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Investigation of the Process of Electrification of Composite Polymer Coatings in the Case of Frictional Interaction with the Fibrous Mass

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Abstract. The processes of electrization of polymer and composite polymer materials and coatings based on them have been studied during frictional interaction with raw cotton, depending on the type and nature of polymers and organomineral fillers.
It has been established that the specificity of the contacting bodies (composite-cotton-raw) is determined by the processes of electrification of the composite polymer coatings affecting the surface layers and thereby affecting their electrophysical and physical-mechanical properties. It was found that a decrease in the electrification of composite polymer coatings improves their antifriction properties. This makes it possible to purposefully change and regulate the anti-electrostatic and antifriction properties of composite polymer coatings working in interaction with raw cotton. Thus, the occurrence of an electrostatic charge in the contact zone of the composite-raw cotton negatively affects the coefficient of friction, wear resistance and durability of composite polymer coatings, and also increases the fire hazard in the process of processing raw cotton.
The main regularities of electrification and changes in the electrophysical properties of composite polymer coatings during sliding with raw cotton have been established. It is shown that the most effective effect on the electrostatic properties of composite polymer coatings is electrically conductive fillers (soot, graphite), which provide optimal physical and mechanical properties of anti-electrostatic composite polymer coatings.
The aim of the study is to establish the regularities of the process of electrification of composite polymer materials and coatings based on them during frictional interaction with raw cotton and changes in their electrophysical, physical and mechanical properties.

Keywords. Polymer, raw cotton, coating, composite polymer coating, electrification process, kinetics, electrostatic properties, density, surface charge density, electrostatic charge, filler, sliding speed.

INTRODUCTION

It is known that the processes of interaction of composite polymer coatings with raw cotton have a complex nature. In this case, the specificity of the contacting bodies (composite–cotton-raw) is determined by the processes of electrification of the composite polymer coatings affecting the surface layers and thereby affecting their electrophysical and physical-mechanical properties. In addition, it was found that a decrease in the electrification of composite polymer coatings improves their antifriction properties. This makes it possible to purposefully change and regulate the anti-electrostatic and antifriction properties of composite polymer coatings working in interaction with raw cotton [1-5].

Thus, the occurrence of an electrostatic charge in the contact zone of the composite-raw cotton negatively affects the coefficient of friction, wear resistance and durability of composite polymer coatings, and also increases the fire hazard in the process of processing raw cotton.

The elimination of these phenomena, perhaps, will be through in-depth study and purposeful control of the electrophysical and strength properties of the material and the creation of effective compositions of anti-electrostatic-antifriction composite polymer materials that provide low coefficient of friction and wear, increase the durability of coatings for working bodies of cotton machines and mechanisms operated in ginneries, processing and

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transportation of raw cotton.

In works it is noted that machines and mechanisms used for processing raw cotton have structural, technological and a number of specific disadvantages, which include [6-8]:

- damage to cotton fibers and crushing of cotton seeds, the occurrence of noise and fire hazard;
- high coefficient of friction;
- sharp edges and burrs, roughness and submicron roughness;
-increased fire hazard arising from the collision of parts of the working bodies of machines with solid inclusions in the raw cotton.

The use of composite polymer coatings in the working bodies of machines and mechanisms contributes to the elimination or minimization of a number of these disadvantages. In this case, the coatings work under static and dynamic loads, as well as vibrations, under the influence of climatic factors and aggressive environments.

In accordance with the above, the choice of polymer materials as the basis for anti-electrostatic polymer compositions was carried out by the following criteria:

- manufacturability and efficiency of the used polymer material, techniques and equipment for applying coatings on the surface of parts of the working bodies of machines;
- a set of electrical and physical and mechanical properties necessary for operating conditions, maintaining stability at temperatures from -20 to +80°C and ambient humidity up to 80%, as well as under the influence of climatic factors and aggressive environments;
- when operating under friction conditions, they must have high antifriction properties in the range of speeds up to 8 m / s (sometimes up to 25 m/s) and loads from 0,005 to 0,05 MPa and relatively low electrical resistivity.

METHODS

Epoxy resin ED-16, furan-epoxy resin FAED-20 and furano-epoxy-shale oligomer FAEIC-30, polyethylene polyamine (PEPA), dibutyl phthalate (DBP), mineral fillers - kaolin and talc, carbon-graphite fillers-soot and graphite, metal powder fillers-copper oxide, iron powder, aluminum powder, bronze flour and iron oxide. They most fully meet the general and special requirements and operating conditions of cotton processing machines and mechanisms. These polymeric materials have the best antifriction properties, high heat resistance, manufacturability of coatings [9-11].

As a counterbody, raw cotton of the selection variety C-6524, hand-picked and machine-picked, was used, the humidity of which varied from 7,0 to 50,0 %.

