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INVESTIGATING THE INFLUENCE OF FINE-DISPERSED ALUMINUM, NICKEL AND TITANIUM ON THE PROPERTIES OF PHENYLONE

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Summary. *The article examines the impact of metallic fillers on physical and mechanical properties of aromatic polyamide phenylone. It is shown that under the influence of fillers phenylone structure is partially subject to structuring effects, thereby improving its mechanical and tribological characteristics. Also, the article discusses the possibility of applying the developed metal-containing polymers in friction knots of machines and mechanisms. Some practical examples of application and profitability of replacing traditional materials with the developed metal-containing polymers are cited.*

Key words: *aromatic polyamide, metal-containing polymers, aluminum, nickel, titanium, physical and mechanical properties, tribotechnical characteristics, application.*

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Setting the problem. It is known, that one of the ways to a successful resolution of the problem of increasing the reliability and wear resistance of machines is applying polymeric materials (PM) in friction knots. These materials possess specific properties and provide for a new way to solve a number of technical problems that aim at increasing the life of machines. However, the use of the initial PM in friction knots is usually impossible due to quite a high coefficient of friction and lack of wear resistance.

The analysis of recent research. In order to decrease the drawbacks of PM, various layered antifriction additives (graphite, molybdenum disulfide, boron nitride) are introduced, which enhances the wear resistance by more than an order of magnitude, but sharply reduces strength properties by 2–4 times [1]. To increase the strength of the PM, they are filled with solid particles, namely with metals [2–5], however, due to the uneven distribution of the latter, this leads to a deterioration in tribological performance.

On the other hand, thermoplastics and composites based on them possess a great potential in increasing the reliability of friction knots. Because of their high processability and economical processing into articles, thermoplastic polymers have become most widespread and advantageous over thermoreactive resins. It is particularly important to develop thermoplastics that can operate in extreme temperature conditions, while possessing a high modulus of elasticity and strength [6]. An aromatic polyamide phenylone is of a particular scientific interest due to the combination of high heat resistance and good physical and mechanical properties. However, attempts to fill it with the excipients often lead to deterioration of the latter. This is due to the increased rigidity of macromolecules and strong intermolecular interactions, which leads to the aggregation of filler particles [7].

The purpose of the article. Based on the mentioned above, studying the effect of metal dispersed fillers on phenylone properties in case of their even distribution within the polymer matrix is of great interest.

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Results and Discussion. Today, the significant development of technology favored the expansion of the use of thermo- and heat-resistant polymers, characterized by long-term availability in a wide range of temperatures, high strength properties, resistance to deformations and exposure to corrosive media. Such polymers include the aromatic polyamide phenylone C-1 (according to TU 6-05-221-101-71 standard) (APP), a polymer analogous to Nomex by DuPont, which was chosen as a binder for the manufacture of metal-containing polymers (MP).

APP is a promising thermally stable polymer for structural purposes, which can be used for a long time to a temperature of 533 K, which is not inferior in strength to the best brands of reinforced plastics. However, the phenylone recycling in products causes certain difficulties, for example, low deformability and fluidity of phenylone in the softening temperature range narrow the temperature range of its processing and require the application of high pressures, resulting in product size limitations. Modification of phenylone with various kinds of fillers is also accompanied by difficulties associated with insufficient adhesive strength between the polymer matrix and the filler. As a consequence, strength parameters and heat resistance of composites are reduced, and, the more, the higher their content. Therefore, the development of MPs based on heat-resistant APP with an increased adhesion strength between phenylone and filler is an urgent task in the development of composites with increased physical and mechanical properties.

Fine powders of carbonyl nickel (PNK-2K10 according to GOST State Standard 9722–97), aluminum (PA–1 according to GOST State Standard 6058–73) and titanium (PTK–1 (2) according to TU 14–22–57–92 standard) were used as filling materials (Fl).

Due to the processing complexity of the aromatic polyamide into the articles we have developed an original method. Mould compositions of phenylone C-1+5–20 wt.% of fine-dispersed aluminum, nickel and titanium powders have been prepared by means of mixing the components within a rotating electromagnetic field in the presence of nonequiaxial ferromagnetic particles. Due to their chaotic motion, the metal filler has been unevenly distributed within the polymer matrix. After mixing the particles have been removed from the composition by means of magnetic separation. The mixture prepared in this way has been tableted in a hydraulic press at room temperature and the pressure of 40 MPa.

Further on, the tableted samples have been dried in an oven at the temperature of 473–523 K, as processing undried phenylone degrades its strength characteristics and leads to surface defects [6]. Dried samples have been processed into articles (8x10 mm) by compression molding at the temperature of 593 K and the pressure of 40 MPa. The exposure at this temperature has made 10 minutes.

