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Influence of carbon fiber on tribotechnical characteristics of polyetheretherketone

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Abstract

Superstructural thermoplastic polymers, including polyetheretherketone, are now widely used in many industries. However, its rather high coefficient of friction and insufficient wear resistance limits its use in friction units of machines and mechanisms. This article covers the influence of T700 Toray carbon fiber on the tribotechnical characteristics of Victrex150G aromatic polyetheretherketone. As a result of the researches it has been found out that the developed carbon plastics exceed the base polymer in friction coefficient and wear 1.2-1.54 and 1.7-8.8 times, respectively, due to the formation of a stable "transfer film" on the steel counterbody (so-called antifriction layer): finely dispersed particles of the polymer matrix and crushed products of wear of carbon fiber penetrate into the microcavities of the counterbody. This is confirmed by the fact that the roughness of carbon plastics has decreased by 50 % in cpomparison with the base polymer. The greatest improvement in tribological properties is observed at 10 mass%, of carbon fiber content, then the properties get worse. That can be explained by the increase in defects of the material due to the dominant loosening at the "polymer-fiber" boundary that confirms the results of microhardness and ultrasonic control. The obtained results show that the composite with an effective carbon fiber content (10 mass%) can be recommended for the manufacture of parts of movable joints of machines and mechanisms operating under friction without lubrication in various industries: agricultural, automotive and textile. etc.

Key words: aromatic polyetheretherketone, carbon fiber, wear, friction coefficient, ultrasonic control, microhardness, friction units

Introduction

One of the important factors limiting the trouble-free and stable operation of agricultural, aviation and automotive equipment is the wear (up to 6 mm) of the contact surfaces of the sliding friction units [1] that are equipped with metal parts. The use of polymer composite materials (PCM) based on thermoplastic polymer matrices allows to solve this problem and get a number of advantages. Thus, plain bearings made of PCM are characterized by high mechanical and tribotechnical characteristics combined with low weight, chemical and thermal resistance. In addition, a wide variety of polymer composites, which differ in their technical indicators, allows to select an effective material for specific operating conditions. Another important advantage of PCM is the ability to develop new and improve (in order to get strong adhesive bonds that largely determine the technical characteristics of polymer composites) that allows to expand their use and increase their competitiveness with other traditional materials [2].

Literature review

Carbon fiber (CF) is now one of the most common fillers for the creation of PCM based on thermoplastic binders - carbon plastics (CP) for tribotechnical and structural purposes [3]. Thus, the use of CF as a filler allows to obtain composites with high specific strength, high environmental friendliness, the ability to work in heavily loaded friction units without lubrication [4], low density and almost zero coefficient of thermal linear expansion (CTLE), lightness that allow them to compete with known serial materials (bronze, titanium, babbitt, cast iron, etc.). CF have been widely used to fill polyetheretherketone (PEEK). However, there are disadvantages that hinder the widespread implementation of these CP: anisotropy of characteristics due to the uneven distribution of CF in the polymer matrix, insufficient high operating temperature, high cost of manufacturing products [5]. Taking into account the above, the search for new carbon fiber based on PEEK with high performance indicators is an urgent task.

Methods

Victrex150G polyetheretherketone (manufactured by ICI) was chosen as the polymer matrix. PEEK is characterized by a unique set of performance characteristics: heat and fire resistance, resistance to many aggressive environments (acetone, trichlorethylene, ethyl acetate, gasoline, etc.), high-energy rays (even ultraviolet rays lead only to slight yellowing of the material) and radiation, low water absorption, high temperature of long (from 233 to 533 K) and short-term operation (up to 623 K). However, polyetheretherketone has high enough coefficient of friction (f> 0.4) and insufficient wear resistance that limits its use in the friction units of machines and mechanisms [6]. Among other plastics, PEEK has the lowest level of emissions of harmful gaseous substances under the influence of an open flame.

Toray T700 carbon fiber was selected as a filler (table 1).

Table 1

The main properties of Toray T700 carbon fiber

Indicator	Value
Density, kg / m3	1700 – 1800
Compressive strength, MPa	230
Modulus of elasticity, GPa	4900
Number of filaments	12000

Compositions containing 5-20 mass% of discrete carbon fiber were prepared by mixing the components in a rotating electromagnetic field in the presence of ferromagnetic particles. Processing of the mixture prepared by this method into block products was carried out by compression pressing at a pressure of 50 MPa and an effective pressing temperature of 628 K, hold time without pressure was 10 min., hold time under pressure was 5 min [7].

The study of tribotechnical characteristics of the base polymer and carbon plastics based on it was carried out in the mode of friction without lubrication on machine with reciprocating motion at a load of 0.637 MPa, a sliding speed of 1.03 m / s. The experiment time was 30 minutes. The samples were made of cylindrical shape Ø = 10, h = 15 mm,38H2MYUA steel was used as a counterbody (45-48 HRC, Ra = 0.16-0.32 μm). The obtained results were processed using the methods of mathematical statistics.

