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ANTIFRICTION ORGANOPLASTICS BASED ON AROMATIC POLYAMIDES

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Abstract: Tribological properties of aromatic polyamide phenylone C-1 and phenylone C-П and organoplastics based on them reinforced with terlon organic fiber were studied. It has been established that the reinforcement of phenylones with organic fiber makes it possible to obtain antifriction polymer composites with a low coefficient of friction and high wear resistance. The maximum effect of improving of the tribotechnical characteristics is observed in the case of reinforcing phenolon C-1 with terlon fiber in the amount of 25 wt%.

Key words: aromatic polyamide phenylone, organic fiber terlon, organoplastics, tribological properties, friction coefficient, intensity of linear wear, performance criterion

Polymer composites are among the most important and widely used classes of modern structural materials. A complex of valuable technological and operational characteristics ensures their application in various technical fields.

Aromatic polyamide phenylone C-1 and phenylone C-П are polymers for structural purposes, which have a number of positive properties, among are their high heat resistance and hardness, preservation of physical, mechanical and electrical parameters at high temperatures, etc. A thermal coefficient of linear expansion of aromatic polyamides in the operation range is quite stable and 2–3 times lower than that of other unfilled plastics. The disadvantages of phenylones include the fact that at high loads and sliding speeds in conditions of poor heat removal, self-heating of the friction unit may occur, and at a temperature of 250–260 °C, the materials lose their performance. In friction units with minor loads, wear resistance of phenylones is quite high, but in the presence of lubrication, the friction coefficient and wear of phenylones are sharply reduced. It is known that aromatic polyamides, when operated under friction conditions at low loads, are more wear resistant than aliphatic polyamides [1–3].

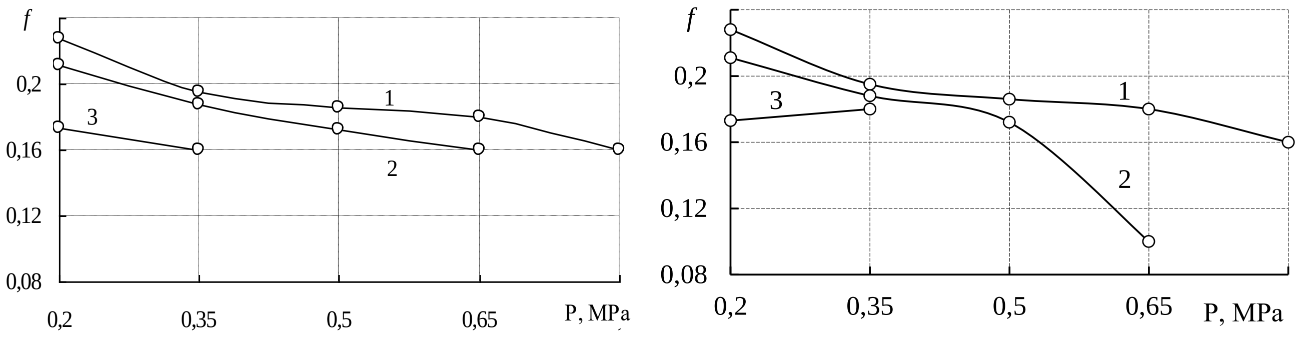
The nature of friction and wear processes of aromatic polyamides is determined by the operating modes in which they work; therefore, the study of the tribological properties of polymer composites based on them is of scientific and practical interest.

In order to create new polymer composites for antifriction purposes, aromatic polyamide phenylone C-1 and C-П brands [4] were reinforced with heat-resistant high-strength organic fiber terlon [5, 6] in the amount of 15 and 25 wt%.

The study of the processes of friction and wear of phenylones and organoplastics (OP) based on them was carried out on a disk friction machine in the friction mode without lubrication at specific loads P = 0.2–0.8 MPa and sliding speeds υ = 1–2 m/s, friction path was 1000 m. A disk made of steel 45 (GOST 1050-74), heat-treated to a hardness of 45–48 HRC with a surface roughness R_a = 0.16–0.32 μm, was used as a counterbody.

