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DEVELOPMENT OF POLYMER COMPOSITE MATERIALS FOR FRICTION ELEMENTS OF CONVEYOR EQUIPMENT

The object of the study is materials with enhanced tribological properties intended for the friction components of conveyor equipment. One of the most critical issues is ensuring the wear resistance of friction units in conveyor systems, particularly under dry friction conditions. A promising solution involves the use of tribotechnical polymer composite materials (PCMs) based on aromatic polyamide.

The research involved the use of modified graphite-containing systems based on aromatic polyamides filled with graphites of various dispersities and at different mass concentrations.

Polymer composites were obtained based on aromatic polyamide modified with organosilicon fluid and filled with graphites differing in nature and morphology. A correlation was established between the antifriction properties of the polymer compositions and both the filler content and graphite grade.

Under dry friction conditions, the enhancement of antifriction properties is achieved by incorporating graphite into the aromatic polyamide in an effective concentration of 15–20%, at which a stable antifriction film forms on the counterbody surface, acting as a solid lubricant. In this case, the coefficient of friction and the linear wear rate of the material remain low, 0.1 to 0.15 and 0.5 to 1×10^{-9} m/m, respectively. A notable observation is that during friction, the graphite material wears away while the metal remains virtually unaffected. It was found that an excessive filler content (> 20%) leads to brittleness of the composite, which is a critical design limitation.

As a result, the developed material can be effectively used for friction components operating under dry, lubrication-free conditions. This justifies its high utility and environmental benefits, as it eliminates the need for lubricants and their disposal. Compared to traditional materials such as bronze, the proposed composites offer distinct advantages.

Keywords: *screw conveyor, dry friction, composite, graphite-filled polyamide, antifriction film, wear.*

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1. Introduction

Conveyors are among the most widespread types of equipment used across virtually all sectors of industry in Ukraine and leading countries worldwide [1]. They are operated at manufacturing facilities, warehouses, ports, and in both domestic and industrial environments for transporting raw materials, semi-finished goods, finished products, and production waste, as well as for performing loading and unloading operations [2].

One of the key criteria for assessing the performance of conveyor equipment is the reliability and service life of its friction units, which operate under significant dynamic loads, abrasive wear, corrosion, and temperature fluctuations [3].

The study of friction components in conveyor systems remains a relevant task in the current context, aimed at reducing the consumption of metals and energy resources, ensuring the efficient use of raw materials and equipment, and eliminating the need for lubrication.

Traditional metallic friction components in conveyor equipment require lubrication and are typically designed with additional protective elements against abrasive environments, which complicates the overall construction and increases manufacturing costs [4]. One such component is intermediate suspended sliding bearings of screw conveyor shafts for transporting food products (Fig. 1, 2).

In these friction units, which often operate in direct contact with the conveyed product, sliding bushings made of wood or bronze are typically used. The primary drawback of wooden bushings is their low mechanical strength, which limits their ability to withstand high loads; moreover, the supply of appropriate imported wood can be problematic. In the case of bronze bushings, disadvantages include short service life, high cost, and substantial material losses during manufacturing. In both cases, the friction pair requires lubrication – a critical drawback when food comes into contact with lubricant. Only food-grade lubricants are permitted, which are quite expensive.

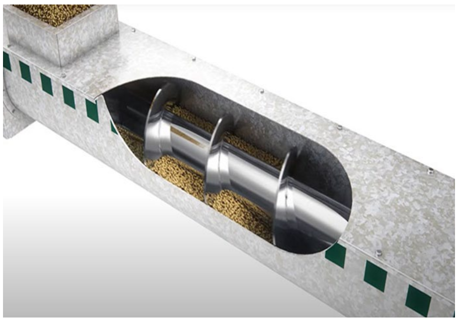

Fig. 1. Screw conveyor for transporting food products

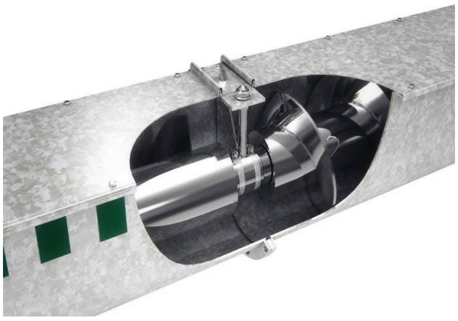

Fig. 2. Intermediate suspended bearing of a screw conveyor

Thus, it can be concluded that modernization of the intermediate suspended bearing in screw conveyors – specifically with the goal of simplifying the design and eliminating lubrication – is a timely and relevant engineering challenge.

