Triboelectricity in the Pairs of Polymeric Materials

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ABSTRACT: The influence of electricity of polymeric films and knitted fabrics on friction parameters is analyzed in this work. The variations of the dynamic friction force were determined (under standard DIN 53375) in polymer sliding on the stands made of glass (organic and nonorganic). The dependencies of these variations on the polymer nature and stand mode were analyzed. The determined values of dynamic friction coefficient and dynamic friction force of 10 polymeric materials from the point of view of different stands are presented. The dependencies of friction parameters on triboelectricity and its influence on the formation of adhesion bonds between the components of the sliding pair are described.
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Key words: materials science; polymers; friction; triboelectricity

INTRODUCTION

Almost in all cases, electrostatic charging of polymers negatively influences the processes of polymer manufacturing, exploitation, and testing.

Most chemical fibers or films produce electric charges due to friction between two different polymers. The intensity of the human body potential when a person moves inside the building depends on soles of walker footwear and the kind of the floor.[1] The resistance of the fiber materials composition and the use of the antistatic have great influence on the textile fibers processing.[2,3]

The chemical structure of polymers determines their electrostatic characteristics.[4–6] Because of the contact between two different polymers, they produce electric charges and adhesive bonds among each other. This bond may interfere with manufacturing or influence the test results.

In the science of textile materials, the devices where the specimen is sliding through the hole between two plates of different materials is used.[7,8] During this sliding process the triboelectricity and adhesive bond may negatively influence values of mechanical parameters.

The aim of this research is to determine influence of polymer nature on their friction parameters in sliding on different surfaces and the dependencies between the intensity of electricity and the mechanical parameters of friction.

METHODS

The tests were performed using the tension machine Zwick/Z005 equipped with a special device (Fig. 1) designed to determine the friction parameters under the DIN 53375 standard. The table (1) covered with the specimen (2) and moved on the glass (G) or organic glass (OG) stand (3) extended up to 700 mm or on the stand covered with investigated polymer material. The velocity of table (1) pulling was 500 mm/min.

Subjects of investigations were five polymeric films and five fiber systems differing in their nature (Table I).

Within the friction test, friction curve *l-F* (Fig. 2) was registered and four friction parameters: coefficient of static friction μ_S, the coefficient of dynamic friction μ_D, the force of static friction F_S, and the force of dynamic friction F_D were calculated using commercial software *testXpert*®. Number of specimens was selected with regard to variation coefficient, which was below 10%.

Selection of stands (glass (G) and organic glass (OG)) is identical to the material of components (with regard to which the specimen is sliding within the test period) of widely described device KTU-Griff-Tester designed for research of mechanical properties of polymeric materials.[8–10]

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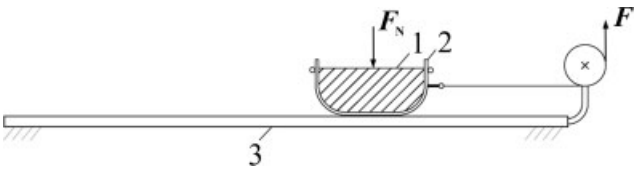

Figure 1 The scheme of determination of friction parameters.

Limiting plates of the device KTU-Griff-Tester are made of organic glass (stand) and the glass (the upper limiting plate). By sliding on the glass and organic glass stands, polymeric specimen may experience electric charge accumulation, which can initiate formation of the adhesive bond.

The potential (positive "+" and negative "−") of the electric charge on the specimen and stand surfaces was controlled during the friction test. The tests were performed with the electrostatic field-meter FMX-002 (the Netherlands).

The electrostatic field-meter FMX-002 with electric potential measurement range of ±20 kV has the accuracy of ±10% when calibration is made in uniform electrostatic field [Fig. 3(a)] and for the measurement conditions when the field-meter is kept in the hand [Fig. 3(b)].

In these Figures HVT is the source of the high direct voltage, V is the kilovoltmeter C96 of the electrostatic system (for ranges of 7.5, 15, 30 kV; with the accuracy of ±1.5%), FMX is the electrostatic field-meter FMX-002, (1) is the flat rectangular potential electrode (20 × 20 cm^2), (2) is the earthed flat electrode of the same dimensions as the first one with the hole in the center for the field-meter FMX, l_0 is the distance between flat electrodes (l_0 = 2.5 cm), R_e is the resistance of the grounding circuit equal to the sum of the resistances of the human's body and the floor.