The depth of abrasion tracks (surface roughness, Ra, μm) of the original polymer and carbon plastics based on it was determined using a 170621profilometer using a sharp and hard needle (probe) that moved along the test surface copying its irregularities. The study of the morphology of the friction surfaces of unfilled polyetheretherketone and carbon plastics based on it was carried out using NEOPHOT-32optical microscope. In the study of microhardness the characteristics of reinforced plastics were obtained in its microvolumes at the "binder - fiber" boundary on the PMT-3M microhardness tester.

Non-destructive quality control (that allows to determine the presence of cracks and pores in the volumes of the composite) of the original polymer and composites based on it was determined by echo-pulse method using a universal ultrasonic UD2V-P46 flaw detector ("KROPUS", LLC "NPP Ukrintech"), in the mode of the automatic signaling of defect (ASD), frequency was 5 MHz, the period was 2,5, PEC was 5 MHz. This device is widely used to identify defects in materials due to its simplicity and high performance, reliability and versatility.

Results

Analysis of the results of tribological studies under friction without lubrication showed that the use of Toray T700 carbon fiber can reduce the coefficient of friction and wear of aromatic polyetheretherketone 1,2-1,54 (Fig. 1) and 1,7-8,8 (Fig. 2) times respectively. These results can be explained as follows. Carbon plastics are characterized by 1.3-1.7 times higher thermal conductivity than PEEK (studied by the authors in the work [8] that according to the fatigue theory of wear it prevents the localization of heat in the friction zone and thermomechanical destruction of polymers).

On the other hand, in the process of friction of carbon plastics (Fig. 3) there is a process of selective transfer [9]: finely dispersed wear products formed during friction fill the microcavities of the steel counterbody resulting in friction on the "transfer film" that acts as a dry lubricant and is characterized by low shear strength and high load capacity. There is a transition from the adhesive-fatigue mechanism of wear to pseudoelastic.

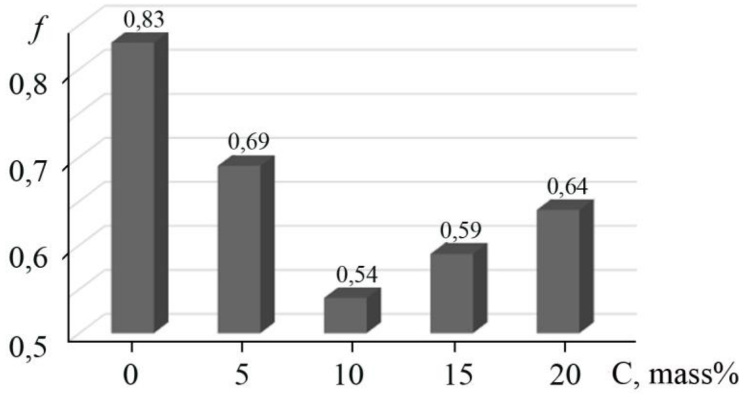


Fig. 1. Influence of carbon fiber on the friction coefficient of polyetheretherketone

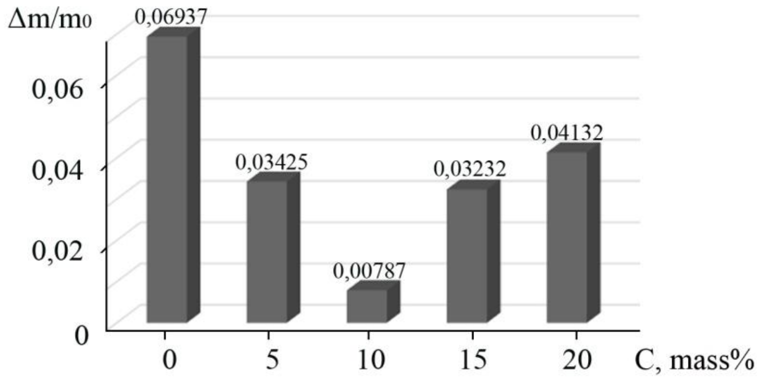
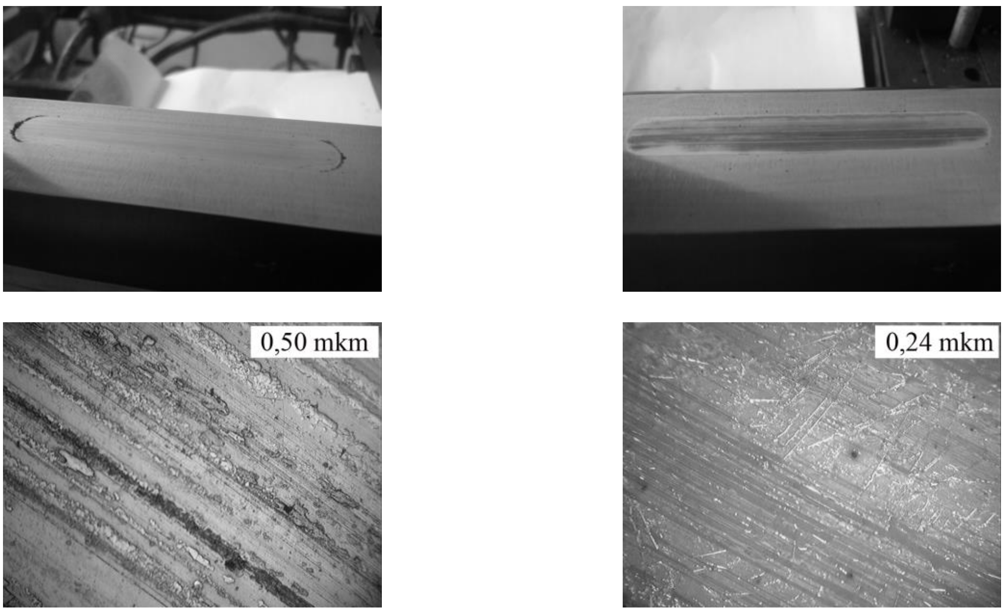


