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Effect of discrete basalt fiber on operational properties of polytetrafluoroethylene

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Abstract

The article examines the effect of discrete basalt fibers on the tribotechnical characteristics of DF-101 polytetrafluoroethylene according to the “disk-pad” scheme under conditions of friction without lubrication. It was established that the introduction of filler leads to decrease in the intensity of wear and the coefficient of friction of the base polymer 1,7 and 360 times, respectively. The improvement of these properties occurs because “anti-friction layer” that is more stable compared to unfilled polytetrafluoroethylene is formed in the process of friction of basalt plastics. As a result, friction occurs according to the “polymer-polymer” scheme. This is confirmed by a profound change in the morphology of the friction surface. For example, deep ploughing furrows and traces of adhesion with the counterbody are observed for polytetrafluoroethylene, while basalt plastics are more resistant to deformations, which, in turn, leads to a reduction of ploughing furrows. A sharp decrease in wear resistance 1,35-3,3 times is observed for basalt plastics containing 30-40 mass.% of fiber. It is probably a consequence of the growth of defects in the volume of the material due to the uneven location of the fiber in the polymer matrix. The confirmation of the presence of defects in the volume of basalt plastics is confirmed by a comparison of the calculated and experimental (hydrostatic) density. It was found that polytetrafluoroethylene loses 10% of its mass at a temperature of 823K, while the temperature of losing 10% of mass increases by 10 degrees for basalt plastic. It was determined that the effective content of the filler in the polymer matrix is 20 mass.%. The obtained basalt plastic (20 mass.% fiber) is recommended in manufacturing rolling and sliding bearings (as anti-friction protection) for tribological units of modern technology operating under the influence of high temperatures, aggressive environments and friction conditions without lubrication.

Key words: polytetrafluoroethylene, basalt fiber, wear intensity, coefficient of friction, friction unit

Introduction

Reliable and failsafe operation of friction units of systems and aggregates of mining, metallurgical and agricultural [1] machinery directly depends on their wear. It is known [2] that in operation process, the working bodies of friction units made of traditional metals undergo catastrophic wear manifested in the destruction of their surfaces, violation of the initial geometric shapes and weight. All the above leads to the loss of efficiency of the friction units, resulting in increased operating costs and a decrease in their efficiency.

Using fluoropolymer composite materials (FPCM) allows us to solve this problem and obtain a number of advantages. Thus, sliding [3] and rolling bearings (like anti-friction protection) [4], as well as piston and seal rings [5] made of FPCM, made it possible to increase the service life of the friction units of KINZE-7600 seeding-machine and sintering pallet cars, piston compressors of SO-7B and 4GM 2,5 U–3,4/2,8–251 2,5 times on average. The effectiveness of using these FPCM consists in the complete rejection of lubricants, increased wear resistance, reduced coefficients of friction and linear expansion, the number of planned preventive maintenances and equipment downtime.

Literature review

Effective fillers for creating wear-resistant FPCM are fibers of various natures such as carbon, organic, glass, etc. However, these composites are characterized by insufficient heat resistance and alkali resistance [5, 6], high hygroscopicity (this indicator is 10-20% for glass fibers).

As the analysis of literary sources [7] showed, basalt fibers (BF) are one of the promising fillers for creating wear-resistant polymer composites. The unique multi-component composition of basalt (except for oxides, it contains almost all the elements of Mendeleev's table) provides the fiber with a successful combination of high technical characteristics [8] which are not inferior to organic, carbon and glass fibers. Thus, basalt plastics (BP) 3 times surpass steel in strength. High damping properties, resistance to aging, corrosion and many natural factors characterize them. Environmental and economic aspects are not the last argument in favor of using BF. BF is a more ecological product compared to glass, carbon, and organic fibers, since the raw material from which it is made is igneous rock (basalt). In addition, the technological process of manufacturing BF has an energy-efficient production technology. Only basalt crushed stone only is used for fiber production, without using acids, dyes and solvents. Given the above, looking for a new BP based on a fluoropolymer matrix with high functional characteristics is an urgent task.

Technique for researching the properties of composites

DF-101 polytetrafluoroethylene (PTFE) (manufactured by Shandong Dongyue Polymer Material Co., Ltd, China) was chosen as the polymer matrix for creating basalt plastics. This polymer is characterized by a unique complex of functional properties (see Table 1) in combination with increased resistance to thermal degradation, erosion, as well as the effect of organic and aqueous environments.

