance with ASTM G77-17.

The mass intensity of wear was determined by the formula [10]:

$$I_m = \frac{\Delta m}{\Delta L}, \quad (1)$$

where Δm is the difference in mass of the sample before and after friction, mg; ΔL is friction distance, km.

The coefficient of friction was calculated according to ASTM G77–17 using the formula [10]:

$$f = \frac{M}{F\,r}, \quad (2)$$

where M is the average arithmetic value of the moment of friction, N·m; F is the load on the pad, N; r is the radius of the metal counterbody (arm), m.

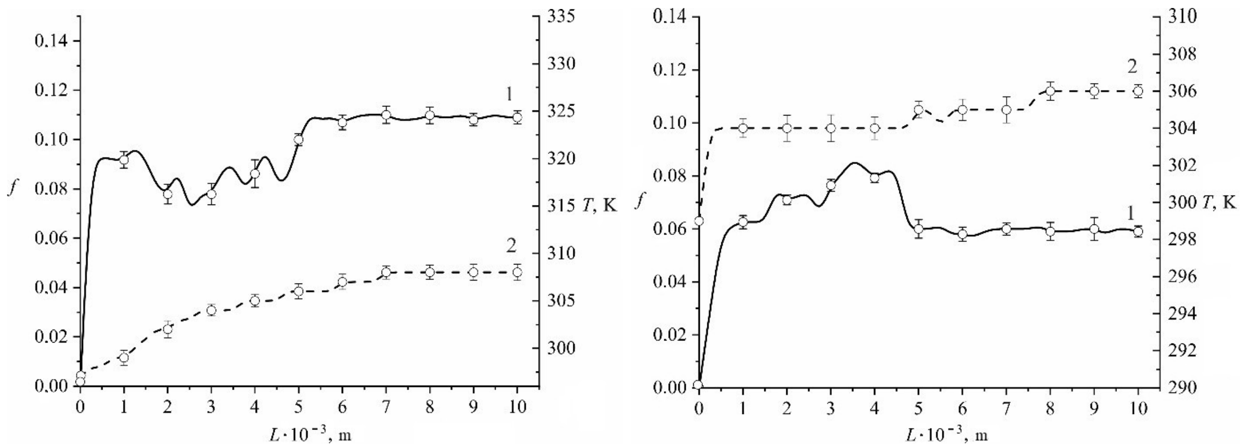
The disk (counterbody) was made of material steel 45, heat-treated to a hardness of 45–48 HRC with surface roughness of Ra = 0.16–0.32 μm [10].

The tribological properties of composite materials that were kept in river water (Dnipro River) and alkaline medium (NaOH 50 %) for 150 days were studied. All studies were carried out under specific load p = 1 MPa and sliding speed υ = 1.0 m/s in accordance with the operating conditions of composite materials. The sliding path of the samples during the tests was 10,000 m.

The temperature in the contact zone was determined using a "chromel-copel" thermocouple, the signal from which was recorded by measuring equipment. The thermocouple was placed at a distance of l_t = 2 mm from the contact area of the sample with the counterbody.