Fig. 2. Influence of carbon fiber on the wear of polyetheretherketone

This is confirmed by the study of the morphology of the friction surfaces of PEEK and carbon plastics based on it. It has been found out that with the introduction of 10 mass% of CF there is a significant smoothing of the microrelief of the carbon fiber surface. The average surface roughness of the initial polymer during carbon fiber reinforcement decreased by 2 times (Fig. 3). That is one of the important contributions to the overall improvement of tribological properties, because when the roughness decreases, the specific load in the contact areas decreases [10].



a b

Fig. 3. The surface of the counterbody and the sample after friction of polyetheretherketone (a) and carbon fiber (b) based on it containing 10 mass% of carbon fiber

On the other hand, the increase in the wear resistance of CP is due to the ability of materials to dissipate energy by reducing internal friction as a result of changes in the structure of the polymer binder (it becomes more ordered) that leads to a decrease in temperature of surface layers. As a result, adhesion zones are almost not observed on the friction surface of the polymer composite, in contrast to non-reinforced polyetheretherketone (Fig. 3).

The most intensive improvement of the tribotechnical characteristics of the initial polymer occurs with the introduction of CF up to 10 mass%. After that it begins to decrease. This is due to the increase in the defect of the material.

The appearance of defects (pores, cracks) in the volume of the material is due to poor impregnation of the polymer matrix of carbon fiber that are formed due to excessive amounts of the latter. This is confirmed by the study of microhardness at the " polyetheretherketone-fiber" boundary (Fig. 4). Thus, when the filler content is 15-20 mass%, the value of microhardness decreases by 10%. This indicates that at a fiber content of 5-10 mass% the ordering process of the binder prevails over loosening, and vice versa in the case of 15-20 mass%.

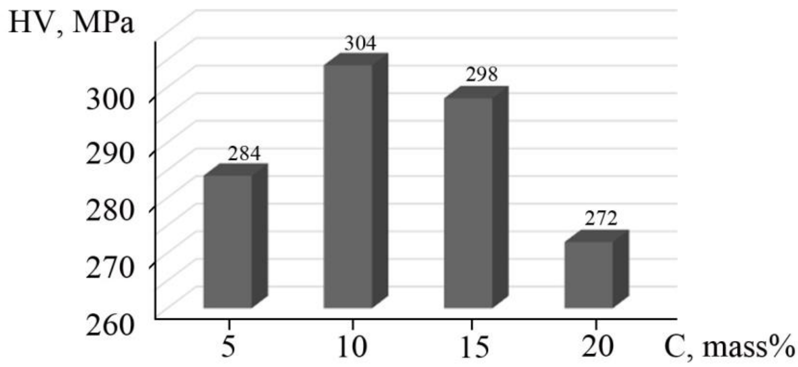


Fig. 4. Microhardness of carbon fiber at the "polymer-fiber" boundary

Another confirmation of this conclusion may be the data of ultrasound monitoring (Fig. 5).

