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TRIBOLOGICAL PROPERTIES OF OXIDE COATINGS PRODUCED ON EN AW-5251 ALLOY USING DIFFERENT DISTANCES BETWEEN ELECTRODES

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Abstract: The subject of the presented work was the analysis of the influence of the distance between the electrodes using in the coating process on the tribological properties of oxide coatings. Oxide coatings were prepared on EN AW-5251 aluminum alloy samples. The samples surfaces were subjected to hard anodizing process in a multicomponent electrolyte based on sulfuric acid with an addition of organic acids. Anodizing was carried out with a constant electric charge density of 180 $A \cdot min/dm^2$. The distances between the electrodes for subsequent samples increased every 0.125 m up to 1 m. The tribological partner in a sliding couple with oxide layers was pin of PEEK/BG. Tribological tests were conducted on a T-17 tester in reciprocating motion, in technically dry friction conditions. Before and after tribological test, examination of the geometrical structure of counter-specimens' surface was carried out using the Form Talysurf contact profilographometer, via a 3D method. The most satisfactory tribological parameters were obtained for the PEEK/BG association with the coating produced at a distance between the electrodes equal to 0.25 m.
Keywords: anodic oxide coating, distance between electrodes, tribological properties

1. INTRODUCTION

The sliding association commonly, which allows to obtain high reliability and durability of devices, are those which cooperate with each other metal-plastic pairs (Friedrich, 2018). Increasingly, oxide coatings produced on aluminum alloys are also used in piston-cylindrical systems. One of example of such application can be an oil-less pneumatic cylinder. The cylinder is made of an aluminum alloy which is hardened internally by anodizing. The polymer ring provides the piston guidance on the cylinder surface (Bara, Służałek and Bąkowski, 2009). During work of such sliding association, the polymeric material is transferred to the cylinder's surface (Kmita and Bara, 2012). The wear of plastic in this type of associations is closely related to the material transfer process and the formation of a polymer sliding film (Korzekwa et al., 2016). Different dimensions of the anodized elements of piston-cylinder systems determine the use of various electrode distances in the anodizing process. Changing the distance between the electrodes, in turn, affects the change of the porosity of the coatings, which can cause excessive wear of the polymer ring, and thus decrease in the durability of piston-cylindrical devices.

The purpose of this article is to check how the change in the distance between the electrodes affects the tribological properties of the coatings associated with the popular sliding material.

2. MATERIALS AND METHODS

The oxide coatings were produced on the EN AW-5251 aluminum alloy. Samples with an area of 1×10^{-3} m^2 were etched in 5% KOH solution, and then in a 10% HNO_3 solution before the anodizing process. Anodizing of the surface samples was carried out in an aqueous solution of acids: H_2SO_4, $C_2H_2O_4\cdot2H_2O$. The addition of $C_8H_6O_4$ allows obtaining the hard layers at room temperature. Anodization was carried out using the constant current method using a stabilized GPR-25H30D power supply. The anodizing process was performed for 1 h at a current density of 3 A/dm^2. The electrolyte temperature was 296 K. The spacing between electrodes from 0.125 m to 1 m increased as 0.125 m for next samples. After anodizing the samples with the Al_2O_3 layer were rinsed in distilled water. The produced coatings have showed the surface porosity characteristic for Al_2O_3 coatings (Fig. 1a). The tribological partner in the sliding association with oxide coatings was a pin with a diameter of 9×10^{-3} m, made of PEEK/BG plastic. This composite, thanks to the addition of PTFE, graphite and carbon fibers to PEEK (Fig. 1b), provides high mechanical strength, high stiffness and hardness as well as reduced sliding movement resistance, even at higher temperatures (Lu and Friedrich, 1995).

a) b)

