

Kinetics of changes of tribotechnical properties of polymeric materials in period of running-in

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Abstract. The article presents the study results of the influence of the type of polymers and friction modes on the duration of the running-in of polymeric materials during friction with various materials. The kinetics of changes in the temperature in the friction zone (T_{fr}), friction coefficient (f), the height of micro asperities (R_z), and the radius of the tops of asperities (r) during the running-in period have been studied.

1 Introduction

At present, polymeric materials and coatings are widely used in mechanical engineering due to their high antifriction, anti-corrosion, and other physical, mechanical, and operational properties, the ability to control properties, etc.

The complete effect of using polymeric materials can be achieved if the complex properties and behavior of polymeric materials in various operating conditions are known and considered and their rational choice for the working parts of machines.

The widespread use of polymers and other synthetic materials in engineering industries significantly improves products' technical and economic performance, reducing their weight, manufacturing labor intensity, and cost, as well as increasing corrosion resistance.

However, polymeric materials have such disadvantages as low mechanical strength, insufficient thermal conductivity and heat resistance, high coefficient of thermal expansion, hygroscopicity, relatively high cost, and scarcity. Currently, there are several problems, the solution of which is of both scientific and practical interest. Not thoroughly studied:

- durability of machine-building polymeric materials and coatings based on them, especially in the initial period of their operation, i.e., during the run-in period;

In this regard, studying the physicomaterial and tribo-technical properties of polymeric materials and coatings during the running-in period, increasing their performance during friction with various materials that meet the modern requirements of machines and mechanisms, is an urgent task.

For polymeric materials used in the working parts of machines and mechanisms operating in the friction zone, the following requirements are imposed: low coefficient of friction, high class of surface cleanliness, low wear rate and electrification, manufacturability, non-deficiency, and low cost.

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Considering the functional purpose, operating conditions, manufacturability, and lack of scarcity, Epoxy resin, Furano-epoxy resin, Polypropylene, and Pentaplast were chosen as the object of study.

2 Methods of research

To prepare the surface of metal parts for applying polymer coatings, the method of grinding parts using an eccentric rotary brush according to patent No. 03685 [1] was used. The roughness parameters were determined using a probe profilometer and a profilograph.

The tribological properties of polymeric materials and coatings based on them are determined on an improved tribometer, for which the Patent of the Republic of Uzbekistan No. 1989 was obtained [2].

3 Results and discussion

The operating factors, pressures P , and sliding speed V were modeled in experimental studies as their product, i.e., PV factor. The selected values of the PV factor for experimental studies correspond to the actual operating conditions of machines and mechanisms.

It is known [3-4] that during the friction of polymeric materials with a fibrous material, in contrast to the friction of solid parts, the process of frictional interaction is accompanied by the formation of temperature in the friction zone. In most cases, their values are quite large, especially the temperatures in the friction zone, which can significantly change the surface properties of the interacting materials.

In this regard, we studied the kinetics of changes in the temperature in the friction zone (T_{fr}), friction coefficient (f), the height of micro-roughness (R_z), and the radius of the tops of asperities (r) during the running-in period.

Fig. 1 shows that the run-in duration differs for one polymers class. For example, for polypropylene and epoxy polymer with a factor value of $PV = 0.04 \text{ MPa} \cdot \text{m/s}$, the temperature of the charge in the friction zone in the initial period of running-in intensively increases, and then, reaching a maximum value ($T_{fr} = 312$ and 309°K) and stabilizes. It can be seen that the time at which the value of the studied parameters reaches stable values depends on the type and properties of the coating material. Therefore, to stabilize the value of the established temperature in the friction zone, it is observed when the density of the triboelectric charge already has a constant value. With an increase in the PV factor, the maximum of the steady-state temperature shifts towards a shorter running-in duration, i.e., run-in time is reduced.

The absolute value of the established temperature varies differently depending on the type of coating material (Fig. 1). At $PV=0.04 \text{ MPa}\cdot\text{m/s}$, the highest temperature value in the friction zone is observed in polyethylene (314 K) and Furano-epoxy (312 K) polymers, which is explained by their physical and mechanical properties and structure.