When determining the primary factors influencing friction in the sliding bushing of an intermediate bearing in screw conveyors, considerations included the mechanical characteristics of the materials, sliding speed, load, and the coefficient of friction both in lubricated and dry conditions [5].

One of the most significant factors affecting the wear rate of the bushing is the linear sliding speed on the shaft surface v (m/s), which is determined by the following relationship

$$v=\pi\cdot D_{shaft}\cdot n, \tag{1}$$

where D_{shaft} – shaft diameter (m), n – shaft rotational speed (rev/s).

Considering the force acting on the bushing, the *friction force* F_{fr} (N)

$$F_{fr}=F\cdot f, \tag{2}$$

where F – force acting on the bushing (N), f – coefficient of friction.

Next, the *friction torque* M (N · m) is calculated as

$$M=F\cdot r\cdot f, \tag{3}$$

where r – shaft radius (m), F – force acting on the bushing (N), f – coefficient of friction.

The *lubricant consumption* Q (m^3/s) is estimated using the following relationship

$$Q=k\cdot A\cdot v, \tag{4}$$

where k – lubricant flow coefficient, A – contact surface area (m^2), v – linear sliding speed (m/s).

The *power* P_{fr} (W) consumed due to friction is calculated by

$$P_{fr}=F_{fr}\cdot v, \tag{5}$$

where F_{fr} – friction force (N), v – linear sliding speed (m/s).

The rotational speed of the screw shaft indicates the operating velocity of the bushing. Mechanical losses at the bushing (friction torque) are critical when selecting a suitable bushing material and lubricant to ensure effective reduction of wear intensity and overheating. The lubrication system must be properly adjusted to minimize friction, under which conditions the coefficient of friction (f) remains relatively low.

However, when the sliding bushing operates without lubrication, the situation changes significantly: the friction between the screw shaft and the bushing increases markedly, which may lead to severe overheating, accelerated wear, and even material failure. In this case, the coefficient of friction (f) between the contacting surfaces becomes higher, and mechanical losses increase accordingly.

The selection of an appropriate bushing material must therefore take into account the applied load, the operating environment, and the coefficient of friction.

In this context, the use of polymers and their composites as materials for friction-interacting components presents significant interest. One such group of materials is *aromatic polyamides* [6], which represent an advancement over traditional materials such as bronze, brass, and wood [7]. The use of aromatic polyamide for manufacturing friction components of conveyor equipment addresses several key challenges: it eliminates the need for lubrication, enables waste-free manufacturing technologies, reduces overall machine weight, and extends the service life of equipment [8].

In recent years, efforts to rationalize the use of polymers have continued, as evidenced by domestic and international research. This objective is being pursued through the modification of polymer properties by influencing both external and internal factors that govern the structure and characteristics of polymer systems. Studying the mechanisms of structural modification enables targeted control of polymer system formation, allowing the creation of materials with predetermined property sets [9].

One notable polymer based on aromatic polyamides is *poly-meta-phenylene isophthalamide*, which exhibits high chemical resistance, thermal and heat stability, and mechanical strength. Components made from this material can operate at temperatures up to 523 K and withstand alternating loads of up to 230 MPa. Additionally, parts made from aromatic polyamide can function effectively in machine friction units under dry, lubrication-free conditions [10].

Therefore, the use of aromatic polyamide as a base material for manufacturing friction unit components in conveyor systems is a well-founded and technically justified solution.

The aim of this research is to develop polymer composites based on aromatic polyamide, modified with organosilicon fluid and filled with graphites of various types and morphologies.

2. Materials and Methods

2.1. Materials

The object of this study is materials with enhanced tribological properties intended for friction components of conveyor equipment operating under frictional interaction.

Aromatic polyamides are linear polymers whose macromolecules consist of aromatic fragments of various structures linked by amide bonds. The simplest aromatic fragment is the phenyl radical, while more complex ones include radicals such as diphenyl sulfone, diphenyl ether, and others [3].

In this study, the aromatic polyamide used was poly-meta- and para-phenylene isophthalamide. Its structural formula is shown in Fig. 3.