At the initial stage of research, a comparative analysis of the processes of friction and wear of the initial polymers was carried out. The results obtained showed that phenylone samples were more efficient when tested under conditions of a minimum sliding velocity υ = 1 m/s (Fig. 1). With an increase in the sliding speed, the coefficient of friction of polymers decreased, and more significantly (more than 30%) for phenylone C-1, while for phenylone C-П it changed insignificantly, being in the range of 0.15–0.17. This is due, on the one hand, to a reduction in the frictional bond time between the polymer sample and the steel counterbody, and, on the other hand, to an increase in the tangential component of the sliding velocity, which contributed to the effective removal of wear particles from the friction zone [7, 8].

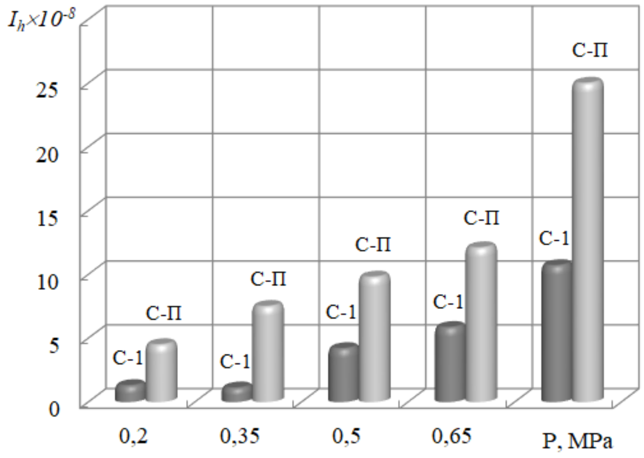
With an increase in the load mode, the difference in the values of the friction coefficients of phenylones at υ = 1 m/s decreased. So, if at a minimum load P = 0.2 MPa the friction coefficient of phenylone C-П was 31% lower than that of phenylone C-1, then at P = 0.8 MPa this difference was only 5%.



a **b**

Fig. 1. Effect of specific load on the coefficient of friction of phenylone C-1 (a) and phenylone C-П (b), studied under dry friction conditions at sliding speeds 1 (1), 1.5 (2) and 2 m/s (3)

As regards the wear resistance of the studied polymers, a general trend emerged here: with an increase in the sliding speed, the intensity of linear wear of the samples increased. For example, under the conditions of the minimum sliding speed at P = 0.2–0.5 MPa, the intensity of linear wear of samples of phenylone C-1 and phenylone C-П increased 3.2 and 2.5 times, respectively [9]. Under more stringent test conditions (υ = 1.5 m/s, P= 0.8 MPa and υ = 2 m/s, P= 0.5–0.8 MPa), polyamide binders wore out catastrophically and lost their performance (Fig. 2). The latter, obviously, can be explained by the fact that, under these conditions, a temperature close to the softening temperature of polymers developed in the friction zone, which led to the adhesion of polymers to the surface of the counterbody and, as a consequence, to the intensification of the wear processes of plastics [7, 8].



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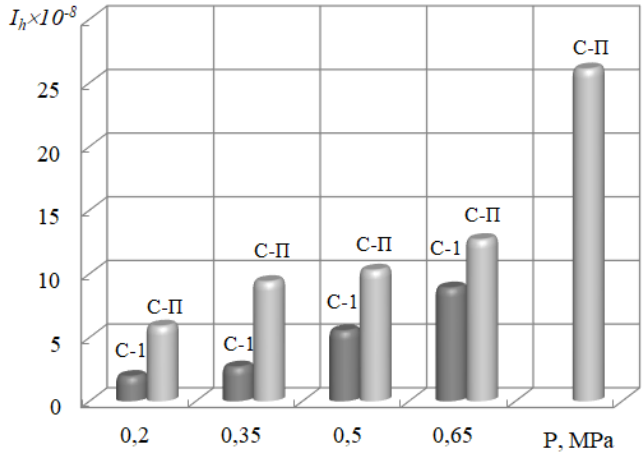

