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Research on tribological properties of compositions based on phenylone

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The influence of the content of carbon fiber, graphite and their mixture on the tribotechnical characteristics of composite materials on the basis of aromatic polyamide phenylone C-2 was considered in the article. It was shown that the filling of basic material with the mixture of carbon fiber and graphite had a positive impact on its tribological properties such as reduction of the coefficient of friction and intensity of wear by a factor 2.85–4 and 22–32, respectively. It was established that the composite which contains 30 wt. % of carbon fiber and 15 mass % of graphite has the optimal complex of properties (increased wear resistance, low coefficient of friction and low linear coefficient of thermal expansion). That's why, this composite can be recommended for manufacturing of the parts of movable joints of machines and mechanisms working under conditions of friction without greasing.

Keywords: coefficient of friction, wear, carbon fiber, graphite, mixture, coefficient of thermal linear expansion.

Рассмотрено влияние содержания углеродного волокна, графита и их смеси на триботехнические характеристики композиционных материалов на основе ароматического полиамида фенилон марки С-2. Показано, что наполнение исходного материала смесью углеродного волокна и графита положительно влияет на его трибологические свойства: ведет к уменьшению коэффициента трения и интенсивности изнашивания в 2,85–4 и 22–32 раза соответственно. Установлено, что оптимальным комплексом свойств (повышенной износостойкостью, низким коэффициентом трения и термического линейного расширения) обладает композит, содержащий 30 мас.% углеродного волокна и 15 мас.% графита, в результате чего его можно рекомендовать для изготовления деталей подвижных соединений машин и механизмов, работающих в условиях трения без смазки.

Дослідження трибологічних характеристик композицій на основі фенілону. *О.І.Буря, А.-М.В.Томіна.*

Розглянуто вплив вмісту вуглецевого волокна, графіту та їх суміші на триботехнічні характеристики композиційних матеріалів на основі ароматичного поліаміду фенілон марки С-2. Показано, що наповнення вихідного матеріалу сумішшю вуглецевого волокна та графіту позитивно впливає на його трибологічні властивості: зменшення коефіцієнту тертя і інтенсивності зношування у 2,85–4 та 22–32 рази відповідно. Встановлено, що оптимальним комплексом властивостей (підвищеною зносостійкістю, низьким коефіцієнтом тертя та термічного лінійного розширення) володіє композит, що містить 30 мас.% вуглецевого волокна та 15 мас.% графіту, у результаті чого даний композит можна рекомендувати для виготовлення деталей рухомих з'єднань машин і механізмів, що працюють в умовах тертя без змащування.

1. Introduction

A wide use of polymer composite materials (PCM) took place in many branches of the industry during the last years. It is obvious that the using of them is caused by the increase of requirements of modern technique and high-technology branches. Practice showed that it is possible to produce practically any products with the combination of operational and technological properties, which were previously noticed [1], by the selection of content and properties of binder and filler and their ratio.

The process of PCM reinforcing by hybrid fillers that include three and more components can be related to one of the effective methods to improve their properties. These materials make it possible to deal with the row of problems that cannot be eliminated while using mono-reinforced PCM [2]. The basic idea of using hybrid composites is that each of their components plays a certain role, but at the same time they create a synergistic effect. As a result, functional properties of the composites considerably increase [3].

One of the important tasks of the modern materials science is the increasing of the service life of many machine parts and mechanisms of metallurgical and road construction industry, drilling equipment, agriculture. It is known [4] that the wear of working surfaces of friction assemblies is the main reason of equipment failure.

One of the ways to increase the service life is the using of anti-friction polymer composite materials. That is due to the row of their advantages like low cost manufacturing, high wear resistance, low coefficient of friction, reduction of spending on maintenance and repair of mechanisms [5, 6].

In recent years, scientists are very interested in developing of hybrid polymer composite materials because it gives the possibility to make materials with specific properties.

Some of the most promising fillers for making the hybrid PCMs are carbon fibers (CF) and dispersible fillers that are graphites, the use of which provides advantages compared with glass-fiber and mineral fillers, such as: increased specific viscosity, less density, increased water resistance, reduction of thermal tensions [7].

2. Experimental

Aromatic polyamides are the most perspective polymer materials that combine the high level of physic-mechanical and thermo-physical properties. That's why the aromatic polyamide phenylone C-2 (TS 6-05-221-226-72) was chosen as a binder. It is a white-colored finely dispersed powder with a bulk density of 0.2–0.4 g/cm^3. In some cases it was the only material that keeps capacity of the pneumo- and hydro-automatic joints which were operated in harsh conditions.

