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Научный журнал
Издается ежемесячно с декабря 2013 года
Является печатной версией сетевого журнала
Universum: технические науки

Выпуск: 2(131)

Февраль 2025

Часть 8

Москва
2025

METALLURGY AND MATERIALS SCIENCE

DOI: 10.32743/UniTech.2025.131.2.19435

**THE ROLE OF GRAPHITE AND FIBROUS FILLERS IN MODULATING
THE ANTI-FRICTION PROPERTIES OF POLIMER COMPOSITES*****Olim Eshkobilov****Doctor of Technical Sciences, Professor,
Karshi Engineering-Economics Institute,
Uzbekistan, Karshi
E-mail: polegon11@mail.ru****Sunnat Meyliev****Senior Lecturer,
Karshi Engineering-Economics Institute
Uzbekistan, Karshi****Zulfikor Chulliev****Assistant Lecturer,
Karshi Engineering-Economics Institut,
Uzbekistan, Karshi****Rakhmiddin Elmurodov****Master's Student,
Karshi Engineering-Economics Institute
Uzbekistan, Karshi****Raykhona Ruzimurodova****Undergraduate Student,
Karshi Engineering-Economics Institute
Uzbekistan, Karshi***РОЛЬ ГРАФИТА И ВОЛОКНИСТЫХ НАПОЛНИТЕЛЕЙ В РЕГУЛИРОВАНИИ
АНТИФРИКЦИОННЫХ СВОЙСТВ ПОЛИМЕРНЫХ КОМПОЗИТОВ*****Эшкобилев Олим Холикулович****д-р техн. наук, профессор
Каршинского инженерно-экономического института,
Узбекистан, г. Карши****Мейлиев Суннат Нуриддин угли****старший преподаватель
Каршинского инженерно-экономического института,
Узбекистан, г. Карши****Чуллиев Зулфикор Фуркат угли****Ассистент
Каршинского инженерно-экономического института
Узбекистан, г. Карши****Элмуродов Рахмиддин Содик угли****магистр,
Каршинского инженерно-экономического института,
Узбекистан, г. Карши*

Рузимуродова Райхона Акмал кизи

студент,

Каршинского инженерно-экономического института

Узбекистан, г. Карши

ABSTRACT

This study investigates the influence of carbon graphite and fibrous fillers on the anti-friction characteristics of polyolefins, specifically high-density polyethylene and polypropylene. Experiments were conducted to determine the relationship between filler concentration and the mechanical and tribological properties of the composites. The findings demonstrate that the incorporation of carbon graphite and fibrous fillers significantly enhances wear resistance and reduces the coefficient of friction in these polymer matrices. Based on an analysis of experimental data, optimal filler concentrations are proposed to achieve maximum performance characteristics. The results hold significant implications for the development of high-performance polymer composite materials with enhanced functional properties.

АННОТАЦИЯ

В данном исследовании изучается влияние углеродного графита и волокнистых наполнителей на антифрикционные характеристики полиолефинов, в частности, полиэтилена высокой плотности и полипропилена. Проведены эксперименты по определению зависимости механических и трибологических свойств композитов от концентрации наполнителей. Результаты исследований демонстрируют, что введение углеродного графита и волокнистых наполнителей приводит к значительному улучшению износостойкости и снижению коэффициента трения полимерных материалов. На основе анализа экспериментальных данных предложены оптимальные концентрации наполнителей, обеспечивающие достижение максимальных эксплуатационных характеристик. Полученные результаты имеют важное значение для разработки высокоэффективных полимерных композиционных материалов с улучшенными функциональными свойствами.

Keywords: filler, carbon graphite, glass fiber, coefficient of friction, wear, temperature, electrostatic charge.

Ключевые слова: наполнитель, углеродный графит, стекловолокно, коэффициент трения, износ, температура, электростатический заряд.

Introduction. The current level of development in polymer composite materials (PCM) allows for the creation of unique materials capable of functioning under extreme conditions, including low and high temperatures, varying pressures, and aggressive or abrasive environments [1, 2]. A key trend in this field is the development of highly filled, reinforced, and exceptionally strong PCM with tunable operational properties for structural, specialized, and multifunctional applications [3, 4].

