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The influence of nickel-clad chromium carbide on the tribological properties of composite based on phenylone aromatic polyamide

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The paper examines the influence of nickel-clad chromium carbide (PKHN-15) on the tribological properties of phenylone C-1 aromatic polyamide under friction conditions without lubrication. It was established that the introduction of a filler in the amount of 10-25 wt.% leads to a decrease in the degree of linear wear of the polymer matrix by almost 15 times, reaching minimum values at 20 wt.% of the filler. The lowest coefficient of friction is observed for the polymer composite containing 10 wt.% PKHN-15. The improvement of the tribotechnical properties of polyamide is due to the fact that harder filler particles strengthen the polymer matrix. As a result, the composites are better able to withstand mechanical loads, micro-impacts and destruction.

Keywords: phenylone aromatic polyamide, nickel-clad chromium carbide, PKHN-15, intensity of linear wear, coefficient of friction

Вплив карбіду хрому плакованого нікелем на трибологічні властивості композитів на основі ароматичного поліаміду фенілон. *Я.Є. Яровий, К.А. Єрьоміна, А.-М.В. Томіна*

У роботі розглянуто вплив карбіду хрому плакованого нікелем (ПКХН-15) на трибологічні властивості ароматичного поліаміду фенілон марки С-1 в умовах тертя без змащення. Встановлено, що введення наповнювача у кількості 10-25 мас.% призводить до зменшення інтенсивності лінійного зношування полімерної матриці майже у 15 разів, сягаючи мінімальних значень при 20 мас.% наповнювача. Найменше значення коефіцієнту тертя спостерігається для полімерного композиту, що містить 10 мас.% ПКХН-15. Покращення триботехнічних характеристик поліаміду обумовлено тим, що більш тверді частки наповнювача зміцнюють полімерну матрицю, внаслідок чого композити краще чинять опір механічним навантаженням, дії мікроударів і руйнуванню.

1. Introduction

In recent years, the use of polymer composite materials (PCMs) in friction units of high-performance equipment [1] in various areas of modern industries, such as aviation, metallurgy, textile and food [2], as well as in agriculture, has become widespread. This is due to their unique functional properties compared to metals: high resistance to abrasive, cavitation and corrosion wear [3], and stable operation in friction mode without lubrication or with limited use of lubricants. Also, the benefits of using PCMs include a more technologically advanced method of forming finished products.

PCMs based on aromatic polyamides (PAs) are an excellent alternative to metals. Among many polymer materials, PAs are characterized by wear resistance, resistance to corrosion and most aggressive environments. Due to their unique functional properties and various processing methods (injection moulding, extrusion and compression pressing), PAs have become an integral component of modern technology. The introduction of discrete carbon [4] and or-

ganic [5] fibres, pure metals [6] and amorphous alloys [7], carbides [8], silica gel [9] and graphite [10] into PAs made it possible to obtain PCMs, whose technical characteristics surpass those of widely used tribological materials such as bronze, D-12 oilstone, Gr3 and Gr2D2.5 metal ceramics, and steel. The use of these PCMs in friction units of pipe-rolling pilgrim mills, brake pads of Škoda 14Tr and PMZ T1R trolleybuses, KP "Maxym" cultivator, "John-Deere 1780" and Turbosem-2 seeding complexes allowed increasing the productivity and reliability of the equipment, while simultaneously saving funds aimed at maintenance. However, insufficient attention is paid to the use of clad metals as fillers (FLs) in the analysed literary sources. It is known [11] that the use of VKNA, PKHN-15 and PH20N80 clad powders makes it possible to increase the service life of parts. Given the above, the scientific interest was in the study of the influence of clad powders on the properties of PAs. Considering the above, **the article aimed to** study the effect of nickel-clad chromium carbide (PKHN-15) on the tribological properties of PCMs based on the phenylone PA.

2. Experimental

Phenylone C-1 aromatic PA was selected for the creation of new PCMs. Phenylone is a heterochain polymer containing phenyl radicals interconnected by groups – NH – CO. This polymer can work stably under the influence of high temperatures (up to 533 K), and it is frost-resistant even at the temperature of liquid nitrogen. Aromatic PA has proven itself excellently in the production of parts of friction units of various machines that work under the influence of high loads, speeds, and temperature changes [6].

Dispersed (40-100 μm) PKHN-15 powder (manufactured by "COMPOSITION SYSTEMS", Zaporizhzhia, Ukraine) was chosen as a filler (FL). It is dispersed chromium carbide (Cr_3C_2) clad with 15% nickel, achieved using the manufacturer's modern technologies. The nickel coating significantly enhances the performance of chromium carbide, providing superior hardness, high-temperature stability, improved wear resistance, and superior corrosion resistance. PKHN-15 is characterized by high indicators of wear resistance even at high temperatures (up to 1173 K) and in a corrosive environment. Therefore, we can expect an increase in the functional characteristics of PCMs containing clad powders as FLs [11].

