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Features of Contact Interaction of Anti-Friction-Wear-Resistant Polypropylene Composite Materials with Raw Cotton

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ABSTRACT

Based on the concepts of the theory of interaction and research in the course of researching the process of studying the interaction of composite polymer materials using the method of modeling interaction - the mechano-electric theory of contact interaction. The proposed formula for determining the coefficient of friction of composite polymer materials using pulp (raw cotton).

KEYWORDS: Molecular-mechanical theory of friction, molecular-mechanoelectric theory of friction, molecular component, electrical component, contact.

INTRODUCTION

Raw cotton occupies an important place in the economy of the Republic of Uzbekistan. Therefore, increasing the efficiency of cotton growing due to the comprehensive mechanization of all processes, from harvesting to processing cotton, improving the working capacity and productivity of the machines and mechanisms used is the main technical and economic task facing scientists and designers of the republic.

FORMULATION OF THE PROBLEM

An analysis of the operating conditions of the main working bodies of machines and mechanisms intended for the comprehensive mechanization of the processes of harvesting, transportation and processing of raw cotton shows that these machines and mechanisms have general and specific disadvantages, which include damage to the fiber and cotton seeds, the formation of free fiber as a result impact during the interaction of metal working bodies with raw cotton, the possibility of ignition of raw cotton upon impact with solid and heavy impurities present in cotton, as well as due to the generation of static electricity in the friction zone of a cotton-metal pair and a high coefficient of friction when interacting with cotton - raw.

Proceeding from this, the problem arises of studying the processes of contact interaction of polymers with raw cotton.

THEORETICAL FOUNDATIONS OF RESEARCH

As is known [1-4], contact interaction of solids is a multifactorial process accompanied by rather complex mechanochemical and physical phenomena caused by external and internal conditions of the material environment. In the course of studying the process of contact interaction of solids during friction, a number of theories have appeared, including the molecular-mechanical theory of friction [5-7]. According to this theory, friction is mainly caused by the deformation of the thin surface of the material layer by embedded irregularities and the resistance to fracture of the films of the covering bodies. The theory is based on the assumption that when bodies come into contact, there is always a relative penetration of bodies.

In accordance with the molecular-mechanical theory, friction forces arise not along the outer contact area, but only in separate contact zones, i.e. on the actual contact area (ACA). The resultant of these forces is the total frictional force. The dual nature of frictional bonds lies in mechanical and molecular interactions. Therefore, friction can be carried out in three ways: mutual introduction of contacting surfaces, molecular adhesion of surfaces, mutual adhesion of micro-roughness’s.

THE MAIN FINDINGS AND RESULTS

Analysis of the molecular and mechanical components of the friction coefficient shows that the molecular-mechanical theory of friction does not fully reflect the nature of the adhesive interaction of polymeric materials with raw cotton, since it does not take into account the occurrence of electrical phenomena during the contact interaction of two bodies, although they play an important role in the contact of two metals, a metal with a semiconductor, a metal with a dielectric, and especially when two dielectrics come into contact, such as polymer-cotton pairs.

In the course of studying the process of contact interaction of composite polymer materials with raw cotton in the development of the molecular-mechanical theory of friction, the molecular-mechanoelectric theory of contact interaction was put forward, in which the influence of the electrical components of friction forces on the mechanism and nature of friction was revealed [8, 9].

According to this theory, the friction coefficient consists of molecular ($f_{\text{мол}}$), mechanical ($f_{\text{мех}}$) and electrical ($f_{\text{элек}}$) components:

$$f = f_{\text{мол}} + f_{\text{мех}} + f_{\text{элек}} \qquad (1)$$

Considering that the contact interaction in a polymer-cotton pair is carried out mainly through fibers participating in the contact and causing an increase in the molecular component with increasing pressure, and also taking into account that molecular interaction occurs on the areas of actual contact, we have derived a formula for determining the molecular component coefficient of friction:

$$f_{\text{мол}} = \frac{\tau_0}{P_a}\eta_r + \beta, \qquad (2)$$

Where: τ_o - shear resistance, Н/м^2;

P_a - nominal contact pressure, Н/м^2;

η_r - the relative area of contact of a polymer-cotton pair, which is determined by the formula:

$$\eta_r = P_a\sqrt{\frac{8d}{\pi E' g_1 g_2}}\left[\sqrt{g_2} + m\mathrm{A}^c_{n1}\left(\sqrt{g_1} - \sqrt{g_2}\right)\right], \qquad (3)$$

Where: d -the fiber diameter;

E`- the reduced modulus of elasticity of the polymer-cotton system;

m- the average number of seeds per unit area;

A^c_{n1}-the area of the nominal cross-section of seeds;

g_1,g_2- specific load per unit length of contact strips;

β -the coefficient of strengthening of the molecular bond of the piezoelectric coefficient.