TABLE I
Characteristics of Investigated Objects

Polymeric material	Structure	Symbol	Thickness δ (mm)
Polyethylene (high pressure)	Film	PE	0.12
Polypropylene	Film	PP	0.05
Polypropylene (with filler)	Film	PPv	0.03
Polyvinylchloride	Film	PVCH	0.28
Polytetrafloruretylene	Film	FE	0.07
Cotton	Knitted fabric	CO	0.72
Viscose	Knitted fabric	CV	0.64
Acetate	Knitted fabric	CA	0.60
Polyester	Knitted fabric	PES	0.50
Polyamide	Knitted fabric	PA	1.00

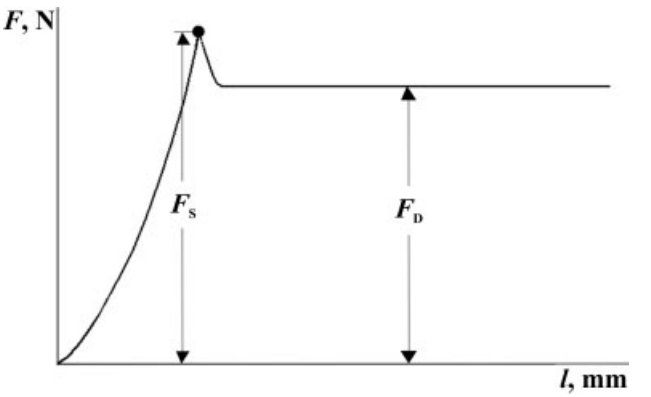

Figure 2 Typical friction curve.

Table II shows that because of the measurement errors, both for the measurement conditions while keeping the meter in a hand and in the uniform electrostatic field do not exceed the accuracy limit (of 10%) of the field-meter FMX, the density of surface charge can be calculated from the equations of the uniform electrostatic field.

The strength of the uniform electrostatic field is

$$E = \frac{U_x}{l_0} \times 10^5 = \frac{U_x}{2.5} \times 10^5, \quad (1)$$

where U_x is the potential measured with the field-meter FMX, kV; l_0 is the distance between electrodes, cm, l_0 = 2.5 cm; E is the field strength, V/m.

The surface charge density is given by

$$\sigma = \varepsilon_0 E = \frac{8.85}{2.5} U_x \times 10^5 \times 10^{-12} = 354 U_x \times 10^{-9}, \quad (2)$$

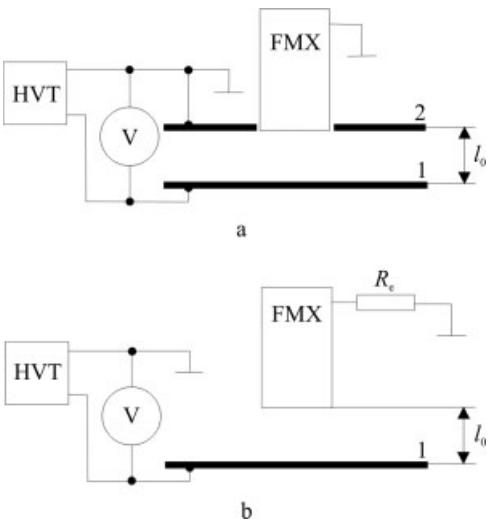

Figure 3 The scheme of the calibration with the gauge FMX in the uniform field (a) and while keeping it in a hand (b).

TABLE II
Calibration Results of the Electrostatic Field-Meter FMX

	Scheme 1		Scheme 2	
U_0 (kV)	U_x (kV)	δ_{Ux} (%)	U_x (kV)	δ_{Ux} (%)
1.0	0.95	5.0	0.94	6.0
2.0	1.9	5.0	1.9	5.0
3.0	3.0	0	3.0	0
4.0	4.0	0	4.0	0
5.0	5.1	2.0	4.9	2.0
6.0	6.1	1.7	6.0	0
7.0	7.2	2.8	6.9	1.4
8.0	7.8	2.5	7.7	3.7
9.0	8.8	2.2	8.6	4.4
10.0	9.8	2.0	9.5	5.0

where U_x is the potential measured with the field-meter FMX, kV, σ is the density of surface charge, C/m^2. The measurement results given in Table IV are calculated from (2) equation. In all the cases of the electrostatic charge measuring the number of specimens was selected with regard to relative error value, which was below 10%. The reliable results were determined by using 7–10 samples in electrostatic charge measurements and 4–8 specimens in friction tests. All the experimental tests and measurements of parameters were performed under controlled environmental conditions: $T = (22 \pm 1)°C$, $\varphi = (65 \pm 2)\%$.