We used following materials as fillers:

— carbon fiber Ural-24 (TS 6-06-11-124-85); high thermal stability and durability that 2–3 times exceeds the durability of ordinary chemical fibers are the basic advantages;

— silvery graphite GL-2 (GOST 5279-74) that has a lot of unique properties, such as chemical resistance, plasticity, diamagnetism.

Preparation of compositions based on phenylone C-2 was carried out by the method of dry mixing in the machine with the rotating electromagnetic field (0.12 Tl) with the help of ferromagnetic particles that were magnetically separated from the prepared composition. The prepared mixture was tableted at a room temperature and pressure of 30 MPa.

All the materials should be carefully dried up before forming the phenylone C-2 and compositions. Processing of undried materials into products makes their indexes of durability worse that results in formation of superficial defects (shells, bubbles etc.). Drying of the blanks was conducted in festooning oven SPT-200 during 2–3 h at 473–523 K. The tablet from festooning oven was immediately loaded in a press-form heated to 523 K. After loading in the press-form, the material was heated to 598 K and kept without pressure for 10 min.; then it was kept for 10 min. at the pressure of 40 MPa at the same temperature. Then the product was cooled at the permanent pressure to the temperature of 523 K. After that the pressure was relieved.

Tribological properties (coefficient of friction (f) and intensity of linear wear (I_h)) were studied under conditions of friction without greasing on the disk friction machine [8] with the pressure of 1 MPa, sliding speed of 2 m/s; the distance of friction was 3000 m. The samples of the compositions for tests had cylindrical form $\varnothing = 10$, $h = 10$ mm; steel 45 (45-48 HRC, $Ra = 0.16–0.32$ μm) was used as a counterbody.

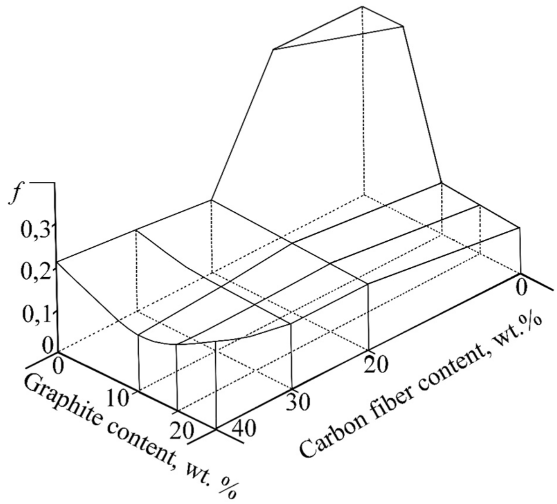

Fig. 1. Dependence of the coefficient of friction on the content of fillers.

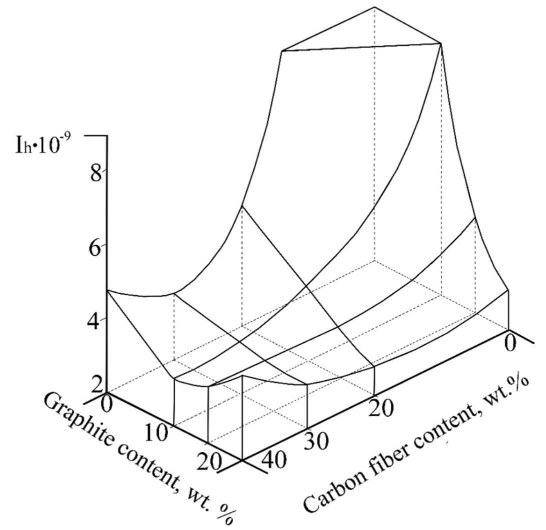

Fig. 2. Dependence of the intensity of linear wear on the content of fillers.

3. Results and discussion

Analyzing the results of the researches (see Fig. 1, 2) on the influence of the percentage of fillers on tribological properties of the PCM based on phenylone, it is evidently that the filling polymer matrix with 20–30 wt. % of CF gives a sharp decrease in friction coefficient and intensity of linear wear by a factor 2.8–3 and 10.2–247, respectively in comparison with an initial polymer ($f = 0.54$, $I_h = 8.9 \cdot 10^{-8}$). The only one possible explanation for it can be the fact that finely dispersed wear debris, which fill micro cavities on the surface of the counterbody, appear in the process of carbon plastic (CP) wear. In addition, friction takes place on the wear debris, but not on the steel.