This formula establishes a direct relationship between the molecular component of the coefficient of friction and the relative ACA, which is linear. It makes it possible to analytically determine the molecular component of the coefficient of friction of a polymer-cotton pair, taking into account electrification

$$f_{\text{мол}} = \tau\,({}_o/G_S)\rho^{-x} + \beta_2\,(1 + \lambda), \qquad (4)$$

where G_S is a constant coefficient (Н/м^2), depending on the type, physical composition and properties of raw cotton and is numerically equal to the actual contact pressure at bulk density, twice the initial;

ρ^{-x} is the coefficient characterizing the viscous elastic behavior of the contact, depending on the type and physical composition of raw cotton, the type and geometry of the material surface;

β - piezoelectric coefficient consists of two terms:

$$(\beta = \beta_1 + \beta_2),\ \ \beta_2/\beta_1 = \lambda\,, \qquad (5)$$

where λ is the thermal conductivity.

When studying the mechanical component of the friction force during the interaction of polymeric materials with raw cotton, it was revealed that the coefficient of friction increases with increasing irregularities. The surface condition significantly affects the friction force.

Based on the foregoing, the mechanical component of the friction coefficient for a polymer-cotton pair is determined by the formula

$$f_{\text{мех}} = f_{\text{деф}} + f_{\text{зац}}\,,$$

where $f_{\text{деф}}$ is the deformation component of the friction coefficient;

$f_{\text{зац}}$ is the coefficient of friction, which depends on the fiber entanglement with the unevenness of the pavement.

$$f_{\text{деф}} = K\alpha K_1\sqrt{\frac{\Delta h}{r}}\,, \qquad f_{\text{зац}} = K\alpha\left(1 - K_1\right)\frac{h_{cp}}{d}\,,$$

where h_{cp} is the average depth of fiber penetration into microroughnesses of coatings;

K_1- the proportion of solids in raw cotton involved in interaction with the surface of the polymer material;

K - coefficient depending on the type of contact;

Δh - the depth of penetration of solid irregularities of raw cotton substances in the surface of the polymer coating;

r - is the radius of curvature of the tops formed as a result of the interaction of raw cotton and polymer coating;

d - cotton fiber diameter;

α - is an empirical coefficient.

Then the mechanical component of the friction coefficient will have the form:

$$f_{\text{мех}} = K\alpha K_1\sqrt{\frac{\Delta h}{r}} + K\alpha\left(1 - K_1\right)\frac{h_{cp}}{d} \qquad (6)$$

Thus, the mechanical component of the friction coefficient mainly depends on the value of the relative penetration (h/r) and the conditions of fiber engagement (h_{cp}/d), as well as on the fraction of their solids K_1 in the interaction zone. From this it follows that when fibrous materials friction with a polymer material, in contrast to the friction of solids, an engagement process occurs, the value of which is determined by the engagement condition (h_{cp} /d) and their shares (1-K_1).

According to the molecular mechanoelectric theory of friction, the formula for the coefficient of friction will have the form

$$f=\left(\frac{\tau_o}{G_s}\right)\rho^{-x}+\beta\left(1+\lambda\right)+\frac{K\alpha K_1}{2}\left[\sqrt{\frac{\Delta h}{r}}+\left(\frac{1}{K_1}-1\right)\frac{h}{d}\right] \qquad (7)$$

On the basis of modern ideas about the theory of interaction of two bodies, that is, the molecular-mechano-electrical theory, further studies were carried out to determine the optimal compositions and technological parameters for obtaining antifriction-wear-resistant composite materials and to study their physical, mechanical and tribotechnical properties.