However, existing polymer materials and their compositions have yet to see widespread use in the working components of machines and mechanisms across various branches of mechanical engineering [5, 6]. Specifically, in the cotton processing industry, this is attributed to the lack of advancements in creating reliable, impact-resistant, wear-resistant, and anti-friction PCM based on local raw materials, as well as the absence of efficient production technologies [7, 8]. Additionally, there is a need for improved manufacturing processes for mechanical engineering products and components designed for structural and specialized purposes.

To enhance production capabilities and develop export-oriented products, it is essential to create new PCM using ingredients derived from local raw materials for various branches of mechanical engineering [9, 10]. However, despite the growing interest in filled polymer materials, there is a lack of specific recommendations regarding the optimal amounts of fillers to be incorporated into their compositions. Consequently, determining the ideal filler content during PCM development is of significant importance. In this context, one of the key technical challenges is the development of impact-resistant, wear-resistant, anti-friction, and anti-friction

wear-resistant PCM utilizing local raw materials, along with the technology for manufacturing mechanical engineering products and components [11, 12]. These materials are intended for use in friction pairs within the working components of machines and mechanisms in the mechanical engineering industry.

Under these circumstances, studying the influence of fibrous and carbon-graphite fillers on the anti-friction properties of polyolefins - specifically high-density polyethylene (HDPE) and polypropylene (PP) - holds both theoretical and practical significance [13, 14]. This research is particularly relevant for the development of new PCM based on local raw materials.

Research methodology

The matrix polymers selected for this study are HDPE, grade 1-0754, with a density of 0.954 g/cm³ and a melt flow index (MFI) of 6.70 g/10 min, as well as PP, grade 05P10-20, with an MFI ranging from 1.2 to 3.6 g/10 min and a density of 0.905 g/cm³. These materials are produced by the Shurtan and Ustyurt gas-chemical complexes [15, 16]. HDPE and PP were chosen due to their cost-effectiveness and suitability for producing large-sized products and components through injection molding.

The fibrous fillers used in this study include glass fiber and cotton lint, while the carbon-graphite fillers include carbon black and graphite [17, 18]. These fillers were selected based on their availability and significant cost advantages compared to other filler options. The technical specifications of the selected fillers are provided in table 1.

Table 1.

Characteristics of carbon-graphite and fibrous fillers

Fillers	Density g/sm ³	Specific surface area, m ² /g	Moisture content, %	Particle size, μm	Particle shape
Carbon-graphite fillers: ATG-70 carbon black, GL-2 graphite	1,8 2,3	60-70	-	0,35-0,50 20-50	platy
Fibrous: cotton lint, glass fiber	1,12-1,18 2,5	-	5,0-8,0	0,06-1,27 mm	fibrous fibrous

The study was conducted in accordance with standardized testing protocols: composite density, specific impact toughness, flexural strength, Brinell hardness, and volumetric shrinkage [19, 20].

Fibrous fillers (glass fiber and cotton lint) and carbon-graphite fillers (carbon black and graphite) were incorporated into the composite formulation at concentrations of 5–50 wt% relative to 100 wt% of the polymer matrix, comprising HDPE and PP.

Prior to processing, the fibrous and carbon-graphite fillers underwent mechanical activation [21]. Each filler was milled for 60–90 minutes, utilizing impact, compression, and abrasion mechanisms to achieve particle size reduction. The composite composition-consisting of a polymer binder (HDPE or PP), fibrous fillers (glass fiber, cotton lint), and carbon-graphite fillers (carbon black, graphite) - was prepared via established dry mixing methods. Components were precisely dosed, mixed for 30–50 minutes, and subsequently loaded into an injection molding machine hopper. The mixture was fed into a heated injection cylinder (493–533 K) and molded into experimental samples under the following conditions [22]:

- HDPE: 85–90 MPa at 493 K;
- PP: 110–120 MPa at 513 K.

