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ANTIFRICTIONAL POLYMER COMPOSITES BASED ON AROMATIC POLYAMIDE AND CARBON BLACK

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Abstract. Antifrictional polymer composites (PC) based on aromatic polyamide and carbon black were developed. Tribological and physico-mechanical properties of these materials were studied. Influence of concentration and brand of fillers on tribological properties of developed PC was established.

Keywords: polymer composites, aromatic polyamide, carbon black, tribological properties.

1. Introduction

The main priority in the modern industry development is the increment in value of products and reduction of its cost. This can be achieved by increasing the effective working time of machines and mechanisms that produce these products. One way to accomplish the main aim is to reduce the number of scheduled preventive maintenance of machines and mechanisms by increasing their reliability and durability.

It is known from [1-4] that the reliability of the machines and mechanisms is closely related to the durability of friction units. Therefore, an urgent task is to increase their service life. One of the best solutions to this problem is the development of new materials with high level of tribological properties for the production of friction units of machines and mechanisms which will exceed the known analogues by its characteristics.

It is well known [5-8] that polymers and composites based on them have high level of wear resistance. The details made from them can increase the life of the friction unit and improve its reliability. One of the most promising polymer matrixes to create such materials are aromatic polyamides.

The most common aromatic polyamides include: phenylon P, phenylon C1 and phenylon C2. Table 1 shows the physico-mechanical and thermal properties of these polymers.

As follows from the table a polyamide brand of phenylon C2 has the highest level of properties. Therefore, we chose it as the matrix polymer to create a tribological PC with a high level of physical, mechanical and thermal properties.

One of the shortcomings of phenylon C2 is its relatively high coefficient of friction in friction process without lubrication. For removal of this disadvantage the polyamide was injected by solid lubricants [10-12] (graphite, molybdenum disulfide, boron nitride, PTFE-4, bentonitic clay), which significantly improved the tribological properties of the PC as compared with the base polymer, but led to a significant reduction in their physical and mechanical properties.

Therefore, the main task is to develop the PC based on aromatic polyamides with a high level of physical and mechanical properties for friction units of machines and mechanisms.

2. Experimental

2.1. Materials

Phenylon C2 is a copolymer of polymeta- and polyparaphenyleneisophthalamide, which structural formula is shown in Fig. 1.

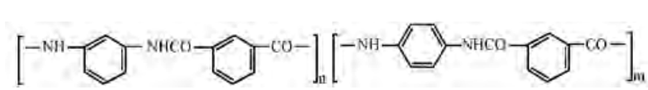

Fig. 1. The structural formula of phenylon C2

In its original form phenylon C2 is a finely divided brown colored powder with a basic size of the particles in the range of 20–40 μm, produced by OOO Uniplast, Vladimir (Russia).

As a filler we selected the carbon black with grades: N220, N550, N650 produced by PrJSC "Kremenchug Carbon Black Plant" (Ukraine). The initial form is granules having a major dimension of 0.5–2 mm. Using a filler of such size does not allow to obtain the PC with high level of properties, so the carbon black beads were crushed on a high-speed mixer. The basic size of the crushed carbon black particles is 2–7 μm.

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Table 1

Physico-mechanical and thermal properties of aromatic polyamides [9]

Parameter	Phenylon P	Phenylon C1	Phenylon C2
Density, kg/m^3	1330	1330	1330
Strength, MPa:			
– tensile	100–120	110–120	120–140
– flexural	130–150	150–170	220–240
Compressive yield stress, MPa	210–230	220–230	210–230
Impact strength, кJ/m^2	20–30	30–40	40–50
Brinell hardness, MPa	300	280	290
Vicat softening temperature, K	543	548	563

2.2. Methods of Obtaining PC

The samples were prepared as follows: mixing the powder phenylon C2 with micronized carbon black, tableting, drying the tablets, compression molding, and cooling.

The polymer was mixed with carbon black in a laboratory blade-type mixer, which due to the high speed of the blades and complicated shape provides intensive mixing of the composition. The resulting composition was tableted to obtain tablets with the density of 0.75–0.85 g/cm^3. The resulting tablets were dried in an oven at 453 K for 1 h. Test specimens were prepared by compression molding in molds heated at 613 K under the pressure of 40 MPa, as follows: loading tablets into the mold at the mold temperature of 543 K, heating to 613 K for 5 min; holding the pressure of 40 MPa for 5 min; cooling under pressure to 493 K.