Table 1

Main properties of DF-101 polytetrafluoroethylene

Indicator	Value
Density, g/cm^3	2,13-2,16
Tensile strength, MPa	27,0
Elongation at rupture, g/L	500 ± 100
Moisture content, %	0,04
Operating temperature, K	4-533

The disadvantages of PTFE are a high coefficient of thermal expansion, the ability to undergo irreversible deformation under the influence of mechanical loads at room temperature, a tendency to residual deformation and low resistance to abrasion, which is why it is recommended to use fillers.

Discrete BF (Research Institute of Fiberglass and Fibers PJSC (NDISV in Ukrainian), Ukraine) was chosen as filler for PTFE. BF was produced using compression moulding according to the method given in the paper [3].

The tribotechnical characteristics of polytetrafluoroethylene and basalt plastics based on it were studied using the “disk-pad” scheme on SMC-2 friction machine, under conditions of friction without lubrication, at a load of 1,0 MPa, and a sliding speed of 1,0 m/s. Steel 45 (45-48 HRC, R_a=0,32 μm) was used as a counterbody. The density of PTFE and BP based on it was determined using hydrostatic weighing method.

The study of the friction surfaces of the unfilled polymer and BP based on it was carried out using a BIOLAM-M optical microscope.

The thermal stability of polytetrafluoroethylene and BF based on it was carried out using the method of thermogravimetric analysis using MOM Q-1500D derivatograph of the Paulik-Paulik-Erdey system (Hungary). The temperature range of the research was 273-900 K, the rate of temperature rising was 10 K/min, the weight of the test sample was 100 mg.

Results

According to the results of tribotechnical characteristics research (Table 2), it was established that the introduction of BF leads to a decrease in the coefficient of friction and the intensity of linear wear of PTFE 1,7 and 360 times, respectively, reaching the minimum values of the latter at a fiber content of 20 mass.%. The improvement of these properties occurs because finely dispersed products of frictional transfer of BP fill in the microdepressions of the steel counterbody and form a more stable, compared to pure PTFE, an “anti-friction layer” [9]; as a result, friction occurs not according to the “metal–polymer” scheme, but according to the “polymer-polymer” scheme [10].

Table 2

Tribotechnical characteristics of basalt plastics based on polytetrafluoroethylene

Indicator	Basalt fiber content, C, mass.%				
	0	10	20	30	40
Coefficient of friction, f	0,35	0,33	0,32	0,20	0,20
Intensity of linear wear, $I_h \times 10^{-9}$	1120	5,31	3,12	4,30	10,40

The study of friction surfaces of PTFE and BP showed a deep change in the surface morphology. It can be seen from the microstructure of the friction surface of PTFE that there are traces of adhesion and deep furrows of ploughing of the surface layer on its surface (Fig. 1, a). The introduction of BF leads to the reduction of ploughing furrows (Fig. 1 b and c); it can be explained by the fact that the fibers give stiffness to the soft polymer, and as a result, BP resists deformations.

A sharp decrease in wear resistance 1,35-3,3 times is observed for basalt plastics containing 30-40 mass.% of the filler, which is probably a consequence of the growth of defects in the volume of the material (the formation of microcracks and pores) due to the uneven location of the fiber in the polymer matrixes. Pronounced friction tracks, which are formed due to the dominance of the process of mechanical destruction of the surface, and those formed as a result of the transfer of spent particles to the friction area are observed on the friction surface of basalt plastic containing 40 mass.% of the fiber (see Fig. 1, d).