The electrification and tribotechnical properties of composite polymer coatings were determined on a disk tribometer in accordance with O'zDSt 3330: 2018. The electrical properties of composite polymer coatings were evaluated in accordance with GOST 6433.1-71 with an E6-13 teraohmmeter and a V7-30 voltmeter-electrometer.

RESULTS AND DISCUSSION

Obtained scientific results and their discussion. Studies of electrization processes have shown that under the influence of temperature in the friction zone, composite polymer coatings based on ED-16, FAED-20 and FAEIC-30 insignificantly change the electrical conductivity with an increase in temperature in the composite-cotton contact zone [12-13].

This character of electrical conductivity on temperature determines the processes of establishing an equilibrium state between the formation and leakage of electrostatic charges.

It is shown that it is not possible to explain the dependence of electrification on the type and nature of polymer coatings only from the point of view of the modern theory of donor-acceptor interaction, since in a stable friction mode, composite polymer coatings always acquire a positive sign of charges, and raw cotton-a negative sign. At the same time, the dependence of electrification on the degree of "crosslinking" for thermosetting polymers is revealed.

With an increase in the degree of crosslinking of macromolecules of thermosetting polymers when interacting with raw cotton, the formation of electrification in the contact zone of rubbing pairs increases.

An increase in electrification with an increase in the content of the PEPA hardener to 25-30 wt.h. for FAED-20 and FAEIC-30 and up to 12 wt.h. in ED-16 it is associated with an increase in the degree of structuring and cross-linking of macromolecules and, accordingly, a decrease in electrical conductivity and an increase in microhardness. This reduces the leakage of charges and changes the nature of the contact interaction of polymer coatings with raw cotton. A further increase in the PEPA content leads to a decrease in the surface density of electrostatic charges, which is explained by the plasticizing effect of an excess amount of a hardener on the polymer system, as a result of which the flexibility of the polymer chain and, accordingly, the electrical conductivity increase [14-15].

With an increase in the concentration of DBP plasticizer in ED-16, FAED-20 and FAEIC-30, the electrification first decreases and at a content of 10-15 wt.h. increases. A further increase in the DBP content in the coatings reduces their electrization. This dependence of electrization on the DBP content can be explained by the effect of “antiplasticization”, as a result of which, at low concentrations of DBP, due to the denser chain packing and physical “crosslinking” of the polymer, the electrical conductivity decreases and the electrification of the coatings increases. Increasing the concentration of DBP more than 15 wt.h. promotes an increase in the mobility of chains of polymer macromolecules and, accordingly, an increase in charge leakage due to an increase in electrical conductivity.

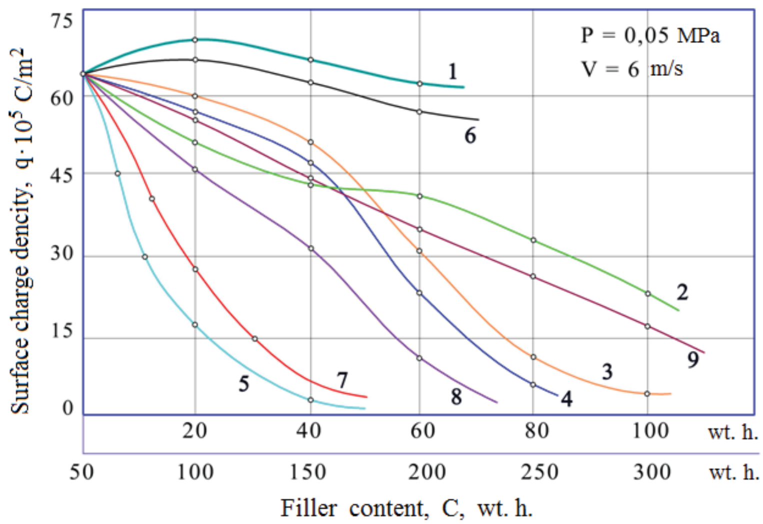
Thus, the research results made it possible to establish the basic laws governing the electrification of composite polymer coatings during sliding friction with raw cotton, depending on the type and nature of thermosetting materials. As can be seen from the results obtained, thermosetting polymers electrify most rapidly during friction with raw cotton 0.04-0.06 s and the value of the charge density is in the range 64-75 $q \cdot 10^6$ C/m^2, and polymer coatings with raw cotton electric charges remain on the surface of coatings for a long time. So, for coatings made of FAED-20, ED-16 and FAEIC 30, the charge density after 6.0 s is in the range of 28-10 $q \cdot 10^6$ C/m^2.