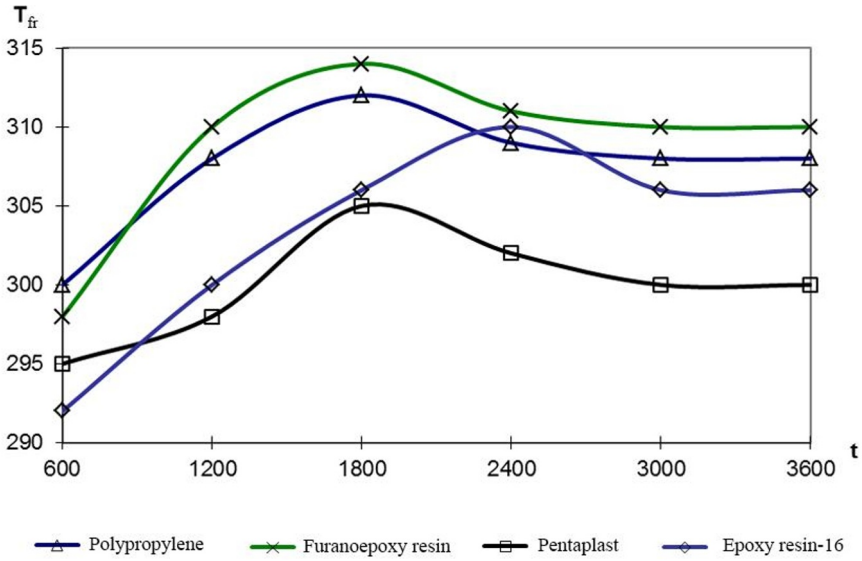


Fig. 1. Temperature dependence in friction zone of polymer coatings on duration of their running-in. $\rho v = 0.04 \text{ MPa} \cdot \text{m/s}$.

The coefficient of friction (f) for the epoxy polymer, depending on the duration of the running-in, monotonically increases, and after $(3.5-4.5) \cdot 10^3 \text{ c}$ it stabilizes (Fig. 2). The increase in the friction coefficient in the initial period of running-in is explained by a change in the surface (roughness parameters) properties of the coatings, which contribute to an increase in the actual contact area [3-20] and the triboelectric component of the frictional interaction force due to an increase in the density of the triboelectric charge.

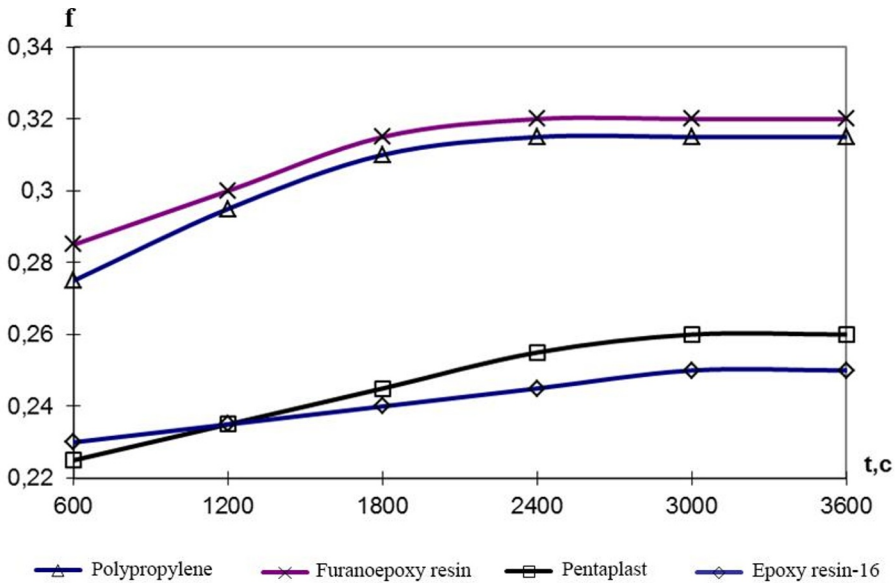


Fig.2. Dependence of coefficient of friction of polymer coatings on duration of their running-in. $\rho v = 0.04 \text{ MPa} \cdot \text{m/c}$.

