The functional relationship of tribological and anti-icing properties of multifunctional ultrathin fluoropolymer coatings

A S Vokhidov

“Avtostankoprom” (ASPM), 190020, Saint Petersburg, Russia

E-mail: rvokhidov@list.ru

Abstract. The paper discusses the relationship between the physicochemical properties of film-forming polymer fluorine compounds, which form the so-called Langmuir-Blodgett structures on a treated surface in the form of ultrathin coatings and nanosize films, giving the treated surface tribological, anti-icing, and hydrophobic properties.

1. Introduction

The world experience of using tribosystems in combination with synthetic oils shows that they provide a standard ultrathin film. The C–H bond in the oil molecule is covalent to forming a thick oil layer on the metal surface and regulates frictional forces, where the thickness of the oil film is limited by the oil molecule height in dynamics. Oil molecule interacts with the metal surface due to hydrocarbon and fluropolymers chains, where their branching is greater, and in synthetic ones, due to a set of hydrocarbons; in mineral oils, there is a variation in the interaction length is intermittent. The physicochemical properties of thin-layer coatings (epilamizing) tribosystems lead to the interaction between the oil and the positive surface charge (quantum charge). Despite the fact that synthetic oils containing polyalphaolefins and esters give the thinnest film, an oil molecule interacts with the metal surface due to hydrocarbon chains. In some cases, tribosystems can be components of anti-icing film-forming compositions, as they not only have anti-friction properties (reducing ice and snow friction), but also hydrophobic and anti-corrosion ones. The study and application of fluropolymers is a promising area, as molecules of fluorine-containing tribological preparations orient themselves under the action of a solid body and are bonded to the surface by chemisorption forces.

2. Research of the anti-ice characteristics of ultrathin fluoropolymer coatings

The research of the surface morphology was carried out using a NTEGRA probe nano-laboratory by NT-MDT. Using the method of atomic force microscopy, we studied the morphology of a monomolecular layer: the surface of Langmuir-Blodgett films obtained by applying a thin coating. In the imaging, it is easy to see that a layer of oriented molecules is formed on the coated (epilamized) surface, that not only radically changes the surface energy: molecules – polymeric fluoride compounds form the so-called Langmuir-Blodgett structures in the form of a thin coating and a uniform monolayer.

The wetting angle is measured in various available ways, by determining the marginal wetting angle, where we obtained values of 91 to 124 degrees. A LK-1 electronic goniometer with a Levenhuk C130 digital camera was used to measure the wetting angle. The images were processed using a special software.
Figure 1. The profilogram treated surface by de-icing composition "FLUORA-C».

Figure 2. Without coating and with anti-ice coating parts of the wheel (the right half coated by anti-ice composition "Fluora-C").

It is known that the charge of molecules reduces the surface energy of a material, to be adsorbed, chemisorbed by the hydrophilic tail (the polar layer), whereas the hydrophobic tail remains on the surface (the non-polar layer). There are different activation methods, for example, the ultrasonic one. In the papers by V E Panin et al., the use of ultrasound accelerates the diffusion and adhesion processes when applying a coating with different materials [1]. This source indicates that the analysis of the ultrasound effect on the structure is determined by the penetration of ultrasound (and charges) into the coating liquid phase layer; this changes the structure of the alloy (material) properties, reducing the grain size. The previous works [2] discussed the mechanism for activating the composition structure under the influence of ultrasonic vibrations, which represents a specific process affecting the composition structure.

3. Analysis of the tribology parameters of ultrathin fluoropolymer coatings

There are other achievements in the field of molecules activation, where chemisorption effects are formed by a set of photons, rather than by electromagnetic waves resulting from Maxwell’s equations [3, 4], which reflects the experimental data about the absence of magnetic charges on the treated surface. It is worth noting that a high adsorption capacity at the liquid – solid body interface is determined by the nanofilm adsorption rate, what is often described by the following equation [5]:

\[ \alpha = 0.856 \times 10^{-11} + 8.900 \times 10^{-7} \ C. \]

This corresponds to a linear dependence in the Henry isotherm area, i.e. the initial stage when the first adsorption layer is formed.

Tests of the resulting coating corrosion resistance as per the State Standard GOST 9-308-85, method No. 6, showed resistance to the higher values of relative humidity (58%) and temperature (the ambient temperature was 22 °C) with periodic water condensation, whereas the assessment of the corrosion damage to the coating in a G-4 climate chamber after 6 test cycles was 10 points (without damage). Positive corrosion resistance results were also obtained by adding the composition to the “Liquid Key” product and tests as per GOST 9490-75, where the coated metal surface withstands corrosive effects. When applying the liquid, the coating was fixed by molecules deposition and chemisorption, which allows to obtain an unremovable monolayer film with a thickness of 4 to 10 nm. The monolayer chemisorption reduces the surface energy and thereby facilitates the formation of new, smoother and more resistant, surfaces in the interaction (friction) of materials.

We compiled a spectral report on the use of protective coating “Epilam ElektronikA” on ZnSe samples with a BBAR antireflection coating of 2 to 15 um. Were studied the spectra of ZnSe BBAR samples of 2 to 15 um before and after applying the Epilam ElektronikA protective coating on both
sides of the sample. Absorption spectra in the Epilam ElektronikA film were obtained by subtracting the sample spectrum with the film from the sample spectrum before applying the film. The absorption bands of 3.4 um, 5.9 um, 7.3 um, 7.8 um correspond to C–H vibrations; the bands of 8 to 9 um, to C–F vibrations in organic molecules.

![Absorption Spectra](image)

**Figure 3.** Spectra of ZnSe BBAR samples of 2 to 15 um before and after applying the Epilam ElektronikA protective coating on both sides of the sample.

On the N2-3 sample with the greatest intensity of absorption bands, the protective Epilam film was muddy with stains; on the remaining samples, it was clear.

Reflection spectra from the side of ZnSe samples with no BBAR antireflection coating of 2 to 15 um, but with protective Epilam ElektronikA coating. Due to the fact that ZnSe does not transmit radiation shorter than 480 nm, we can see the absorption of radiation reflected from the surface of ZnSe in the Epilam film. We can see that the absorption is noticeably greater in sample 2–3 than in the rest; for comparison, we added the reflection from a plain ZnSe (without film) on the plot. Interference radiation waves on film thickness in UV correspond to film thickness less than 80 nm; the refractive index of the Epilam film is about 1.6. The plots were obtained by subtracting the reflection spectrum from the sample side with Epilam ElektronikA film from the reflection spectrum of a plain ZnSe.

### 4. Conclusions

Tests of tribological parameters using the method developed by the State Scientific Institution “All-Russian Research Technological Institute for Repair and Maintenance of Machine and Tractor Fleet” on a universal lubricant testing device UTSM-1 (tribometer) showed that the values of maximum load before burring were equal to 140 Nm with the wear spot length of 4 mm. For reference: when using mineral oil, the maximum load value is 40 Nm, the wear spot length is 10 mm.

To date, we can assess the effectiveness of the used film-forming composition, i.e. the amount of change of the surface energy, by measuring the wetting angle, studying the coating morphology, and evaluating the adhesion of external factors to the surface.

### References

[1] Panin V E, Klimenov V A et al. 1993 (Nauka, Siberian publishing company) 152

[2] Vohidov A S and Dobrovolsky L O 2011 (St. Petersburg, Films and coatings)
[3] Putilin E S 2010 Textbook (SPb: SPbSU ITMO) 227
[4] Ryss I G 1956 (Moscow)
[5] Ryabinin N A 2002 (April 2002) 16–8