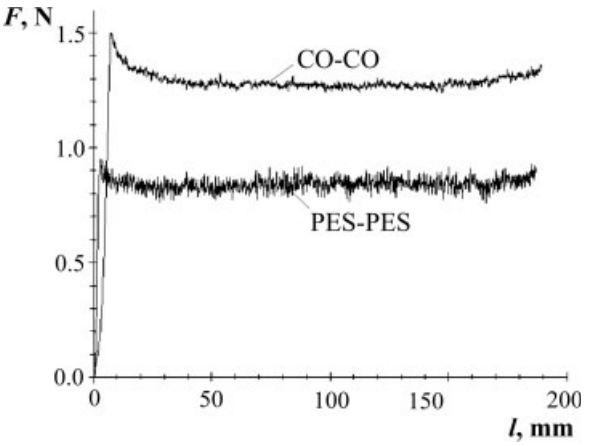

Figure 4 The curves of sliding friction in the pairs of identical polymers.

RESULTS

Triboelectricity research with various materials evidence that in polymer sliding, the dynamic frictional force F_D does not remain stable, which is typical of a pair of conductors or dielectrics "stand-specimen," composed of one type materials (Fig. 4) and assists variations within the wide range (Fig. 5). Force F_D difference depends upon the type of specimen polymer and stand. In some cases F_D ranges within the limits of several hundred percent [Fig. 5(c,d)]. Supposedly it depends on triboelectricity, i.e., electric

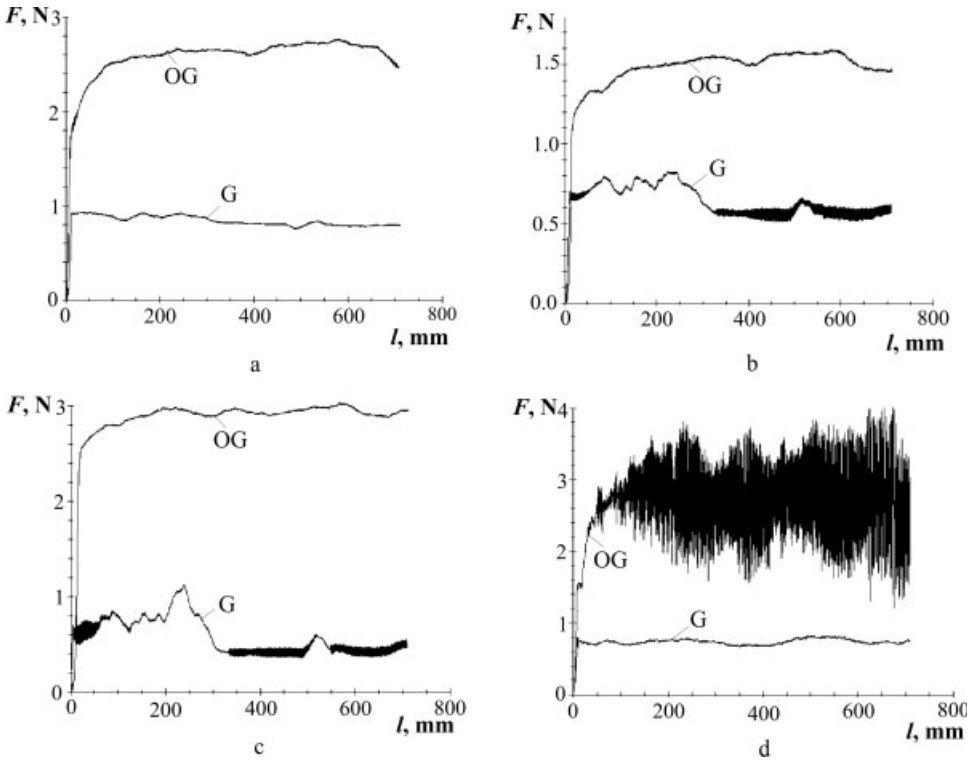

Figure 5 The friction curves for acetate (a), polyester (b), polyamide (c), and polyethylene (d) during their sliding on the surfaces of glass (G) and organic glass (OG).