2.3. Research Methods

Microphotographs were obtained at the optical metallurgical microscope "MIM-6", which is equipped with a digital camera SCOPETEK DEM-130.

The density r of composites was measured according to ISO 1183-1 (method A. Immersion Method) using analytical balance "VLR-200". Compressive stress at yield s_y and modulus in compression E were found according to ISO 604 on a universal tensile testing machine "Heckert FP 100/1". Hardness of composites H was measured by the method of ball indentation according to ISO 1183-1 by testing machine "2013 TShSP". Vicat softening temperature of thermoplastics T_{VC} was determined according to ISO 1183-1 at FWV-633/10 device.

The coefficient of friction in a pair of friction PC-steel and wear of PC were determined by machine "2070 SMT-1" (produced by "Tochpribor", Ivanovo, Russia) by friction without lubrication scheme disc pad. Investigations were carried out with the load of 0.5–1.5 MPa and the sliding speed of 0.75–1.25 m/s. The test composite comes into frictional engagement with counterbody of 45 steel (Ra = 0.32 μm, 45–50 HRC).

3. Results and Discussion

For the complex investigations PC based on phenylon C2 were manufactured. They were filled with 5–30 wt % of particulate carbon black. The filler content in the polymer was selected based on the studies of PC similar composition [13].

As a result of tribological tests by friction developed PC for steel we obtained concentration dependences of the friction coefficient and the linear wear intensity of materials based on phenylon C2 and crushed carbon black (Fig. 2).

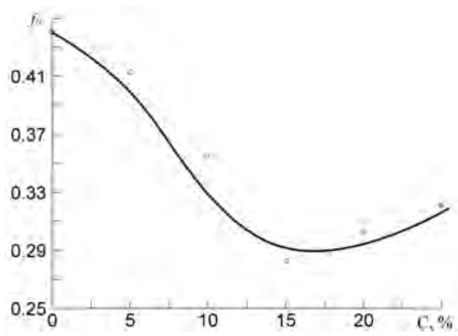
The extremes are observed in the area of filler content in the polymer 15 wt %. In this area, the tribological characteristics of friction pairs have the best value. Thus, the friction coefficient and wear intensity of the investigated composites are 1.5 and 7 times lower than those of the original polymer.

The reduction of the friction coefficient and the intensity of linear wear of PC developed by friction on steel is connected with the formation of the regions of PC transportation onto steel sample as a result of tribochemical reactions occurring in their frictional interaction (Fig. 3).

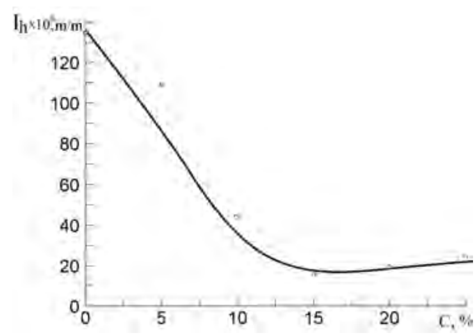
By comparing the micrographs of steel samples surfaces before and after frictional engagement with the initial phenylon C2 it was established that these surfaces have a similar surface morphology (Fig. 3a, b). On the surface of the steel specimen after frictional engagement with the composite 85 % phenylon C2+15% carbon black transfer portions on a steel surface were observed (Fig. 3c). The existence of such areas contributes to changing the nature of friction and reduces the friction coefficient and wear of the friction pair steel-PC.

It is interesting to study the effect of the filler mark on the tribological properties of the composite 85 % phenylon C2 + 15 % milled carbon black at its friction with steel. For this purpose, as a filler we used the crushed carbon black of N220, N550 and N650 brands. Fig. 4 shows the results of tribological tests.

It was found that the highest level of the tribological properties at friction with steel has a composite filled with shredded technical N220 grade carbon. The coefficients of friction and wear rate of the composite line are respectively lower by 35–50 and 15–25 % than those for composites filled with pulverized carbon black N550 and N650 grades.