Results and discussion

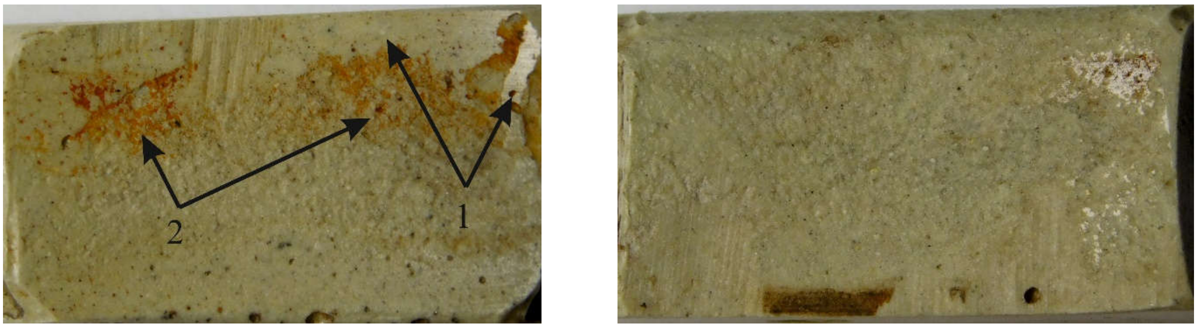
In this paper, the effect of aggressive river water environment (Dnipro River) and alkaline medium (NaOH 50 %) on the tribological properties of the developed composite [11–12] with the content of mica (20 wt. parts) and hexagonal boron nitride (60 wt. parts). Previously, the samples were kept for 150 days in these environments with further testing after the specified period expired. The choice of test environments is directly connected with the introduction of developed materials in the transport industry. When studying the tribological properties of composite materials, a comparison was made with a composite of the same composition and molding technology tested under dry friction conditions, which is characterized by the following indicators of the studied properties: coefficient of friction f = 0.14–0.16, working temperature T = 357–360 K, burn-in path l = 2800–3000 m and wear intensity Im = 13.9–14.1 mg/km [11]. The coefficient of friction of the material kept in river water has decreased from f = 0.14–0.16 (during dry friction) to f = 0.09–0.11, and the intensity of wear decreased significantly from Im = 13.9–14.1 to Im = 0.18–0.20 mg/km (Fig. 1). However, the burn-in path increased from l = 2800–3000 to l = 4700–5000 m. This is obviously due to the formation of friction products in the contact zone and oxidation of the counterbody with subsequent formation of oxides. Since the oxides have less strength than the counterbody material, they break down faster on contact, as a result of which the duration of the burn-in stage increases until the stable wear zone is established. This theory was confirmed by the analysis of the friction surface of the material (Fig. 2, *a*), on which the oxidation products of the counterbody are present. The working temperature in the contact zone was T = 308–309 K (Table 1). The obtained results can be explained by the influence of river water on the friction process. It is known that during liquid lubrication, the resistance to body movement is determined by internal friction (viscosity of the liquid) and consists of the sliding resistance of liquid layers along the thickness of the lubricating layer. Comparing the values of the coefficients of friction of the material when lubricated in grease and river water, it was found that the coefficient of friction of CM in river water is lower, which follows from the lower viscosity of river water compared to grease.



a) *b)*

a) testing in river water; b) testing in an alkaline NaOH environment (50 %)

Figure 1 – Dependence of the coefficient of friction (1) and operating temperature (2) from the testing path of the composite material



a) *b)*

a) testing in river water; b) testing in an alkaline environment

Figure 2 – The surface of the composite material, which was kept in river water and NaOH environments after friction with an increase in 3 times

Table 1 –Tribological properties of CM, which were kept in aggressive environments

Parameters	Testing CM in the conditions of	
	river water	NaOH (50 %)
Operating time *M,* N·m	0.44–0.59	0.24–0.32
Coefficient of friction *f*	0.09–0.11	0.05–0.06
Operating temperature *T*, K	308–309	305–306
Burn-in path *L*, m	4700–5000	4600–4800
Wear intensity I_m, mg/km	0.18–0.20	0.10–0.20

For the material tested under conditions of an alkaline environment influence, the values of the friction coefficient and wear intensity decreased from $f = 0.14–0.16$, $I_m = 13.9–14.1$ mg/km (in case of dry friction) to $f = 0.05–0.06$, $I_m = 0.10–0.20$ mg/km, respectively. At the same time, the section of stable wear for such material begins after the burn-in path $l = 4600–4800$ m. The value of the operating temperature in the contact zone was $T = 305–306$ K. The absence of significant changes in the studied characteristics along the entire friction path indicates the resistance of the developed material to the influence of aggressive highly concentrated alkaline environment. The similarity of the values of the coefficient of friction by friction in grease and alkaline media can be explained by the increase in the viscosity of the NaOH solution at a concentration of 50 % alkali. It is obvious, that the influence of an aggressive environment does not reduce the adhesive strength between the matrix and the fillers. The obtained results of the CM study, namely, low indicators of the coefficient of friction and intensity of wear, indicate the feasibility of using the developed material in aggressive alkaline environments.

