

Frictional transfer and the self-organization phenomenon in the friction

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Abstract. The paper is devoted to the investigation of the mechanism and kinetics of the surface structures formation in the process of metal-polymer frictional contact. IR spectroscopy methods have showed that the formation kinetics of a frictionally transferred film is determined by the adhesion of the composite components and the direction of the electric field at the contact.

The phenomenon of energy and matter transfer plays a determinant role in many technological and operational processes, including friction units of rolling stock. All polymer self-lubricating materials form a transferred film having the properties of a lubricant. The lubricating action of such a film is defined by the polymer nature, its structure, components, counterbody material, and roughness.

As is known, in closed systems processes pass in the direction of increasing entropy and establishing an equilibrium state.

As for tribosystems, they are open systems, exchanging matter and energy with each other and the environment. Being nonequilibrium, tribosystems can develop unpredictably even under the same operating conditions. If there is no possibility to impose a development path for closed systems, then such a path can be selected for an open tribological conjugation system taking into account the inherent elements of self-regulation.

Structural self-organization is carried out due to the formation of secondary structures. The composition and properties of surface structures are determined primarily by the material of the frictional pair [1, 2]. As for metal-polymer tribosystems, there is no doubt that a film transferred from a polymer sample to a metal counterbody has a significant effect on the friction and wear of the metal-polymer conjugation. However, the kinetics and mechanism of friction transfer have not been studied sufficiently. In particular, the role of temperature, triboEMF in the formation of the frictionally transferred film has not been clarified. Besides, the qualitative and quantitative composition of transferred films has not been evaluated as well. A set of methods was used to investigate the mechanism of the surface structures formation of in the process of metal-polymer frictional contact. The methods are characterized with a high sensitivity to changes both on the friction surface and in the structure of the materials selected for the study.

As a result of a purposeful search, such thermoplastic polymers as Polycaproamide PCA and Phenylone C2 were chosen as polymeric binders for antifriction composite materials. F4MBP polytetrafluoroethylene powder in an amount of 5–10 wt. % was selected as antifriction filler. Nanodimensional additions of manganese spinel (40–100 μm) with a concentration not exceeding 1.5–3 wt. %. were introduced into the composite in order to improve its characteristics. After



obtaining the nanodimensional components on a MicroCer bead mill, a size analysis of particles in the range of 0.01 to 40 μm was carried out using a CPS24000 measuring system.

The process of samples formation consists of several stages. The briquetting of Phenylone C-2 powder with fillers in a mold is carried out without heating at a pressure of 500 kg/cm^2 . Drying of the obtained briquette of Phenylone with fillers is carried out at 200 $^{\circ}\text{C}$ for one hour. Hot briquettes are placed in a preheated mold and maintained for 1 min. Then they are pressed at temperature of 320–340 $^{\circ}\text{C}$ and at a pressure of 500 kg/cm^2 for 1 min. Final operation is the sample cooling together with the mold to 100 $^{\circ}\text{C}$, followed by pressing out the finished sample.

Tribological tests were carried out at a fixed speed of sliding and a stepped loading on the friction machine AI-5018 by a «finger-roller» scheme. The finger was made of composite material, and the roller was made of steel 45.

The tests were carried out at a roller speed of 3 rev/s and a discretely varying load (in the ranges of 209, 310, 420, 520, 620, 720, 820, 920, 1020 N) with a constant registration of the friction coefficient (figure 1). After the end of the test, the amount of wear of the polymer sample and the roller was determined as the difference between the weight before and after the tests.

Besides, tribological tests were carried out on the end type friction machine «finger-flat disk» constructed in the laboratory at loads $P = 2$ MPa and sliding speed $V = 0.5$ m/s (figure 2). Such construction of the machine allows controlling the condition of tribomating surface, the presence, the kinetics of formation and stability of the friction transfer film or a lubricating film in any time intervals, without disturbing the surface.

We investigated the mechanism of the transferred film formation on the counterbody's metal surface to determine the causes of low friction and high wear resistance of composite polymeric materials with antifriction fillers and nanodimensional additives. The investigations of the elemental composition and chemical bonding of transferred films on a surface with a metal counterbody, as well as the depth of films were carried out using IR spectroscopy.

