Evolution of tribological properties of the composite coatings on AMg3 aluminum alloy after atmospheric exposure

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The formation of wearproof protective surface layers on aluminum and its alloys is an important scientific and practical task [1]. One of the possible ways to solve this problem is the creation of the composite polymer-containing coatings [1, 2]. Plasma electrolytic oxidation (PEO) could be a suitable method for such composite layer formation. The results of our research indicate a high level of protection provided by such coating to aluminum alloy [3, 4], however, it is necessary to verify the obtained parameters under appropriate exploitation conditions. In this regard, studies have been carried out on the evolution of tribological properties of the PEO-coating sealed with fluoropolymers during the one-year atmospheric testing in natural condition.

For the formation of PEO-layers on AMg3 aluminum alloy sheets with size of 50 × 50 × 2 mm, a two-stage bipolar mode was used. At the first stage the voltage during the anode period was increased from 30 to 540 V at a rate of 3.4 V/s, and then the voltage value was maintained at 540 V for 750 s. The electrolyte contained 20 g/L $Na_2SiO_3 \cdot 5H_2O$, 10 g/L $Na_2B_4O_7 \cdot 10H_2O$, 2 g/L NaF and 2 g/L KOH.

To form PVDF/SPTFE-coatings, SPTFE particles were added to the PVDF solution in various proportions 1:1, 1:2, 1:3, 1:4, 1:5. Then the samples were dip-coated using respective suspension and dried at 65 °C for 3 h (Fig. 1).

For comparison, coatings were obtained by applying both polymers separately. 15 % suspension of superdispersed polythetrafluoroetylene (SPTFE in isopropyl alcohol) was used to form composite coating on the sample with the PEO-layer by dip-coating method (SPTFE sample). The samples were then heat treated at 315 °C for 15 min to provide the best pores filling with a fluoropolymer material. The PVDF-layer was formed by immersing the sample in a 6 % solution of polyvinylidenefluoride (PVDF) in N-methyl-2-pyrrolidone followed by drying at 70 °C for 2 h (Fig. 2).

The atmospheric corrosion testing of the samples during one year exposure was carried out at the Marine Corrosion Test Station of the Institute of Chemistry of FEB RAS, located on Russkiy Island, Rynda Bay.

The morphology of the PEO- and composite coatings was investigated by scanning electron microscopy (SEM) using equipment from Carl Zeiss Group. Tribological tests were carried out at a load of 10 N and a linear rotation speed of 50 mm/s of corundum ball.