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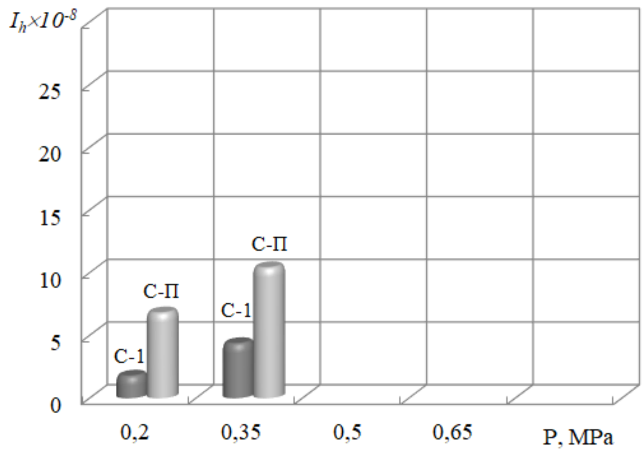
Fig. 2. Influence of operating modes on the intensity of linear wear of C-1 and C-П phenylones tested at sliding speeds of (a) 1.0, (b) 1.5 and (c) 2.0 m/s

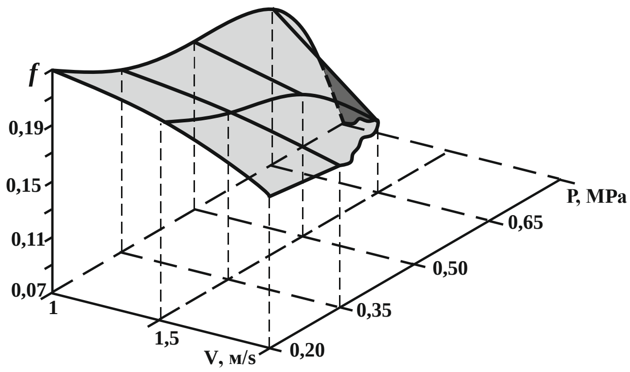


c

In the entire range of operating modes, samples of phenylone C-1 were more wear-resistant. In particular, tests at a sliding speed of $\upsilon = 1$ m/s in the load range $P = 0.2–0.8$ MPa showed that the intensity of linear wear of phenylone C-П was on average 2.5–3.5 times higher, than for phenylone C-1.

The research results allow us to conclude that the tribological properties of phenylones were determined by their chemical structure. It was found that specimens based on C-1 phenylone had high wear resistance and low coefficient of friction.

The tribological properties of the developed OPs (Fig. 3) depended on the degree of reinforcement of the binders with terlon fiber: with an increase in the amount of reinforcing filler, the friction coefficient of all the studied materials decreased. The minimum values of the friction coefficient in the investigated operating modes had an OP containing 25 wt% of terlon.



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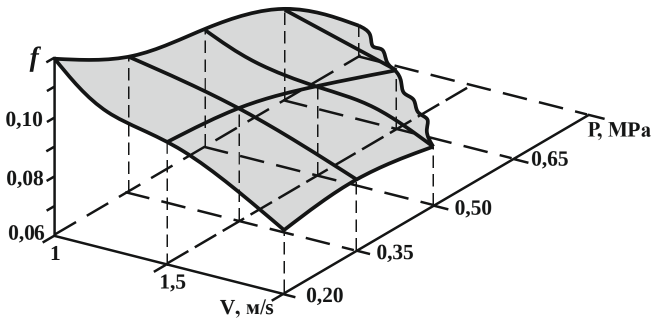

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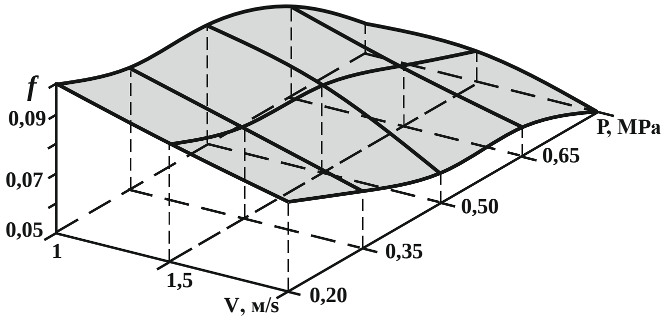
Fig. 3. Influence of operating modes on the coefficient of friction of phenylone C-1 (a) and organoplastics based on it, reinforced by 15 (b) and 25 (c) wt% of terlon