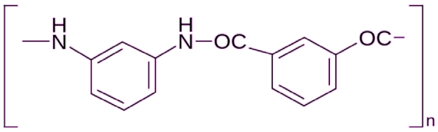

Fig. 3. Structural formula of aromatic polyamide

This aromatic polyamide is a product of the polycondensation of aromatic diamine and the acid chloride of isophthalic acid. It is characterized by a high glass transition temperature (563 K) and melting point (703 K), a relatively high long-term service temperature (up to 533 K), and elevated resistance to radiation and chemical exposure, among other valuable properties. The molecular weight of poly-meta- and para-phenylene isophthalamide suitable for processing into final products ranges from 20,000 to 70,000. This polymer has an amorphous structure and crystallizes rapidly at temperatures of 313–323 K, or at lower temperatures with prolonged heating.

Pressing materials based on the selected aromatic polyamide are produced in the form of fine powders with a white-yellow color, a bulk density of 200–400 kg/m^3, and an intrinsic viscosity of not less than 0.8 for a 0.5% solution in dimethylformamide with 5% lithium chloride.

To improve processability, the aromatic polyamide was modified with a silicone-based polydimethylsiloxane liquid (grade PMS-100). This class of compounds was chosen because these substances are commonly used to modify polymers or for surface treatment of powder or fibrous compositions. Their high chemical and thermal stability allows them to be processed together with aromatic polyamides at elevated temperatures. The excellent lubricating properties of PMS-100 are expected to improve the antifriction characteristics of the modified aromatic polyamide [11].

Graphite was selected as the antifriction filler for the aromatic polyamide due to its higher effectiveness compared to other solid lubricants such as molybdenum disulfide, boron nitride, or polytetrafluoroethylene (PTFE).

Graphite is an allotrope of carbon with a layered crystalline structure. The individual crystal layers are weakly bonded and slide easily over one another, which provides a low coefficient of friction. The density of industrial-grade graphite is approximately 2000 kg/m^3. Graphite is stable in atmospheric pressure up to 873 K, and in vacuum up to 3773 K. It exhibits electrical conductivity similar to metals, is chemically and radiationally stable, insoluble in water, and resistant to strong acids and alkalis.

In this study, various grades and particle sizes of graphite and graphite-based materials were used, including B-1 (GOST 5245-50), ELP-V (TU 6-08-314-74), C2 (GOST 8295-73), GK-1 (GOST 4404-78), and GAK-1 (GOST 10273-79). The main characteristics of these materials are presented in Table 1.

Table 1

Key characteristics of the investigated graphite materials and graphite-based preparations

No.	Name	Grade	Ash Content, %	Particle Size/Sieve Residue
1	Battery graphite	GAK-1	≤ 0.5	Residue on sieve No. 016 (160 μm) ≤ 50%, on sieve No. 0063 (63 μm) – 90–50%
2	Pencil graphite (for drawing and office pencils)	GK-1	≤ 1	Residue on sieve No. 0063 (63 μm) ≤ 0.5%
3	Dry colloidal graphite preparation	C1	≤ 1.5	Particle size 4–6 μm
4	Aqueous colloidal graphite preparation	B-1	≤ 2	Particle size ≤ 0.5 μm
5	Aqueous colloidal graphite preparation	ELP-V	≤ 1	Particle size ≤ 0.5 μm

2.2. Method of specimen fabrication

Aromatic polyamides are characterized by high melt viscosity, which makes direct processing challenging. Therefore, specimens for the comprehensive evaluation of the developed materials were produced using compression molding in heated molds.

The molding process was conducted according to the following procedure:

1. Preheating of the mold to 523 K and loading of the material.
2. Heating of the mold with the material to the pressing temperature and holding at that temperature without applying pressure for 5 minutes.
3. Thermal treatment under a pressure of $P_{pr} = 50$ MPa for 5 minutes.
4. Cooling of the material under pressure down to 493 K.
5. Opening of the mold, removal of the specimen, and subsequent mechanical finishing.

All test specimens were subjected to mechanical and tribological testing no earlier than 24 hours after fabrication.

2.3. Research methods

Tribological testing of the developed materials was conducted under both lubricated and dry friction conditions using an SMC-2 tribometer, with applied contact pressures up to 20 MPa. A steel 45 disc was used as the counterbody. The total sliding distance of the test specimens was 10,000 meters, and the rotation speed of the disc was varied within the range of 1–3 m/s. For lubricated tests, Industrial 45 oil was used as the lubricant.

