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INVESTIGATION OF OPERATIONAL PROPERTIES POLYMER MATERIALS

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Abstract:
This article discusses the procedure for determining the basic laws of dry friction and determining the sliding friction coefficient of polymer materials, as well as measuring the coefficient of friction and wear resistance of polymer materials.

Keywords: polymer materials, friction, sliding, wear resistance, high strength, chemical structure.

Introduction

Technological progress in the military-industrial complex and the development of a number of modern branches of technology require the creation of not only new structural materials (high-strength, corrosion-resistant, wear-resistant, etc.), but also fundamentally new methods of processing them based on high-precision productive equipment.

The main task is to establish precise connections at the atomic and molecular level between the chemical structure and physical structure of the material, on the one hand, and its operational consumer properties, on the other hand. It is extremely important to determine the degree of imperfection or defect in the structure of materials and the effect of this defect on properties.

The relevance of solving this main task for various types of structural and electrical materials has been steadily increasing in recent years, since in many modern structures, especially in special equipment, materials work in extreme conditions at the limit of their physical capabilities.

Optimal design of modern high-quality

and especially promising samples of special equipment, machines and devices are impossible without objective data and in-depth knowledge about the properties of materials used in structures. At the same time, the operational working properties of many materials are not independent, but are realized

in products during their manufacture. This circumstance is especially true in the design and manufacture of large-sized injection molding products made of multicomponent metal alloys and continuously reinforced composites and ceramics.

Currently, there are about 70 thousand names of engineering materials with a huge range of properties, structures and operational characteristics that can withstand the effects of external factors for a long time. Choosing the basic materials for a new machine, structure, and product is a difficult and demanding task. Therefore, the designer must possess not only reference data, but also know the properties of the starting materials and understand the nature of possible structural changes in them during the long-term operation of the designed product, taking into account the impact of the entire complex of operational factors: mechanical loads, electromagnetic fields, temperature, external climatic conditions and other aggressive factors.

Friction forces arise when touching bodies or their individual parts are relatively displaced. The friction observed between the surfaces of two bodies in the absence of lubrication between them is called dry. The friction between a solid and a liquid or gas, as well as layers of liquid or gas, is called viscous. The occurrence of the friction force is related to the structure of the substance. The physical nature of the friction force lies in the electromagnetic interaction of the molecules of matter. When the protrusions of a rough surface containing micro-dimensions are deformed, positively charged atomic nuclei converge and they repel. As a result, elastic forces arise between the protrusions of inhomogeneities. They add up, this leads to the appearance of a friction force. The friction force is directed opposite to the movement. In addition, upon contact, the micro-dimensions fluctuate, these vibrations are transmitted to neighboring atoms, and some of the energy goes away into the warmth. The second cause of friction is manifested when the rubbing surfaces are brought closer to a very small distance, at which attractive forces arise between the molecules. These forces are also directed against the movement

and they also manifest themselves in the form of friction force. Thus, the causes of friction are the roughness of the rubbing surfaces, as well as the intermolecular attraction of materials.

The friction forces are directed tangentially to the rubbing surfaces of the body in the direction opposite to the direction of movement of the body. There are three types of dry friction: resting friction; sliding friction; rocking friction.

The resting friction force occurs when trying to cause one body to slide over the surface of another. Let's consider two bodies in contact - 1 and 2 (Fig.1). moreover, body 2 is fixed motionless.

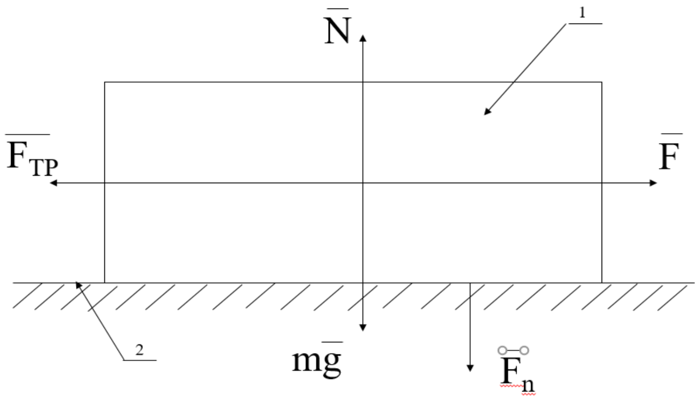


Fig. 1. Kinematic scheme

Suppose that in the direction perpendicular to the contact surface, body 1 acts on body 2 with a force called the normal pressure force.The strength of the Gpa may be due to gravity and other reasons.If an external force G is applied to the body 1, directed parallel to the contact surface, then at values of the external force lying within