For anti-friction testing, raw cotton served as the counterface. Key tribological parameters evaluated included:

- Coefficient of friction
- Wear intensity
- Frictional temperature

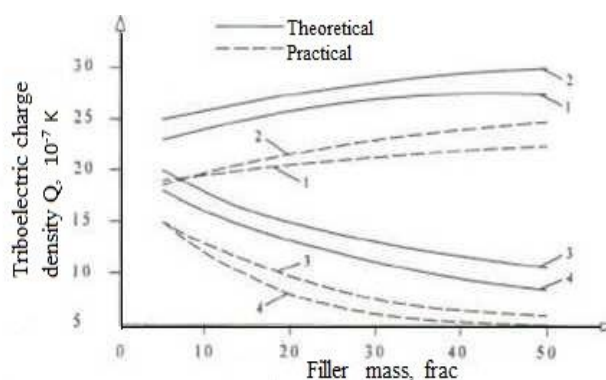
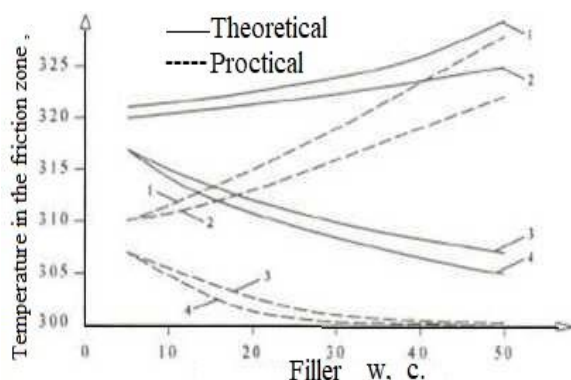
- Static electricity charge magnitude.

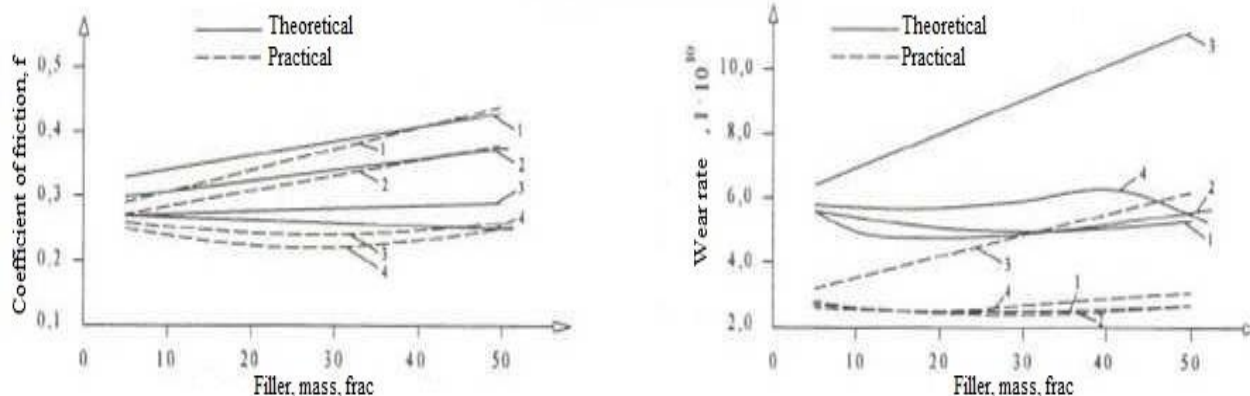
A disk tribometer (O'zDSt 3330:2018) was employed to measure friction coefficients, wear intensity, temperature, and static charge [23]. Wear intensity was quantified via surface profilometry using a profilograph-profilometer (Model 201). Frictional temperature was recorded with a Type 1111-63 potentiometer. Static charge potential was determined using a C-50 voltmeter, with electrodes and a sensor for charge measurement and dissipation.

Results and discussion

The friction coefficient (*f*) of the polymer composite increased with higher glass fiber and cotton lint content [24]. Conversely, the introduction of graphite and carbon black reduced the friction coefficient, with the minimum value observed at 15–20 wt% filler content (Figure 1).

The reduction in the friction coefficient of compositions filled with talc and kaolin is associated with their lamellar structure and fine dispersion, while for compositions filled with soot and graphite, it is due to their relatively low thermal conductivity, low specific surface resistance, and electrification [25, 26]. The increase in the friction coefficient of compositions with raw cotton at high filler content is attributed to the increased surface roughness caused by filler aggregation and the physical-mechanical characteristics of the material, as well as the low adhesion between the polymer matrix and the filler particles.





1-cotton lint, 2-glass fiber, 3-graphite, 4-carbon black.

Figure 1. Dependence of the tribological properties of polymer composites on filler type and concentration

Analysis of the research results on the change in the intensity of linear wear of compositions during friction with raw cotton shows that the introduction of graphite and soot increases the wear intensity, which correlates with the change in the friction coefficient. The increase in wear intensity of compositions with higher soot and graphite content is explained by the reduction in hardness and the increase in material brittleness [27].