The friction force was measured using a strain gauge method, while wear was assessed through micrometry and mass loss measurements using an analytical balance (VLR-200) with an accuracy of $\pm 10^{-4}$ g.

The linear wear was calculated using the following formula

$$l = \frac{m}{\rho \cdot S}, \tag{6}$$

where l – linear wear (m), m – mass loss due to wear (kg), ρ – density of the specimen material (kg/m^3), S – contact surface area (m^2).

The linear wear rate was determined by dividing the linear wear by the total sliding distance during the test.

3. Results and Discussion

To improve their performance characteristics, aromatic polyamides can be filled or modified with materials of various natures and morphologies, allowing for targeted adjustment of the resulting polymer composite properties.

In this study, an aromatic polyamide was modified with organosilicon additives possessing high thermal stability and chemical resistance. This modification results in reduced intermolecular interactions within the polymer, which leads to decreased melt viscosity, a wider processing temperature range, and other positive effects [12].

To enhance the tribological properties, the modified aromatic polyamide was further filled with graphite and graphite-based preparations of different particle sizes. These act as highly efficient solid lubricants and significantly increase the wear resistance of friction units overall [13]. Fig. 4, 5 show the concentration dependences of the linear wear rate and the coefficient of friction for composites based on modified aromatic polyamide and graphite.

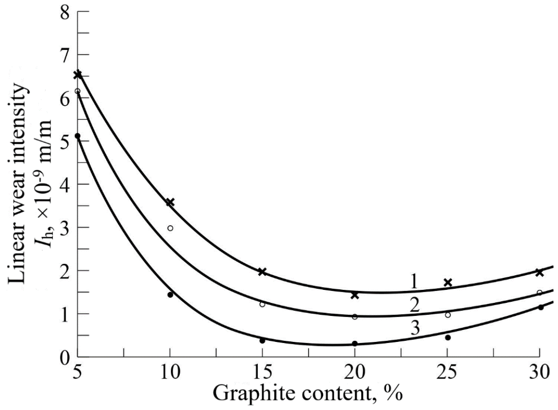

Fig. 4. Dependence of the linear wear intensity (I_h) of aromatic polyamide-based polymer composites on graphite content: 1 – ELP-V; 2 – B-1; 3 – C-1

The study found that both the type and amount of filler (graphite) have a substantial influence on the friction and wear performance of the obtained composite materials. As the graphite content increases, the wear intensity of the tested materials decreases sharply; however, introducing graphite beyond 20–25% results in a slight increase in this indicator. The wear intensity curve reaches its minimum at a graphite content of 15–20% (Fig. 4).

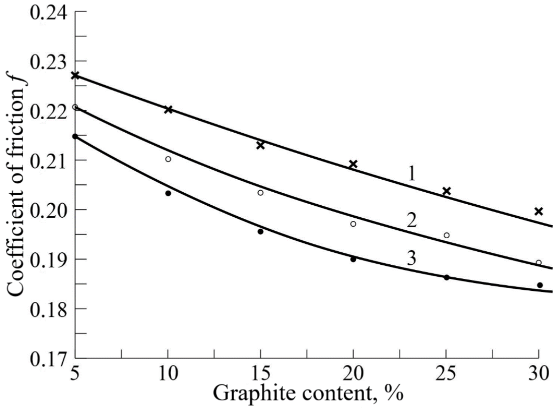

Fig. 5. Dependence of the coefficient of friction (f) of aromatic polyamide-based polymer composites on graphite content: 1 – ELP-V; 2 – B-1; 3 – C-1

During the friction process, graphite forms a film on the counter body surface that resembles solid alloys in its properties, retaining its crystalline structure and creating conditions for graphite-on-graphite sliding. Under load, graphite particles become embedded in the counter body surface; owing to their hardness, which can even exceed that of metals, they act as nuclei around which a film builds up through chemisorption and adsorption of wear products. As a result, dry friction occurs between the polymer sample surface and the formed solid film, which acts as a dry lubricant. This explains the stability of the antifriction performance of graphite-filled aromatic polyamide under dry friction conditions, where the coefficient of friction remains low.

A characteristic feature is that during operation, only the graphite material undergoes wear, while the metal remains virtually unaffected. Changes in motion direction during reciprocating sliding do not disrupt the orientation of graphite particles relative to the working metal surface.

