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FOUNDRY

Highly Thermostable Ceramic Molds for Shaped Castings of Titanium Alloys

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Abstract—The questions of applying the organoaluminum and yttrium aluminum binders when fabricating high-thermostable ceramic corundum molds are considered. This technology is a promising direction in the formation of ceramic shell molds for intricately shaped high-duty investment castings made of titanium alloys. The use of silica-free binders, which possess a series of advantages when compared with many currently widespread ones, in casting houses makes it possible to solve many questions associated with the thermochemical stability of ceramic forms, as well as to decrease the volume of finish operations and rejects during casting parts made of chemically active metals and alloys, thereby providing an increase in the quality of exact important castings.

Keywords: casting with investment patterns, corundum ceramic form, ethyl silicate binder, organoaluminum binder, yttrium aluminum binder

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INTRODUCTION

Titanium and its alloys, due to their high properties such as low density, high strength, good corrosion resistance, cool resistance, nonmagnetic state, and a series of other valuable physicomechanical characteristics, are applied in various branches of industry.

The tendencies of the development of the modern production of cast products, especially high-duty parts, dictate the necessity of a continuous increase in quality, accuracy, and operational reliability. In connection with this, the fraction of complexly shaped castings of titanium alloys, which are formed by casting into ceramic molds by investment patterns, increases.

However, the formation of cast parts using such materials is associated with definite technical complexities. In particular, titanium and its alloys in the molten state actively interact with most refractory materials. This phenomenon results in the formation of a contaminated surface layer with an increased content of interstitial impurities (oxygen, nitrogen, and carbon) in a casting, which lowers the operational reliability of cast titanium products because of increased sensitivity to the stress concentration [1].

The surface layer is saturated with impurities, first and foremost, because of the physicochemical interaction of metal with gases isolated from the ceramic mold, as well as during the immediate contact with its material.

One way to increase the thermochemical stability of the molds is to select initial binder and shaping compositions that are more inert with respect to titanium and which exclude the immediate contact of the product metal with the mold material [2].

Casting molds currently in use possess a series of substantial disadvantages. The molds based on carbon materials possess the largest chemical stability with respect to titanium. They have found broad application both in domestic and in foreign practice. However, the application of graphite as the mold material for casting titanium alloys considerably increases the laboriousness, cost, and time of fabrication process of castings. In addition, the production of graphite molds is associated with environmentally negative factors, in particular, with the isolation of graphite dust, phenol, and heavy hydrocarbons.

The use of ceramic molds based on silica binders (ethyl silicate and silica sols) is retarded by the formation of a glassy gas-saturated layer with a very high hardness on the casting surface, which cracks during operation. This leads to the appearance of large complexities in mechanical treatment and negatively affects the operational characteristics of products

Comparative characteristics of binders

Binder characteristic	Organoaluminum	Yttrium–aluminum	Sol silicates	Ethyl silicate
Oxide after thermal treatment	α-Al_2O_3	$xAl_2O_3 \cdot yY_2O_3$	SiO_2	SiO_2
Readiness to use	Ready binder		Ready binder	Hydrolysis process is required
Ceramic mold refractoriness, °C	>1800	>1800	1500	1500
Mold stability to the alloy effect	Chemical inertness to refractory and titanium alloys		Interacts with components of the refractory titanium alloy with the formation of the hard-to-remove burning-in and gas-saturated layer	
Binder persistence in a closed vessel, days	Unlimited		Unlimited	10–30
Suspension persistence in a closed vessel, days	Unlimited		Unlimited	1–5
Drying the ceramic mold layers	Chamber with humidity higher than 90%		Convective drying	Vacuum-ammonia chamber

especially operating in conditions of long-term alternating-sign loads and vibration [2–4].

A promising way to eliminate the surface glassy gas-saturated layer is the creation of highly refractory and thermochemically stable ceramic molds, which should provide refractoriness to 2000°C and form a chemically inert barrier layer [5–8].

Organoaluminum and yttrium aluminum binders for casting with investment patterns were developed at the State Research Institute of Chemistry and Technology of Organoelement Compounds based on organoaluminum compounds [9, 10]. Jointly with collaborators at the Moscow Aviation Institute, the fabrication technology of silica-free ceramic molds by investment patterns for productions of especially high-duty castings from chemically active steels and alloys was developed and protected with patents [11].

This work is aimed at increasing the quality of cast products made of titanium alloys due to a decrease in the difficult-to-remove gas-saturated layer by means of replacing conventional silica binders (ethyl silicate and silica sol) with organoaluminum or yttrium–aluminum ones when fabricating the ceramic molds.

