Improved installation for determining antifriction properties of materials

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Abstract. The paper presents an improved installation and method for determining friction-electro-thermal properties - friction coefficient, temperature, and value of electrostatic charge in the friction contact zone of machine-building composite wear-resistant-antistatic-thermal conducting polymeric materials during interaction with raw cotton. The existing methods and installations working at the frictional influence of polymers and composite materials with raw cotton have been studied. The general disadvantages of existing devices have been revealed, particularly the impossibility of investigating the frictional properties of materials with cotton.

Theoretically and experimentally substantiated principle technological scheme of antifriction interaction of polymeric materials with cotton, where the polymeric material under study is represented as a flat disc rotating in a horizontal plane on which surface cotton is pressed along the normal using a piston in a bottomless box having a cylindrical lateral surface, which leads to minimization of lateral pressure. The developed scheme of antifriction interaction allows maximum imitation of working conditions of working elements of real machines. And also, the antifriction and physical-mechanical properties of composite polypropylene and polyethylene materials filled with organomineral ingredients determined by the developed method and improved installation - tribometer are given.

1 Introduction

One of the most important operational characteristics of the material for machine tools, which ensures maximum preservation of the natural properties of cotton, is its antifriction property [1].

As is known, the 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. It has a different nature, even for one pair of solids, depending on the contact conditions and the environment. However, the variety of conditions for the contact interaction of solids does not mean that for certain processes of contact interaction of solids, including composite polymer materials, completely satisfactory regularities cannot be obtained [2].

In the earliest studies of the contact interaction of solids, the study considered the

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interaction of rough surfaces of solid, absolutely rigid bodies, i.e., purely mechanical representations prevailed in them. Based on this idea, a hypothesis about the mechanical nature of the contact interaction of solids was formulated for the first time, which was further developed in the works.

The common disadvantage of existing devices, particularly those considered, is that it is impossible to study the friction properties of materials with cotton on these devices [3].

Some devices and methods for determining the antifriction properties of structural materials are based on the end interaction of samples with rotational motion. Currently, there are quite a lot of such devices.

The common disadvantage of existing devices, in particular, is that it is impossible to study the friction properties of materials with cotton on these devices [4].

With the development of research in this area, a hypothesis was put forward about the predominance of molecular attraction forces and that the friction force increases with a decrease in roughness due to an increase in molecular adhesion between the contacting bodies, which is a consequence of a closer approximation of their contact surfaces.

2 Methods

In contrast, combined theories have emerged. The combined theory, which is based on mechanical deformation representations and considerations about molecular adhesion interactions, was put forward by I.V.Kragelsky [5].

Subsequently, he proposed the molecular mechanical theory of friction, which has found the greatest acceptance. According to this theory, friction is caused mainly by the deformation of a thin surface layer of material by embedded irregularities and by the fracture resistance of films covering the bodies. The theory assumes that when bodies are in contact, there is always a relative embedding of the bodies.

According to the molecular mechanical theory, friction forces do not occur over the entire contact area but only in individual contact zones, i.e., on the actual contact area (ACA). The result of these forces is the total friction force. Moreover, friction can be carried out by mutual penetration, molecular coupling, and mutual coupling of the contacting surfaces [6].

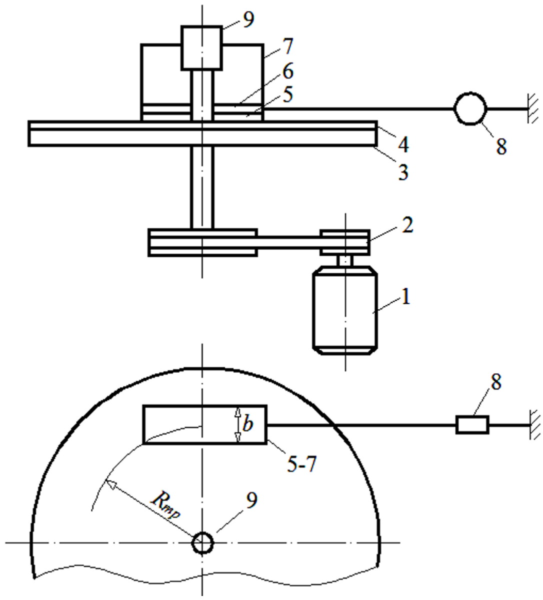
The magnitude of the friction force is the sum of two components: molecular and mechanical:

$$F = F_{mol} + F_{mech} \quad (1)$$

The coefficient of friction, according to the molecular mechanical theory, is expressed by a three-term dependence:

$$f = \frac{\tau_0}{P_r} + \beta + K + \alpha\sqrt{\frac{h}{R}} \quad (2)$$

where τ_o is specific force of molecular interaction; P_r is actual pressure; β is the coefficient characterizing the increase in shear strength with an increase in normal pressure; K is coefficient depending on the type of contact; α is empirical coefficient; h is depth of embedding surface irregularities; R is the radius of the introduction of surface irregularities.
Let's consider a disk-type tribometer, which, in our opinion, is the most acceptable for modeling the frictional interaction of materials with cotton [7]. The Kragelsky-Vladimirov tribometer, based on rotational motion, on which the authors studied the coefficient of friction of fibrous materials. A disk with a diameter of 0.6 m rotates in a horizontal plane on a vertical spindle (Fig. 1).



1 is electric motor; 2 is V-belt transmission; 3 is drive disc; 4 is removable disc; 5 is plate; 6 is test material; 7 is cargo; 8 is torsion dynamometer; 9 is tachometer

Fig. 1. Schematic diagram of tribometer Kragelsky-Vladimirov

The DC electric motor 1 through the V-belt transmission 2 allows you to change the sliding speed from 0.25 to 15 m/s. Removable disks of the test material are attached to the disk with screws. A rectangular plate 5 is mounted on top of the disk 4, on which the test fibrous material is fixed. The pressure is created by replaceable weights 7. The plate is connected to a torsion dynamometer 8, which measures the friction force. The advantage of this device is the ability to adjust the fastening of the yarn. However, the device does not allow friction study at speeds less than 0.25 m/s.

A significant contribution to the further development of the molecular mechanical theory of friction was made by N.M. Mikhin, N.B. Demkin and others. They showed that in the process of contact interaction of solid bodies, not only the geometry of the surfaces of the contacting bodies and FPC but, consequently, the deformation component of the friction forces plays a significant role [8].

It is well known that the working tools of machines and mechanisms are directly in contact and are constantly in contact with raw cotton. Raw cotton electrifies when rubbed with polymers and has comparatively easy flammability and scoring properties. Therefore, when choosing polymeric materials to manufacture parts, working bodies must consider the tastes and tastes of raw cotton, the nature of wear, electrification, etc.

For the first time, studies of the process of contact interaction of fibrous materials with various structural materials were carried out by A.Yu.Ishlinsky and I.V.Kragelsky. Their work showed that the coefficient of friction with cotton increases with an increase in the surface roughness of the material [9].

And then R.G.Makhkamov investigated the interaction of raw cotton with the surfaces of structural materials, particularly metals, from the point of view of optimizing the roughness of the counterbody surface, aimed at reducing the mechanical damage of fibers [10]. He showed that the force of interaction of raw cotton with metal surfaces increases either due to the micro-cutting of cotton fibers on microprotrusions of surfaces or due to an increase in adhesive interactions associated with an increase in the moisture content of raw cotton. According to his data, micro-cutting of fibers intensively occurs when the corner radius is less than 100 μm.

S.S.Negmatov for the first time, conducted fundamental studies of the contact interaction of polymer and composite materials with raw cotton [11]. The conducted studies have shown that for most of the materials under study, with an increase in the sliding speed, the coefficient of friction initially increases and reaches an extreme and then decreases with a further increase. In particular, it was found that the dependence of the coefficient of friction of polymer materials with raw cotton on the sliding speed at low and medium pressures has an extreme character and is described by the formula I.V. Kragelsky:

$$f = (a + bv)e^{-cv} + d \quad (3)$$

and in the zone of sufficiently large pressure values, it has a complex character and is described by the formula of G.E. Svirsky [12]:

$$f = (c_1 + c_2 v^2)e^{-\lambda v} sinv + cv \quad (4)$$

where, a, b, c, d, c_1, c_2, λ are parameters determining friction; v is sliding speed.

