ELECTRON BEAM COLD HEARTH REMELTING OF HIGH-TEMPERATURE TITANIUM ALLOYS HARDENED BY SILICIDES

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Technology of electron beam melting of titanium alloys with increased content of silicon is presented. Influence of weight share of elements in the initial charge on their content in ingots is studied, distribution of hardness and microstructure of produced ingots are investigated. A new method for layer-by-layer solidification of ingots, which allows improving their quality, is suggested.

Keywords: electron beam remelting, silicide, high-temperature alloys, layer-by-layer solidification

Development of aircraft and missile construction, nuclear power engineering, chemical machine building and other branches of industry causes the need not just to improve quality of existing structural materials, but to develop new lighter and stronger in operation under normal and increased temperatures materials, whereby they have to be sufficiently ductile, tough, and resistant to action of corrosive environment. These requirements are met by the titanium-base alloys.

Nowadays commercial high-temperature titanium alloys have working temperatures not higher than 600 °C (VT18U and VT-25), and further increase of the level of their properties by means of the solid solution hardening is practically exhausted [1]. That's why lately traditional method of the disperse hardening of the metals by different interstitial phases ---- oxides, nitrides, carbides and borides ---- are used.

The most promising method for improvement of the titanium alloy high-temperature properties is intermetallic hardening. Preferential intermetallic compounds for this purpose are Ti_3Al and TiAl titanium aluminides and Ti_5Si_3 silicide [2, 3].

In recent years great attention is paid to new generation of high-temperature titanium alloys with increased content of silicon [3–6]. These new complex alloyed titanium-base alloys are, in contrast to commercial titanium alloys, characterized by the principally different mechanism of hardening, implemented due to addition of a big volume share of the ceramic component ---- Ti_5Si_3 silicide or, depending upon alloying, ---- Ti, Zr_5Si_3 [5, 6]. Theses materials got the name «cermets» and are «natural» composites, because in the process of their solidification the structure, typical for composite materials ---- plastic matrix, reinforced by stretched and branched crystals of the refractory and high-strength phase (silicides) ---- is formed.

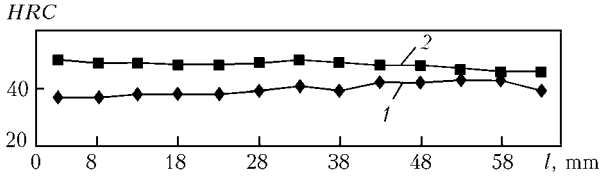

Figure 1. Curves of *HRC* hardness change over section of ingots after one-time electron beam remelting: *1* — No.352; *2* — No.366; *l* — distance from free surface of mould deep into ingot

For increasing high-temperature strength and heat resistance a certain amount of aluminium and zirconium (up to 5 wt.% and more) is introduced into these alloys. Main task of metallurgical technologies in production of multicomponent alloys is ensuring of homogeneity of chemical composition and structure of the ingots, because in the process of electron beam cold hearth remelting (EBCHR) elements with high pressure of vapor, in particular aluminium, evaporate from the melt [2].

In this work the EBCHR peculiarity of the Ti–Al–Si–Zr system alloys is investigated.

According to the calculated conditions experimental melts of ingots in the closed bottom mould, having dimensions 145 × 130 × 490 mm, with content of silicon 2–3 % and aluminium and zirconium 5–6 %, were carried out. Mixing was carried out on basis of previous experience of producing PT-3V and VT-6

Chemical composition of ingots of Ti–Al–Si–Zr alloy system after electron beam remelting

Ingot No.	Weight share of elements, %					
	Al			Si	Zr	Ti
	In charge	Calculation	In ingot			
352	8.4	6.0	6.7	2.22 / 2.2	5.11 / 5.3	84.22 / 85.8
366	7.0	4.7	6.1	3.6 / 3.2	7.0 / 6.4	82.4 / 84.3

Note. In numerator weight share of element in charge, and in denominator in ingot is indicated.

Figure 2. Microstructure of Ti–Al–Si–Zr system alloy with 3.2 % Si (×200)

alloys [2]. Chemical analysis of each ingot was made (Table).

As showed practice, final content of aluminium usually exceeds the calculated one, which requires change of the melt conditions. Mentioned effect is, evidently, connected with peculiarities of phase equilibrium diagram of the Ti–Si system [7]. As far as silicon reduces melting point of titanium almost by 320 °C, evaporation of aluminium occurs to a lower degree, which requires specifying both composition of the charge and conditions of melting. Significant difference in calculated and actual content of silicon and zirconium was not noted.

For the purpose of studying uniformity of distribution of the alloying elements, cutting of the ingots was carried out. On produced after cutting specimens *HRC* hardness was measured along each of them in the direction from surface of solidification deep into the ingot, and microstructure and chemical composition were investigated.

In Figure 1 change of the *HRC* hardness over section of the ingot in the direction from free surface of its solidification deep into its middle is shown. Under free surface of solidification surface of the ingot is meant, which had not contact with the mould and was constantly subjected to the electron beam action. One can see from the presented diagram that hardness changes insignificantly over section of the ingot. This proves sufficient chemical and structural homogeneity of the ingot.

In Figure 2 microstructure of the Ti–Al–Si–Zr system alloy with 3.2 % Si is presented. This alloy relates to hypoeutectic ones and consists of lamellae of α-phase, which occurred inside primary β-grain. Thin interlayers of β-phase are located between lamellae of α-phase and edged by fine silicides of eutectic origin (secondary silicides).

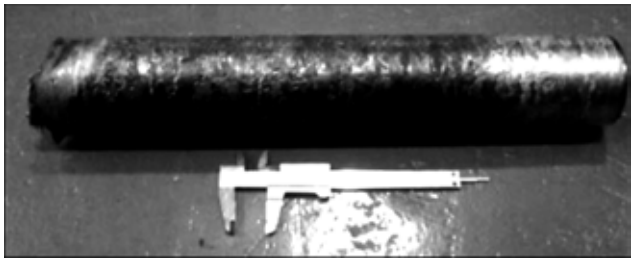

Figure 3. Ingot of 75 mm diameter and 500 mm length of Ti–6.1Al–3.2 Si–6.4 Zr alloy

For increasing chemical homogeneity the ingots were subjected to secondary remelting in open-bottom mould of 75 mm diameter, whereby dimensions of the intermediate unit were increased from $50 \times 110 \times 210$ (used for primary remelting) to $70 \times 225 \times 373$ mm, and additional mixing with necessary components was carried out for ensuring more accurate correspondence of the chemical composition of the ingots to the calculated one. Complex of the investigations was repeatedly carried out, which showed improvement of chemical homogeneity of the ingots. However, certain produced ingots had surface defects in the form of «breaks». In this connection a new technology was developed for melting ingots by the method of layer-by-layer melt solidification in the mould, and optimal conditions of melting were selected.

Method of layer-by-layer solidification consists in the fact that after pouring of next in turn portion of molten metal into the mould, power of electron beams put into the mould is reduced. This allows solidifying of the melt, after which next in turn portion of the molten metal is fed. Produced in this way ingots had good surface without «breaks» (Figure 3); in respect to other properties they did not differ from the ingots described above.

This technology requires for further investigations and approbation on ingots of bigger section.

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