EXPERIMENTAL

Organoaluminum and yttrium–aluminum binders were performed according to the procedure described in patents [9, 10].

Ceramic molds were fabricated according to conventional casting technology by investment patterns by means of the layer-by-layer deposition of the ceramic suspension consisting of the organoaluminum binder (5.5% Al) and filler (dusty fused corundum) with the subsequent dusting of each layer with granular fused corundum. Each ceramic layer was hardened at room temperature in a wet medium and in air. In total, 12 layers were deposited.

To compare the casting-surface quality, a ceramic corundum mold with one protective corundum layer on the yttrium–aluminum binder was fabricated. A waxlike model mass was removed in hot water according to conventional technology.

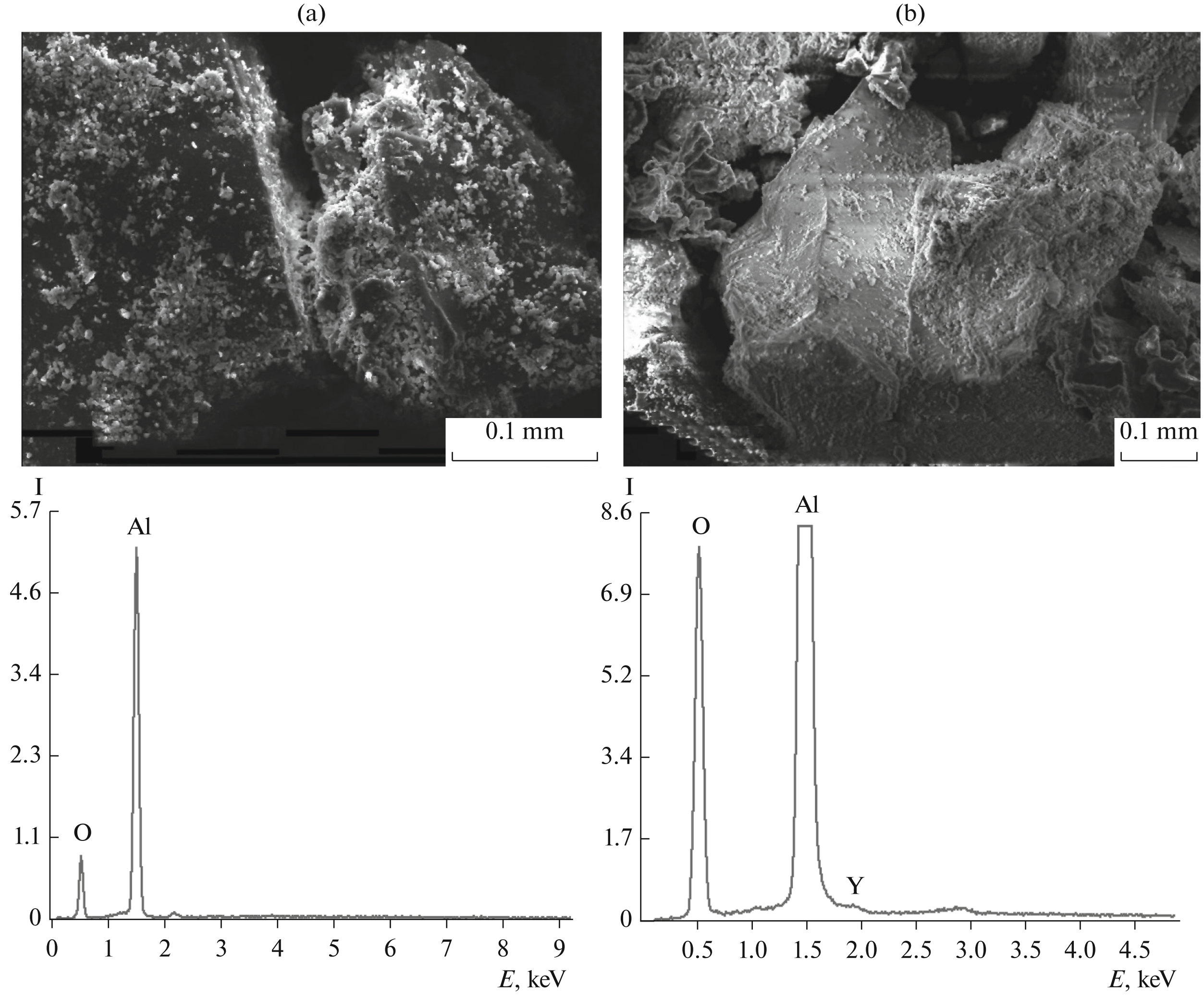
Multilayer experimental ceramic molds were calcined in a SNOL 12/16 electric resistance furnace to 1300°C in air with holding for 1 h. Corundum molds were poured with the VT5L titanium alloy using a centrifugal method in a vacuum arc scull furnace with a consumed electrode.