New PCMs based on the aromatic PA phenylone were produced according to the method given in [6], which includes the activation of the filler in the magnetic field of a vortex mixer. The tribological properties were studied on a friction machine SMC-2 using the "disk-pad" scheme, simulating the real operating conditions of friction units of high-performance equipment, in the friction mode without lubrication at a sliding speed of 1 m/s and a load of 1 MPa. Steel 45 (45-48 HRC, R_a=0.32 μm) was chosen as the counterbody. The microhardness at the interface between PA and PKHN-15, as well as the morphology of the friction surfaces were studied using a PMT-3M microhardness tester and a BIOLOM-M microscope. The hardness of aromatic PA and PCMs based on it was determined using a 2074 TPR hardness tester. The temperature in the friction zone was measured using a FLUS ET-939 thermometer with a thermocouple fixed in the sample at a distance of 0.3-0.5 mm from the surface of contact with the counterbody.

3. Results and Discussion

Table 1 shows the data on tribotechnical properties of aromatic PA and composites based on it. It was established that the introduction of PKHN-15 clad powder leads to a decrease in both the linear wear and the coefficient of friction of phenylone aromatic PA by almost 15 and 1.8 times, respectively. In sliding friction, the force of friction is determined by adhesive and deformation components, which are additive, that is, the greater their sum, the greater the total friction force.

The adhesive component of the friction force for polymers is due to weak hydrogen or Van der Waals frictional bonds that are formed at the "polymer-metal" friction interface and are destroyed during further movement. The deformation component of the friction force makes a greater contribution to the total friction force and is caused by the ploughing of a softer surface in the friction pair with the formation of friction tracks.

The introduction of solid FL particles into the composites leads to an increase in the total hardness (see Table 1) and, as a consequence, to a decrease in the deformation component of friction. In this regard, the friction coefficient of the composite containing 10 wt.% FL is 1.8 times lower than for the polymer. On the oth-

Table 1 – Characteristics of aromatic polyamide and composites based on it

Indicator	Content of PKHN-15 powder, wt.%				
	0	10	15	20	25
Intensity of linear wear, Ih·10-8	58.7	5.99	4.30	4.11	5.14
Coefficient of friction, f	0.51	0.28	0.30	0.35	0.40
Microhardness at the border "PA-PKHN-15", HV, hardness units	-	172.0	193.5	225.6	171.7
Hardness, hardness units	80	85	86	89	90
Temperature in the friction zone, K	453	449	449	445	447

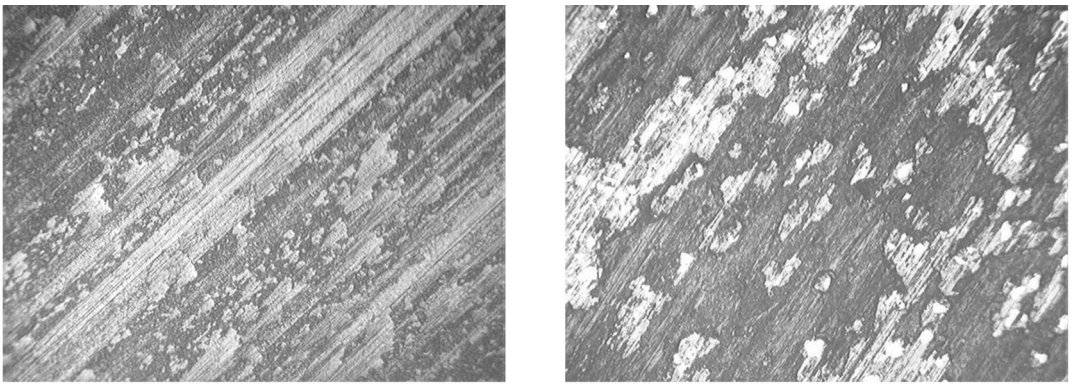
er hand, increasing the amount of filler leads to an increase in the friction coefficient f by 25 - 43%, due to the nature of the filler. Nickel, which is part of the filler, actively interacts with aromatic PA, as shown in [6]. As a result, the presence of stronger hydrogen bonds between FL and polymer can lead to the formation of stronger friction bonds at the "composite-metal" friction interface, which will contribute to an increase in the adhesive component of friction with an increase in the FL content. Taking into account the fact that the hardness of the composite changes by only 5% with an increase in the amount of FL from 10 to 25 wt.% (see Table 1), i.e., the deformation component of the friction force changes insignificantly, and the friction coefficient of the composites will increase proportionally to the value of FL due to the increase in the adhesive component of the friction force.