The study results showed (Fig.1-2) that, unlike the epoxy coating, due to the low microhardness and strength, the period of running-in of the Furano-epoxy coatings ends much faster than that of the epoxy coatings. Similar results were obtained for pentaplast and polypropylene polymeric materials. Moreover, the duration of the pentaplast run-in is less than that of the epoxy polymer, and the Furano-epoxy polymer is longer than that of polyethylene.

As can be seen from the research results (Fig. 3), the PV factor significantly affects the duration of the running-in period of polymeric materials. An increase in the PV factor leads to decreased running-in duration for all polymeric materials studied. For example, with an increase in PV from 0.04 MPa*m/c to 0.1 MPa*m/c, the run-in duration for polypropylene and Furano-epoxy polymers decreases from $40 \cdot 10^2$ and $45 \cdot 10^2$ c to $18 \cdot 10^2$ c and $28 \cdot 10^2$ c, respectively.

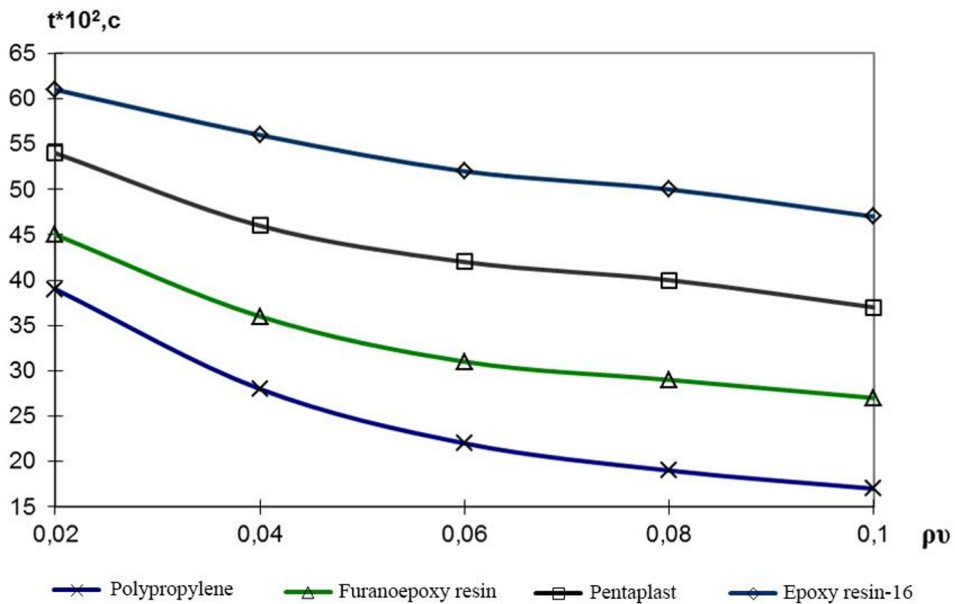


Fig. 3. Dependence of running-in duration on energy factor ρv .

The decrease in the duration of the running-in period with an increase in the PV factor is explained by an increase in temperature and an increase in the density of the triboelectric charge in the friction zone, leading to the intensification of the process. The steady-state value of the studied parameters for different coatings is not the same; for example, the values of the steady-state friction coefficient for the Furano-epoxy resin is 0.35, and for epoxy and pentaplastic polymers, it is 0.27 and 0.35.

This is explained by the physical state of the surface layer of polymeric materials and its change due to frictional-thermomechanical influences. It should be noted that the duration of the burn-in period is quite well correlated with the glass transition temperature and polymer hardness. Moreover, the higher the glass transition temperature and the microhardness of the coatings, the longer the running-in process (Table 1).

To study the influence of roughness parameters on the duration of the running-in period, we carried out special experiments, the results of which are shown in Fig. 4-5.