The surface morphology and elemental composition of the contact layer of the ceramic mold were investigated using a Philips SEM505 scanning electron microscope equipped with a Sapphire energy dispersive spectrometer with the Si(Li) crystal of the SEM10 type and a Micro Capture SEM3.0M image capture system.

The gas-saturated layer on the casting surface was determined by measuring microhardness on an inclined slice. Metallographic investigations of the slices of experimental castings were performed using a Philips XL30 ESEM scanning electron microscope equipped with a Sapphire energy dispersive spectrometer with the Si(Li) crystal and an ultrathin window 1.3 μm thick. The quantitative and qualitative analyses of castings were performed using an EDAX microanalyzer.

RESULTS AND DISCUSSION

An organoaluminum binder is a solution of chelate-tagged alkoxyalumoxanes in alcohol (ethanol or isopropanol) and can be stored in a hermetically closed container for the unlimited time. When adding



Element	wt %	at %
O*K*	41.40	54.37
Al*K*	58.60	45.63

Element	wt %	at %
O*K*	41.40	54.37
Al*K*	58.60	45.63
Y*L*	00.94	00.22

Fig. 1. SEM images and X-ray spectra of a contact ceramic layer. (a) All layers on the organoaluminum binder and (b) protective layer on the yttrium–aluminum binder.

the specified amount of yttrium acetylacetonate hydrate into it, an yttrium–aluminum binder was formed. These are ready binders which do not require any additional treatment, in contrast with ethyl silicate, which is widely used in industry; the use of the latter requires performing a complex chemical operation of hydrolysis in casting houses.

When supplying hydrolyzed ethyl silicate, its storage time before use considerably shortens, which negatively affects the production flexibility. In addition, in order to provide high strength properties of ceramic molds, catalytic drying with the use of gaseous ammonia should be applied. This procedure shortens the drying duration but makes the process toxic and fire-hazardous and explosive.

Organoaluminum and yttrium–aluminum binders are hardened with the help of making wetting in a drying chamber higher than 90% (see table).

After pouring and knocking-out titanium castings from shell corundum molds, the microstructure and chemical composition of the contact ceramic surface, as well as the presence of a gas-saturated layer in cast products, were investigated.

The surface morphology and elemental composition of the ceramic contact layer on the organoaluminum and yttrium–aluminum binders according to the scanning electron microscopy (SEM) data are presented in Fig. 1.

The elemental analysis of the ceramic surface based on the organoaluminum binder confirms the presence