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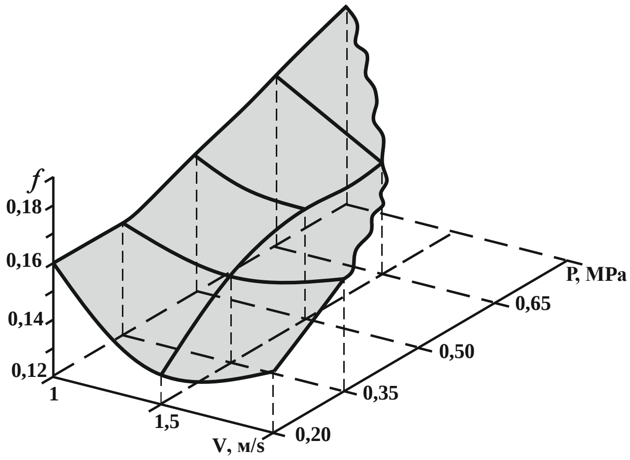
In particular, for an OP based on phenylone C-1, reinforced with 25 wt% of terlon, at υ = 1 m/s in the range of specific loads P = 0.2–0.8 MPa, the friction coefficient decreased by 27–63% compared to the initial polymer. At υ = 1.5–2 m/s, the OP remained operational up to maximum loads and had a friction coefficient, on average, 2.5 times lower than that of C-1 phenylone. A sample of the original polymer at υ = 1.5 and 2 m/s remained operable up to specific loads of 0.65 and 0.35 MPa, respectively, while an OP, containing 25 wt% of terlon, under the indicated operating conditions showed good performance and had a low coefficient of friction (0.08–0.09). The sample of an OP containing 15 wt% of terlon worked stably at υ = 1.5 and 2 m/s up to specific loads P = 0.65 and 0.5 MPa, respectively, having a friction coefficient of 0.12–0.08.

Interestingly, with an increase in the sliding speed, the coefficient of friction of C-1 phenylone and OP based on it decreased by an average of 30–40%. Under conditions of the maximum sliding speed, stably low values of the friction coefficient in the entire studied range of specific loads were characteristic of an OP containing 25 wt% of terlon (Fig. 3).

Based on the data obtained, it can be concluded that the performance criterion

PV (the product of the specific load and sliding speed) of an OP containing 25 wt% of terlon is more than 2 times higher than the criterion of *PV* of the binder and OP reinforced with 15 wt% of terlon (1.6 and 0.7 MPa m/s, respectively) [10].

The results of tribological studies of OP based on phenylone C-Π indicate that at υ = 1.0 m/s (Fig. 4) the friction coefficient at all loads decreased by 50-74%, while



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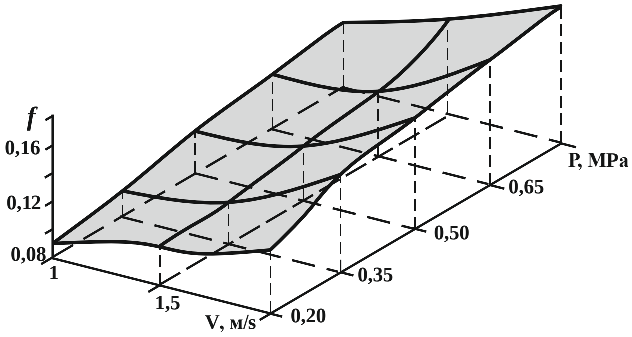