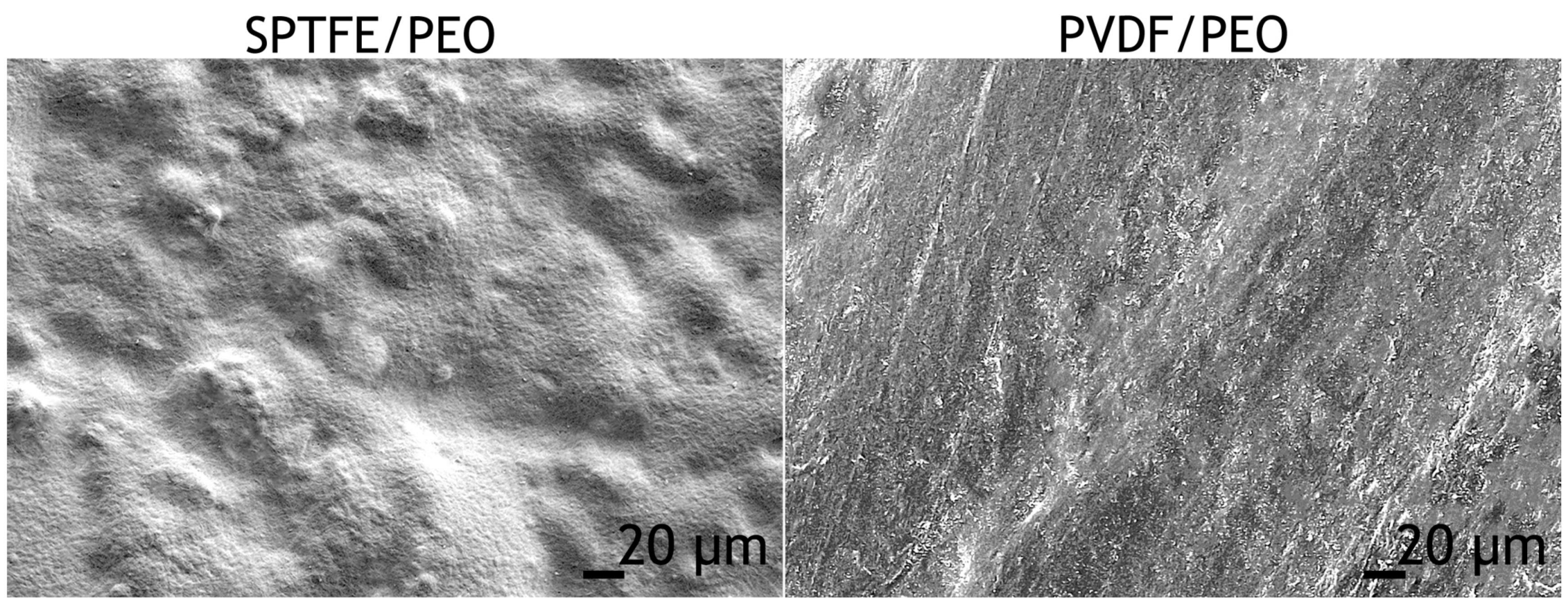

Fig. 2. SEM-images of the composite coatings formed on the sample with the PEO-layer

The electrochemical studies of the samples with the protective composite coatings previously carried out in [4] established that the layers obtained by applying a mixture of PVDF and SPTFE at a ratio of 1:5 have shown a very good results of the corrosion protection. To assess the impact of the corrosive environment on the tribological properties, the samples with composite coatings were texposed to atmosphere for 3, 6, and 12 months. The results of tribological testing demonstrate that all composite layers have a low wear ($9.7 \cdot 10^{-5}$–$4.4 \cdot 10^{-4}$ $mm^3/(N \cdot m)$) and significantly reduce the coefficient of friction, which increases from 0.03–0.06 to 0.54–0.58 due to uniform abrasion of the polymer film to aluminum substrate (Fig.3).