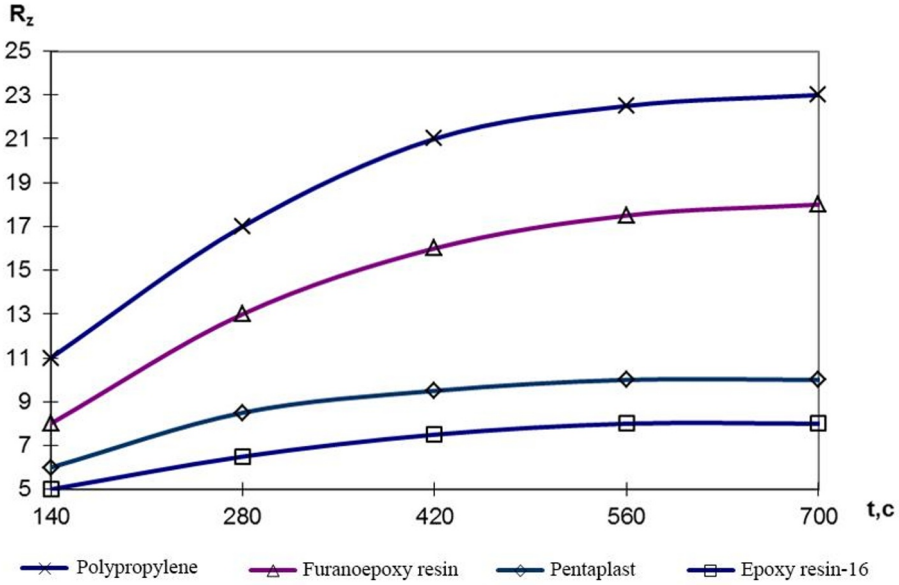


Fig. 4. The dependence of the height of microroughnesses of polymer coatings on the duration of running-in. $\rho v = 0.1 \text{ MPa} \cdot \text{m}/\text{c}$.

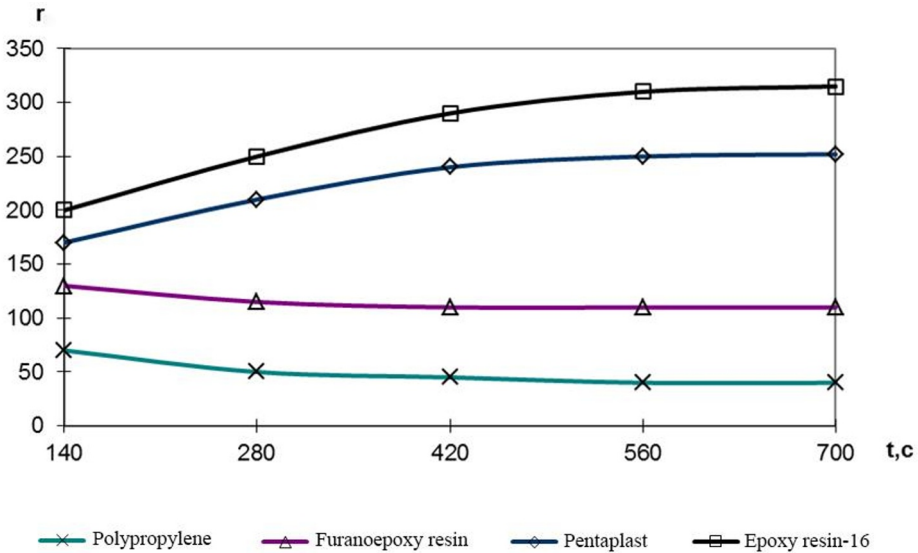


Fig. 5. Dependence of radius of peaks of asperities of polymer coatings on duration of running-in. $\rho v = 0.1 \text{ MPa} \cdot \text{m}/\text{c}$.

The parameters of the surface roughness of polymers during the running-in period vary in different ways. Thus, at values of $PV = 0.04 \text{ MPa} \cdot \text{m}/\text{s}$, for all the studied polymers, a decrease in the height of micro asperities and an increase in the radius of their tops are observed, while for polyethylene, it is vice versa. In addition, with an increase in the PV factor, an increase in the height of microroughnesses is observed regardless of the material of the coatings, and the radius of their tops varies depending on the properties of the coatings. In this case, each polymer is characterized by a significant change in the

roughness parameters of polymeric materials and coatings based on them. The greater the value of the radius of their vertices, the lower the steady value of the height of the irregularities.