While studying the friction surface of the initial polymer and developed composites, it was detected that the deep furrows of ploughing appeared on the surface of phenylone (Fig. 3, a) testify to the adhesion mechanism of wear. The distinguishing feature of this mechanism is frictional transference of ribbons of binder on the surface of the counterbody; that is conditioned by the presence of local connections between contacting surfaces. During the wear of the carbon-fiber-reinforced plastic, a smooth glassy surface appears. There are clearly visible chaotically distributed fibers and ribbons (furrows) of ploughing (Fig. 3, b) that testifies to a pseudoelastic mechanism of detrition of the carbon plastics [9]. That provides the longest service life for movable joints.

With further increase in the number of CF to 40 wt. %, we observe an increase of the coefficient of friction and intensity of wear that is conditioned, from one hand, by crumbling of solid fiber particulates (Fig. 3, c) [10], and, from the other hand, by fluffing of CP on the "polymer binder — carbon fiber" boundaries. It is better to use graphite as filler in terms of improvement of anti-friction properties and wear resistance. The comparison of tribotechnical characteristics of CP and GP which contain 20 wt. % of filler shows that clearly. So, wear resistance and coefficient of friction of graphitoplastics with such content of filler are 2 and 1.5 times better than analogical indexes for carbon-fiber-reinforced plastic. It can be explained by the fact that in the process of maintenance, graphite [11] forms a structure on the surface of friction similar to the structure of liquid crystals that plays the role of dry grease and is characterized by low movable supports and high loading ability. Both CP and graphitoplastics are characterized by the pseudoelastic mechanism of detrition: a smooth glassy surface appears (Fig. 3, d) [9].

An improvement of tribotechnical properties of polymer matrix occurs while using hybrid filler. The coefficient of friction and wear decreases 2.85–4 and 22–32 times, respectively. The results can be explained by the fact that CF and graphite have high heat-conductivity, which encourage dispersion of energy vibrations that reduce self-warming of the material in the zone of friction due to the decline of internal friction force and shear stresses.

The combination of these two components results in a synergistic effect which in turn