The speed of film formation, its uniformity, and its density are directly dependent on the amount of filler in the polymer composite. This explains the sharp increase in wear resistance of composites containing 15–20% graphite. Further increases in graphite content lead to a significant reduction in strength and increased brittleness of the composite, resulting in a higher share of fatigue wear and thus a decrease in wear resistance for graphite contents above 20%.

The nature of the filler also has a significant impact on the wear resistance of the composite plastic. The average particle size of the graphites increases in the order ELP-V, B-1, C-1. Composites with coarser graphite particles exhibited higher wear resistance. Meanwhile, the coefficient of friction decreases with increasing graphite content in the aromatic polyamide, regardless of particle size.

Tribological studies were also conducted on polymer composites containing powdered natural graphites (grades GK-1, GAK-1) and artificial graphite C-1 at a concentration of 20%. Under various friction conditions, the material containing GK-1 graphite demonstrated the highest antifriction performance (Fig. 6, 7).

The mechanism for improving the antifriction properties of aromatic polyamide by introducing graphite is explained by the combined interaction of graphite as a high-quality lubricating material and the aromatic polyamide as a polymer binder with enhanced physical, mechanical, and antifriction characteristics [14].

Aromatic polyamide tends to absorb significant amounts of atmospheric moisture during long-term storage. In the friction process, frictional heating promotes the desorption of water vapor from the specimen's bulk, allowing it to enter the contact zone. The presence of water vapor positively influences the friction behavior of carbon – graphite materials. In addition, during the friction of composite plastics, mechanical-chemical processes occur in the contact zone, accompanied by the formation of active radicals. Gaseous products are chemically sorbed and adsorbed by active centers on the graphite crystals, thereby creating favorable conditions for friction.

Fig. 8 shows the dependence of the friction heating temperature and the friction coefficient of the studied pair on the sliding distance.

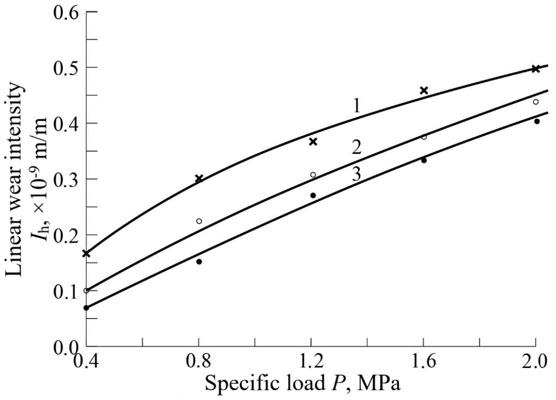

Fig. 6. Dependence of the linear wear intensity (I_h) of aromatic polyamide – graphite-based polymer composites (1 – GAK-1; 2 – C-1; 3 – GK-1) on the specific load (P)

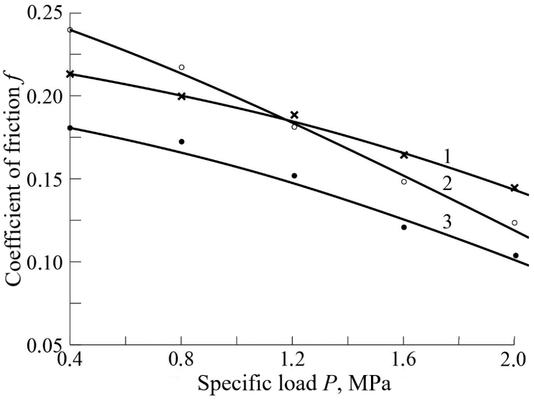

Fig. 7. Dependence of the coefficient of friction (f) of aromatic polyamide – graphite-based polymer composites (1 – GAK-1; 2 – C-1; 3 – GK-1) on the specific load (P)

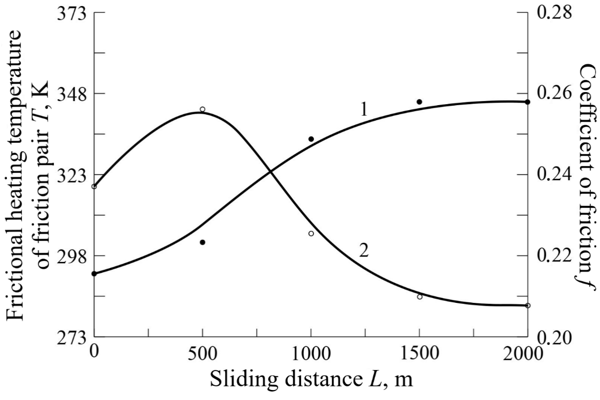

Fig. 8. Dependence of (1) frictional heating temperature (T) and (2) coefficient of friction (f) of the graphite-filled aromatic polyamide – steel 45 friction pair on the sliding distance (L)

In the initial stage, characterized by relatively low frictional heating temperatures, the coefficient of friction rises. Then, as the contact temperature increases, the coefficient of friction reaches its maximum and begins to decrease. Upon stabilization of the thermal regime, the coefficient of friction also stabilizes.