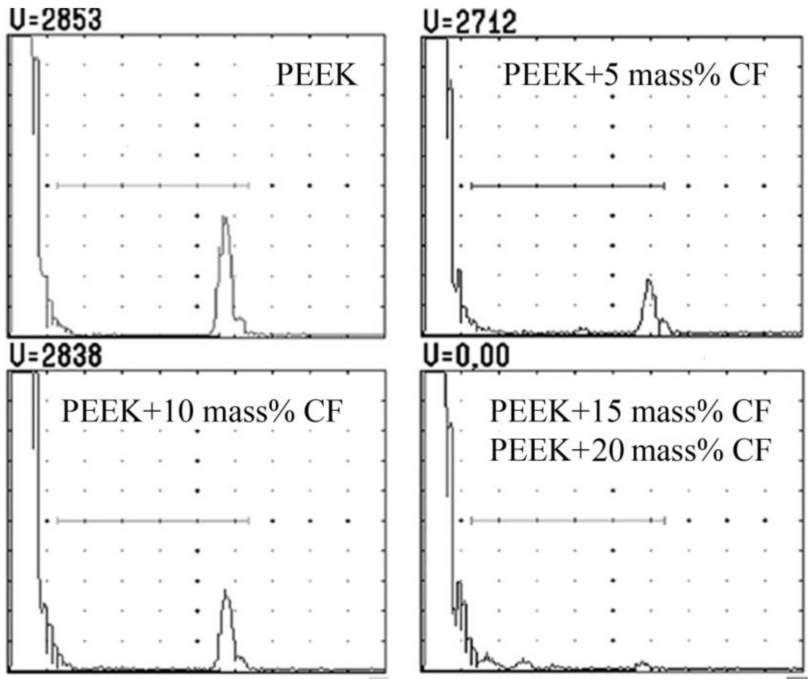


Fig. 5. Pulses of reflected "bottom" signals

Unfilled polymers and composites are characterized by lower speeds of ultrasonic wave propagation in the volume that allows to study samples of small thickness (3-4 mm). In this regard, the evaluation of the reflected "bottom" pulse, the speed of wave propagation, as well as the length of the ultrasound path was carried out on the samples made of PEEK and carbon fiber based on it [11].

The speed of propagation of the ultrasonic wave in the CP varied in the range of 2712-2838 m / s, the amplitude of the reflected signal was in the range of 90%. As it can be seen from Fig. 5 with an increase in the percentage of CF up to 15-20 mass% in the polymer binder the burst from the reflected pulse is absent on the screen of the device, that is, the defect (accumulation of fiber) completely covers the ultrasonic beam [12].

Conclusions

Analysis of the results of tribological studies of developed PCM showed that the use of Toray T700 carbon fiber as a filler for aromatic polyetheretherketone is a promising way to improve its tribological properties: reducing the coefficient of friction and wear by 1.5 and 1.8 times, respectively. When the percentage of carbon fiber (15-20 mass%) increases, it becomes difficult to distribute the binder on its surface evenly. Therefore, tribotechnical characteristics are improved only until the achievement of effective (10 mass%) filling, after which they decrease; this can be explained by the increase in defects of the material due to the dominant loosening at the boundary that confirms the results of ultrasonic control and microhardness measurement. Based on the obtained results, a composite with an effective carbon fiber content can be recommended for the manufacture of plain bearings (agricultural, automotive and textile) that operate in friction conditions without lubrication.

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Буря О.І., Томіна А.-М.В., Начовний І.І. Вплив вуглецевого волокна на триботехнічні характеристики поліефірефіркетону

Суперконструкційні термопластичні полімери, у тому числі поліефірефіркетон, сьогодні активно використовуються у багатьох галузях промисловості. Проте, досить високий коефіцієнт тертя та недостатня зносостійкість обмежує його використання у вузлах тертя машин і механізмів. У статті розглянуто вплив вуглецевого волокна Toray T700 на триботехнічні характеристики ароматичного поліефірефіркетону марки Victrex150G. У результаті проведених досліджень, встановлено що розроблені вуглепластики, перевершують базовий полімер за коефіцієнтом тертя та зносостійкістю у 1,2-1,54 і 1,7-8,8 відповідно, що обумовлено утворенням на сталевому контртілі стабільної «плівки переносу» (так званого антифрикційного шару): дрібнодисперсні частки полімерної матриці та подрібнених продуктів зношування вуглецевого волокна проникають до мікровпадин контртіла. Підтвердженням сказаного служить той факт, що шорсткість вуглепластиків у порівнянні з базовим полімером зменшилася на 50%. Найбільше покращення трибологічних властивостей спостерігається при вмісті вуглецевого волокна 10 мас.%, після чого вони погіршуються, що можна пояснити зростанням дефективності матеріалу за рахунок домінуючого розпушення на межі поділу «полімер-волокно», що і підтверджують результати вимірювання мікротвердості та ультразвукового контролю. Отримані результати досліджень, свідчать що композит, із ефективним вмістом вуглецевого волокна (10 мас.%) може бути рекомендована для виготовлення деталей рухомих з'єднань машин і механізмів, що працюють в умовах тертя без змащення у різних сферах промисловості: сільськогосподарській, автомобільній та текстильній тощо.

Key words: поліефірефіркетон, вуглецеве волокно, зношування, коефіцієнт тертя, ультразвуковий контроль