Fig. 2 shows the friction surfaces of the samples tested in river water and an alkaline environment. The friction surface of the composite, which was tested in river water, has traces of lapping 1 in Fig. 2, *a*. Also, as mentioned above, there are oxides of the counterbody on the surface of the material (2 in Fig. 2, *a*), which indicates the corrosive activity of the river water environment. In the photo of Fig. 2 *b*, there are no typical friction tracks, which allows us to assert about liquid lubrication of the friction surfaces material and the presence of a layer of liquid lubricant (alkaline medium) in the contact zone. It should be noted that the viscosity of the lubricant is not a function of the coefficient of friction, but the oiliness of the lubricant is such a characteristic. Therefore, analyzing the surfaces of the material and the coefficients of friction, it can be stated that alkaline environment is more oily compared to river water.

Comparing the results of the study of the epoxy-polyester composite during friction in different environments, it can be stated that the studied properties, namely, the coefficient of friction, the intensity of wear decrease by 1.5–2.8 times and 50–150 times, respectively, compared to dry friction. At the same time, the burn-in path increased by 1.3–1.7 times, which, together with the decrease in wear intensity, indicates a decrease in wear. Therefore, the obtained results of the tribological properties of CM with the content of mica and hexagonal boron nitride (20 : 60 wt. parts) indicate the expediency of using such materials in the friction nodes of mechanisms that work under the influence of aggressive environments of river water and alkali NaOH (50 %).

Conclusions

According to the results of studies of the tribological properties of the composite material in the environment of river water, the following indicators were established: coefficient of friction $f = 0.09–0.11$, burn-in path $l = 4700–5000$ m, wear intensity $Im = 0.18–0.20$ mg/km, operating temperature $T = 308–309$ K. For the composite material, which was tested in alkaline conditions, the value of the coefficient of friction decreased from $f = 0.14–0.16$ (during dry friction) to $f = 0.05–0.06$, wear intensity from $Im = 13.9–14.10$ mg/km to $Im = 0.10–0.20$ mg/km. At the same time, the burn-in path and operating temperature in the contact zone were $l = 4600–4800$ m and $T = 305–306$ K, respectively. The results of the study were confirmed by optical microscopy. The obtained results of the study of the tribological properties of CM with the content of a bidisperse filler (mica, h-BN) indicate the feasibility of using the developed materials in the friction nodes of mechanisms that operate under the influence of an aggressive environment (river water, alkaline environment).

The publication contains the results of research within the framework of R&D of young scientists "Development of anti-friction nanocomposite materials in order to improve the operational characteristics of friction nodes of land and water transport" (state registration number 0120U101566).

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Дослідження трибологічних властивостей наповнених епоксиполімерних композитів для підвищення експлуатаційних характеристик вузлів тертя засобів транспорту

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Досліджено трибологічні властивості наповнених епоксидних полімерних композитів з метою покращення експлуатаційних характеристик вузлів тертя транспортних засобів. Полімерна матриця композиту сформована на основі епоксидного олігомеру ЕД-20 (q = 100 мас. частин) з додаванням ортофталевої дициклопентадієнової ненасиченої попередньо прискореної поліефірної смоли ENYDYNE H 68372 TAE (q = 10 мас. частин на 100 мас. частин епоксидної смоли), водночас використовували затверджувач холодного твердіння поліетиленполіамін (ПЕПА) (q = 10 мас. частин), ініціатор для поліефірних смол Бутанокс-М50 (q = 1,5 мас. частин). До складу епоксидно-поліефірного композиту введено модифікатор метилендифенілдіізоціанат (q = 0,25 мас. частин) та наповнювачі: гексагональний h-NB 8–10 мкм (q = 60 мас. частин) та слюду 20–40 мкм (q = 20 мас. частин). Трибологічні властивості композитів вивчали на машині тертя 2070 СМТ-1 після витримки протягом 150 діб в агресивній річковій воді (р. Дніпро) та лужному середовищі (50 % розчин NaOH).

Ключові слова: *агресивне середовище, антифрикційний матеріал, епокси-поліефірний композит, інтенсивність зносу, коефіцієнт тертя, трибологічні властивості.*