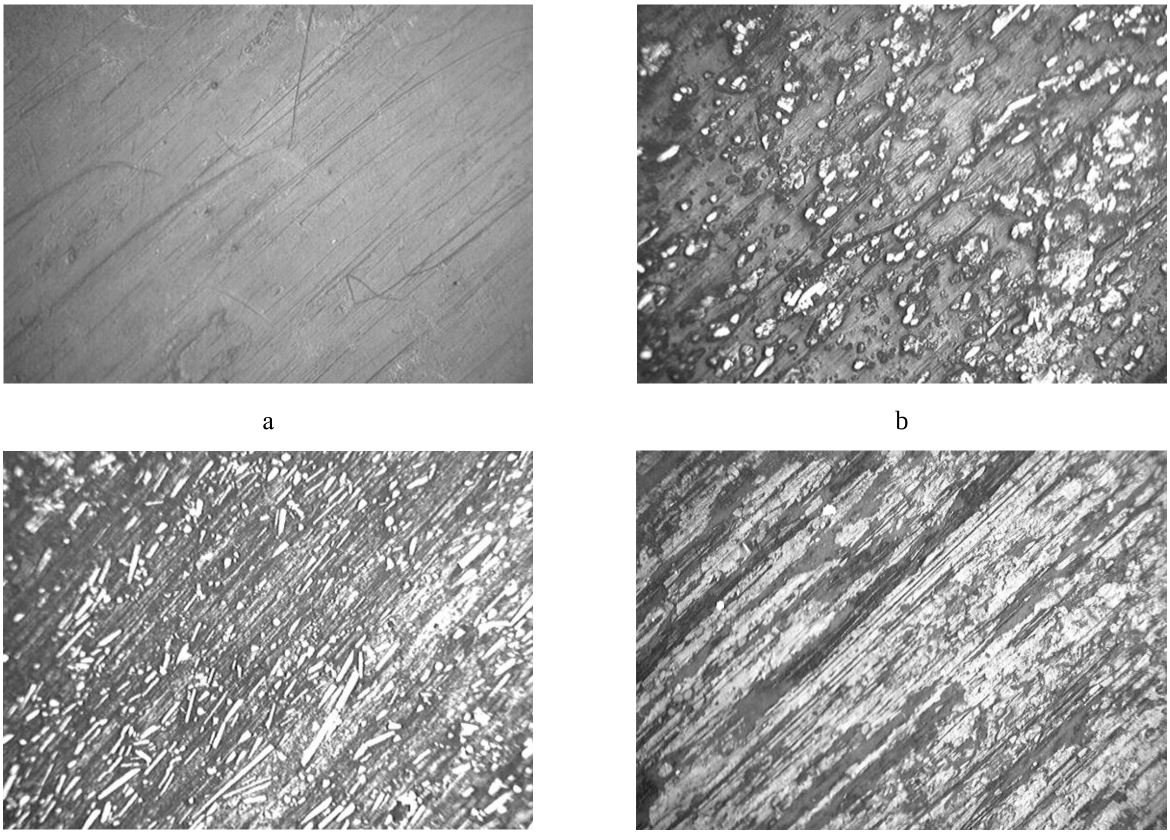

Fig. 1. Microstructures (×150) of friction surfaces of polytetrafluoroethylene (a) and basalt plastics based on it, containing: 10 (b); 20 (c), 40 (d) mass.% of basalt fiber

The confirmation of the presence of defects in the volume of BP is confirmed by the comparison of the calculated and experimental density. It can be seen from fig. 2 that experimental BF density is higher than the calculated one at a BF content of 10-20 mass.%. According to this, we conclude that the supramolecular structure of the obtained materials is more ordered due to strong intercomponent interaction at the “polymer-fiber” interface. With a further increase in BF content, the opposite dependence is observed, which can be explained by the fact that it becomes more challenging to achieve a uniform distribution of polytetrafluoroethylene on its surface; as a result, during the formation of the surface layer, the packing of macromolecules in it becomes looser, therefore, the material contains pores.

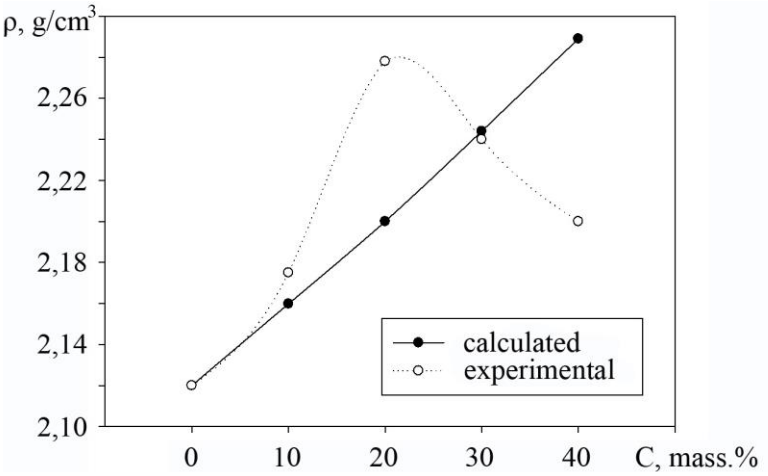

Fig. 2. Dependence of calculated and experimental density (ρ, g/cm^3) of polytetrafluoroethylene on basalt fiber content (C, mass.%)

Another important property that ensures the stable operation of friction units is the thermal stability of the composite. It was established that the introduction of BF (Fig. 3) leads to an increase in the thermal stability of PTFE.