The effect of sliding velocity and pressure in the friction zone in the polymer-cotton system on the amount of static electricity charge is also investigated [13]. It is established that with increasing velocity and pressure, the charge value increases and is within $12 \div 42 \cdot 10^{-7}$ Kl.

During the study of the process of contact interaction of composite polymer materials with fibrous mass and in the development of the molecular mechanical theory of friction, S.S.Negmatov put forward a molecular mechanical-electrical theory of contact interaction, in which the influence of the electrical components of friction forces on the mechanism and nature of friction was revealed [14]. Then the author proved the acceptability of this theory in studies of the contact interaction of antifriction-wear-resistant composite materials with raw cotton.

According to the molecular-mechanical-electrical theory, the coefficient of friction consists of the molecular (f_{mol}), mechanical (f_{mech}), and electrical (f_{elec}) components [15]:

$$f = f_{mol} + f_{elec} \quad (5)$$

Considering that the contact interaction in a polymer-cotton pair is carried out mainly through fibers involved in contact and causing an increase in the molecular component with increasing pressure, as well as taking into account that the molecular interaction occurs in the areas of actual contact, the formula for determining the molecular component of the friction coefficient is derived [16].

3 Results and Discussion

The essence of the method consists in the fact that the friction of the fibrous material is carried out on a flat surface of a rotating disk sample of the material under study at several preset pressure values P and sliding speeds V, the values of friction forces, temperatures and values of electrostatic charges of the test sample are measured in the friction zone with raw cotton, after processing the measurement results, it is possible to judge the range of permissible values P, V the working conditions of the tested material are determined [17].

Based on the above, the developed installation must meet the following requirements:

1. The test facility must, first of all, provide:

- regulation of the rotational speed of the disk sample with the possibility of setting the required sliding speed V the center of the contact pad from 0.5 m/s to 10 m/s, in increments of 0.5 m/s, with an error of no more than 5% of the set value [18];

- step-by-step regulation of the pressure P of pressing the fibrous mass to the movable sample from 0.001 to a maximum of 0.05 MPa;
- measurement of the friction forces of the contacting surfaces over the entire range of the set sliding speeds and the created clamping pressures;
- measurement of temperatures in the friction zone from room temperature to 150 0C with an error of no more than 5% of the measured value;
- measurement of the values of the electrostatic charges of the test sample with an acceptable basic error of ± 5% [19].

2. To minimize the difference in linear velocities of sections with boundary radial distances determined by the diameter of the box, the ratio should guide one:

$$\frac{r}{d} \geq 3 \quad (6)$$

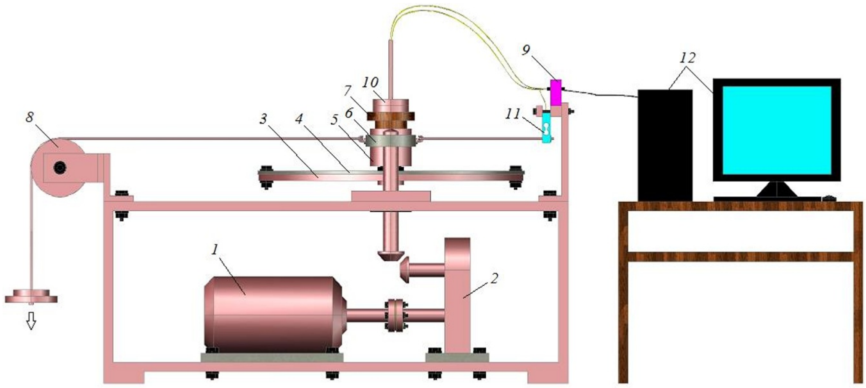
where, r is the distance between the axes of the disk and the box; d is the diameter of the box.