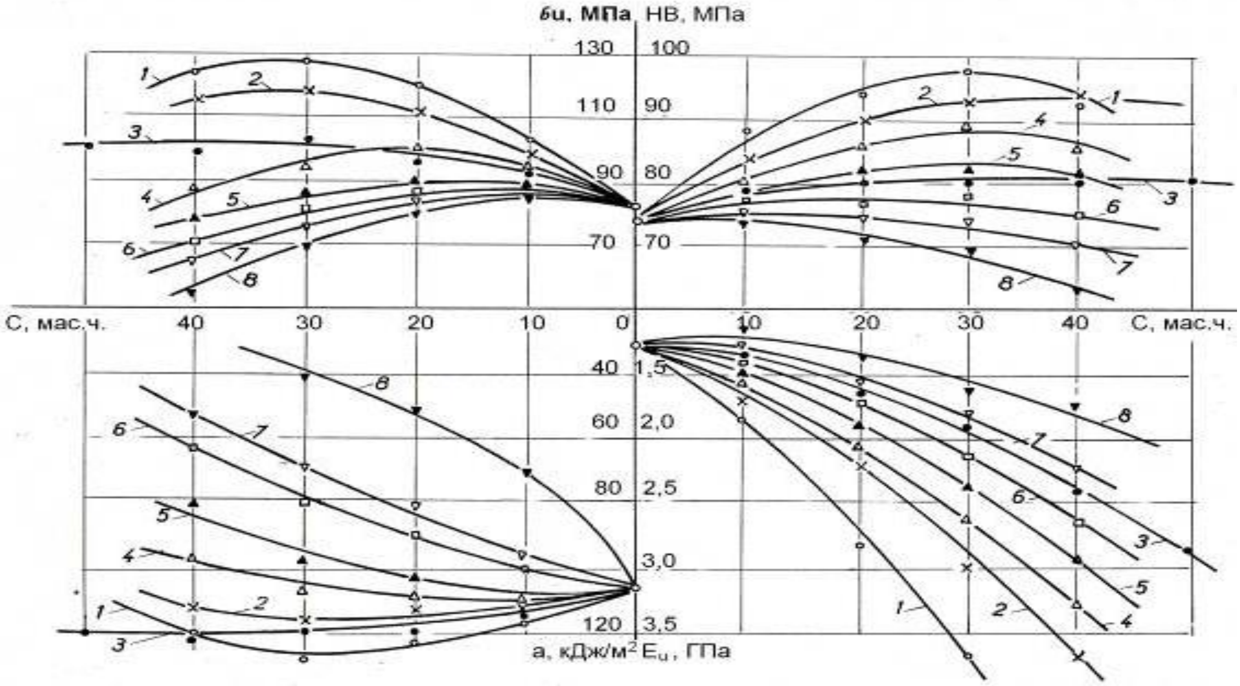
OBJECTS AND RESEARCH METHODS

The object of the study was an industrial sample of polypropylene (PP) grade 05P10-20 with a melt index of 1.2-3.6 g / 10 min and a density of 0.905 g / cm^3, potentially satisfying general and special requirements for materials, taking into account the functional purpose and operating conditions of working bodies of means of mechanization of the cotton ginning industry, low cost, manufacturability and lack of scarcity. The following powdered mineral substances of various chemical nature and dispersion were used as a filler: talc, kaolin, cement, wollastonite; carbon-graphite - soot, graphite; fibrous - fiberglass, cotton linters. The choice of these fillers is due to their availability and significant low cost in comparison with other fillers.

Samples for research were obtained by injection molding a mechanically activated molding mixture of the compositions. The physical and mechanical properties of the cast samples were determined by standard well-known methods, and the tribo-technical properties were determined on a disk tribometer (UzSt 3300: 2018).

Dependences of the physical and mechanical properties of polypropylene-based composite materials on the type and content of fillers.

The results of studies on the study of the dependences of the main physical-mechanical and tribo-technical properties of polymers on the type and content of mineral, carbon-graphite and fibrous fillers are shown in Figures 1 and 2.



σ_u- breaking stress in bending; ***HB*** - Brinell hardness;
a – impact strength; E_u is the modulus of elasticity in bending; ***C*** - content of fillers.

Fig. 1. Dependences of physical and mechanical properties CBM based on polypropylene) on the type and content of fillers: 1-fiberglass, 2 - cotton lint, 3 - wollastonite, 4 - chalk, 5 - kaolin, 6 - talc, 7 - graphite, 8 - carbon black.