As shown by studies of the structure designed metal-containing polymers, mixing compositions within the rotating electromagnetic field leads to an even distribution of the filler within the polymer matrix (Fig. 1).

It is known [8] that introducing fillers into polyamides affects the structuring processes. In the presence of a filler there is a tendency to the formation of ordered structures, as they act as initiators in the formation of crystallization nuclei.

It is known [9] that phenylone is characterized by a globular structure (see Fig. 2 a). Aluminum, nickel and titanium have a structuring effect that results in the formation of fibrillar structures (see Fig. 2 b, c, d), which confirms the active effect of excipients on the polymeric matrix. The tendency to the structuring of the polymer matrix was confirmed by X-ray diffraction analysis [10].

New structured areas have a positive impact on the set of physical and mechanical properties of the developed metal-containing polymers (Table 1), because globular structure provides phenylone with low mechanical properties due to the possibility of brittle fracture on the globules' boundaries.

Fibrillar structure has a positive effect on physical and mechanical properties, increasing in hardness by 34–45%, yield strength at compression by 14–18%, proportional limit by 33–70%, elasticity modulus by 13–22%, wear resistance by 2.6–11 times.

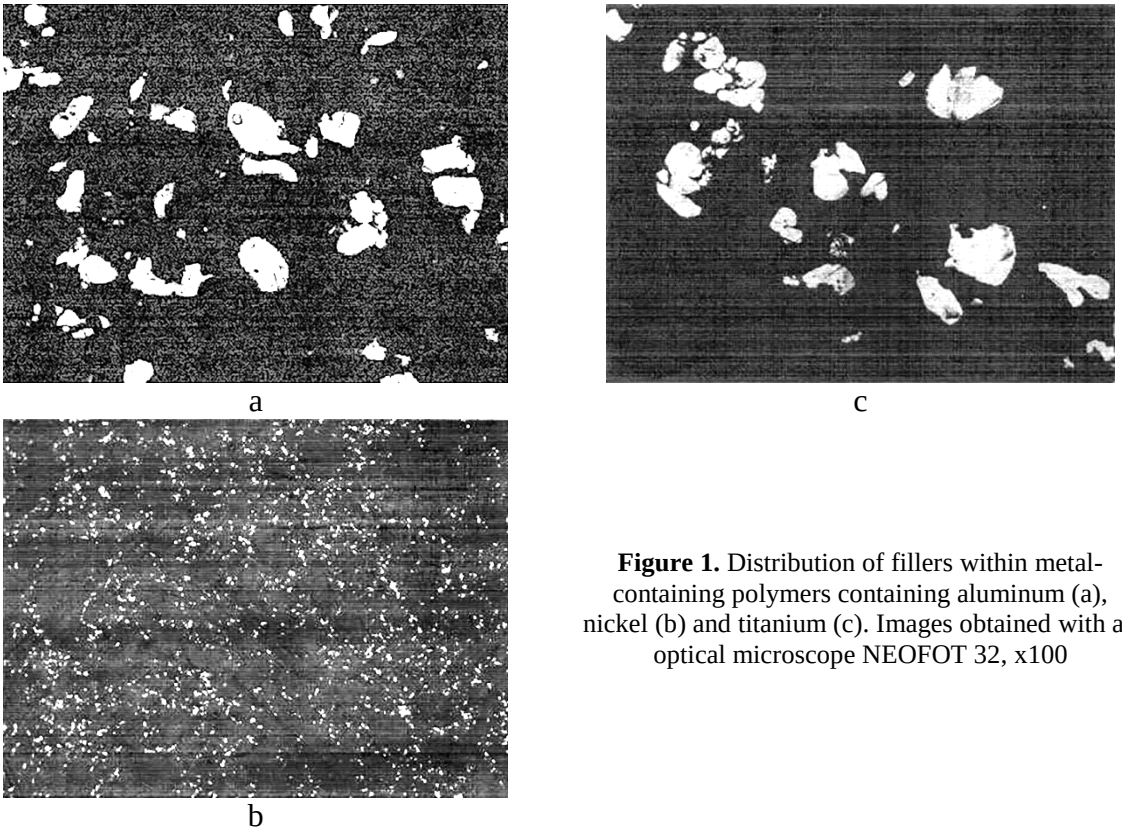

Figure 1. Distribution of fillers within metal-containing polymers containing aluminum (a), nickel (b) and titanium (c). Images obtained with an optical microscope NEOFOT 32, x100