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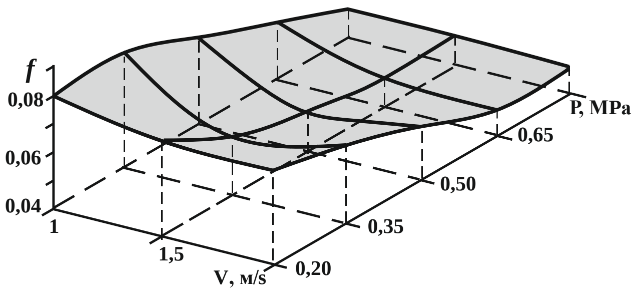
Fig. 4. Influence of operating modes on the coefficient of friction of phenylone C–Π (a) and organoplastics based on it, reinforced 15 (b) and 25 (c) wt% of terlon



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with their increase in the load mode, the difference in coefficients of friction of the binder and OP increased from 2 to 4 times. The minimum coefficient of friction had an OP reinforced with 25 wt% of terlon (0.08–0.05). At υ = 1.5 m/s, the friction coefficient of an OP reinforced with 25 wt% of terlon, with increasing load decreased from 0.08 to 0.05 and was 39–69% lower than that of phenylone C-Π. At the maximum load *P* = 0.8 MPa, the original polymer samples lost their performance, as a result of which their friction coefficient could not be determined (Fig. 4). At υ = 2 m/s, phenylone C-Π worked stably only at *P* = 0.2–0.35 MPa, while OP samples were operated at *P* = 0.2-0.8 MPa, but were significantly worn out.

The intensity of linear wear of samples of aromatic polyamides depended on the specific load (Table 1). Under the conditions of the minimum sliding speed at

Table 1.

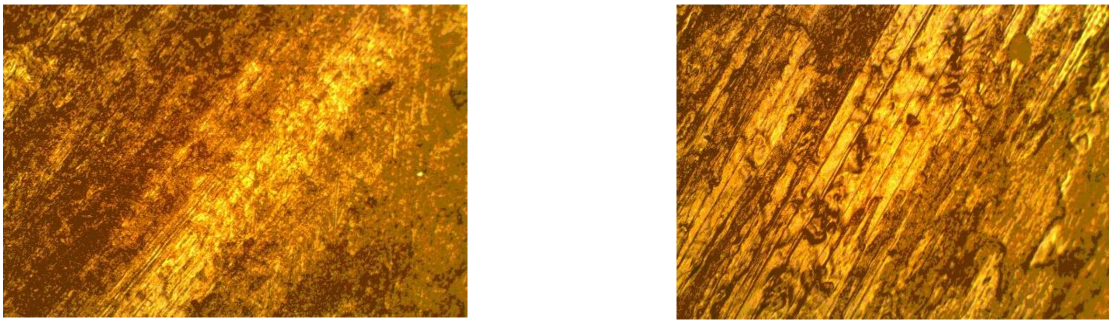
Dependence of intensity of linear wear ($I_h \times 10^{-8}$) of phenylones C-1, C-П and organoplastics based on it from operating modes

Material	Specific load, MPa				
	0.20	0.35	0.50	0.65	0.80
Sliding speed – 1.0 m/s					
C-1 / C-П	1,29 / 4,5	1,11 / 7,5	4,19 / 9,8	5,85 / 12,1	10,7 / 25
C-1+15T / C-П+15T	1,52 / 3,5	0,96 / 6,9	1,65 / 8,6	1,91 / 9,3	2,84 / 10,5
C-1+25T / C-П+25T	0,12 / 3,5	0,2 / 5,7	0,48 / 7,5	0,49 / 8,2	2,84 / 10,1
Sliding speed – 1.5 m/s					
C-1 / C-П	1,95 / 5,9	2,69 / 9,4	5,53 / 10,3	8,9 / 12,7	– / 26,1
C-1+15T / C-П+15T	0,62 / 5,4	1,39 / 8,7	4,97 / 9,0	5,5 / 10,4	– / 11,2
C-1+25T / C-П+25T	0,19 / 4,0	0,2 / 7,2	1,17 / 8,7	0,82 / 9,9	3,23 / 10,9
Sliding speed – 2.0 m/s					
C-1 / C-П	1,76 / 6,8	4,35 / 10,4	–	–	–
C-1+15T / C-П+15T	1,3 / 5,9	2,34 / 9,6	– / 10,3	– / 11,7	– / 12,8
C-1+25T / C-П+25T	0,2 / 6,2	0,33 / 8,4	0,67 / 9,3	0,75 / 10,2	2,41 / 11,5