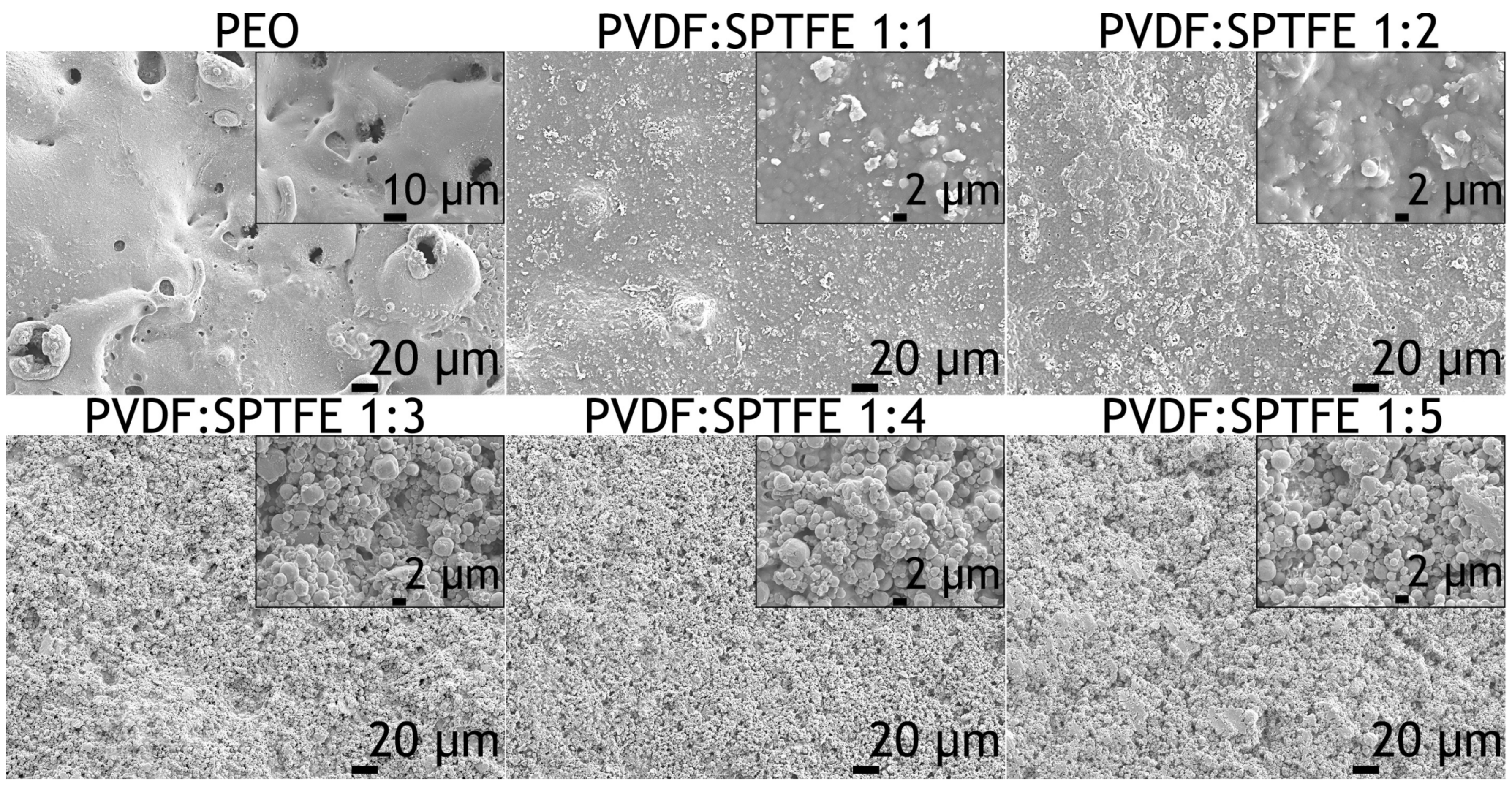

Fig. 1. SEM-images of the PEO-layer and composite coatings formed on the AMg3 aluminum alloy

Analysis of SEM-images of the PEO-coating indicates that the base PEO-layer has a developed surface morphology, expressed in the presence of a large number of pores and microdefects (Fig. 1). The application of CC-PVDF and CC-SPTFE layers leads to a significant increase in surface relief uniformity and a decrease in the number of microdefects and pores (Fig. 2). The study of the morphology of combined coatings allows us to conclude that an incorporation of fluoropolymer materials in a ratio of 1:1 and 1:2 does not lead to significant increase in surface uniformity. As the concentration of SPTFE microparticles in a PVDF solution increases, there is an increase in the uniformity of surface morphology and in the number of pores and microdefects filled with fluoropolymers. Moreover, when the proportion of PVDF and SPTFE reaches 1:3–1:5, the agglomeration of particles is observed, which leads to the formation of a multimodal surface roughness (Fig. 1).

