Study of influence of micro-arc oxidation process duration on the characteristics of thermal control coatings for space applications

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Abstract. Thermal control coatings were obtained on the AMg6 aluminum alloy with the aid of micro-arc oxidation (MAO) process. The dependences of the thickness, roughness, porosity and thermal control properties of the coating on MAO process duration were studied. The thermal control properties (solar absorbance $\alpha_s$ and emissivity $\varepsilon$) were investigated by ultraviolet–visible–near infrared spectrophotometer instrument and solar absorption reflectometer. The analysis of thickness, roughness and MAO process duration influence on the thermal control properties of the coating was carried out.

Thermal control coatings for space applications are ordinary of white or black color. Black coating prepare in the electrolyte based on Na$_2$SiO$_3$, Na$_3$PO$_4$, NaOH, EDTA-2Na and NH$_4$VO$_3$, Na$_2$WO$_4$, KMnO$_4$, Cu(CH$_3$COO)$_2$ [1–6] as well as graphene [7] as additives. Aluminum and its alloys are widely used in space instrumentation. However, these materials have some disadvantages, the effect of which can be reduced by additional surface treatment. One of the most promising methods for surface modification is micro-arc oxidation (MAO).

To study the effect of the duration of the technological process on the thermal control properties, MAO was carried out on samples of the AMg6 aluminum alloy in the anodic-cathodic mode with a frequency of 50 Hz at a total current density of 10 A/dm$^2$ and equality of the anodic and cathodic currents. The coatings were formed in accordance with the method described in the patent [8]. The MAO duration was varied from 30 to 135 min for white MAO-coating, and from 15 to 45 min for the black ones.

The thickness of the obtained coatings was determined using VT-201 eddy current thickness gauge. The thermal control properties (solar absorbance $\alpha_s$ and emissivity $\varepsilon$) were investigated by ultraviolet–visible–near infrared spectrophotometer instrument and solar absorption reflectometer. The dependences of white and black coatings thickness on duration of MAO process are shown in figure 1.

Figure 1 shows that the thickness of the optically black MAO-coating has an almost linear dependence on the processing time. At the same time, for white MAO-coating, a thickness difference is observed in the interval from 105 to 120 min.

The dependences of coatings roughness on the duration of MAO process are shown in figures 2 and 3. The roughness of white MAO-coating increases with an increase in the pores density on the coating surface and their diameter, and decreases with a decrease in the pores density, while maintaining their
diameter. An increase in the size of globules formed by aluminum and silicon compounds also contributes to a decrease in roughness.

![Figure 1. The dependence of coatings thickness on MAO treatment duration.](image)

![Figure 2. The dependence of roughness on MAO treatment duration for white coatings.](image)

![Figure 3. The dependence of roughness on MAO treatment duration for black coatings.](image)

The roughness of black coating (figure 3) also increases at the initial stage, but becomes practically unchanged after 30 minutes of processing. This may be due to the fact that the surface does not have a pronounced globular morphology (figure 4), and the ratio of pore density and pore diameter is stabilized and remains unchanged with the continuation of processing.

Figures 5–7 show the dependence of thermal control properties (solar absorbance $\alpha_s$ and emissivity $\varepsilon$) of white coatings on its thickness and roughness.

The graphs presented in figures 5–7 show that with increasing thickness of the coating, solar absorbance $\alpha_s$ decreases and emissivity $\varepsilon$ increases. At a thickness of more than 50 microns, the radiation from the alloy is completely absorbed by the coating. At the same time, as the roughness increases, $\alpha_s$ increases and $\varepsilon$ decreases. This fact is explained by an increase in the total surface area, which allows more efficient heat dissipation, but also increases the absorption area of solar radiation.

At coating thicknesses less than 50 $\mu$m, the opposite picture is observed: with an increase in roughness, $\alpha_s$ decreases and $\varepsilon$ increases. With a small thickness of the MAO-coating, an increase in the total area makes it possible to more efficiently absorb the radiation of the base material.
Figures 8–10 show the dependence of the thermal control properties of black coating on the thickness and roughness.

Analyzing the changes in thermal control properties, thickness and roughness of black coating on the duration of the MAO-coating production process (figures 8–10), we can draw the following conclusions:

− at the initial stage, an increase in the thickness of the coating with an increase in the duration of treatment leads to a decrease in $\alpha_s$ and an increase in $\varepsilon$, and an increase in roughness corresponds to an increase and decrease in the coefficients of thermal control properties;

− after 25 min of treatment, an increase in the thickness of the coating leads to an increase in $\alpha_s$ and a decrease in $\varepsilon$ (figures 9, 10), and the roughness does not affect these indicators, while it reaches $Ra = 3.5$ and does not increase further.

The change in thermal control properties is probably explained by the peculiarity of the formation of black MAO-coating. With MAO, vanadium oxide is incorporated into the structure of the upper layers of the coating, like other components of the electrolyte. But due to the relatively large particle size, it practically does not penetrate deep into the coating. At the initial stage, the coating layer containing vanadium compounds grows, which leads to a decrease in $\alpha_s$ and an increase in $\varepsilon$. With further processing, the growth rate of the "vanadium layer" slows down, and the release of components from the depth of the coating through the pores increases. As a result, there is a change in the thermal control properties of the coating towards the class of "solar reflectors" characteristic of white MAO-coating that does not contain vanadium.
The thickness of the coatings increases with the duration of MAO treatment. The roughness of coatings is determined by the density of pores on the surface and their diameter and practically does not depend on the duration of MAO treatment.

As the thickness of white MAO-coating increases, solar absorbance $\alpha_s$ decreases and emissivity $\varepsilon$ increases. Whereas with increasing roughness, $\alpha_s$ increases and $\varepsilon$ decreases. However, at small coating thicknesses, the opposite picture is observed: with an increase in roughness, $\alpha_s$ decreases and $\varepsilon$ increases.

At the initial stage of black coating forming, an increase in thickness leads to a decrease in $\alpha_s$ and an increase in $\varepsilon$, and an increase in roughness corresponds to an increase in the both coefficients of thermal control properties.

For black coatings after 25 min of MAO treatment, an increase in the coatings thickness leads to an increase in solar absorbance $\alpha_s$ and decrease in emissivity $\varepsilon$.

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