Analysis of the obtained experimental data (Fig. 1) showed that the introduction of fillers - fiberglass, cotton linters, wollastonite and cement up to 20-30 mass fraction leads to an increase in the breaking stress in bending ($\sigma_{и}$)of the compositions to a maximum and then a further increase in the content of these fillers is accompanied by a gradual decrease in the value of $\sigma_{и}$. With the introduction of talc, kaolin, soot, and graphite in PP, $\sigma_{и}$ decreases with increasing filler content. However, the $\sigma_{и}$ value remains quite high for compositions filled up to 15-20 mass parts of talc, kaolin and up to 5-10 mass parts of soot and graphite.

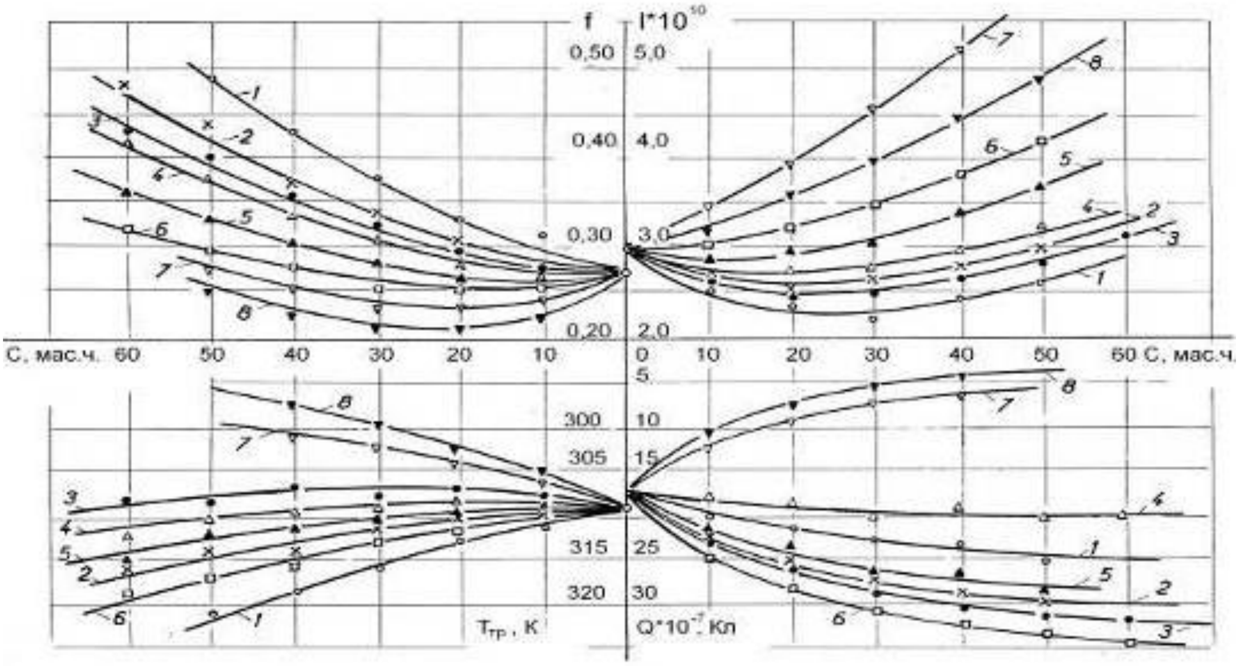
The impact strength (*a*) of compositions with the introduction of fiberglass, lint, wollastonite up to 30 parts by weight, cement up to 10-15 parts by weight also increases and then decreases. With the introduction of other fillers, the value of the impact strength of the composition gradually decreases with an increase in the content of fillers.

The hardness ($H_б$) of compositions with the introduction of fiberglass, lint, cement, kaolin up to 30 parts by weight, talc, soot and graphite up to 10-15 parts by weight increases, and then a decrease is observed. The flexural modulus ($E_и$) of the composition gradually increases with an increase in the content of fillers.

As you know, the process of friction is accompanied by a complex of different phenomena: the interaction of contacting surfaces, physicochemical changes in the surface layers of rubbing pairs, destruction (wear) of surfaces. In connection with the discreteness of the frictional contact, the difference in temperature and stress states at different points of contact and the uneven wear of the contact, these phenomena are of a statistical nature. Of course, the analysis of the dependence of the friction coefficient on a number of important parameters of the friction process provides scientifically grounded recommendations for the selection and optimization of the properties of materials and composites.