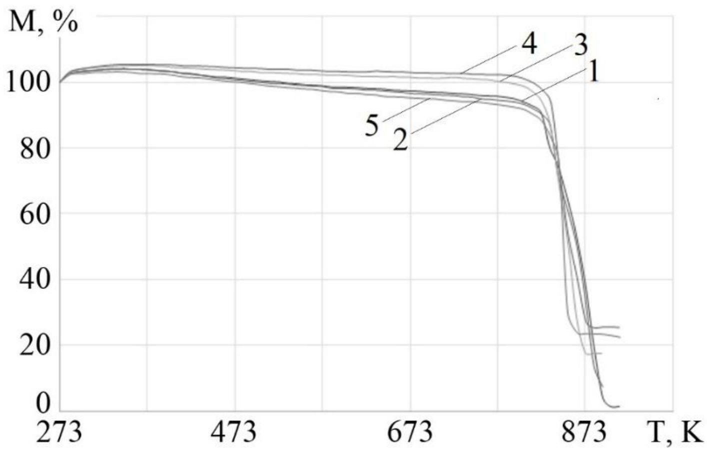

Fig. 3. Dependence of mass loss (M, %) on temperature (T, K) of polytetrafluoroethylene (1) and basalt plastics based on it containing: 10 (2); 20 (3), 30 (4), 40 (5) mass.% of basalt fiber

There is no mass loss observed up to 423 K on the thermogravimetric curves of PTFE and basalt plastics based on it; that is, the materials are hydrophobic [7]. It is interesting to note that PTFE loses 10% of its mass (T_{10}) at a temperature of 823 K, while for BP the temperature of losing 10% of mass increases by 10 degrees, which is due to a decrease in the mobility of molecular chains of PTFE when reinforcing its BF. It, in turn, leads to an increase in its thermal oxidation resistance. There is a significant mass loss after 823 K due to intensive thermal destruction of both PTFE and BP based on it.

Fig. 4. Sintering cars of Zaporizhstal PJSC

The positive results of laboratory studies allowed us to proceed to production ones. Basalt plastic with an effective (20 mass.%) filler content was used as an anti-friction protection for sliding bearings (No. 315) of sintering cars of Zaporizhstal PJSC (Fig. 4).The friction units of the cars work in dusty conditions and under high temperatures (about 573 K). The bearings with the developed BP worked without failure for 11 months, which made it possible to recommend bringing them into serial production

Conclusions

According to the results of tribological studies using the “disk-pad” scheme, it was established that the introduction of discrete basalt fiber leads to a decrease in the coefficient of friction and the intensity of linear wear of DF-101 polytetrafluoroethylene 1,7 and 360 times, respectively. At the same time, the thermal stability of basalt plastics increases. Based of the obtained results, BP with an effective fiber content (20 mass.%) is recommended for manufacturing friction units of machines and mechanisms of modern technology that operate under the influence of high temperatures and friction conditions without lubrication.

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Єрьоменко О.В., Томіна А.-М.В., Рула І.В. Вплив дискретного базальтового волокна на експлуатаційні властивості політетрафторетилену

У статті розглянуто вплив дискретного базальтового волокна на триботехнічні характеристики політетрафторетилену марки DF-101 за схемою «диск-колодка» в умовах тертя без змащення. Встановлено, що введення наповнювача призводить до зменшення інтенсивності зношування та коефіцієнту тертя базового полімеру у 1,7 та 360 разів відповідно. Покращення даних властивостей обумовлено тим, що в процесі тертя базальтопластиків утворюється більш стабільний, порівняно з ненаповненим політетрафторетиленом, «антифрикційний шар», внаслідок чого тертя відбувається за схемою «полімер–полімер». Підтвердженням цього служить глибока зміна морфології поверхні тертя. Так, для політетрафторетилену спостерігаються глибокі борозни проорювання й сліди схоплювання з контртілом, в той час як базальтопластики чинять більший опір до деформацій, що в свою чергу призводить до зменшення борозн проорювання. Для базальтопластиків, що містять 30-40 мас.% волокна спостерігається різке зменшення зносостійкості у 1,35-3,3 рази, що імовірно, є наслідком зростання дефектів в об’ємі матеріалу через нерівномірне розташування волокна в полімерній матриці. Підтвердження наявності дефектів в об’ємі базальтопластиків підтверджує порівняння розрахункової та експериментальної (гідростатичної) густини. Встановлено, що політетрафторетилен втрачає 10% маси при температурі 823 K, в той час як для базальтопластику температура втрати 10% маси збільшується на 10 градусів. Визначено, що ефективний вміст наповнювача в полімерній матриці складає 20 мас.%. Отриманий базальтопластик (20 мас.% волокна), рекомендовано при виготовленні підшипників кочення та ковзання (як антифрикційний захист) для трибологічних з’єднань сучасної техніки, що працюють під впливом високих температур, агресивних середовищ та умовах тертя без змащення.

Ключові слова: політетрафторетилен, базальтове волокно, інтенсивність зношування, коефіцієнт тертя, вузол тертя