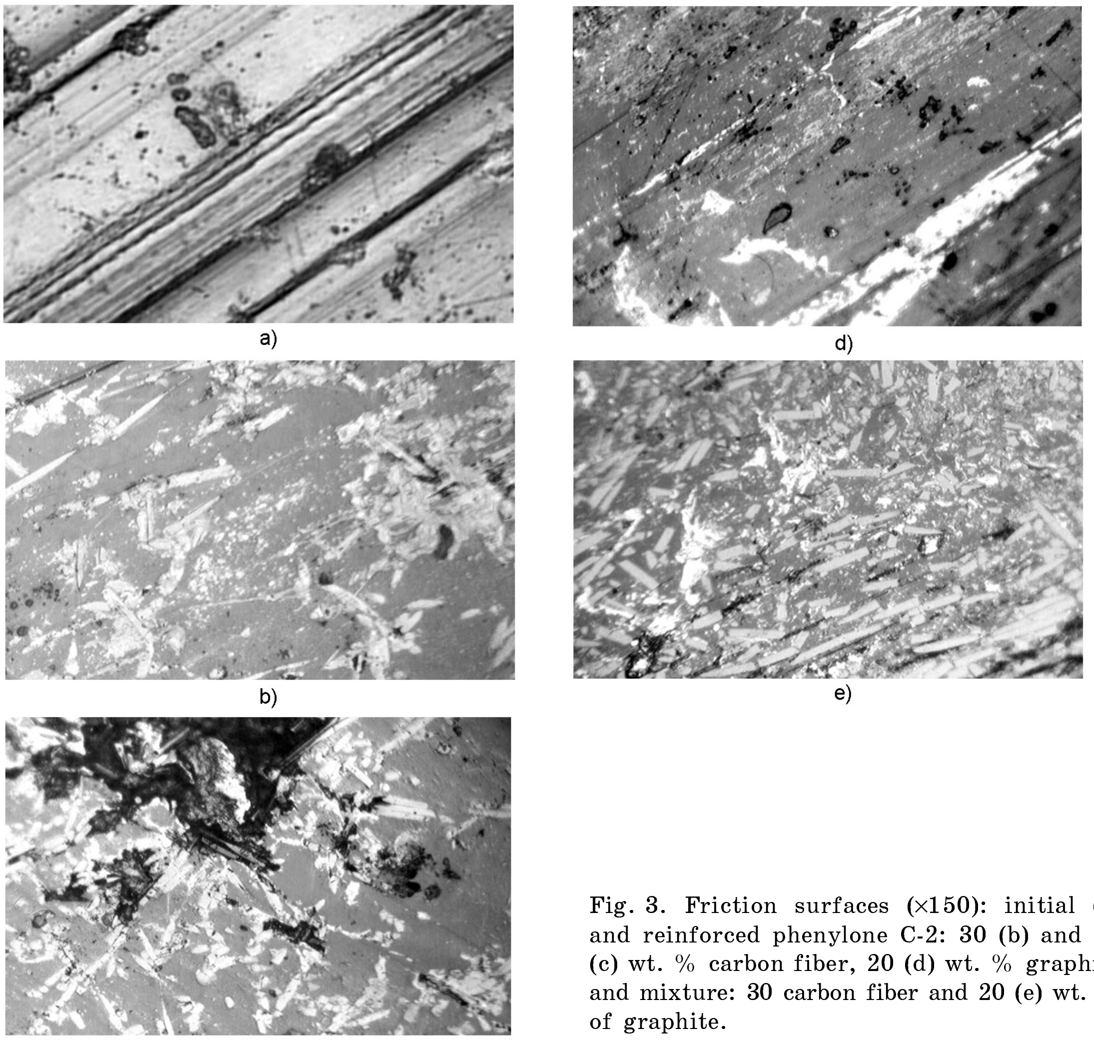

Fig. 3. Friction surfaces (×150): initial (a) and reinforced phenylone C-2: 30 (b) and 40 (c) wt. % carbon fiber, 20 (d) wt. % graphite and mixture: 30 carbon fiber and 20 (e) wt. % of graphite.

leads to the reduction of friction in PCM [12]. As to the mechanism of wear, in both cases (with CP and GP), between the sample and counterbody there is a pseudoelastic mechanism of detrition: wear debris appear in a negligible quantity and mainly retire in the process of friction outside the counterbody, and a smooth glassy surface appears (Fig. 3, e).

One of the important characteristics of faultless work of a friction unit is a coefficient of thermal linear expansion (CTLE). It is known [13] that polyamides have higher CTLE (approximately by a factor 20) in comparison with steel and cast-iron. It causes friction when temperature changes in the unit are from 293 to 393 K. That leads to wedging of billow as a result of changing size of the assured gap.

It is shown on the Fig. 4 that introduction of an optimal quantity of hybrid filler (30 CF and 15 wt. % of graphite) results in more rapid (by a factor 3) decrease of CTLE

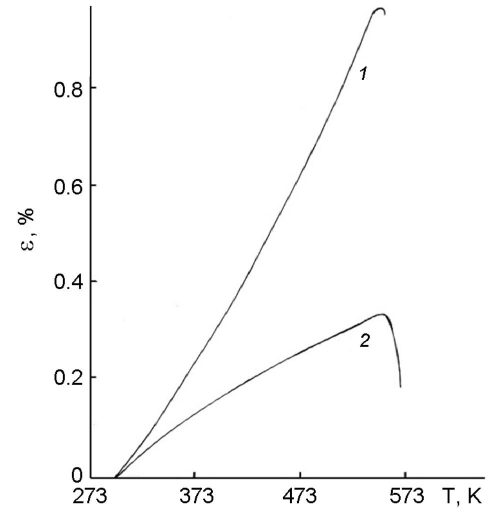

Fig. 4. Dependences of relative deformation on temperature: phenylone C-2 (*1*) and composite (*2*).

Table. CTLE of phenylone and a composite with hybrid filler

Temperature range, K	$\alpha \times 10^{-6}$, K^{-1}	
	phenylone	composite
298–323	26.42	18.29
323–373	35.57	6.48
373–423	37.64	20.49
423–473	43.57	13.44
473–523	48.50	16.54

compared with an initial polymer (see Table). It can be explained by the fact [14] that introduction of inert fillers (including carbon fiber and graphite) diminishes segmental mobility of macromolecules of binder and coefficient of diffusion of moisture, and strengthens intermolecular copulas between the matrix and filler [15].

4. Conclusion

Analysis of the resulted properties of the developed polymer composite materials shows that the using of mixture of carbon fiber and graphite as fillers is the perspective way of increasing tribotechnical properties of initial polymer; coefficient of friction and wear are reduced by a factor 2.85–4 and 22–32, respectively. It is established that PCM which contains 30 wt.% CF and 15 wt.% of graphite has the optimal complex of properties (increased wear resistance, low coefficients of friction and thermal linear expansion). Thereby, this composite can be recommended for manufacturing of the parts of movable joints of machines and mechanisms working under conditions of friction without greasing.

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