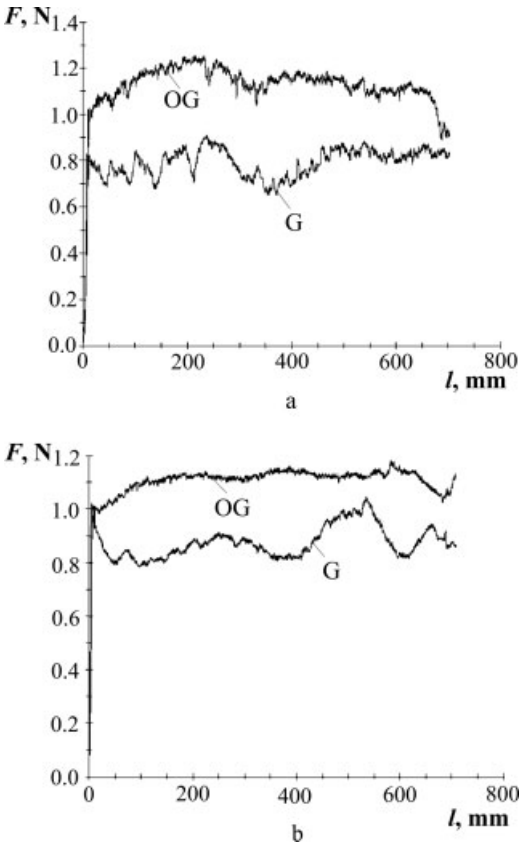

Figure 6 The friction curves for PVCH (a) and PP (b) during their sliding on the surfaces of glass (G) and organic glass (OG).

charge accumulation on sliding surfaces and formation of adhesive bond among the specimen and stand. It should be noted that the type of friction curves *l*-*F* (Fig. 6) is directly related to pulsation of electric charge. Nevertheless, this pulsation is of incidental origin as even in case of extremely long stand (three times as long as the reference stand) no uniform sections of *l*-*F* curves were found, which could account for periodic character of the process.

When the specimen is sliding on the stand mode of the specimen material, $F_D = \text{const}$ (Fig. 4) within the whole period of sliding and undependable of chemical composition of the specimen. When the same specimen is sliding on glass (G) or organic glass (OG) stand, the frictional force F_D varies. With all specimens, dynamic frictional force with regard to organic glass F_D^{OG} exceeds analogical force in case of glass F_D^G except for a film FE. In some cases this difference amounts up to 4–6 times. Acetate CA polyester PES and polyamide PA materials (Fig. 5) exhibited extremely great differences.

It should be considered that significant variation of the force F_D is noticed when the polymeric specimen is sliding on the stand surface. Evidently, it depends on periodic pulsation of electric charge

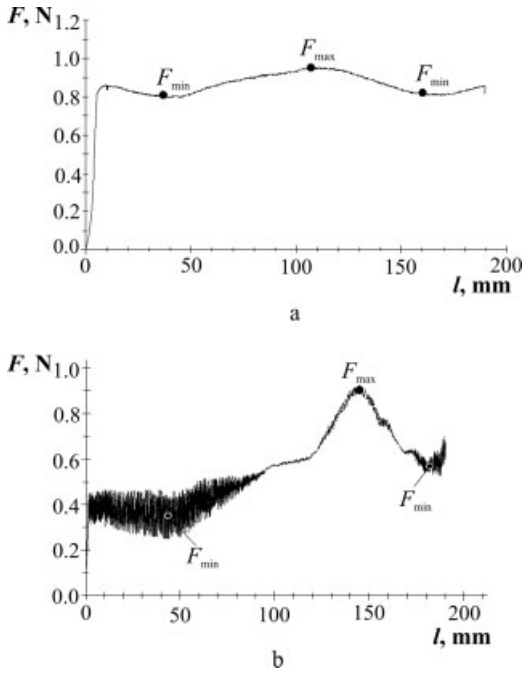

Figure 7 The friction curves for polymers CO (a) and CA (b) during their sliding on the surfaces of glass (a) and organic glass (b).

seen in the friction curves (Fig. 7). Differences between extreme points of curves F_D^G exceed up to several times [Fig. 5(c,d)].