Dependences of the tribotechnical properties of polypropylene-based CBM on the type and content of fillers. As can be seen from Figure 2, the coefficient of friction (f) of the polymer composition increases with an increase in the content of fiberglass, cotton linters, wollastonite, chalk, talc and kaolin. With the introduction of graphite, soot and talc in the composition, a decrease in the coefficient of friction is observed. The minimum corresponds to the content of the filler in the range of 15-20 parts by weight of graphite and carbon black.

The friction coefficient f of the polymer composition with an increase in the content of fiberglass, cotton linters, wollastonite and chalk to 5-10 parts by weight remains at the level of unfilled polymers and increases monotonically as the filler content increases.



f - the coefficient of friction; ***I*** –the intensity of wear; $T_{тр.}$- temperature in the friction zone; ***Q*** - the amount of static electricity in the friction zone; ***C*** –content of fillers

Fig. 2. Dependences of the tribotechnical properties of polypropylene-based composite materials on the type and content of fillers (P = 0,02 МПа, V = *2,0 м/с*, W = *8,2%*): 1 - glass fiber, 2 - cotton lint, 3 - wollastonite, 4 - chalk, 5 - kaolin, 6 - talc, 7 - graphite, 8 - soot

The findings are associated with the well-known phenomenon of an increase in *f* with an increase in the hardness of rubbing pairs, which is in good agreement with the data on the dependence of the hardness of composites

(Fig. 1) on the content of fillers. With the introduction of kaolin, talc, graphite and soot into the composition within 15 ... 20 mass fraction of an hour, a decrease in the friction coefficient is observed (0.26; 0.25; 0.235 and 0.215, respectively), and then - its increase with an increase in the filler content ... A decrease in the friction coefficient of compositions filled with talc and kaolin is associated with their lamellar structure and fine dispersion; in compositions filled with soot and graphite, it has a relatively high thermal conductivity and low specific surface resistance. An increase in the coefficient of friction of a composition with raw cotton with a high filler content is associated with an increase in the roughness of their surface due to aggregation of the filler and, to a certain extent, a decrease in the physical and mechanical characteristics of highly filled materials.

A decrease in the friction coefficient of a composition filled with talc and kaolin is associated with their lamellar structure and fine dispersion in compositions filled with soot and graphite, with a relatively low thermal conductivity, reduced specific surface resistance and electrification [10]. An increase in the coefficient of friction of the composition with raw cotton at high filler contents is associated with an increase in their surface roughness due to aggregation of the filler and physical and mechanical properties of the material due to the lack of wetting of filler particles with the polymer matrix.

Analysis of the results of the study of changes in the intensity of linear wear (Fig. 2) of composite polypropylene materials during friction with raw cotton shows that with an increase in the content of kaolin and talc to 10 ... 15 the asc part, the wear rate ($2{,}9 \cdot 10^{-10}$ and $3{,}1 \cdot 10^{-10}$, respectively) almost does not change, and this is quite consistent with a decrease in the coefficient of friction in this range. The introduction of graphite and soot increases the wear rate, despite the fact that the coefficient of friction in the range of filler concentration up to 40% is lower than that of unfilled polyolefins. An increase in the wear rate of the compositions with an increase in the soot and graphite content is most likely associated with a decrease in hardness and an increase in the brittleness of the material, which is due to the predominance of the adhesive and abrasive components of wear.

Compositions filled with fiberglass, cotton lint, wollastonite and cement are highly resistant to wear. In these compositions, with an increase in the filler content, the wear rate decreases to a minimum ($2{,}2 \cdot 10^{-10}$;$2{,}6 \cdot 10$-^{10};$2{,}5 \cdot 10^{-10}$ and $2{,}75 \cdot 10^{-10}$, respectively). High strength characteristics lead to a significant decrease in the fatigue component of wear, despite the fact that the coefficient of friction in this concentration range increases.

As a result of the studies carried out, fillers (soot, graphite, wollastonite, talc, kaolin, lint, fiberglass) were identified, an increase in the content of which leads to a decrease in the friction coefficient (soot, graphite, talc, kaolin) and the intensity of wear of the compositions (fiberglass, cotton lint, wollastonite) when rubbing with raw cotton.