3. a box forming a minimum contact area of 50 cm2 provides the most reliable results.
4. The gap between the box and the piston must be at least 0.1 mm and not more than 1 mm [20].
5. To prevent the rolling of the fibrous mass during testing, the bottom of the piston should be equipped with clamps in the form of dispersed metal pins. They can also be used as electrodes for removing residual electrostatic charges by grounding them [21].
6. The gap between the test sample and the box should not exceed 2 mm to exclude measurement errors caused by the jamming of raw cotton seeds in the gap.
7. The sample and the fibrous mass must be electrically isolated from the tribometer bed; the insulation resistance must be at least 10 mOm.

Therefore, many researchers, based on the complexity of the research task, simulated friction with raw cotton on various installations.

Based on this [22], the antifriction properties of machine-building composite polymer materials when interacting with raw cotton were determined on a tribometer, the schematic diagram of which is shown in Fig.1. The installation operates in the pressure range from 0.001 to 0.05 MPa and speeds from 0.5 to 10 m/s. The objects of research in the study of the antifriction properties of the material to develop a method and device for determining the tribotechnical characteristics of materials were selected: high-density polyethylene and polypropylene. As fillers, dispersed graphite, iron powder, and glass fiber were introduced into the polymer. Raw cotton of the 1st grade of the Bukhara-6 variety with a moisture content of 8-10% and a clogging content of 3-25% was used as a fibrous material. The substrate for the polymer coating was St3 steel [23].

A schematic diagram of a tribometer for determining the friction force between a composite polymer material and raw cotton, as well as the temperature and magnitude of the static electricity charge in the friction zone, is shown in Fig. 2.



1 is electric motor; 2 is gearbox; 3 is disk; 4 is sample with polymer coating or composite material; 5 is box; 6 is ball bearing; 7 is piston; 8 is block; 9 is microprocessor with Arduino UNO program; 10 is load; 11 is load cell NH-711; 12 is computer

Fig. 2. Disk tribometer

The tribometer works as follows [24]. A vertical shaft with a horizontal disk 3 mounted on it is driven by an electric motor 1 and a gearbox 2. A sample 4 of the test material is placed on the disk. The disc shaft is mounted on two radial and one thrust bearing to prevent axial and radial runout. The cylindrical box 5, located on eight deep groove ball bearings 6, moves in the longitudinal direction. The use of deep groove ball bearings reduces the friction force between the side walls of the box and the guide frame.

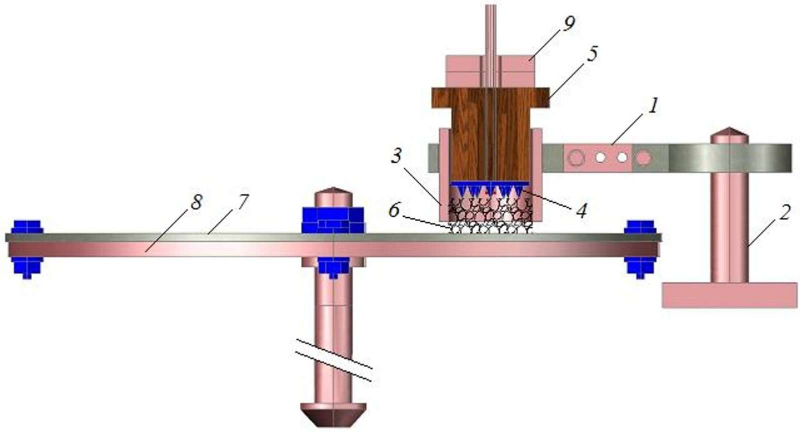
Cables are attached to the box on both sides [25]. One of them is thrown through block 8 and serves for calibration loading. The other cable is also connected to the box, and the second end of it is connected to the measuring beam 11, on which strain gauges are glued.

In the tribometer complex, a microprocessor with the Arduino UNO program and a computer are available to amplify analog signals received from the HX711 and DS18B20 strain gauges and their recordings [26].

