Influence of electric arc treatment of inner surfaces of ceramic molds on the formation of the surface of titanium casting

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Abstract. Influence of the effect of electric arc titanium spraying on the inner surfaces of ceramic molds used for casting titanium was observed. Casting surface and cross-section were examined by electron microscopy with a probe microanalysis system and X-ray photoelectron spectroscopy. It was observed there is an “alpha case” on the casting surface. Its thickness and elemental composition varies through the casting surface.

1. Introduction
When obtaining castings from titanium alloys, a gas-saturated diffusion layer is formed in their surface layers consisting of titanium oxides and compounds containing elements of the mold called “alpha case”. It is characterized by increased hardness, reduced plasticity and tendency to crack formation. It’s an undesirable component of the alloy. One way to reduce the formation of the “alpha case” is the application of technological coatings to the inner surfaces of the molds by an arc method.

Objective: to investigate the effect of electric arc titanium spraying on the inner surfaces of ceramic molds used for casting titanium on the formation of casting surface.

2. Experiments
Arc spraying is a cold process of thermal spraying of metal on a product where the heating of its surface usually does not exceed 150 °C. This excludes changes in the structure of the product and its deformation. This method is used to deposit a coating of titanium on the inner surfaces of a ceramic mold to reduce the thickness of the alpha case. The arc spraying pistol circuit is shown in figure 1. Two wires are fed into the nozzle of the pistol, one of which serves as anode and the other is cathode. An electric arc lights up between them and wire begins to melt. Spraying occurs by the supply of compressed air. The process proceeds at a direct current.

Figure 1. Scheme of arc spraying pistol. 1 - current contact jaw, 2 - Ti wire.
This method has the following advantages:

a) high productivity (up to 40 kg/h of sprayed metal);

b) stronger coatings with high adhesion in comparison with the flame plating method;

c) wires from different metals makes it possible to obtain a coating - a "pseudo-alloy";

d) low operating costs.

The disadvantages of electric arc metallization are:

a) low speed of wire supply terminates to overheating and oxidation of the sputtered materials;

b) burning out of alloying elements of the sprayed materials.

Volt – ampere characteristic of an arc discharge is falling. Working regime: U=25 V, I=200 A, the feed rate of air ~150 m/s.

Ceramic mold consisted of oxides of Mg, Ca, Si, as a binder it was used liquid glass [1]. In the study a casting sample (figure 2) the separation surface of the mold and the cross-section of the boundary layers were considered.

![Figure 2. Photo of a casting sample.](image)

Samples were examined by electron microscopy with a probe microanalysis system (analysis depth 1-3 μm), the chemical composition of sample’s surface was studied by X-ray photoelectron spectroscopy (XPS) (depth of analysis is 5-10 nm).

3. Results and discussions

Electron microscopy researches showed that the sample surface is heterogeneous in structure. Light areas of the surface (Fig. 3, section 1) are characterized by an increased content of Fe, presence of Cr and Mn (Table 1). Since Cr and Mn are not inherent in a titanium alloy, and Fe is present only as an impurity (<0.25%), it can be concluded that these elements are introduced from outside. Most likely, they are the result of destruction of the cutting tool used to make the sample.

Despite the fact that before the test the samples were washed in an alcohol solution with an ultrasonic bath, this did not lead to the removal of oil-soluble impurities introduced into the sample under production conditions, as evidenced by the significant carbon content in all areas of the surface (table 1).

The areas of surface 2 and 3 characterize the “alpha case”. Apart from Ti and Al alloy elements (4% Al is included in the alloy), there are elements of the form: Si, Mg, Fe, and O. The elemental composition of considered sections (table 1) is different, which indicates the heterogeneity of the surface chemical composition.

To study the concentration profile of the samples’ chemical composition, slices were prepared in depth (figure 4). The dark area in electronic images refers to the compound where the sample was pressed. An analysis of the sample image showed that the sample is heterogeneous over the cross section. Light particles on the surface of the sample refer to the components of the grinding wheel, which were brought to the surface during grinding.
The outer layer of the sample is an alpha layer. Based on the electronic images (figure 4) and the map of the distribution of elements along the thickness of the section (figure 5), it is established that the thickness of the alpha layer varies from 2 μm to 14 μm.

Figure 3. Image of investigated sections of the casting surface.

Figure 4. Image of the cross section of the casting slice.
Table 1. The elemental composition of the surface portions of the sample (at.%).

| Regions of the surface | C   | O   | Mg  | Al  | Si  | Ti  | Cr  | Mn  | Fe  |
|------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1                      | 51.53 | 7.16 | 0.15 | 0.22 | 0.74 | 3.10 | 0.15 | 0.23 | 36.73 |
| 2                      | 28.46 | 9.28 | -   | 3.19 | 0.94 | 57.94 | -   | -   | 0.18  |
| 3                      | 26.27 | 21.03 | -   | 3.72 | 1.07 | 47.92 | -   | -   | -    |

Figure 5. The profile of the Ti concentration in the depth of the "alpha case".

The elemental composition varies through the depth of alpha case (table 2). Thus, an area 1 μm from the surface is characterized by an elevated content of the mold elements and carbon. When moving into the interior of the sample (a point at a depth of 3 μm from the surface), a decrease in the content of the shape elements and an increase in the content of the alloy elements (titanium and aluminum) is observed.

Table 2. The elemental composition of the surface portions of the sample (at.%).

| Distance from surface, μm | C      | O      | Mg   | Al   | Si  | Ti    | Ca   | Fe  |
|---------------------------|--------|--------|------|------|-----|-------|------|-----|
| 1                         | 50.87  | 26.27  | 0.14 | 0.96 | 0.95 | 18.89 | 0.36 | 0.23 |
| 3                         | 19.98  | 28.91  | -    | 2.61 | 1.05 | 47.21 | 0.17 | 0.06 |

4. Conclusion
The thickness of the “alpha case” for the TL-3 alloy, which was contacting a 25 mm thick casting, varies from 2 to 13 μm.

The “alpha case” has a variable composition in depth, boundary layers that close to the mold contain chemical elements of the form, and deep layers of the casting mainly contain oxidized titanium.

5. References
[1] A I Khatmullina, E Yu Petrov and A M Lyakhovich Research of boundary layers of molds, used in titanium casting 2017 8th Int. Science and Technical Conf.(Kazan) vol 1 (Kazan: OOO Folianth) pp 357-361

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