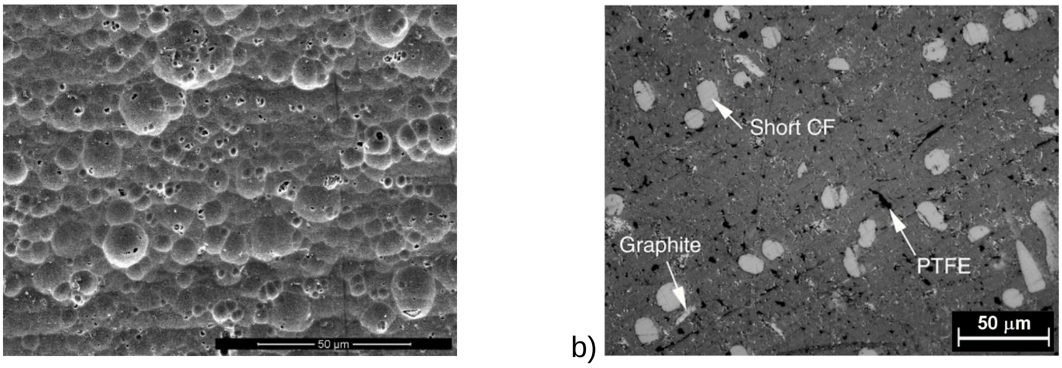

Fig. 1. Image of (a) the surface morphology of the oxide coating, (b) microstructure of PEEK/BG plastic (Zhang et al., 2004)

The thickness of obtained oxide layers was measured by Dualscope MP40 thickness meter. Ten measurements were made on the length of each sample and the average values were calculated. Tribological tests were conducted on a T-17 tester in reciprocating motion, in technically dry friction conditions. The tests were carried out in ambient temperature of 296 ± 1 K at relative humidity of the air of 40 ± 10%. A constant value of 1 MPa unit pressure and a constant value of average sliding speed, 0.2 m/s, were applied for all the investigated couples. The tests were conveyed on a 15-kilometre path of friction. The friction force was measured by means of Spider 8, analog-to-digital converter, using sampling of 50 Hz. The material wear values were determined using electronic analytical scales WPA 60, measuring to an accuracy of 0.1 mg. Prior to and after the tribological test, examination of the geometrical structure of samples surface was carried out, using the Form Talysurf contact profilographometer, via a 3D method. Data were analyzed from an area of 2×2 mm, with a sampling step of 2 μm.

3. RESULTS AND DISCUSSION

The thickness of all coatings was about 50 μm. The thickness measurements of coatings did not show significant differences resulting from the use of different electrode distances (Tab. 1).

Table 1
List of oxide layer thicknesses

Sample (distance of electrodes)	**A 0.125 m**	**B 0.25 m**	**C 0.375 m**	**D 0.5 m**	**E 0.625 m**	**F 0.75 m**	**G 0.875 m**	**H 1 m**
Thickness (μm)	50.5	50.7	51.1	50.3	50.3	50.5	50.7	50.3
Deviation (μm)	0.5	0.2	0.4	0.3	0.5	0.4	0.1	0.3

The results of the tribological tests are presented as the friction coefficient (Fig. 2) and wear for the PEEK/BG material (Fig. 3) as a function of the distances between the electrodes in the anodizing process.

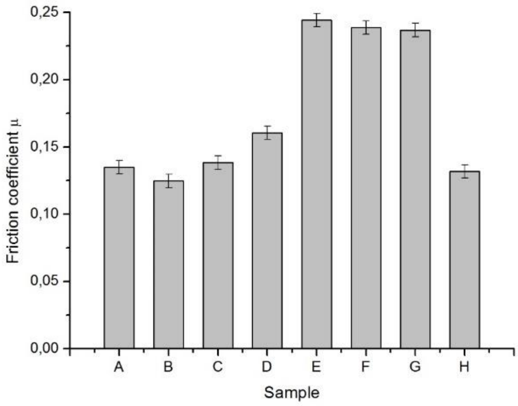

Fig. 2. The influence of the distance between the electrodes in the anodizing process on coefficient of friction

As a result of the tribological tests, in all cases the PEEK/BG material was transferred to the oxide surface. Macroscopic observations showed the influence of the distance between the electrodes in the anodizing process on the creation of the sliding film. Significantly better efficiency of polymer lubrication was obtained for the combination of PEEK/BG material with samples A-C and H, sliding film exhibited adequate thickness and good adhesion to the surface of the coatings (Fig. 4a). It was the result of good cooperation of triboelements and resulted in a low value of plastic wear (1.1 - 5.7 mg). The D-G surfaces exhibited a small covering of the coatings with a sliding film with several adhesions (Fig. 4b), which resulted in the higher value of friction coefficient and plastic wear (11.3 - 50.64 mg).