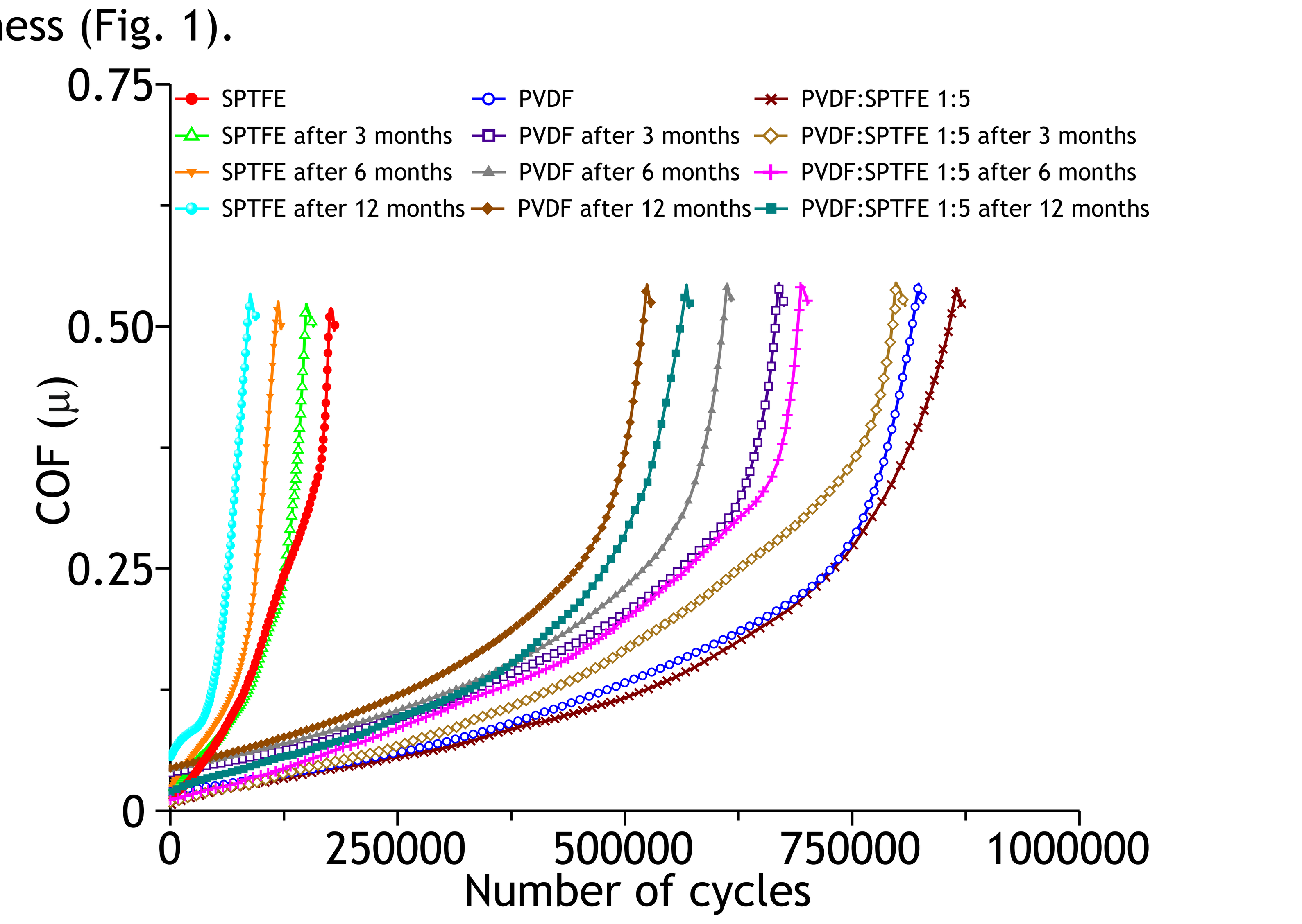

Fig. 3. Dependences of the friction coefficient on the number of cycles for samples with polymer-containing coatings

It has been established by tribometry that an increase in the duration of climatic tests up to 12 months for all types of composite coatings leads to a decrease in their wear resistance by 1.5–2 times. The largest decrease in the number of cycles is observed in the SPTFE coating (from 174.6 thousand to 86.6 thousand revolutions), which is associated with its thinner thickness compared to PVDF and PVDF/SPTFE coatings. For the last two c of similar thickness, the number of cycles decreased from 823.9 thousand to 525.1 thousand and from 864.9 thousand to 556.6 thousand cycles, respectively.

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[1] V.S. Egorkin, I.E. Vyaliy, N.S. Sviridov, A.N. Minaev, S.L. Sinebryukhov, S.V. Gnedenkov. Defect and Diffusion Forum 386 (2018) 315–320.
[2] S.V. Gnedenkov, S.L. Sinebrukhov, D.V. Mashtalyar, V.S. Egorkin, A.K. Tsvetnikov, A.N. Minaev. Protection of metals 44 (2008) 67–72.
[3] S.V. Gnedenkov, S.L. Sinebryukhov, V.S. Egorkin, I.E. Vyalyi, D.V. Mashtalyar, K.V. Nadaraia, D.K. Ryabov, V.M. Buznik. Russ. J. Inorg. Chem. 62 (2017) 1–11.
[4] V.S. Egorkin, D.V. Mashtalyar, A.S. Gnedenkov, V.S. Filonina, I.E. Vyaliy, K.V. Nadaraia, I.M. Imshinetskiy, E.A. Belov, N.V. Izotov, S.L. Sinebryukhov, S.V. Gnedenkov. Polymers 13 (2021) № 3827.