Raw cotton is laid inside the cylindrical box, and a piston with weights is placed on top. When the disc rotates, the polymer coating drags a cylindrical box with a sample of raw cotton and thereby pulls the cable, which, in turn, bends the beam with strain gauges. With the help of strain gauges, the mechanical deformation of the shell is converted into electrical vibrations. These oscillations are amplified by the NH711 and DS18S20 load cell, and the signals are recorded on a microprocessor with the Arduino UNO software and recorded as a graph on a computer monitor [27].

To increase the measurement accuracy and maximize the simulation of the operating conditions of the working bodies of machines when determining the forces of frictional interaction of loose fibrous masses, in particular cotton 6 with composite polymer materials 7, the loading system is made in the form of a cylindrical box 3 with a piston 5 mounted on a boom 1, which is fixed on a vertical fixed axis 2 parallel to the plane of the disk 8 [28]. Moreover, the boom of the loading system is made with a longitudinal groove for installing the box at the required distance from the center of rotation of the disk and can swing around a fixed axis. The weight of the piston is (0.45+0.01) kg. The axis of the cylindrical box 5 must be at least 140 mm away from the axis of rotation (Fig. 3).

The sample must be electrically isolated from the bed of the test device; the insulation resistance must be at least 10 mOhm, and the electrical strength must be at least 30.000 V · cm-1. Copper electrodes 4 for measuring the voltage of static electricity on the fibrous mass should simultaneously serve to fix the fibrous mass, preventing it from rolling during testing [29].



1 is boom; 2 is vertical axis; 3 is cylindrical box; 4 is sliding element; (copper electrode): 5 is piston; 6 is fibrous mass; 7 is sample with composite polymer coating or material; 8 is disk; 9 is load

Fig. 2. Load system of tribometer

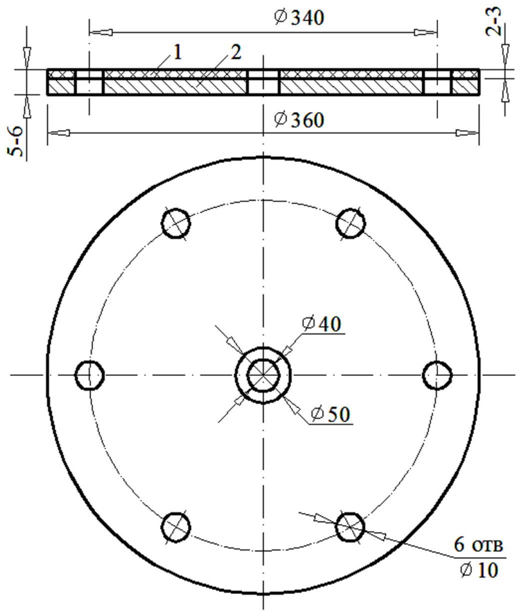
The obtained research results allowed us to conclude that for measuring the surface charge density and temperature in the friction zone of polymer materials with raw cotton, the optimal parameters of the developed installation are the average friction radius $R_{тр}$=140 mm, the diameter of the cylindrical box $d_к$=80 mm and height $h_к$=80 mm. The study of physical phenomena in the friction zone of polymers with raw cotton has shown that the processes of charge formation and temperature are interrelated [30]. The specified parameters of the installation provide the closest to the true values of the values of charges and temperature under the conditions of the interaction of a polymer-cotton pair only for some working bodies of cotton processing machines, for example, such as the RB rioters and the RP feeder disassembler.

It is necessary to select other optimal installation parameters for specific operating conditions of cotton processing machines and mechanisms [31]. The gap between the test sample and the box should be no more than 1 mm. A sample of the test material is made following Fig.3.

The roughness of the working surface of the sample R_z must meet the condition:

$$R_z \leq 0.4 d_{av} \quad (7)$$

where R_z is roughness of the working surface of the sample, d_{av} is the average diameter of the fiber, mm, to prevent the fibers from snagging on the irregularities of the surface of the test material.