The conducted experimental studies have shown that the run-in of polymeric materials is significantly affected by their structure. Polymeric materials with a network structure (Furano-epoxy oligomer) and crystallizing polypropylene differ significantly in the duration of the running-in period, despite their almost identical physical and mechanical properties (Table 1.). Such differences in the break-in period of these polymers are explained by the fact that Furano-epoxy polymers with a relatively high glass transition temperature contribute to an uneven distribution of contact pressures, leading to an increase in the actual contact area (FPC); as a result, their burn-in duration increases compared to the polyethylene polymer.

Table 1. Dependence of the running-in period and friction coefficient on the physical and mechanical properties of the studied polymeric materials

Material	Friction coefficient	Modulus of elasticity, MPa	Glass transition temperature, K	Microhardness, MPa	Adhesion strength, MPa	Run-in time, $t \cdot 10^{-2}$, c
Polypropylene	0.40	730	230	68	22	30
Furanoepoxy resin	0.36	820	310	85	30	40
Epoxy resin-16	0.30	2220	342	192	45	70
Pentaplast	0.28	1100	298	122	28	56

Note: at $PV = 0.04 \text{ MPa} \cdot \text{m}/\text{c}$

The density of the triboelectric charge and the temperature in the interaction zone significantly affect the intensification of the running-in period of polymeric materials. The study's results to determine their share and dominant influence on the running-in are in Tables 2-3. In experiments, the density of triboelectric charges was changed by selecting the thickness of fluoroplastic insulating spacers (from 0 to 50 mm), and the temperature was changed by supplying hot air directly to the friction zone under constant friction modes.

It can be seen from the tables that at lower values of the PV factor, the influence of the charge value is stronger (tab. 2), and at high ($PV > 0.05 \text{ MPa} \cdot \text{m}/\text{s}$) temperatures in the friction zone (tab. 2), leading to a change in the physical state surface layer of coatings. Moreover, the higher the charge and temperature values, the faster the development process is completed.

Table 2. Dependence of running-in duration of CPM on factor ρv at different values of triboelectric charge density

Tribo charge density values ($q \cdot 10$, C/m)	Duration of running-in of PNP ($t \cdot 10^2$, c) at various values of ρv					
	0.01	0.02	0.04	0.06	0.08	0.1
1.75	51	48	46	45	44.5	44
2.75	49	46	44	43	42	41.5
3.75	47	41.5	38.5	37.5	37	36.5

Table 3. Dependence of running-in duration of CPM on factor ρv at different temperatures in friction zone

Temperature values in observations (T^0 , K)	Duration of running-in of Pentaplast ($t \cdot 10^2$, c) at different values of ρv					
	0.01	0.02	0.04	0.06	0.08	0.1
300	53.5	53	52	50	47.5	44
306	51.5	51	49.5	47	43.5	38.5
312	49.5	48.5	46.5	44	40	33.5

The analysis of the results of the study shows (Fig.1-5, tab.1-3) that among the studied polymeric materials, the smallest value of the duration of the running-in period is observed in polypropylene and Furano-epoxy polymers. Pentaplast has the lowest steady-state value of the friction coefficient; despite the glass transition temperature, the elastic modulus and microhardness of pentaplast are higher than those of Furano-epoxy compositions. This is apparently due to the structural feature of the pentaplast, the presence of symmetrically located chloromethyl groups, which shield the main polymer chain from external influences.

4 Conclusions

1. The process of running-in in polymeric materials during friction with fibrous materials is accompanied by changes in the surface properties of polymers. These changes, in turn, affect the physical, mechanical, and tribological properties of polymers, especially in the initial friction period.

2. After a certain time, the tribo-technical parameters stabilize, and stabilization in time occurs according to the following sequence: first, the triboelectric charge density (q) is stabilized, then the temperature in the friction zone (T_{fr}). At the end, the friction coefficient (f), i.e., a ranked series $q < T < f$, is formed, which does not depend on the type and property of the material.

3. Based on the analysis of the research results, the friction coefficient was chosen as the main factor determining the duration of the running-in period of polymer materials in friction with fibrous materials, after stabilization of the value of which the running-in process is considered completed, i.e., the friction pair was completely run in.

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