The heat generated during friction promotes the release of water vapor from the polymer's bulk and the occurrence of chemical sorption processes in the contact zone. This leads to the formation of a film on the counter body surface, which acts as a solid lubricant. The rate of film formation and the stabilization of the friction regime depend on the process parameters, including specific pressure, sliding speed, temperature, and the presence and type of lubricant [15].

The study also established that the friction conditions have a significant influence on the wear and friction behavior of this polymer system. Despite generally high wear resistance, the most favorable mode is dry friction, characterized by the absence of any lubricating medium. This suggests that graphite-filled aromatic polyamide exhibits high self-lubricating properties over a wide load range.

The wear intensity during lubricated friction increases as the load grows, whereas in dry friction its value remains stable within the investigated load range up to 20 MPa (Fig. 9).

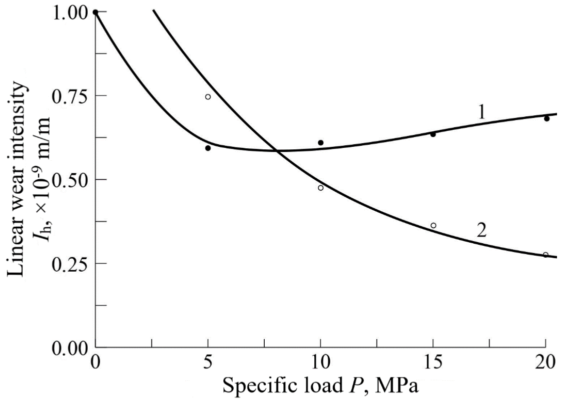

Fig. 9. Dependence of the linear wear intensity (I_h) of graphite-filled aromatic polyamide on the specific load (P) under friction conditions: 1 – with lubrication, 2 – without lubrication

In dry friction mode, the coefficient of friction also shows relative stability as the load increases (Fig. 10). With lubrication, an increase in load up to 5 MPa reduces the coefficient of friction, while further load increases cause a slight rise.

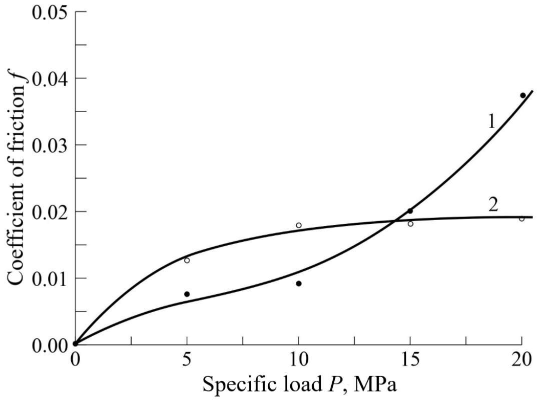

Fig. 10. Dependence of the coefficient of friction (f) of graphite-filled aromatic polyamide against steel 45 on the specific load (P) under friction conditions: 1 – with lubrication, 2 – without lubrication

To further investigate this phenomenon, the surface of the counterbody was examined after testing under both dry and lubricated conditions. During dry friction, wear of the steel counterbody (Fig. 11) was practically absent, indicating the high stability of the formed solid film. Conversely, the presence of a lubricating medium inhibited film formation and led to noticeable wear of the counterbody.

