Research of boundary layers of molds, used in titanium casting

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Abstract. Boundary layers of the mold used for castings from titanium have been investigated by the method of electron microscopy with a system of probe microanalysis. Migration both components of mold and additives of titanium alloy is established to the surface layers of the form.

1. Introduction
Titanium is a metal that has a low specific gravity (titanium density is about 4.5g/cm3), but it has high specific strength. Pure titanium has high plastic characteristics. A sturdy, thin oxide film on the surface of titanium provides very high corrosion resistance. Titanium and its alloys are an important structural material for aviation, space, underwater technology, etc. The main problem of titanium alloys is the formation of a diffusion gas-saturated layer, which has a high hardness, reduced ductility, a cracking tendency, called the "alpha case". Many papers have been devoted to study of the alpha case, for example, [1-3]. Its formation occurs during casting, due to migration of mold elements and environment. The thickness of layer can reach several mm.

Objective: to research boundary layers of the mold used in the casting of titanium to identify the processes that occur during the formation of the alpha case.

2. Experimental
Mold composition MgO (83.2%), CaO (2.9%), SiO2 (1.9%), Na2O (SiO2) n (12%) was analyzed. The calculated content of chemical elements Mg: O: Si: Ca: Na (at.%) in the form is 41.9 : 50.3 : 2.7 : 1.0 : 4.1. The mold was sintered at a temperature of 1000 ± 50 ° C for 6 hours. Before sintering, casting mold was saturated with carbon dioxide to grasp its components. Then it’s cooling for 10 hours in the furnace.

There were two types of samples: the initial casting mold (figure 1 left) and the form after contact with the titanium casting (figure 1 right). “EVO 50 XVP” (Carl Zeiss) scanning electron microscope equipped with the probe microanalysis system “INCA Energy-350” was used to study the relief, elemental composition of the surface and the cross section of the mold.

3. Results and discussion
Three surface regions (figure 2 left) and six regions of the cross-section were investigated in the initial form. (figure 2 right).
It is established that in the sample there is a large number of pores located throughout the volume. The existence of regions with different structures was found on the mold surface. The relief of the cross-section is changing slightly. Investigation of regions of the surface with different structures showed that they differ in the elemental composition (table). The first section is characterized by an excess of the concentration of O and Ca with a reduced content of Mg compared with the calculated and average concentration. Probably, a significant increase in oxygen is associated with the formation of oxides with a higher degree of oxidation, and with formation of salts of carbonic acid. Carbonic acid is formed during the interaction of carbon dioxide with water present in the form.

![Figure 1](image1.png)

**Figure 1.** The samples of the original mold (left) and the form after contact with the casting (right).

![Figure 2](image2.png)

**Figure 2.** Image of the surface (left) and cross-section (right) of the mold before contact with the casting.

| Table. Element composition (at.%) of the mold surface prior to contact with casting. |
|---------------------------------|-------|-------|-------|-------|-------|
| **Element** | **regions** | **1** | **2** | **3** | **surface** | **mean** | **calculation** |
|-------|-------|-------|-------|-------|-----------|-------|-------|
| O     | 64.6  | 46.9  | 57.8  | 59.3  | 50.4      |       |       |
| Na    | 3.0   | 5.1   | 4.0   | 3.5   |  -        |       |       |
| Mg    | 18.2  | 35.5  | 25.6  | 26.6  | 47.7      |       |       |
| Si    | 3.8   | 7.8   | 5.8   | 6.4   | 0.8       |       |       |
| Ca    | 9.4   | 1.3   | 4.1   | 3.2   | 1.2       |       |       |
In the second section, the Si, Na content is greater than in the first section; the third region is characterized by an intermediate content of the elements, between the first and second area. A quantitative study of the elemental composition of the cross section showed that it is close to the average value of the surface composition and is practically the same at the depth examined (figure 3).

|   | Fe   | O*  |
|---|------|-----|
|   | 1.0  | 63.0|
|   | 2.5  | 70.1|
|   | 2.7  | 57.6|
|   | 0.5  | 56.75|
|   |      |     |

Figure 3. Change profile in the elemental composition of the mold.

Four regions of the surface (figure 4 left) and five sections of the cross section (figure 5 left) of form after contact with titanium casting were examined. The relief of the sample surface is uneven, there are depressions and elevations, for which a different elemental composition can be characterized (figure 4 right). This indicates that the mold is separated from the casting by layers located at different distances from the casting. The presence of titanium on the separation surface of the mold can be determined by the migration it from the casting.

Figure 4. The relief image (left) and the elemental composition (right) of the investigated surface regions after contact with the casting.

The cross section of the mold was obtained by its splitting. It has a rough structure. The distribution of elements along the cross section is the same and similar to the composition of the cross section of
the mold without contact with the casting (figure 5 right). It follows that the interfacial layer remaining on the surface of the casting is very thin; most of the interfacial layer remained on the casting.

![Figure 5](image)

**Figure 5.** Image of the cross section (left) and the elemental composition (right) of the investigated regions after contact of the mold with the casting.

4. Conclusions.
There is an increased content of O, Si, Ca and Na in comparison with the calculated values in the boundary layers of the initial mold. Perhaps this is due to the migration of these elements from the mold volume.

There are regions characterized by a different structure and element composition on the surface of the form.

After mold contact with the casting, we observe a migration of titanium to the surface layers of the mold.

Most of the interfacial layer remains on the casting, after peeling off mold from casting.

5. References
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