1 is steel disc; 2 is test coating or composite material

Fig. 3. Sample of studied material

The resulting charges in the friction zone are removed using copper electrodes [32]. The values of static electricity charges are determined by measuring the magnitude of the potential using the 2N3819 sensor. To prevent leakage of charges formed due to friction, individual parts and components of the tribometer are insulated with fluoroplastic gaskets.
The temperature in the friction zone was measured using a DS18B20 thermal sensor, the principle of operation of which is based on a change in EMF depending on temperature.
Figure 4 shows oscillograms and calibration graphs obtained by the friction of composite polymer materials with raw cotton at P = 0.01; 0.02; 0.03 MPa and V = 2 m/s.

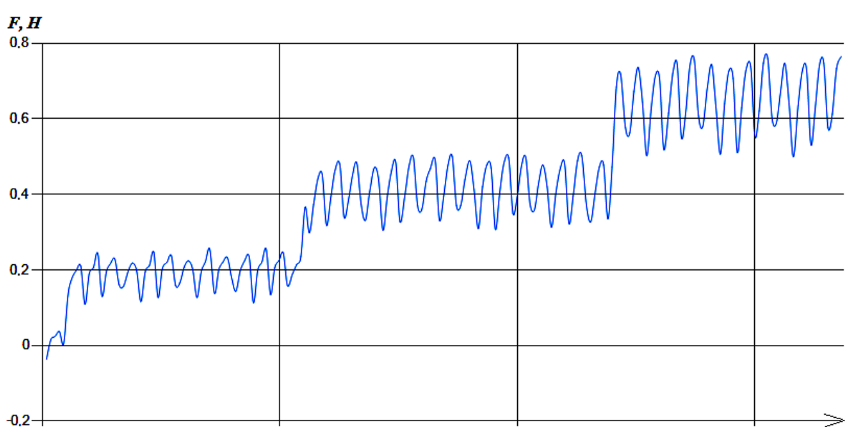


Fig. 4. Friction force of composite polymer materials with raw cotton

Table 1 shows the antifriction and physico-mechanical properties of composite polypropylene and polyethylene materials filled with organomineral ingredients determined by the developed methodology and an improved tribometer installation.

Table 1. Physical-mechanical and antifriction properties of polypropylene (APC) and polyethylene (APEC) composite materials working in contact with raw cotton.

Indicators	Composite polymer materials			
	APC-1	APC-2	APEC-1	APEC-2
Coefficient of friction, f	0.26	0.27	0.28	0.29
The magnitude of the static electricity charge, $Q \cdot 10^{-7}$, Kl	1.91	1.73	2.37	2.03
Temperature in the friction zone, K	319	306	321	315
Wear intensity, $I \cdot 10^{-10}$	3.23	3.12	6.7	6.5
Destructive bending stress, MPa	87.3	90.1	33.4	35.5
Impact strength, kJ/m^2	93.1	97.3	17.5	21.3
Brinell hardness, MPa	77.2	80.3	55.1	58.4
Flexural modulus of elasticity, GPa	1.65	1.85	0.62	0.65

Note: values *I* and *f* by *P*=0.02 MPa, *V*=2.0 m/s.

4 Conclusions

Thus, in this work, a method and installation have been developed with the help of which the antifriction-electro-thermal-physical properties of composite polymer materials are determined when interacting with the fibrous mass using the example of raw cotton.

The maximum charge of static electricity is achieved at different times of friction with raw cotton. As a result of the study of the kinetics of the formation of static electricity charges found that the formation time of the maximum charge for all polymer materials ranges from 20 to 145 seconds. Therefore, in all experiments, the magnitude of static electricity charges was measured 180 seconds after the start of the experiment.

The tests are carried out under ambient air temperature (23 ± 3 °C) and relative humidity (52 ± 3%), as well as with raw cotton humidity from 7.0 to 50.0% and clogging of raw cotton, from 1.0 to 25.0%.

The influence of the main parameters (radius of friction, diameter of the box, height of the box) of the disk tribometer and operating modes of machines on the coefficient of friction is investigated. It was found that with an increase in the nominal pressure on raw cotton, the coefficient of friction of polymer coatings mainly decreases, and the optimal values lie within the following limits: average friction radius $R_{тр}$=140 mm, the diameter of the cylindrical box $d_к$=80 mm and box height h_k=80 mm.

Acknowledgments

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