Composite materials filled with glass fiber and lint exhibit high wear resistance. In these composites, as the filler content increases, wear intensity is minimized, while the coefficient of friction rises [28].

The conducted research identified specific fillers whose increased content reduces the friction coefficient and wear intensity of composites during friction with raw cotton.

It was established that the optimal filler content to achieve the minimum friction coefficient in composites is 5–30 parts per hundred (phr) of carbon black and graphite. For minimal wear intensity, the optimal filler content is 10–30 phr of glass fiber and cotton lint [29].

To explain interaction processes in the polymer-cotton system, alongside analyzing changes in the friction coefficient and wear intensity of composites, studies were conducted on temperature and static electric charge in the friction zone. These factors can reduce the efficiency of machinery, cause fires, etc [30].

Research revealed that introducing fillers such as carbon black and graphite decreases the temperature in the friction zone, whereas glass fiber and cotton lint increase it. Incorporating graphite and carbon black into composites significantly reduces the static electric charge accumulated during friction [31].

Table 2 presents the anti-friction properties of the developed functional anti-friction polyethylene compositions (APEK) and polypropylene compositions (APPK), which provide critical anti-friction and operational properties for composites operating under conditions of interaction with raw cotton (see table 2).

Table 2

The anti-friction properties of polyethylene and polypropylene composites

Property indicators of composites	Anti-friction properties of polyethylene and polypropylene composites			
	APEK-1	APEK-2	APPK-1	APPK-2
Friction Coefficient (at $P = 0.02$ MPa, $V = 1.5$ m/s, $W = 8.2$ %)	0,28	0,29	0,29	0,26
Wear intensity, $1 \cdot 10^{-7}$ (at $P = 0.02$ MPa, $V = 1.5$ m/s, $W = 8.2$ %)	6,7	6,5	3,2	3,15
Frictional temperature (T_f) at the interface with raw cotton, K.	321	315	308	309
The magnitude of the static electricity charge, $Q \cdot 10^{-7}$ C.	23,7	20,3	17,9	17,5

Thus, analysis of the anti-friction properties of composite materials shows that carbon-graphite fillers (graphite and carbon black) and fibrous fillers (glass fiber and cotton lint) can be used as effective additives. However, each has advantages and drawbacks. For example: **Glass fiber and cotton lint** increase the friction coefficient but reduce wear intensity. **Graphite and carbon black** lower the friction coefficient but increase

wear, while improving thermal and electrical conductivity. This reduces temperature and static charge in the friction zone of contacting pairs [32].

Notably, the effectiveness of these fillers, particularly fibrous ones, is most pronounced at lower concentrations. For instance:

- -Small amounts of glass fiber significantly reduce wear, but further increases in content result in only

marginal wear reduction while sharply raising the friction coefficient;

- -The most effective reduction in friction coefficient for composites interacting with raw cotton is achieved with carbon black and graphite.

Conclusions

It has been determined that the optimal filler content for achieving the minimum coefficient of friction in the composite is as follows: 5-30 parts by weight of carbon black and graphite. For minimizing wear in the composite during friction with raw cotton, the optimal filler content is 10-40 parts by weight of glass fiber and flax.

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Based on the obtained research data, APEK and APPK have been developed for functional applications in the working components of cotton machinery and mechanisms.

Thus, the conducted research has demonstrated that HDPE and PP based composites, modified with carbon-graphite and fibrous fillers, can be recommended and utilized in the technology of producing anti-friction composites and manufacturing components for friction pairs in the working parts of cotton machinery and mechanisms, serving as a replacement for imported materials.

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Научный журнал

**UNIVERSUM:
ТЕХНИЧЕСКИЕ НАУКИ**

№ 2(131)
Февраль 2025

Часть 8

Свидетельство о регистрации СМИ: ЭЛ № ФС 77 – 54434 от 17.06.2013

Издательство «МЦНО»
123098, г. Москва, улица Маршала Василевского, дом 5, корпус 1, к. 74
E-mail: mail@7universum.com
www.7universum.com

Отпечатано в полном соответствии с качеством предоставленного
оригинал-макета в типографии «Allprint»
630004, г. Новосибирск, Вокзальная магистраль, 1
16+