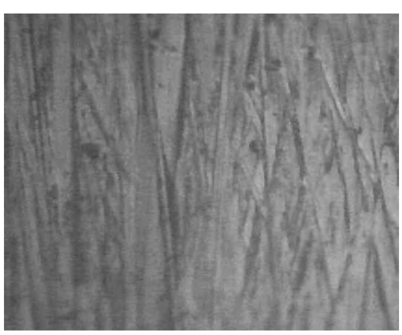


a)



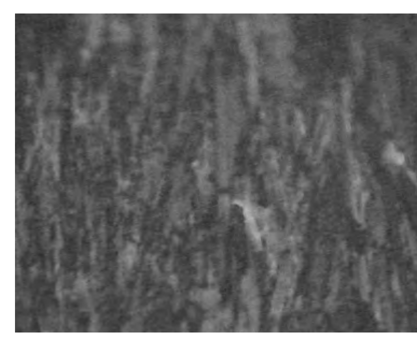
b)

Fig. 2. Concentration dependences of the coefficient of friction (a) and the intensity of linear wear (b) of PC based on phenylon C2 and particulate carbon black



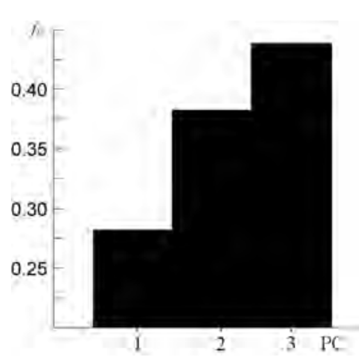
a)

b)

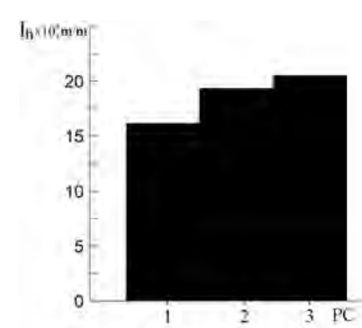


c)

Fig. 3. Microphotographs of the steel sample surfaces before (a) and after (b) frictional engagement with phenylon C2 and composite 85 % phenylon C2 + 15 % milled carbon black (c). Magnification of 400×



a)



b)

Fig. 4. The values of friction coefficient (a) and the intensity of linear wear (b) of the PC 85 % phenylon C2+ 15 % milled carbon black of different brands:N220 (1); N550 (2) and N660 (3)

This is explained by the best interaction of polymer molecules with crushed N220 grade carbon black due to its greater specific surface area and smaller size particles as compared with the particulate carbon black N550 and N650 grades. It is known [14] that fillers having a specific surface area represent the adsorbents on the surface, where highly oriented polymer layers are formed contributing to improvement of mechanical strength, leading to the increase in wear resistance of the PC friction. With all identical characteristics the fillers with a large surface area have a greater multiplier effect on the PC than those with a less developed one.

To investigate the influence of external factors (load and sliding speed) on the coefficient of friction and wear rate of the linear PC in a pair with the steel friction material 85 % phenylon C2 + 15 % milled carbon black (type N220) have been selected. This PC has the highest level of the tribological properties of the friction against steel among all of the materials based on phenylon C2 and crushed carbon black.

Investigations were performed within the load range from 0.5 to 1.5 MPa and sliding velocities from 0.75 to 1.25 m/s. The choice of loads and sliding velocities is conditioned by the fact that most components of machines and mechanisms are operating under such conditions.

As a result of the experiments it was found (Fig. 5) that the coefficient of friction in the test load range decreases with increasing load, which is typical of the normal operation of anti-friction units [15]. Linear wear intensity increases with increasing load and sliding velocity in the test pair of friction.

It should be noted that the friction coefficient and the intensity of linear wear PC in the area of studied loads and sliding speeds vary within limits typical of normal operation of the friction pair.