The analysis and comparison of the friction curves of 10 different polymeric materials (Table I) reveals the following:

1. All cases exhibit greater frictional forces with regard to organic glass (if compared to glass);
2. The friction force of polytetrafluorethylene FE (Fig. 8) shows the reverse progress of the process: its $F_D^G > F_D^{OG}$;
3. The pair PE-G [Fig. 5(d)] is "the clearest" according to the friction curve *l*-F. The

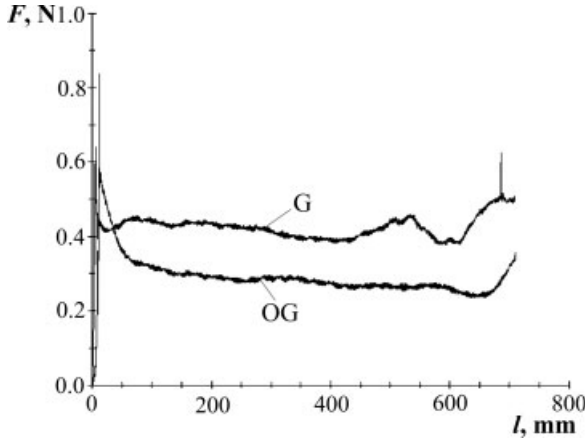

Figure 8 The friction curves of FE during its sliding on the surfaces of the glass (G) and organic glass (OG).

TABLE III
Friction Parameters

Polymer symbol	μ_S[a]		μ_D[a]		F_D[a], N		$F_{D\ max}/F_{D\ min}$[b]	
	G	OG	G	OG	G	OG	G	OG
PE	0.37	0.83	0.37	1.75	0.70	3.31	1.22	2.21
PP	0.58	0.55	0.58	0.59	1.08	1.12	1.27	1.50
PPv	0.51	0.55	0.47	0.58	0.89	1.11	1.32	1.07
PVCH	0.42	0.54	0.42	0.59	0.80	1.12	1.40	1.23
FE	0.35	0.38	0.23	0.15	0.44	0.28	1.39	1.25
CO	0.48	0.38	0.50	0.59	0.96	1.11	1.22	1.56
CV	0.42	0.39	0.47	0.60	0.89	1.14	1.31	1.55
CA	0.48	0.79	0.43	0.34	0.81	2.54	1.11	1.61
PES	0.38	0.40	0.33	0.76	0.63	1.43	1.51	1.21
PA	0.32	0.76	0.34	1.50	0.65	2.84	1.78	1.16

[a] The presented results were determined from the average values automatically calculated by the tension machine Zwick/Z005.
[b] $F_{D\ max}/F_{D\ min}$ was determined from the friction curves *l-F* according the variation of the friction force F_D during the material testing.

specimen PE is sliding on the surface of the organic glass with significant hitch. This is obviously related with the extremely intensive triboelectricity of the polymeric pair PE-OG;

4. According to the increase of average value of the dynamic friction force F_D the investigated materials could be placed in the following order (Table III):
   a. in the case of glass stand (G) → PP-CO-CV-PPv-CA-Pvch-PE-PA-PES-FE;
   b. in the case of organic glass stand (OG) → PE-PA-CA-PES-CV-Pvch-PP-PPv-CO-FE.

When the glass stand is used the sliding of PP is heaviest and that of FE is easiest. The difference is about 2.5 times. When the organic glass stand is used the sliding of PE is heaviest and that of FE easiest. The difference is about 12 times.

The analysis of the parameters of electrostatic charges (Table IV) shows that in the case of glass stand the polymeric specimen is charged negatively and the stand is charged positively. In the case of organic glass stand the analogous situation is true for polymers PE, PP, PVCH, and FE, but the sign changes when polymers PPv, CO, CV, CA, PES, and PA are used, i.e., the sample gets the positive sign "+," and the organic glass stand gets the negative sign "−."