Regarding the wear resistance of composites, the following should be noted. During sliding friction, the wear process of aromatic PA occurs, mainly, by the mechanism of adhesive wear, which leads to the detachment of the material from the surface of the polymer due to the destruction of physical and chemical bonds. Adhesive wear is usually accompanied by the formation of small fragments of material that can remain on the surface or be removed from the friction zone; it is characterized by a moderate intensity of material loss. This wear mechanism is accompanied by the formation of microcracks on the polymer surface (see Fig. 1 a) and the release of particles from the volume of the material.

When aromatic PA is filled with solid FL, the wear mechanism changes from adhesive to partially abrasive; the formation of a stronger structure better resists mechanical loads, micro-impacts and destruction. As a result, the PCM friction surface (Fig. 1, b) is less deformed and a significant increase in the wear resistance of the material is observed. It should be noted that PCM containing 20 wt.% FL is characterized by the highest wear resistance. With a further increase in the FL content up to 25 wt.% in the developed PCMs, a slight decrease in wear resistance is observed, associated with excessive FL activity in a magnetic field. At a high concentration of the FL, the particles begin to interact with each other, forming local clusters (agglomerates) which reduce the contact area between the FL and aromatic PA. This reduces adhesion at the interface, which leads to deterioration of the mechanical properties of the material, including microhardness at the interface (see Table 1). Areas with weak adhesion become vulnerable to mechanical impact that can cause cracking or local destruction resulting in somewhat reduced wear resistance.

It is also worth noting that an important factor is the thermal load, which affects the stability and controllability of the wear process, as well as the ability of the material to retain its properties longer under friction conditions [12]. As can be seen from Table 1, the temperature in the friction zone remains stable. It indicates that the introduction of PKHN-15 does not cause additional thermal loads. In addition, traces of adhesion to the counterbody (areas of the material shifted in the direction of friction), observed for aromatic PA (Fig. 1, a), disappear on the friction surfaces of the composites (Fig. 1, b). It indicates a decrease in local temperature peaks in the friction zone, reducing the risk of thermal damage and accelerated wear.

Considering the high wear resistance of the developed PCM containing 20 wt.% PKHN-15, it was decided to experimentally determine the possibility of further replacing standard parts



a b

Figure 1 – Friction surfaces (magnification ×200) of phenylone aromatic polyamide (a) and a composite based on it, containing 20 wt.% PKHN-15 (b)

with new ones with better technical characteristics. The tests were carried out on the equipment of NANTONG INDUSTRIAL MACHINERY INTERNATIONAL CO. Ltd. Experimental support bushings for the idle branch of the chain drive of a sunflower chain conveyor, serial number TGSS25-10325, with a capacity of 100 t/h, a length from the loading point to the unloading point of 23 m and installed at an angle of 7 degrees were manufactured from the developed PCMs containing 20 wt.% PKHN-15. During the experiment, standard bushings made of wear-resistant high-molecular polyethylene were replaced with experimental ones of the same dimensions, radii, thickness, etc. As a result of the experiment, during the period from April 8th, 2024 to September 8th, 2024, it was established that the experimental bushings had no signs of wear, unlike the bushings of the standard composition, where there were signs of wear from the transport chain on the surface, and from the axis of rotation inside. This indicates their greater wear resistance and longer service life. Also, it should be noted that during the operation of the experimental bushings, no extraneous noises, lack of smooth movement of the transport chain, or an increase in electricity consumption were noticed, which, in turn, indicates their suitability for a full-fledged replacement of bushings of a standard composition and allows the developed composites to be recommended for mass production and use in specified friction units.

4. Conclusion

During the research, it was established that the introduction of PKHN-15 clad powder leads to a decrease in both the linear wear and the friction coefficient of the phenylone aromatic PA by almost 15 and 1.8 times, respectively. It should be emphasized that during sliding friction, the friction force of the developed composites is determined by the adhesive and deformation components. It was established that when aromatic PA is filled with a solid filler, the wear mechanism changes from adhesive to partially abrasive, which significantly increases the wear resistance of the polymer. It has been substantiated that when filling aromatic polyamide with PKHN-15 powder, no additional thermal loads arise, and local temperature peaks in the friction zone are reduced, which reduces the risk of thermal damage and accelerated wear of composites. The results of the operation of the experimental support bushings for the idle branch of the chain drive for sunflower transportation chain conveyor are shown. The designed composites, based on aromatic polyamide containing 20 wt.% PKHN-15, are recommended for serial production and use in friction units.

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