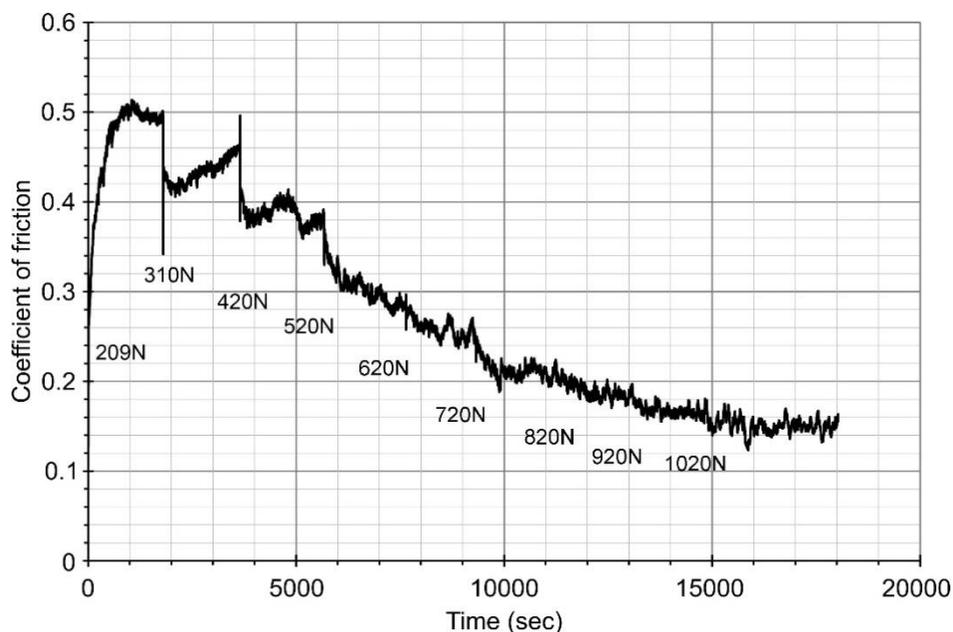


Figure 1. Dependence of the friction coefficient of Phenylone C2 + 10 % F4MB composite on the time at different load values («finger-roller» friction scheme).

As a result of tribological researches, it was established that some polymers like Polycapraamide PCA, Phenylone C2 possess rather strong adhesion at friction to the metal counterbody and do not form a highly oriented film. While the other polymers like polyethylene HDPE and fluoropolymer F4MB have weak adhesion to the metal, but differ in their ability to form transferred particles of friction

polymer with a small tangential drag and a thickness of 0.1...0.3 μm .

For the research of tribocontact surfaces by FTIR spectroscopy of MFTIR we got flat samples with the test surface is not less than 10×30 mm. The design of the end friction machine allows controlling the status of the tribomating surface, i.e. the presence, the kinetics of the formation and stability of the frictionally transferred film in any time intervals without disturbing the surface. To study the surface is necessary to record the reading of FTIR spectroscopy spectra of tribomating surface at different times of tribocontact and determine the ratio of the line intensities in the spectra in different frequency ranges, related to the various components.

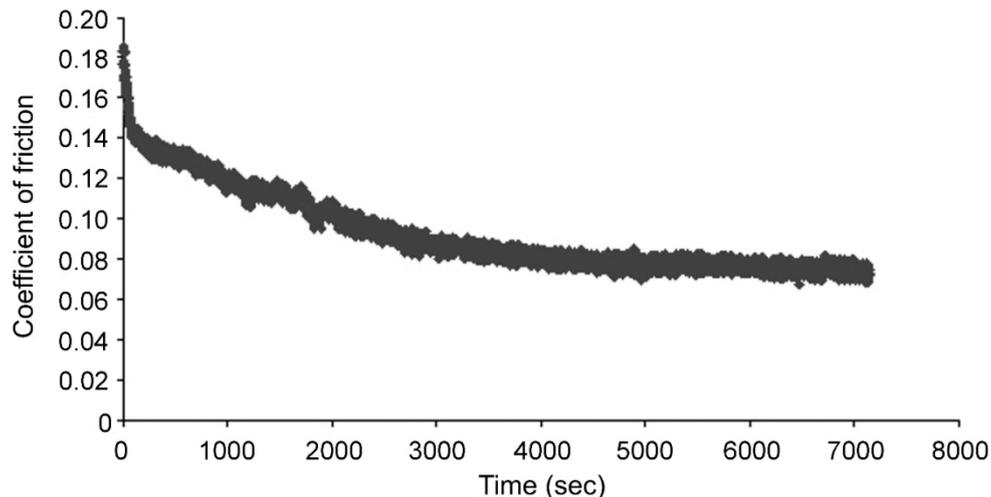


Figure 2. Dependence of the friction coefficient of Phenylone C2 + 10 % F4MB composite on the time obtained on the end type friction machine.

Typically, when recording spectra for the qualitative analysis and for determining the presence of the film on the tribomating surface, most intense lines are selected, for example, lines of valence vibration of C–H polymer molecule (2800–3200 cm^{-1}). The appearance of the absorption bands of symmetric (2900–2870 cm^{-1}) and an asymmetric valence vibration (2990–2950 cm^{-1}) in MFTIR spectrum is the criterion for the presence of a frictionally transferred film in the tribomating area. Deformation vibrations (1000–1350 cm^{-1}) and bands of adjoint oxidizing C=O bonds (1450–1750 cm^{-1}) are more informative while studying the destruction process of the polymer molecule and the structural changes in the surface layer of the sample.