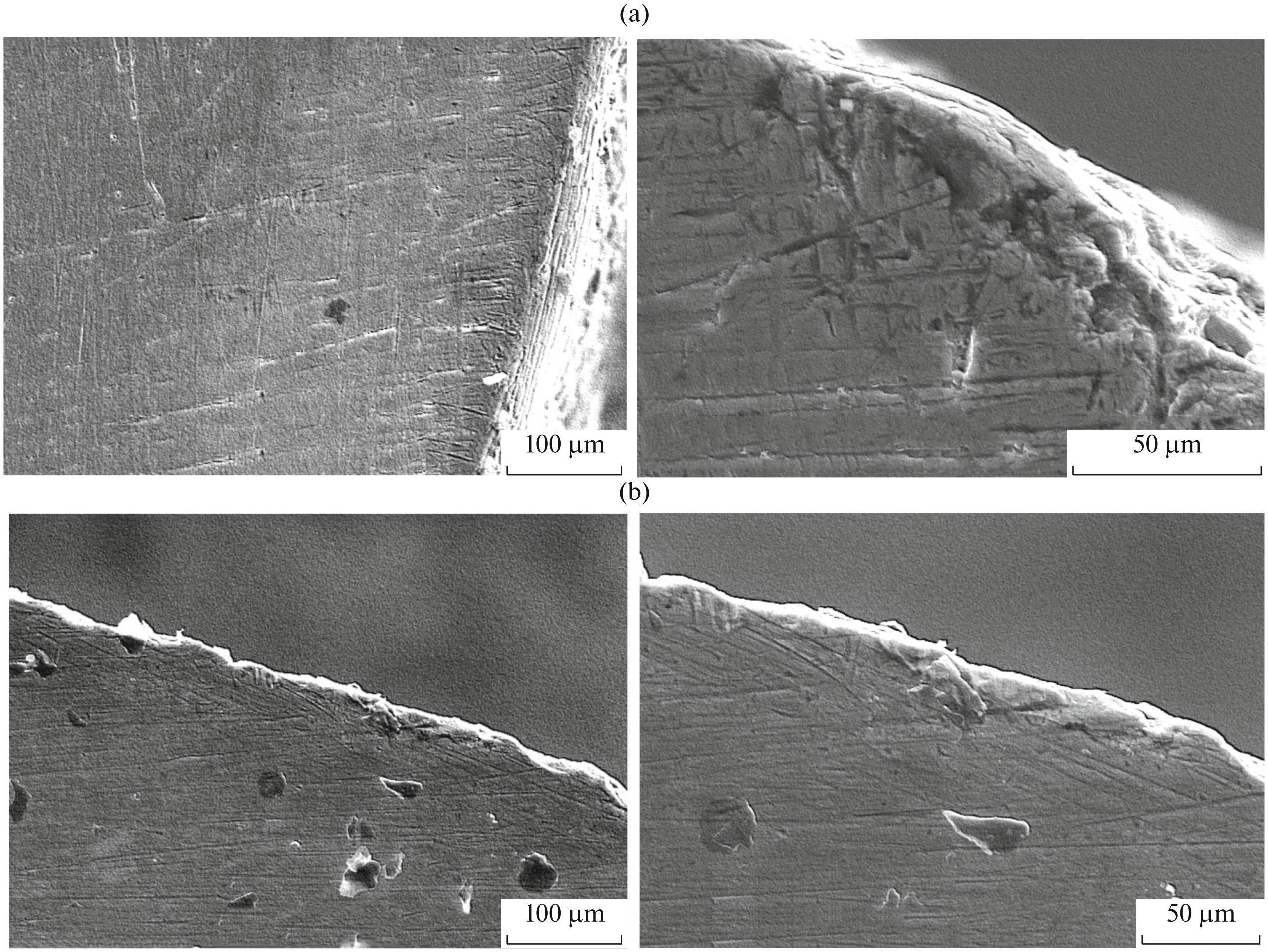


Fig. 2. Microphotographs of the surface layer (end) of the titanium casting. (a) Casting formed in a ceramic corundum mold based on the organoaluminum binder and (b) casting formed in a ceramic corundum mold with a protective layer based on the yttrium–aluminum binder.

of aluminum and oxygen, while when using the yttrium–aluminum binder in the contact layer, the presence of aluminum, yttrium, and oxygen is confirmed. It is seen in microphotographs of the contact layer surface that the binders envelop and sinter corundum grains between each other well (Fig. 1).

We performed comparative investigations of the surface of castings formed in ceramic molds with the use of different binders.

When studying the side near-surface layers of cast products, it turned out that the surface layer of the titanium casting, which is formed in a ceramic mold based on the organoaluminum binder, has a more defective structure. Cracks propagating into the matrix depth for a distance up to 50 μm are seen in the slice photograph (Fig. 2a).

The surface layer of the casting in the mold based on the yttrium–aluminum binder has a more perfect structure. The depth of the gas-saturated layer does not exceed 15 μm (Fig. 2b).