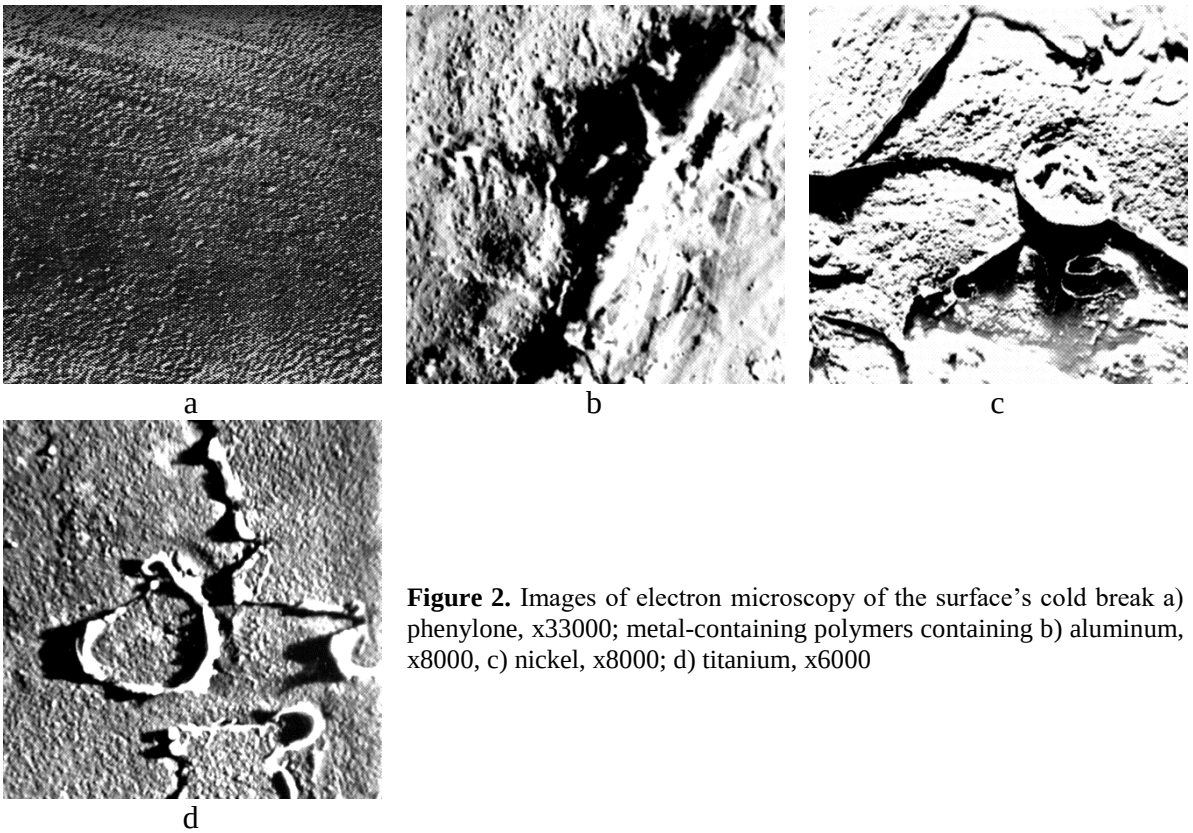

Figure 2. Images of electron microscopy of the surface's cold break a) phenylone, x33000; metal-containing polymers containing b) aluminum, x8000, c) nickel, x8000; d) titanium, x6000

As for the thermal properties of metal-containing polymers, [11] showed that within the operating temperature range, the appearance of metal fillers does not cause any quality change.

Table 1

Physical and mechanical properties of metal-containing polymers

Properties	Containing of filler, wt. %				
	0	5	10	15	20
	Aluminum				
Hardness HB, MPa	180	209.6	223	221	218
Yield strength σ, MPa	228.8	243.5	248	251.3	249
Proportional limit σ_p, MPa	152.6	160.4	172.9	187.5	175.6
Elasticity modulus E, MPa	2750	2910	3050	3310	3210
Wear intensity I_h, 10^{-8}	3.95	1.6	1.1	1.0	1.35
	Nickel				
Hardness HB, MPa	180	185.5	208	241	251
Yield strength σ, MPa	228.8	242	245	259.5	255
Proportional limit σ_p, MPa	152.6	199.0	202.9	212.8	193.1
Elasticity modulus E, MPa	2750	2860	2940	3100	2940
Wear intensity I_h, 10^{-8}	3.95	12	2.5	0.35	0.5
	Titanium				
Hardness HB, MPa	180	189	226	260	256
Yield strength σ, MPa	228.8	255.5	263	269	263.8
Proportional limit σ_p, MPa	152.6	169.5	178.2	203.0	194.8
Elasticity modulus E, MPa	2750	3140	3190	3350	3310
Wear intensity I_h, 10^{-8}	3.95	2.15	1.6	1.5	2.0

Note: physical and mechanical properties have been determined according to the GOST for plastics. The tribological properties under lubrication-free friction conditions were determined on a pin-on-disk wear test machine with a disk of grade-45 steel with a surface roughness Ra = 0.16–0.32 μm. In the experiments, the sliding distance was 1000 m. The specific load was 0.6 MPa and the sliding speed was 1 m/s.