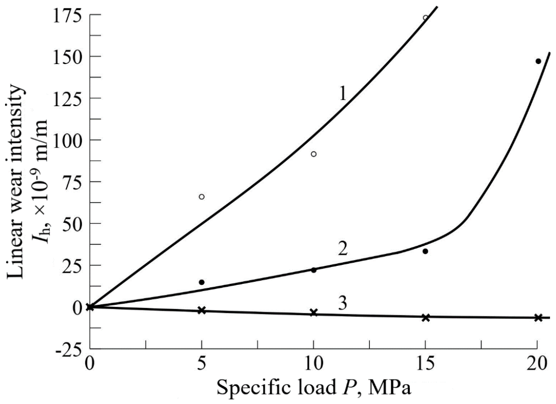

Fig. 11. Dependence of the linear wear intensity (I_h) of the steel counterbody during frictional interaction with (1) bronze (lubricated friction) and graphite-filled aromatic polyamide (friction with (2) and without (3) lubrication) on the specific load (P)

The obtained experimental data indicate that graphite-based composites using aromatic polyamide not only exhibit high wear resistance but also cause less wear on the steel counterbody compared to bronze. This is of significant practical importance for increasing the service life of friction units in conveyor equipment, where one of the main failure causes is wear of the working surface in contact with bronze components.

Further investigation into the physicomechanical and thermophysical properties of the developed composite is of interest. The results are presented in Table 2.

Table 2

Physico-mechanical and thermophysical properties of the base aromatic polyamide and the developed composite based on it

No.	Property	Base Aromatic Polyamide	Composite based on modified aromatic polyamide with 20% GK-1 graphite
1	Density, kg/m^3	1340 ± 10	1410 ± 10
2	Ultimate stress, MPa: in compression in bending in tension	 210 ± 5 230 ± 5 120 ± 5	 195 ± 5 176 ± 5 92 ± 5
3	Specific impact toughness, kJ/m^2	50 ± 4	32 ± 4
4	Compressive modulus, MPa	3200 ± 50	5250 ± 50
5	Hardness, MPa	290 ± 5	350 ± 5
6	Brittleness temperature, K	193 ± 5	196 ± 5
7	Vicat softening temperature, K	563 ± 5	565 ± 5
8	Thermal conductivity, W/m^2·K	0.24 ± 0.02	0.59 ± 0.02
9	Thermal diffusivity, m^2/s	1.62 ± 0.05	4.17 ± 0.05

Based on the obtained data, it can be concluded that the developed composite exhibits similar or even superior properties compared to the base aromatic polyamide. Although the ultimate stresses in compression, bending, and tension of the developed composite are somewhat lower than those of the base polymer, these values are still several times higher than the stresses typically occurring in the friction unit of a conveyor system. The thermophysical properties of the developed composite are significantly better than those of the base aromatic polyamide, enabling it to withstand higher thermal loads and to dissipate heat more effectively from the friction surface.

Practical significance. Due to their high level of properties, the developed composite materials can improve the operational performance of conveyor equipment friction units, eliminate the need for lubrication, and reduce production costs. These materials can be effectively used for manufacturing friction unit components of standard equipment across various industries, replacing costly non-ferrous metals and their alloys. The ability of the developed materials to operate efficiently under dry, lubrication-free conditions supports their considerable practical utility and environmental benefits by eliminating the need for lubricants and their disposal.

Limitations of the study. The use of the study results is currently limited to laboratory testing conditions. For industrial implementation, it is necessary to conduct additional tests under real production operating conditions and to develop a mass-production technology for these components. Further work is also required to improve the design of friction units in order to save materials and to develop a technical framework for the effective servicing of modernized friction units.

Prospects for further research. The main prospects for continued research in this area include the modernization of friction unit designs using the developed materials, as well as practical investigation of the tribological performance of these materials under actual industrial operating conditions. An important future task also remains the continued selection of modifiers and fillers for obtaining aromatic polyamide – based materials with even higher tribological performance.

4. Conclusions

It has been determined that, from the standpoint of tribological properties, the optimal materials are polymer composites based on modified aromatic polyamide filled with 20% graphite. Their coefficient of friction and linear wear intensity during frictional interaction with steel are 0.1–0.15 and $0.5–1 \times 10^{-9}$ m/m, respectively. An excessive filler content (> 20%) leads to brittleness of the composite, which represents an important design limitation.

It was established that the improvement in the antifriction properties of friction units with the developed polymer composites is associated with the formation of an antifriction film on the surface of the steel counterbody, which acts as a solid lubricant. Compared to bronze, the graphite-filled polyamide minimizes wear of the steel counterbody, significantly extending the service life of the equipment.

It was found that the developed composite demonstrates a high level of antifriction properties under various lubrication conditions. The resulting composite material is recommended for use in conveyor equipment friction units operating under harsh conditions, without lubrication, as a substitute for non-ferrous metals, their alloys, and wood. Practical investigation of the tribological characteristics of these materials under real operating conditions in conveyor equipment is a promising direction for further research.