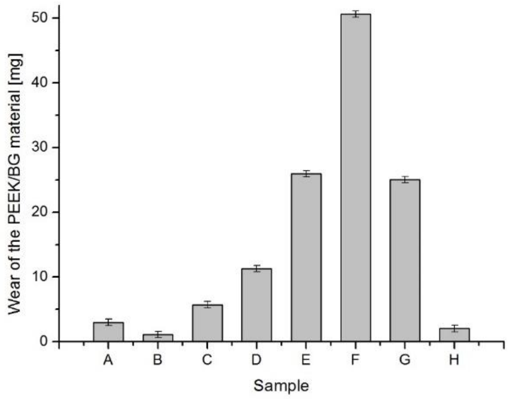

Fig. 3. The influence of the distance between the electrodes in the anodizing process on mass consumption PEEK/BG

The greater wear of PEEK/BG during association with oxide coatings is the result of "dusting of the material" (Fig. 4b).

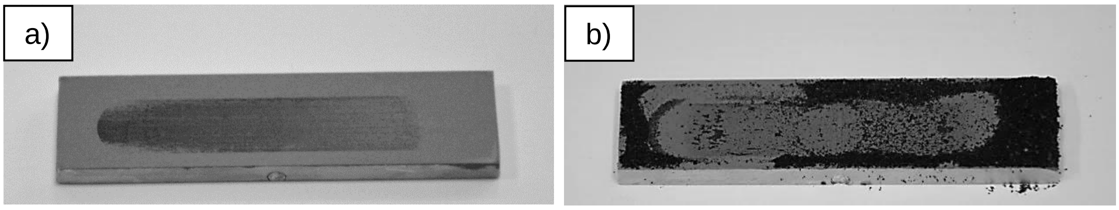

Fig. 4. The oxide coating after a sliding interaction with PEEK/BG: a) sample B, b) sample F

Stereometric tests of coatings carried out before sliding contact with PEEK/BG plastic did not show major differences in roughness that could affect the results of tribological tests (Table 2). The low values of the *Sa* parameter show a favorable roughness of the coatings intended for sliding associations with polymeric materials. As a result of tribological tests, there was a slight decrease in the values of coating roughness parameters. Only for the coating produced at the 0.75 m distance between the electrodes the increased roughness was noticed. The value of *Sa* parameter increased from 0.52 to 0.59.

Table 2
Roughness parameters of oxide coatings

Sample (distance of electrodes)	**A 0.125 m**	**B 0.25 m**	**C 0.375 m**	**D 0.5 m**	**E 0.625 m**	**F 0.75 m**	**G 0.875 m**	**H 1 m**
Sa before the test (μm)	0.45	0.56	0.38	0.38	0.38	0.52	0.56	0.37
Sa after the test (μm)	0.36	0.44	0.29	0.29	0.30	0.59	0.48	0.30

Changing the tendency to the lower *Sa* parameter could be caused by small thickness sliding film and adhesions formed on this surface.

4. CONCLUSION

Tribological tests of Al_2O_3 coatings in sliding associations with PEEK/BG material showed significant differences in the values of friction coefficient and wear plastic resulting by different technological parameters. The lowest wear value of plastic (1.1 mg) was obtained for PEEK/BG association with a coating produced at a 0.25 m distance between electrodes. For this association, the friction coefficient also had the lowest value (0.12). The PEEK/BG plastic usually has favorable low values of tribological parameters. However, research has shown that the oxide coatings produced at distances of 0.5 - 0.785 m, due to intensive wear of PEEK/BG plastic, are not suitable for sliding association with this material. The excessive wear of plastic caused by limiting of sorption of the oxide coating most probably resulted from changes in the porosity of the coatings, which interprets into a change in the nature of the sliding association. Coatings produced according to such parameters should not be used in oil-less kinematic piston-cylinder nodes.

Obtained results may be of interest in other areas of materials science e.g. special coatings technology (Pobedza and Sobczyk, 2013; Korzekwa et al., 2018; Radek et al., 2018), even in combustion applications (Opydo et al., 2016) or laser texturization of surfaces (Gadek-Moszczak et al., 2014; Radek et al., 2014). The data analysis methodology, what was used, may be also inspiring in similar investigations focused on material modifications e.g. (Dudek et al., 2010; Lipinski, 2015, Lipinski, 2018; Szczotok et al., 2018), image analysis methods (Gadek-Moszczak and Wojnar, 2009; Gadek-Moszczak et al., 2015) or even in museum revitalization of old military equipment (Karpisz and Kielbus, 2019), where the original noise level produced by kinematic pairs is unacceptable. Finally, the results should be widely disseminated in scientific and industrial databases (Gawlik et al., 2015).

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