With this regard, bushings have been designed from metal-containing polymers for pivot knots and brake systems of ZIU, UMZ, Skoda trolleybuses instead of bronze. These have shown good performance and reliability at exploitation. Due to the proposed bushings dimensions, the entire range of sleeves repair can be solved and purchases of new ones can be reduced. Before reaching the repair dimensions, the details are processed by conventional methods of machining. Thus, given the reliability and work efficacy of the mentioned bushings, replacing the series parts of trolleybus friction knots made of alloys based on non-ferrous metals with the metal-containing polymers ones becomes profitable.

Also, the elaborated metal-containing polymers were used to produce the eyelets of cam mechanism of crop-harvesting combine DON 1500 which were tested at a stand representing an assembled cam mechanism with a medium part of a reaper screw contained in a hermetic chamber. The chamber bottom was poured with silica sand, which in the rotation process was permeated by the screw cams, creating the conditions for abrasive wear simulation. The results of tests are cited in table 2.

As it can be seen from Table 2, metal-containing polymers are advantageous over the known analogues in terms of their wear resistance and can be recommended for the production of the finger unit eyelets of ZK DON 1500 harvester.

Table 2

The wear of the eyelets of cam mechanism of crop-harvesting combine DON 1500 reaper screw

Materials	Average wear per 600 hours, mm
Caprone of B grade	1.85
Metal ceramics IGr3	0.77–1.85
Metal ceramics IGr2C2, 5	2.0/420 hours/
Aluminum alloy AK-7	2.0/130 hours/
Composition based on Al	0.49
Composition based on Ni	0.47
Composition based on Ti	0.44

Conclusions. The studies have shown that the partial structuring of phenylone with metallic fillers leads to an increase in hardness by 34–45%, yield strength at compression by 14–18%, proportional limit by 33–70%, elasticity modulus by 13–22%, wear resistance by 2.6–11 times. Using metal-containing polymers for manufacturing bushings of pivot knots and brake systems of trolleybuses has shown good reliability in operation, which allows to recommend them as a replacement for the serial ones. The held stand tests of finger unit eyelets of the mechanism of ZK DON 1500 harvester indicate that the developed metal-containing polymers are advantageous over the known analogues in terms of their wear resistance and therefore can be applied in production.

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ВИВЧЕННЯ ВПЛИВУ ДРІБНОДИСПЕРСНИХ АЛЮМІНІЮ, НІКЕЛЮ І ТИТАНУ НА ВЛАСТИВОСТІ ФЕНІЛОНУ

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Резюме. *Розглянуто вплив металевих наповнювачів на фізико-механічні та трибологічні характеристики ароматичного поліаміду фенілон – багатообіцяючий термостійкий полімер конструкційного призначення, який може довго експлуатуватися до температури 533 К та не поступається за міцністю кращим маркам армованих пластиків. Показано, що за наявності дрібнодисперсних металевих наповнювачів (алюміній, нікель, титан) структура ароматичного поліаміду частково піддається структуруючому впливові, що виражається у вигляді фібрилярних утворень та підтверджує активний вплив наповнювачів на полімерну матрицю. Нові структуровані ділянки позитивно впливають на комплекс фізико-механічних та трибологічних властивостей розроблених металополімерів, оскільки вихідна глобулярна структура наділяє фенілон невисокими механічними характеристиками у зв'язку з можливістю крихкого руйнування по межах глобул. Таким чином, введення наповнювачів призводить до підвищення твердості полімерної матриці у 1,2–1,3 раза, межі текучості при стисненні – у 1,1–1,2 раза, межі пропорційності – у 1,3–1,4 раза, модуля пружності – у 1,1 раза, зносостійкості – на 54–79%. Розглянуто можливість застосування розроблених металополімерів у вузлах тертя машин і механізмів для заміни кольорових металів і їхніх сплавів, а також зарубіжних полімерних аналогів. Зокрема, використання металополімерів для виготовлення втулок шкворневих вузлів, а також гальмівних систем тролейбусів показало добру надійність при експлуатації, що дозволяє рекомендувати їх для заміни серійних деталей. Проведені стендові випробування вічок пальчикового механізму шнека жатки ЗК ДОН-1500 свідчать, що розроблені металополімери перевершують за зносостійкістю відомі світові аналоги й можуть бути використані для серійного виробництва.*

Ключові слова: *ароматичний поліамід, металополімер, алюміній, нікель, титан, фізико-механічні властивості, триботехнічні характеристики, застосування.*

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