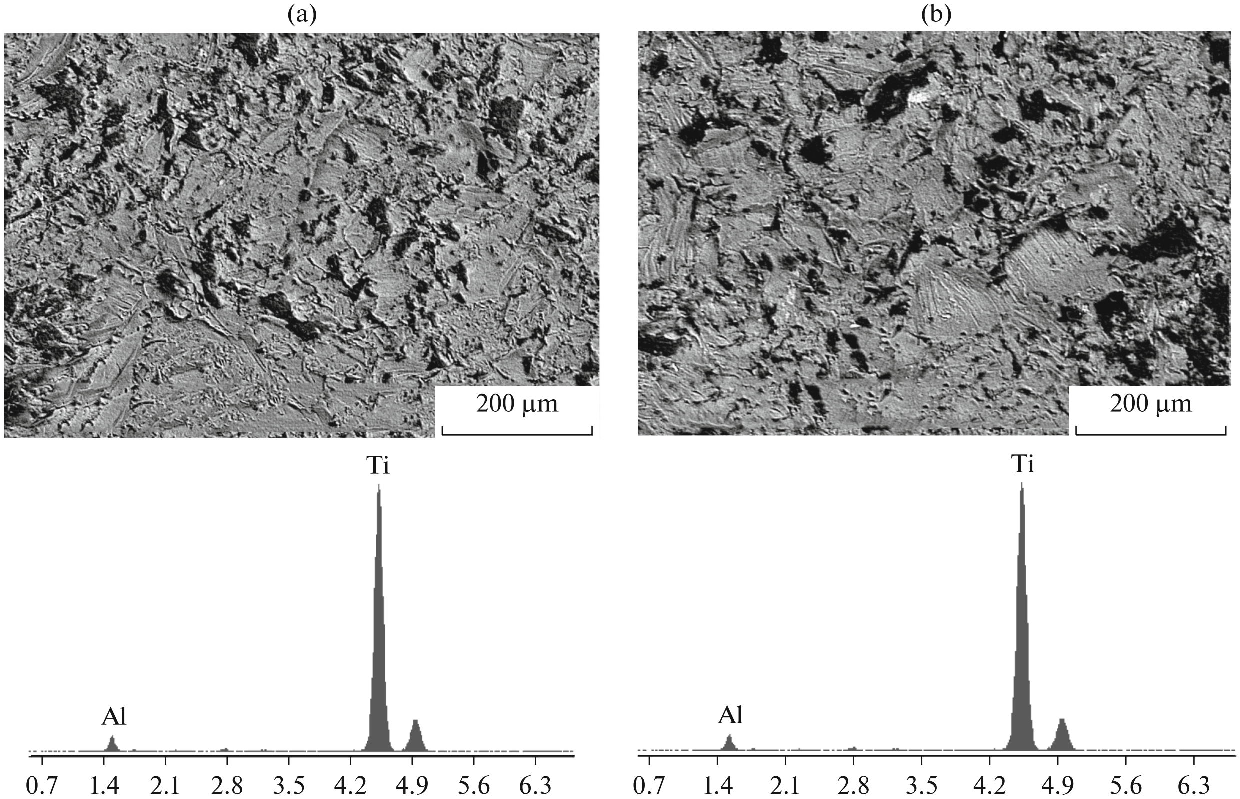
The quantitative analysis of the outer contact layers of titanium castings showed that the sample surface is enriched with oxygen in both cases; aluminum oxide is also present (black inclusions in Fig. 3).

The quantitative elemental analysis in the middle of a cast sample corresponds to the chemical composition of the poured VT5L titanium alloy.

Investigations of the microhardness distribution over the titanium casting depth showed that the gas-saturated layer with microhardness of 3.3–3.5 GPa is observed on the surface of cast samples, while that one in their core is 2.1–2.3 GPa.

CONCLUSIONS

The comparative analysis of the surface quality of castings and the mold based on the organoaluminum and yttrium–aluminum binders after pouring and solidification of the VT5L alloy is performed. It is established that the depth of the gas-saturated layer of the titanium casting formed in a ceramic corundum



(a)

Element	wt %	at %
Contact sample surface		
O*K*	33.59	56.05
Al*K*	16.04	15.87
Ti*K*	50.37	28.08
Total	100.00	100.00
Sample middle		
Al*K*	6.22	10.53
Ti*K*	93.78	89.47
Total	100.00	100.00
Dark inclusions		
O*K*	51.11	63.81
Al*K*	48.89	36.19
Total	100.00	100.00

(b)

Element	wt %	at %
Contact sample surface		
O*K*	35.47	58.99
Al*K*	11.97	11.81
Ti*K*	52.56	29.20
Total	100.00	100.00
Sample middle		
Al*K*	6.26	10.60
Ti*K*	93.74	89.40
Total	100.00	100.00
Dark inclusions		
O*K*	51.11	63.81
Al*K*	48.89	36.19
Total	100.00	100.00

Fig. 3. Microphotographs of side surfaces of ingots and elemental composition of the samples. (a) Using the yttrium–aluminum binder and (b) using the organoaluminum binder.

mold based on the yttrium–aluminum binder does not exceed 15 μm, while that one on the organoaluminum binder is 50 μm.

The results of the comparative analysis allow us to conclude that the yttrium–aluminum binder provides a higher quality of cast billets made of the VT-5L alloy and, consequently, better operational characteristics of products under conditions of long-term alternating-sign loads.

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