Conflict of interest

The authors declare that they have no conflict of interest regarding this research, including financial, personal, authorship-related, or any other type that could have influenced the study and its results presented in this paper.

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Data availability

The manuscript does not include related data.

Use of artificial intelligence

The authors confirm that no artificial intelligence technologies were used in the preparation of this work.

References

1. Woodcock, C. R., Mason, J. S. (2012). Screw conveying. *Bulk Solids Handling.* Dordrecht: Springer, 335–357. https://doi.org/10.1007/978-94-009-2635-6_10
2. McGlinchey, D. (Ed.) (2008). *Bulk Solids Handling.* Wiley-Blackwell, 304. https://doi.org/10.1002/9781444305449
3. Zapletnikov, I. M., Myronchuk, V. H., Kudriavtsev, V. M. (2020). *Ekspluatatsiia i obsluhovuvannia tekhnolohichnoho obladnannia kharchovykh vyrobnytstv.* Kyiv: Tsentr uchbovoi literatury, 344.
4. Dykha, O. V. (2013). *Rozrakhunky vuzliv tertia mashyn.* Khmelnytskyi: KhNU, 175.
5. Avanesiantc, A. G. (2010). *Transportiruiushchie mashiny nepreryvnogo deistviia.* Odesa, 177.
6. Trigo-López, M., García, J. M., Ruiz, J. A. R., García, F. C., Ferrer, R. (2018). Aromatic Polyamides. *Encyclopedia of Polymer Science and Technology.* New Jersey: John Wiley & Sons, Inc., 1–51. https://doi.org/10.1002/0471440264.pst249.pub2
7. Kabat, O., Sytar, V., Derkach, O., Sukhyy, K. (2021). Polymeric Composite Materials of Tribotechnical Purpose with a High Level of Physical, Mechanical and Thermal Properties. *Chemistry & Chemical Technology, 15 (4)*, 543–550. https://doi.org/10.23939/chcht15.04.543
8. Kabat, O., Bannyk, N., Voronyi, O. (2025). Polymer Composite Materials of Special Purpose for the Aerospace and Rocket Industry. *Science and Innovation, 21 (1)*, 95–103. https://doi.org/10.15407/scine21.01.095
9. Aulin, V., Rogovskii, I., Lyashuk, O., Tykhyi, A., Kuzyk, A., Dvornyk, A. et al. (2024). Revealing patterns of change in the tribological efficiency of composite materials for machine parts based on phenylone and polyamide reinforced with arimide-t and fullerene. *Eastern-European Journal of Enterprise Technologies, 3 (12 (129))*, 6–18. https://doi.org/10.15587/1729-4061.2024.304719
10. Kabat, O., Girin, O., Heti, K. (2023). Polymer composites based on aromatic polyamide and fillers of spherical and layered structure for friction units of high-performance equipment. *Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 237 (11)*, 2269–2276. https://doi.org/10.1177/14644207231176796
11. Kurta, S. A. (2012). *Napovniuvachi – syntez, vlastyvosti ta vykorystannia.* Ivano-Frankivsk: Vydavnytstvo Prykarpatskoho natsionalnoho universytetu imeni Vasylia Stefanyka, 302.
12. Kim, Y.-H., Kumar, S., Li, X., Kim, S.-Y., Shin, D.-H. (2025). Temperature-dependent mechanical properties and material modifications of carbon fiber composites for optimized structures in high-end industrial applications. *Composites Part B: Engineering, 303*, 112602. https://doi.org/10.1016/j.compositesb.2025.112602
13. Shan, Z., Jia, X., Wang, D., Yang, J., Wang, Z., Song, H. (2025). Nanocellulose domain-limit fluorinated graphite to achieve efficient lubrication of engineered steel surfaces. *Sustainable Materials and Technologies, 45.* https://doi.org/10.1016/j.susmat.2025.e01445
14. Yu, S., Zhu, C., Wu, H., Yao, L., Mahapatra, M., Xu, Y. (2025). Graphite-Enhanced PTFE/PEEK composite coating for improved friction and wear resistance. *Applied Surface Science, 700.* https://doi.org/10.1016/j.apsusc.2025.163214
15. Gong, L., Wu, H., Wang, X., Li, L., Zhang, H., Zeng, S. et al. (2025). Friction and wear properties of graphite/SiC composites built by SLS. *Tribology International, 206.* https://doi.org/10.1016/j.triboint.2025.110589

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