It was found that to obtain the minimum coefficient of friction of the composition, the following filler content is optimal: soot and graphite 5-30 as part, talc 10 -30 as part, kaolin 10 -30 as part. To obtain a minimum wear rate of the composition, the content of fillers is optimal - 10 - 40 as part (glass fiber, lint and wollastonite) and 5 - 15 as part (kaolin and talc).

To explain the processes of interaction in the polymer-cotton system, in addition to analyzing changes in the coefficient of friction and the intensity of wear of the composites, studies were carried out on the temperature and charge of static electricity arising in the friction zone, since these factors can lead to a decrease in the productivity of machines and mechanisms, to the occurrence of a fire, etc.

As can be seen from the research results (Fig. 2), in the case of a composition of polypropylene with graphite, soot and wollastonite, up to 30-40 wt. h., the temperature in the friction zone decreases (300.0; 297.5 and 306.5 K, respectively), and with the introduction of fillers cotton linters, fiberglass, talc and kaolin, an increase in temperature is observed (314.0; 318.0; 315.0 and 312.0 K, respectively). A slight decrease in temperature in the friction zone in the case of using soot and graphite is apparently associated with good heat dissipation due to the thermal conductivity of these compositions.

From the results of experimental studies, it can be seen that in the process of friction, electric charges arise and accumulate. As a result, the tension and electric forces in the double electric layer increase, which, possibly, leads to an increase in the total frictional force.

With an increase in the content of talc and kaolin in polypropylene compositions, the degree of electrification of them increases, the value of charges at 40 asc part is equal to $31{,}5 \cdot 10^{-7}$ and $26{,}7.10^{-7}$ C, respectively. Apparently, this is due to the fact that talc significantly improves the electrical insulating properties of the compositions, increases the electrical resistance and reduces the leakage paths of static electricity charges formed during friction. Filling the composition with graphite and soot causes a strong decrease in the amount of static electricity when rubbed with raw cotton ($6{,}0 \cdot 10^{-7}$ and $5{,}0 \cdot 10^{-7}$ C, respectively), due to the good conductivity of these compositions, which is quite consistent with the main the provisions of the molecular-mechano-electrical theory of the process of interaction of the CBM with raw cotton.

The analysis of studies of the physicomechanical and tribotechnical characteristics of composites showed that in the development of antifriction-wear-resistant compositions, various mineral (talc, kaolin, wollastonite), carbon-graphite (soot and graphite) and fibrous (fiberglass, cotton linters) fillers can be used. Since when fillers are separately introduced into the polymer, the latter do not always ensure the efficiency of the friction units of machines, for a more complete realization of the advantages of each filler, a system of fillers was introduced into the composition of the polymer material, which gives the material a set of necessary properties. The possibility of varying performance characteristics within wide limits depending on the type and content of the filler creates the prerequisites for the use of synergistic approaches.

As a result of the studies carried out, fillers have been established, with an increase in the content of which, the coefficient of friction and the intensity of wear of the composition when rubbed with raw cotton are reduced.

It was revealed that for the minimum value of the coefficient of friction of the composition, the following content of fillers is optimal: soot and graphite 5-30 as part, talc 10-30 as part, kaolin 10-30 as part. For the minimum value of the intensity of wear of the composition during friction with raw cotton, the optimal content of fillers is 10-40 asses part of fiberglass, lint, wollastonite and cement, 5-15 asses part of kaolin and talc.

The study of changes in the coefficient of friction and the intensity of wear of the composition does not explain the processes of interaction in the polymer-cotton system without the results of studying the temperature and charge of static electricity in the friction zone, which can lead to a decrease in the performance of machines and mechanisms, to the occurrence of a fire, etc.

The studies carried out to study the occurrence of temperature and static electricity in the friction zone (Fig. 2) showed that with the introduction of fillers: soot, graphite, the temperature in the friction zone decreases, and with the introduction of fillers: glass fiber, lint, talc, kaolin and chalk, an increase in temperatures in the friction zone. Filling the composition with graphite and soot causes a strong decrease in the amount of static electricity when rubbed with raw cotton.

When designing anti-friction-wear-resistant polypropylene materials, it is necessary to take into account the requirements of the minimum coefficient of friction and the minimum intensity of wear. It is advisable to choose graphite, carbon black, wollastonite, glass fiber, kaolin, talc, lint as fillers for such compositions.