One of the ways to regulate the electrophysical, electrostatic and antifriction properties of composite polymer materials is the introduction of electrically conductive and semiconducting organomineral fillers into their composition. In addition, the introduction of organomineral fillers makes it possible to improve the tribotechnical properties of polymer coatings due to the optimal regulation of their physical and mechanical properties – microhardness, glass transition temperature, etc [16-17].

The influence of the electrophysical nature and concentration of the selected fillers on the process of electrization of polymer coatings with raw cotton has been investigated.

The research results showed that when fillers were introduced, regardless of the type of polymer and filler, the positive polarity of the coating and the negative polarity of raw cotton remained in the steady-state sliding friction mode. Figures 1-3 show the results of experimental studies on the effect of the filler content on the electrification of the selected polymeric materials during sliding friction with raw cotton of the C-6524 variety. As you can see, the introduction of the mineral filler kaolin slightly increases the electrification of composite polymer coatings with a content of 20–40 wt.h. for ED-16, FAED-20 and FAEIC-30 and at higher concentrations, it only slightly reduces the surface charge density. This effect of kaolin on the electrification of polymer coatings is obviously associated with their rather high electrical insulating properties. Kaolin content up to 20–40 wt. h. in the composition of ED-16, FAED-20 and FAEIC-30 does not change the electrophysical properties of composite polymer coatings and at the same time affects the physical and mechanical properties (Figures 1-3), which causes a certain increase in the surface charge density. A decrease in the electrization of composite polymer coatings with a further increase in the kaolin content is obviously associated with a decrease in the specific volumetric electrical resistance ρ_v and specific surface electrical resistance ρ_s of the composition, since the electrical properties of the fillers themselves are lower than that of the binder [18-20].

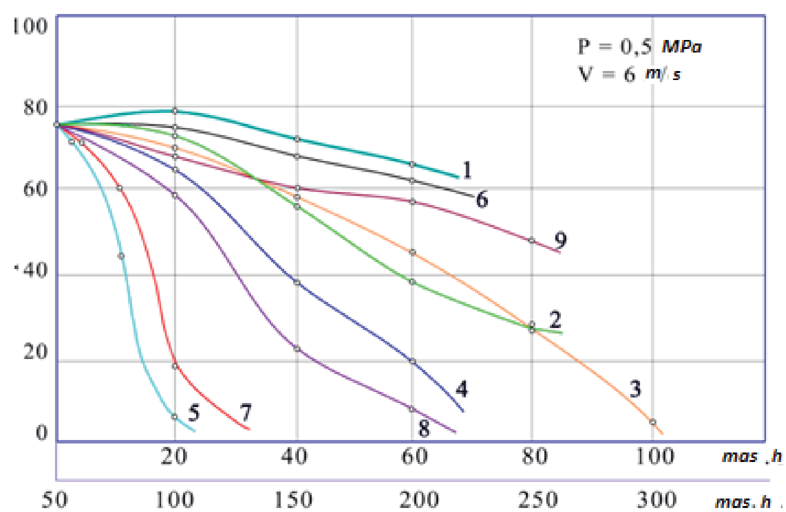
When kaolin is introduced into the composition of epoxy and furan-epoxy polymers, thermal degradation products are formed during heat treatment, which, being absorbed on the surface of kaolin, contribute to the formation of a spatial network [6], which significantly affects the electrical conductivity of the composition and, accordingly, the electrification of coatings. The greatest decrease in the surface charge density, as expected, is observed with the introduction of such electrically conductive fillers as iron powder, aluminum and bronze powder, soot and graphite.



1-kaolin; 2-copper oxide; 3-iron powder; 4-aluminum powder;
5-carbon black; 6-talc; 7-graphite, 8-bronze flour; 9-iron oxide

FIGURE 1. Dependence of the surface charge density of composite polymer coatings based on ED-16 on the type and content of fillers

Moreover, soot and graphite most effectively reduce the electrification of polymer coatings, which is due to its high electrical conductivity, as a result of which the specific surface and specific volume resistance of polymer coatings is sharply reduced already at 5 wt.h. soot in PNP and 10 wt.h. soot in FAED-20, FAEIS-30 and ED-16.

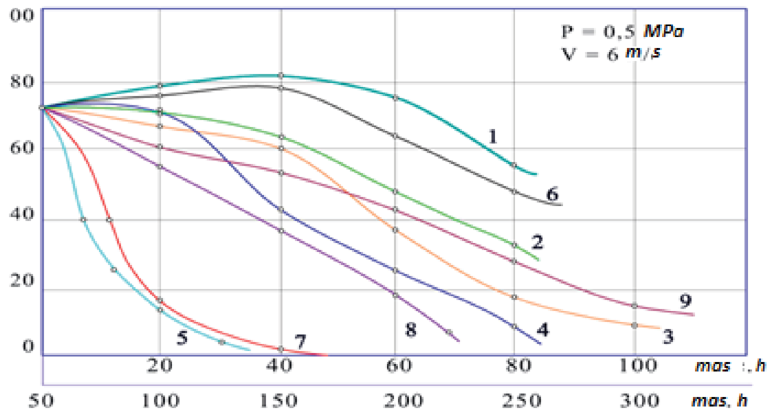


1-kaolin; 2-copper oxide; 3-iron powder; 4-aluminum powder;
5-carbon black; 6-talc; 7-graphite, 8-bronze flour; 9-iron oxide