$0 < G < G_0$, body 1 will remain at rest.At the same time, in accordance with Newton's second law, the force G is balanced by a force equal to it in magnitude and opposite in direction, which is the friction force of rest Gtr.The resting friction force automatically takes on a value equal in modulus to the external force of the load. The value of G0 is the maximum value of the resting friction force.When the external force exceeds its modulus, the body begins to slide.At the same time, the friction force continues to act on the body - in this case, it is called the sliding friction force. The magnitude of the sliding friction force depends on the sliding speed.

The nature of this dependence is determined by the nature of the bodies and the treatment of their surface.

In Fig. 2 shows the commonly occurring type of dependence of the friction force on the relative velocity of V.

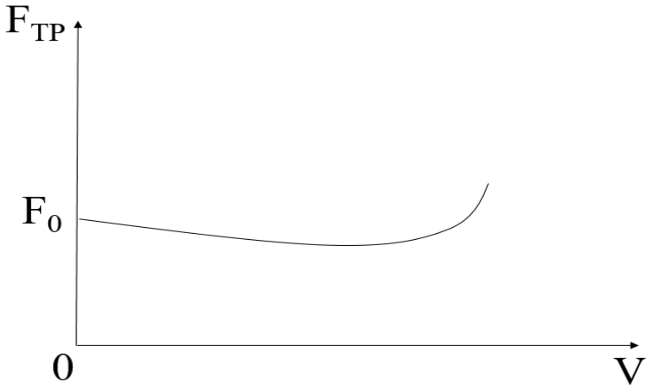


Fig. 2. Dependence of the friction force on the speed of movement

In the case of homogeneous pairs of solid materials, the sliding friction force is practically independent of velocity and is equal to the maximum friction force at rest. This can also be achieved with special treatment of touching surfaces.

The laws of dry friction are formulated by Coulomb and are

as follows. The maximum resting friction force and the sliding friction force equal to it:

do not depend on the area of contact of bodies;

it is proportional to the strength of the normal pressure.

The dimensionless coefficient of proportionality k is called the coefficient of friction (rest or sliding, respectively). The value of the coefficient of friction depends on the nature and degree of treatment of the rubbing surfaces. According to Newton's third law, the force of normal pressure Gn is equal in magnitude and opposite in direction to the force N of the normal reaction of the support: G_n = -N. Therefore, we can rewrite formula (2.1) in the following form:

$$F_{TP} = kN \quad (2.2)$$

moreover, this ratio is valid for both horizontal and inclined surfaces.
When sliding, the coefficient of friction is weakly dependent on the relative velocity of the rubbing surfaces. Therefore, for engineering purposes, the coefficient of friction within a fairly wide range can be considered independent of speed.
Rolling friction forces occur if a body (for example, a cylinder or a ball) it rolls over some surface. Rolling friction differs significantly from rest and sliding friction by its coefficient of friction. The coefficient of rolling friction is significantly less than the coefficient of sliding friction for similar materials.
Friction forces play an extremely important role in our lives. For example, it is the frictional forces of rest that arise when walking between the soles
and the ground that allow a person to move. The frictional forces of rest are used
in the technique for transferring force from one part of the machine to another (belt drives, belt conveyors, etc.), the fastening of parts with nails and screws is based on friction phenomena.
However, in many cases, friction plays a negative role, causing braking of movement, so measures have to be taken to weaken it.
In order to reduce dry friction, the following are used:
- lubrication of rubbing surfaces (at the same time, the coefficient decreases by 8-10 times);
- replacement of sliding friction by rolling friction.
Since friction occurs with every movement in terrestrial conditions, it is necessary to take into account the friction forces when calculating the movement.
The external friction of polymers is understood as the ability of polymer materials to resist the relative tangential displacement of two bodies in contact under normal load. The friction properties of polymer materials determine the main performance characteristics when they are used as sliding supports for braking devices and clutches, tires of automobile and aviation tires, seals of sliding interfaces. In addition, friction is of great importance in the processing of textiles, since the individual fibers forming them are held only by friction forces. An extremely important characteristic of polymer materials is the destruction of the surface layer during friction-abrasion.
Due to the roughness and undulation of the surfaces of solids, friction occurs only in certain areas of contact (friction contacts). The main quantitative characteristics of friction are:
1) Sliding friction coefficient:

$$V\mu = \frac{F}{N} \quad (2.3)$$

where F — friction force;
N - normal load;
2) rolling friction coefficient:

$$k = \frac{F \cdot R}{N} \qquad (2.4)$$

where R – the radius of the swinging body;

$$\Psi = \frac{F_1}{N} \qquad (2.5)$$

where $F_1 < F$- incomplete friction force.

In general, it depends on the normal load N, surface roughness, sliding speed V, temperature T, and duration of contact.

The dependence of friction on load, roughness and the nature of the contacting bodies is satisfactorily explained by the molecular mechanical theory (I.V. Kragelsky). According to this theory, the total area of the friction contacts is the actual contact area Sr, which is always less than the nominal area Sa, determined by the geometric dimensions of the contacting surfaces. Accordingly, the actual pressure $P_r = N/S_r$ and the nominal pressure $P_a = N/ S_a$ are distinguished. The work of friction forces consists mainly of the molecular component spent on overcoming intermolecular interaction, which leads to the formation of strong joints (welding bridges) in friction contacts, and the mechanical component spent on deforming irregularities on the surface of bodies involved in friction. Accordingly, the friction force has two components:

$$F = F_a + F_g \qquad (2.6)$$

where F_a - the adhesive component of the friction force;
F_g - the deformation component of the friction force.

Significantly less work is spent on electrification and accumulation of elastic energy in the deformable sample.

It is assumed that in the case of sliding, the shear resistance in the contact zone should be less than in deeper layers, i.e. the rule of "shear resistance gradient" should be observed. Therefore, for friction pairs, it is also necessary to select polymers in which thermal, mechanical or thermo-oxidative degradation occurs under friction conditions, as a result of which a layer with low shear resistance forms on the surface. In the case of polymer-metal pairs, low molecular weight compounds formed during degradation can lead to an adsorption decrease in the strength of metals. In addition, they can polymerize under friction conditions, forming, in particular, metal polymers. A surface layer with a low shear resistance can also be obtained as a result of dissolving the metal with a polymer, softening the polymer, and smearing it on the metal.

The surface layer separating two rubbing bodies can be considered as a third body (friction body). If we assume a sufficiently high molecular mobility in it, then the molecular component of the sliding friction coefficient can be characterized by a shear resistance l, similar to the tangential stress in Newtonian flow. The increase in shear resistance with increasing pressure is expressed by the formula:

$$\tau = \tau_0 + \beta \cdot P_r \qquad (2.7)$$

where τ_0 - the value of t at $P_r = 0$;
β - piezoelectric effect of the molecular component of friction.
Constants τ_0 *and* β experimentally determined for many metal-polymer pairs. Paired with steel τ_0 varies from 0.35 MH/m² for fluoroplast
up to 1,5 MH/m² for nylon, a β – respectively from 0.02 to 0.04. The deformation component μдеф The coefficient of friction is expressed by the formula: $\mu_{def} = \alpha + C + \sqrt{\frac{h}{r}}$ (2.8)
where α - a constant expressing hysteresis energy losses during repeated elastic deformation of irregularities;
C – the coefficient determined by the surface profile (the contact of a rough rigid surface with a deformable smooth counterbody is considered);
h – maximum depth of implementation of a single irregularity;
r – the radius of its curvature.
For thermoplastics and rubbers μдеф it is large, for reactoplasts it is small. The total coefficient of friction is determined by the expression:

$$\mu = \tau_0 + P_r \cdot \beta + \alpha \cdot C \cdot \sqrt{\frac{h}{r}} \qquad (2.9)$$