Note: C-1 + 15T, C-1 + 25T, C-П + 15T, C-П + 25T - phenylone C-1 and C-П, reinforced with 15 and 25 wt.% of terlon fibers

P = 0.2-0.5 MPa, the intensity of linear wear of samples of phenylone C-1 and C-П increased, respectively, by 3.2 and 2.5 times, respectively. At higher loads, the wear of materials increased significantly, and for phenylone C-П this trend began to manifest itself earlier (P = 0.65 MPa) than for phenylone C-1 (P = 0.8 MPa).

Microstructural studies of the samples (Fig. 5) showed that during friction of binders over the surface of a steel counterbody, their surface layer was directly destroyed by cutting, and for phenylone C-П this process began to manifest itself at lower temperatures and more intensively (Fig. 5b).



a b

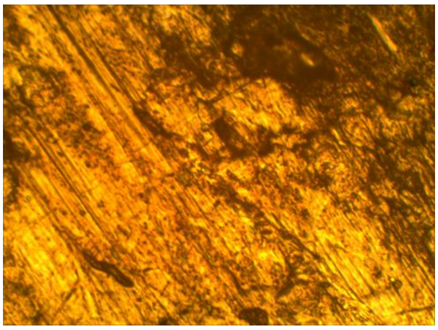
Fig. 5. Microstructure of a friction surface of the samples phenylone C-1 (a) and phenylone C-П (b). Magnification × 180

The analysis of the surface of a counterbody showed the presence of a dense film on it, formed from the products of tribodestruction of aromatic polyamides. The formation of a surface film was due to the fact that as a result of the temperature increase in the contact zone between the polymer sample and the counterbody, the adhesion forces between the polymer and the steel disk increased. In the process of friction of polymer samples as a result of wear, formation of finely dispersed products, which accumulated on the surface of a steel disk, was observed, as a result of which friction of polymers in the course of research was carried out not along the surface of the counterbody but along the wear products.

As a result of tribotechnical tests, it was found that with an increase in the content of terlon fiber in polyamide binders, the wear resistance of the developed OPs increased (Table 1). In particular, tests at $\upsilon = 1$ m/s showed that the intensity of linear wear of phenylone C-П increased almost 6 times, while for OPs containing 15 and 25 wt% of terlon, it increased less than 3 times. Consequently, the reinforcing filler has a positive effect on the wear resistance of C-П phenylone, increasing it by 2 times.

The best wear resistance indicators were typical for samples based on C-1 phenylone. In the studied operating modes, the intensity of linear wear of an OP based on phenylone C-П was higher than that of an OP based on phenylone C-1 by an average of 3.5–30 times.

The friction surface of all the studied samples was vitreous. This indicates that both binders and OPs based on them wore out according to the fatigue mechanism (Fig. 6).



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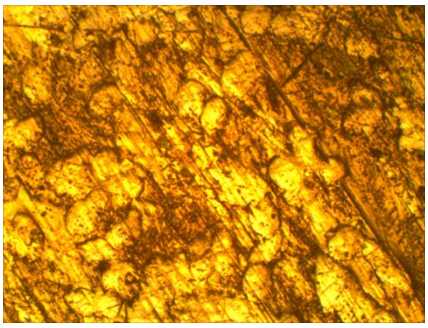

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Fig. 6. Appearance of samples of phenylone C-1 and organoplastics based on it after friction at operating modes: υ = 2 m/s, *P* = 0.2 MPa

Thus, the study of the features of the processes of friction and wear of aromatic polyamides phenylone C-1 and C-П, as well as OPs based on them, indicate that the composite based on phenylone C-1 containing 25 wt% of terlon fiber has improved tribological properties.

This OP has a low coefficient of friction and high wear resistance, operates in a wide range of loads and sliding speeds, and may be successfully used as an antifriction material in friction units of moving joints of machines and mechanisms.

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