FIGURE 2. Dependence of the surface charge density of polymer coatings based on FAEIC-30 on the type and content of fillers

In this case, the charge leakage paths increase and, accordingly, the electrification of the coatings decreases. The high electrical conductivity of polymer coatings with the introduction of electrically conductive fillers is due to the formation of a chain structure in the bulk of the polymer [21-22].

The general nature of the decrease in the surface charge density with an increase in the content of electrically conductive fillers is obviously due to the fact that in the three-component system raw cotton-polymer-filler, the areas of contact of raw cotton with the filler increase, as a result of which the charges formed on the surface of the polymer coating are diverted along the chain formed by the electrically conductive filler. A more effective effect of soot compared to graphite on the electrification of polymer coatings, despite its greater electrical resistivity, is associated with the interaction of polymers with the active surface of soot particles due to the presence on their surface of functional groups containing double bonds and capable of forming chemical bonds, especially with polar polymers.



1-kaolin; 2-copper oxide; 3-iron powder; 4-aluminum powder;
5-carbon black; 6-talc; 7-graphite, 8-bronze flour; 9-iron oxide

FIGURE 3. Dependence of the surface charge density of polymer coatings based on FAED-20 on the type and content of fillers

Research results have shown that soot reduces the electrification of FAED-20 and FAEIC-30 more effectively than ED-16. This is obviously due to their better compatibility of soot with FAED-20 and FAEIC-30, since these resins are less viscous and the distribution of filler particles is more uniform to the volume of the coating [23-25].

The introduction of aluminum powder into the composition of polymer materials, despite a decrease in the electrification of polymer coatings, leads to a deterioration in the antifriction properties of the coatings. At the same time, the deterioration of the physical and mechanical properties is due to the ability of the aluminum powder to clump and form microdefects. At the same time, the lower ability of aluminum powder to reduce electrification as compared to soot is associated with its higher electrical resistance and lower activity of interaction with the polymer matrix.

Copper oxide is a semiconductor by its electrophysical properties, and therefore its introduction into the composition of a polymer coating led to a slight decrease in electrification and, in terms of its ability to act on an electrostatic coating, occupies an intermediate position between kaolin and aluminum powder.

CONCLUSIONS

Analysis of the results obtained (Figures 1-3) shows that the electrical resistivity of iron powder is higher than that of carbon black, graphite and less than that of aluminum powder. At the same time, the surface density of electrostatic charges of polymer coatings filled with iron powder is also slightly higher than that of coatings filled with soot and aluminum powder. And only at high fillings of polymer coatings with iron powder, a sharp decrease in the surface density of electrostatic charges is observed. Obviously, this is due to the fact that at the same filler content in the volume of the polymer coating, an unequal volumetric distribution of filler particles is formed due to different densities. So with the content of fillers (kaolin, aluminum powder, soot and copper oxide) and up to 50 wt.h. iron powder, their distribution is observed in the form of separate unconnected particles. With a further increase in the filler content, a spatial chain structure is obviously formed, and the leakage of electrostatic charges occurs both over the surface and over the volume of the coating. Due to the high specific gravity of the iron powder, its distribution over the volume of the polymer is uneven. Thus, in composites based on ED-16, FAED-20, and FAEIC-30, iron powder settles in the polymer layer during their curing, a chain structure is formed near the substrate, and the iron powder is distributed in the form of individual particles near the friction surface. This distribution of iron powder particles leads to the fact that the electrification of polymer coatings is significantly reduced only at high fillings.

The nature of the polymeric materials also affects the distribution of filler particles in the coating volume. So, in less viscous furan-epoxy coatings, a more uniform distribution of filler particles is observed, with the exception of iron powder. This leads to a more significant decrease in the electrification of the FAED-20 and FAEIC-30 in comparison with the ED-16.

Thus, the processes of electrization of polymer and composite polymer materials and coatings based on them have been studied during frictional interaction with raw cotton, depending on the type and nature of polymers and organomineral fillers. The main regularities of the electrification of composite polymer coatings during sliding with raw cotton have been established. It is shown that the most effective effect on the electrostatic properties of polymer coatings is electrically conductive fillers (soot, graphite) that provide optimal physical and mechanical properties of anti-electrostatic composite polymer coatings.

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