The intensity and energy position of these bands is sensitive to breaks in polymer chain, adjoint end groups, chemical elements and compounds formed at tribomating. The conclusions about these processes can be made by comparing the intensity and the energy position of the spectra lines obtained from the friction surfaces with the spectra of initial polymer compositions.

The presence and condition of the frictionally transferred film at friction with various tested composites studied under different loads and tribomating times were evaluated based on analytical lines in the FTIR spectra of the friction surfaces

As a result of conducted researches it was also established that the formation process of transferred film takes place in several stages. At first mainly due to products of binding friction transfer, as at the initial stage (20–40 min) only phenylone bands 1300–1750 cm^{-1} are recorded in MFTIR spectrum and their intensity is relatively weak (figure 3, curve 1). Then an increase of friction transfer products of F4MB filler takes place (figure 3, curve 2). In the spectrum the bands of valence bond CF (1150–1200 cm^{-1}) appear. Their intensity is increasing with time of tribocontact until the process stabilization (60–90 min).

We carried out a range of studies determining the triboEMF on the transferred film during its formation to confirm that the antifriction layer of F4MB products is retained on the first PCA by

electrostatic forces. It was proved that at the first stage of the film formation the charge sign is positive due to products of frictional transfer of the binder composite.

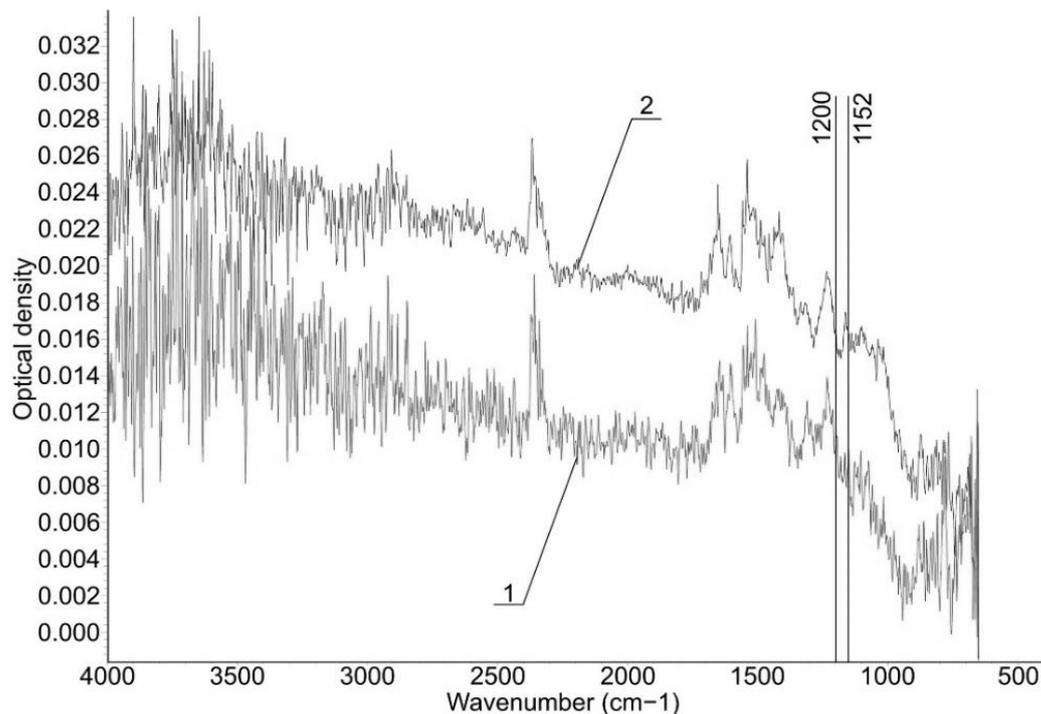


Figure 3. FTIR spectra of the frictionally transferred films on a steel disk while tribomating with composites Phenylone C2 + 20 % F4MB at the load 2 MPa and the sliding velocity of 0.5 m/s for different times of tribocontact: (1 – 30 min; 2 – 60 min).

At the second stage, when there is an increase of F4MB products, the charge sign is negative. The obtained result suggests the following mechanism of the polymeric PFP formation. First, the wear products of the binder are firmly retained by adhesion on the metal counterbody's surface at friction. Then, the wear products of the F4MB filler form a second layer, which is retained by the electrical forces on the binder due to their heteropolarity. As a result, a highly oriented transferred film is formed on the metal counterbody, which makes it possible to provide a small coefficient of friction.

Acknowledgment

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References

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