Taking these principles into account, antifriction polypropylene compositions (APPC) and anti-friction-wear-resistant polypropylene compositions (AWRPC) for functional purposes were designed for working bodies of cotton machines and mechanisms (table) [11-15].

Table. Physicomechanical and tribotechnical properties of the developed antifriction (A) and antifriction-wear-resistant (AI) compositions based on polypropylene (PP)

Indicators	APPC *-1	APPC -2	APPC -3	AWRPC **-1	AWRPC -2	AWRPC -3
Breaking stress in bending $\sigma_{и}$, MPa	85,7	88,4	90,1	91,8	92,5	93,3
Impact strength, a, kJ / m^2	91,3	94,2	97,3	100,1	101,5	103,7
Brinell hardness $H_{б}$, MPa	76,2	78,9	80,3	69,7	72,3	73,8
Flexural modulus, $E_{и}$, GPa	0,75	1,80	1,85	1,6	1,65	1,7
Friction coefficient f (at P = 0.01 MPa, V = 1.5 m / s, W = 8.2%)	0,29	0,26	0,27	0,30	-295	0,29
Wear rate $I.10^{10}$ (at P = 0.01 MPa, V = 1.5 m / s, W = 8.2%)	3,2	3,15	3,12	2,6	2,75	2,8
Temperature in the friction zone, T_{tr}, K	308	309	306	312	311,5	311
The amount of static electricity charge, $Q.10^{-7}$ C	17,9	17,5	17,3	-	-	-

* APPC - antifriction polypropylene composition

** AWRPC - anti-friction and wear-resistant polypropylene composition

The table shows that the physicomechanical and tribotechnical properties of the designed anti-friction-wear-resistant composite polymer materials based on PP fully meet the functional requirements imposed on the materials of the splitting heads of the working bodies of cotton machines and mechanisms of the cotton ginning industry, and can be recommended for their manufacture.

CONCLUSION

Thus, a principle has been developed for the design of highly effective anti-friction-wear-resistant functional compositions based on PP, which consists in the introduction into the polymer matrix of a system of hybrid fillers from local raw materials and production wastes of different structures and nature in their established optimal ratios, providing functionally important physical-mechanical, tribotechnical and performance properties of composite polymeric materials operating under conditions of interaction with raw cotton.

LIST OF DESIGNATIONS

f - coefficient of friction;
$f_{мол}$ *- molecular component of the coefficient of friction;*
$f_{мех}$ *- mechanical component of the coefficient of friction;*
$f_{элек}$ *- electrical component of the coefficient of friction;*
$f_{деф}$ *- deformation component of the friction coefficient;*
$f_{зац}$ *- coefficient depending on fiber entanglement with material irregularities;*
τ_o *- shear resistance;*
G_S *- constant coefficient depending on the type, physical composition and properties of raw cotton and is numerically equal to the actual pressure at the contact at bulk density, twice the initial;*
ρ^x *- coefficient characterizing the elastic-viscous behavior of the contact, depending on the type and physical composition of raw cotton, the type and geometry of the material surface;*
P_a *- contact pressure;*
η_r *- relative contact area of a polymer-cotton pair;*
β *- molecular bond hardening coefficient of piezoelectric coefficient;*
λ *- thermal conductivity;*
h_{cp} *- average depth of fiber penetration into microroughnesses of polymer material;*
K_1 *- the proportion of solids in raw cotton involved in interaction with the surface of the polymer material;*
K - coefficient depending on the type of contact;
Δh *- the depth of penetration of solid irregularities of raw cotton substances in the surface of the polymer material;*
r - radius of curvature of vertices formed as a result of the interaction of raw cotton and polymer material;
d - cotton fiber diameter;
E` - reduced modulus of elasticity of the polymer-cotton system;
m - average number of seeds per unit area;
A^c_{n1} *- nominal cross-sectional area of seeds;*
g_1, g_2 *- specific load per unit length of contact strips;*
α *- empirical coefficient;*
σ_u *- bending stress;*
a - impact strength;
$H_б$ *- Brinell hardness;*
E_u *- flexural modulus;*
I - wear rate;
Q - static electricity charge;
P - specific pressure;
V - sliding speed;
W - moisture content of raw cotton;
PP - polypropylene;
APPC - antifriction polypropylene composition;
AWRPC - anti-friction - wear-resistant polypropylene composition.

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