It must be noted that in the case of organic stand the values of the electric charge potential are higher compare to the ones in the case of glass stand. This was characteristic for the polymers PE, FE, CV, CA, and PA. The differences between the determined values of dynamic friction force of the above-mentioned polymers according to the stand material (glass and organic glass) were the highest (Fig. 5). Supposedly, these differences of the friction curves *l-F* and the dynamic friction forces F_D can be influenced by polymer electricity.

The correlation between the dynamic frictional force F_D and potential *E* resulting from the friction

TABLE IV
The Electrostatic Charge Sign and the Surface Charge Density in nC/m^2 After the Contact with the Stands

Polymer symbol	Glass		Organic glass	
	Specimen	Stand	Specimen	Stand
PE	−149 ± 11	+57 ± 2	−43 ± 4	+4637 ± 230
PP	−18 ± 1	+149 ± 8	−28 ± 2	+163 ± 7
PPv	−18 ± 2	+57 ± 6	+39 ± 1	−266 ± 14
PVCH	−400 ± 28	+71 ± 4	−5664 ± 267	+173 ± 12
FE	−120 ± 9	+163 ± 8	−180 ± 11	+4708 ± 230
CO	−64 ± 3	+170 ± 9	+120 ± 4	−1558 ± 71
CV	−28 ± 1	+149 ± 11	+53 ± 2	−5770 ± 260
CA	−50 ± 2	+64 ± 4	+67 ± 5	−3859 ± 190
PES	−32 ± 1	+149 ± 5	+11 ± 1	−35 ± 1
PA	−28 ± 3	+156 ± 7	+177 ± 10	−5558 ± 180

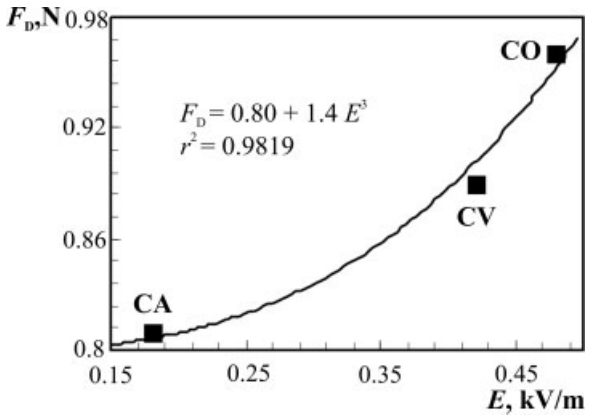

Figure 9 The relationship between the strength E of electric field caused by electrostatic charge, accumulating on the glass stand after the tribo contact with the cellulose origin fibrous materials, and the dynamic friction force F_D.

on the surfaces of stand and specimen does not exists. Selection of the fabrics of similar nature, i.e., cellulose fabrics (CO, CV, CA), influenced the correlation between parameters E and F_D. Figure 9 show that the potential E accumulated on glass stand highly correlates [$r^2 = 0.9819$] with the frictional force F_D, whereas the size of electrostatic charge accumulated on the specimen surface is undependable on dynamic frictional force.

The research of the triboelectricity done in this work could be useful in estimating the interaction of the pair of two dielectrics from the point of view of mechanics. The analysis of the friction curves of the investigated polymers exhibited that the dynamic friction force F_D has the pulsating character and is constantly greater than the static friction force F_S. This means that the adhesive bond between the sliding pair elements because of their electrostatic charge may have an impact on indications of the devices wherein such charge is accumulated. Thus the accuracy of determination of the dynamic friction coefficient μ_D according to the standard DIN 53375 when the sliding pair (the specimen and the stand) is two different dielectrics encounter with some metrological problems. There are also materials testing devices[11] where the fibrous polymer sample slides in regard to different dielectrics. In this case the adhesive bond due to triboelectricity may have also impact on the data accuracy.

CONCLUSIONS

Mechanical testing of friction may be beneficial in explanation of electricity and formation of adhesive bonds influenced by it in the friction pairs of the dielectrics rubbing to each other.

The variation of the dynamic frictional force depends on the dynamics of the changes of electrical charges produced by rubbing together two dissimilar substances.

The organic glass if compared with nonorganic glass generates more intensive electrostatic charge between the stand and polymer except the nonpolar polymer (polytetraflouretylene which under the conditions of dry friction was determined as the most antifrictional polymer.

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