According to this ratio, the dependence of μ on the load and the degree of roughness is characterized by a minimum. This allows us to explain the essence of "burn-in" during friction - the degree of roughness of the rubbing surfaces changes so that at a given load the value of μ is minimal.
When choosing a friction pair, materials must meet the following requirements: have a maximum coefficient of friction for friction materials and a minimum coefficient for antifriction materials; lack of inclination
to bully (jamming), i.e. the exclusion of the possibility of the transition of external friction into internal, low wear; stable value of the friction force; high thermal conductivity and heat resistance. The listed properties are determined by the physico-chemical properties of the bodies involved in friction and the medium in which they are located, the friction mode (normal load, relative velocity, temperature at the contact surface). Usually, polymers are not in their pure form in friction nodes, but composite materials with various fillers having high heat resistance and thermal conductivity.
Methods for quantifying the frictional properties of polymers are quite numerous, but the most common are such as: measurement of the friction force when a hemispherical indenter slides over the polymer surface; measurement when a polymer sample slides over a flat metal (polymer) surface; the method of crossed filaments.

Among the equipment for evaluating the coefficient of friction of polymer materials, rotational motion devices are most widely used, since they make it possible to measure in a wide range of sliding speeds and normal loads, while allowing all methods of interaction of friction pairs to be carried out: a metal spherical indenter on a polymer; a polymer on a metal counterbody (polymer film).

The study of the wear resistance of polymer materials

The wear (or abrasion) of polymer materials determines the durability of a wide range of products made of composite and polymer materials operating under friction conditions. In the process of abrasion, the surface layer is destroyed and the material is separated from the friction surface. When testing a material for wear resistance, the specifics of its operation in specific products are taken into account by various methods. At the same time, friction heat resistance is determined for friction PM: polymer coatings
and tread rubbers are tested in rolling conditions with slippage. For comparative characteristics of the material, regardless of the operation of the products, wear is carried out at low speeds (up to 0.5 m/s) and loads
(up to 10 kg / cm2) in order to prevent significant heating.
Wear is forced, increasing the surface roughness of the counterbody. In this case, two types of counterweights are used, which carry out fatigue and abrasive wear. In the first case, friction is produced on a surface with blunt protrusions (along a metal grid), in the second - on a surface with sharp protrusions (along a corundum web).
The intensity of linear wear under specified external conditions is estimated by a dimensionless value:

$$J_h = \frac{h}{L} = \frac{V}{A \cdot L} \qquad (2.10)$$

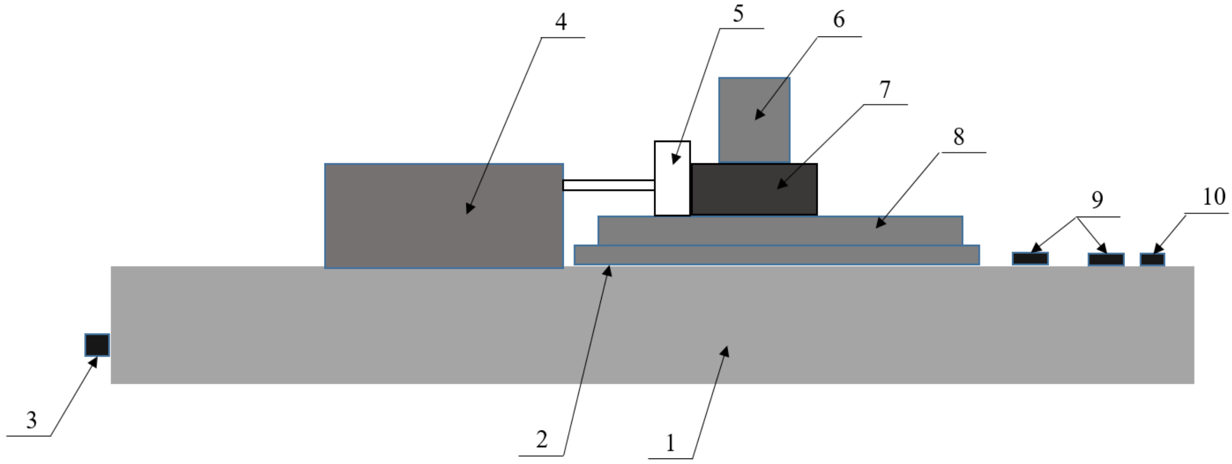
where h - the thickness of the worn layer;
V - the volume of the worn layer;
L - The friction path;
A - the nominal friction surface area, characterized by either the volume V or the mass g of the worn material, as well as the thickness
h of the worn layer.
Tests of polymer and composite materials are carried
out in accordance with GOST "Method of testing plastics for abrasive wear". The method is based on determining the reduction in the volume of the sample as a result of abrasion. The volume wear index of the sample was determined as follows:

$$V_1 = \frac{(g - g_1)}{\rho} \qquad (2.11)$$

where g - sample weight before abrasion, г;
g_1 - weight after abrasion,g;
ρ - sample density,g/sm³.
The density of the samples was calculated based on the weight and volume of the sample.

Description of the MM-P-OCT-16 installation and measurement method.

The coefficient of friction is determined on the measuring stand M-P-OCT-16 (Fig. 2.), which is a modern digital version of the tribometer.



1 - housing; 2 - trolley; 3 - power switch; 4 - measuring unit; 5- stop of the measuring unit; 6 - load; 7 - sample; 8 - sliding surface (replaceable plate); 9 - motion control buttons; 10 - LCD display.

Fig.2. Diagram of the test bench

The installation consists of a housing 1, which houses the electric drive and control systems. These systems ensure uniform movement of the trolley 2. The direction of movement of the trolley is set by the control buttons 9, FORWARD and BACKWARD. The movement of the trolley on both sides is limited by limit switches. The force measurement is carried out by the measuring unit 4, which is based on a load cell. The readings from the load cell are transmitted to the controller, which calculates and displays the effective force value, the average force value and the maximum force value (Fig.3.).

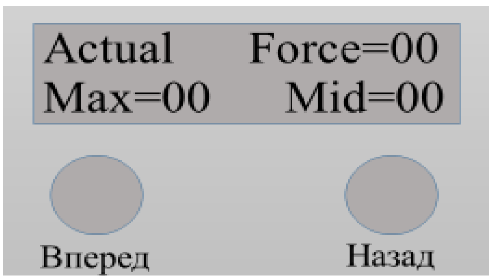


Fig.3. Display

On the display, "Actual Force" is the effective value of the friction force, "Max" is the maximum value of the friction force per movement, "Mid" is the average value of the friction force per movement.

In operation, a sliding surface 8 is installed on the platform of the trolley 2, which can be made of various materials. A sample 7 of the test material is placed on the surface close to the stop 5. A load 6 is placed on the sample, which presses the sample, after which the installation is ready for operation.

When moving the trolley, the replacement plate creates a force equal to the friction force on the sample. The sample creates a force at the stop, transmitted through the rod to the load cell in the measuring unit. The load cell changes its geometric dimensions, thereby changing the electrical signal coming from it. This electrical signal is perceived by the controller and converted into force. Thus, the friction force arising between the plate and the sample is perceived and transmitted to the controller without any loss.

The sliding friction force is calculated using the basic equation of translational motion (Newton's second law). To do this, it is necessary to consider Figure 1 and expression (2.2). Thus, the coefficient of friction will be:

$$k = \frac{T}{F_{TP}}$$

Summing up, we can say that important factors in the optimal choice of material, especially for multi-series products, are manufacturability, accessibility and cost. Therefore, a modern designer of machines, devices, especially samples of special equipment, in addition to special knowledge and design skills, must have a wide range of knowledge in materials science, materials technology, methods of testing, and also have the necessary minimum of economic knowledge.

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