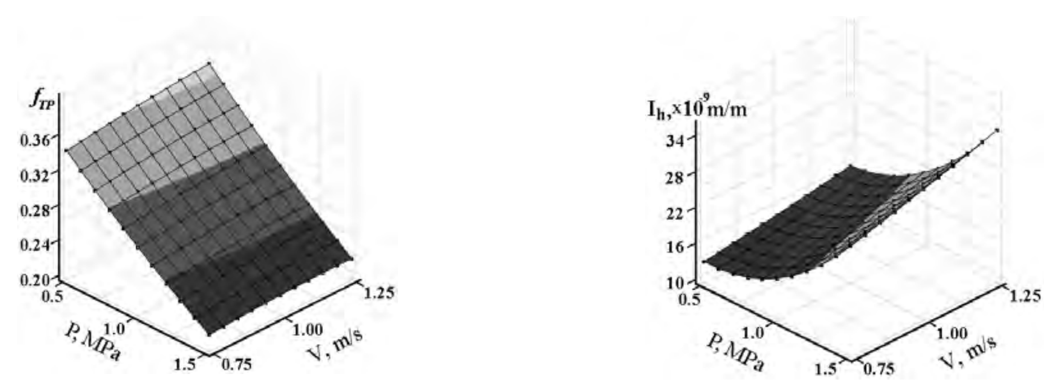
For the convenience of determining the tribological characteristics of composite 85 % phenylon C2 + 15 % milled carbon black at frictional interaction with the steel the mathematical dependences (formulas 1 and 2) were derived, which describe the influence of external factors (load and sliding speed) on the coefficient of friction and the intensity of linear wear of test PC.

$$f_{TP} = 0.021 \cdot P^2 - 0.028 \cdot V^2 - 0.151 \cdot P + 0.104 \cdot V - 0.024 \cdot P \cdot V + 0.359 \quad (1)$$

$$I_h = 16.533 \cdot P^2 + 1.956 \cdot V^2 - 23.381 \cdot P + 0.032 \cdot V + 6.857 \cdot P \cdot V + 16.692 \quad (2)$$

Mathematical dependences were also obtained using MathCAD software package by the method described in the literature [16].

It is interesting to explore the physical, mechanical and thermal properties of composite with the highest level of tribological properties (85 % phenylone C2 + 15 % milled carbon black) in friction against steel. Table 2 shows the results of these studies.



a) b)

Fig. 5. Dependences of friction coefficient (a) and the intensity of linear wear (b) on the load and sliding speed acting on the friction pair PC (85 % phenylone C2 + 15 % milled carbon black) − steel

Table 2

Physical, mechanical and thermal properties of the composite 85 % phenylone C2 + 15 % carbon black

Property	Value
Density ρ, kg/m^3	1340
Hardness H, MPa	206
Compressive stress at yield s_y, MPa	210
The elastic modulus in compression E, MPa	3000
Vicat softening temperature T_{VC}, K	565

The experimental results show that the composite with 15 % mass carbon black has a high level of physical and mechanical properties. So, at a density of 1340 kg/m^3 its compressive stress at yield equals to 210 MPa and hardness is 206 MPa.

According to its physical and mechanical properties the developed PC is far superior from the tribological similar materials [17-19].

4. Conclusions

From the results of the tribological tests of PC based on phenylon C2 and carbon black in frictional interaction with the steel it was established that introduction of the crushed carbon black in phenylon C2 reduces the friction coefficient and wear intensity line. This phenomenon is explained by the formation of the composite transfer islets onto the steel sample at friction, leading to the changes in the nature of friction in PC-steel pair. It was found that the highest level of the tribological properties of friction with steel has the composite of 85% phenylon C2 + 15% milled carbon black (grade N220). The values of the friction coefficient and wear rate of the composite line in the loaded range from 0.5 to 1.5 MPa and the sliding velocity from 0.75 to 1.25 m/s are within the allowable change to normal operation of the friction pair. It was found that the physical, mechanical and thermal properties of the composite 85% phenylon C2 + 15% milled carbon black significantly surpass the similar tribological materials.

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АНТИФРИКЦІЙНІ ПОЛІМЕРНІ КОМПОЗИЦІЙНІ МАТЕРІАЛИ НА ОСНОВІ АРОМАТИЧНОГО ПОЛІАМІДУ ТА ТЕХНІЧНОГО ВУГЛЕЦЮ

Анотація. *Отримано та досліджено полімерні композиційні матеріали (ПКМ) на основі ароматичних поліамідів та технічного вуглецю. Встановлено, що наповнювач покращує триботехнічні властивості ПКМ при фрикційній взаємодії із сталюю в режимі тертя без змащування. Визначено оптимальні концентрації технічного вуглецю у ПКМ та досліджено вплив різних його марок на триботехнічні властивості розроблених ПКМ.*

Ключові слова: *полімерні композиційні матеріали, ароматичний поліамід, технічний вуглець, триботехнічні властивості.*