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CHAMBER ELECTROSLAG REMELTING (CHESR)- A NEW METHOD FOR ENHANCED QUALITY OF INGOT PRODUCTION

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Abstract

The paper provides the results of the work devoted to the development of the theoretical basis of chamber electroslag remelting, the study of its basic lows and implementation of the technique of obtaining ingots from different metals and alloys including chromium, titanium and stainless steel.

Keywords: chamber electro-slag remelting, metallic calcium, slag, refining, oxygen, nitrogen, alloying, titanium, chromium, austenitic stainless steel, intermetallic alloys

Today Vacuum Induction Melting, Vacuum Arc and Electroslag Remelting processes, Electron Beam and Plasma-Arc Cold Hearth Melting are the main technological processes of metals and alloys producing for critical fields of application, aviation for example. It seems that these processes are well studied and standardized. Nevertheless, in recent years the new information concerning the standard process as Electroslag Remelting has been received by Ukrainian researchers. This information is the evidence of principally new possibilities of ESR as for metals and alloys refining. These investigations are conducted in Donetsk National Technical University and Aachen University and directed for detailed investigation of refining possibilities of ESR in the controlled atmosphere in chamber furnace under the calcium-containing fluxes**.**

Presence of chamber and controlled atmosphere creates the favorable conditions for effective refining and alloying of metals and alloys due to using of metallic calcium during the remelting process. At the same time, the addition of metallic calcium in slag is the cause of the considerable changes of electric regime of remelting. In its turn, it has the influence on the velocity of melting of consumable electrode, power balance of the process and forming the remelted ingot [1-3].

Theoretical basis of Chamber Electroslag Remelting process is developed in Donetsk National Technical University, basic laws are investigated and technologies of manufacturing of commercial ingots from different metals and alloys, including titanium are created and realized [4].

On the basis of the thermodynamic analysis of active fluxes characteristics, the mathematical model of behavior of metal-containing slag system components on fluoride basis (CaF_2–Ca) have been created. This model allows calculating the concentration, activity, partial pressure, velocity of evaporation of metallic component and its fluoride, limiting concentration of metallic component in melted slag system CaF_2–Ca [5,6].

The fulfilled theoretical investigations show that for practical realization of this process the additional modernization of existing commercial ESR furnaces is necessary. In this work much attention was devoted to the development of additional equipment, which would make possible re-equipment (without large investments) the of existing commercial ESR units in chamber furnaces for remelting in controlled atmosphere. For today the projects have been developed and re-equipment of laboratory and industrial scale ESR furnaces into chamber-type ones has been fulfilled (figure1).As a result of fulfilled works, technology of refining and producing of various metals and alloys under the slag of CaF_2-Ca system in argon atmosphere by Chamber Electroslag Remelting method was developed [4,8].

In particular, the problem of chromium ingots producing with purity close to electrolytic one from «cheap» consumable electrodes has been solved. These electrodes were manufactured from material after calcium-hydride and alumothermic reduction. It is necessary to note that in the past the ESR technology wasn’t used for pure chromium melting due to high temperature of chromium melting and high vapor pressure of it. It explains the difficulties of chromium production by other methods (vacuum remelting in particular). The technological parameters of ESR process for chromium and its alloys were developed. After ChESR the ingots of chromium with low content of oxygen and aluminum were received. From obtained chromium ingots the cathodes for ion-plasma deposition of coatings in “Bulat” unit and targets for magnetron coating deposition were manufactured. The pilot shipment of cathodes was tested in industrial conditions. Results of tests confirm the high technological effectiveness and increased performance of them [7-9].

Figure1 – The chamber type of the electroslag remelting furnaces

The following problem which has been solved is connected with titanium. Is it possible to refine titanium from oxygen and nitrogen at the metallurgical processing of titanium sponge and wastes in ingots by the traditional methods of special electrometallurgy – vacuum-arc, plasma-arc and electron beam remelting? Many works are devoted to this question, both in our country and abroad. Their results allow drawing conclusion, that these processes permit to get a ingot with content of oxygen at the level of initial charge, i.e. not to contaminate titanium at remelting. The same can be said about a «classic» electro-slag remelting.

In Donetsk National Technical University interesting data about melting of titanium ingots (electro-slag remelting under the flux of the system of CaF_2–*Ca*) in the furnaces of chamber type have been obtained.

Nitrogen is one of the most dangerous impurities for titanium. At manufacturing of high-quality titanium and its alloys the one of key problems is the refining of them from nitrogen-rich inclusions that present the high danger for physical-mechanical properties of material. So-called nitrogen-rich inclusions also known in literature as “hard alpha” inclusions, are very brittle in nature and may be responsible for cracks nucleation in metal. In this case the problem is not the general content of nitrogen in the system, but the concentration of nitrogen into local inclusions that are inclined to activate cracks. Elimination of nitrogen-rich inclusions or minimization of their size has become a significant problem in the titanium industry [10-11].

Removing of these inclusions in the process of different metallurgical techniques, in particular at refining remeltings, due to melting and transformation, and also due to emerging from metallic bath, is impossible due the followings causes: 1 – the temperature of melting of NRI is higher than temperature of melting of titanium, 2 – the density of titanium nitride (5.43 g/cm^3) exceeds the density of titanium (4.5 g/cm^3) and its alloys substantially.

We supposed that the refining of titanium from NRI can take place due to chemical destroying in metallic bath, and also in a slag at ESR-ChESR on the interphase boundary «slag-electrode» and slag and metallic baths at creation of certain conditions.

Thermodynamics calculations have shown that additions of metallic calcium can provide partial pressures of nitrogen in a slag (10^{-12} Pa) and in a gas phase (10^{-22} Pa) substantially below, than in the nitride inclusion (10^{-3} Pa). It was confirmed by the series of the fulfilled experiments, that at ChESR under a calcium containing flux destroying of NRI takes place due to interaction of inclusion with a slag in the conditions of the formed gradient of partial pressures of nitrogen in working space of chamber furnace at a speed of 0.7-1.1 mm/s [12-16].

On the developed technology series of ingots is melted from a titanium alloy Ti6-4 for a company «General Electric» (USA). The results of tests of metal confirmed high efficiency of technology that allowed to company «General Electric» recommend it for an commercial testing [17-18].

To the number of basic admixtures in technically clean titanium, rendering substantial influence on its properties, oxygen, which unlike nitrogen and hydrogen renders not only negative but also positive influence on properties of titanium, belongs. Controlling its content in a metal up to certain point, it is possible to obtain optimum correlation of plastic and strength characteristics of titanium alloy.

In this connection a possibility was considered both of refining of titanium materials, and alloying of titanium by oxygen.

Possibility of titanium refining from oxygen was tested experimentally. Technological wastes of titanium in the shape of stalactite overgrowths on the lids of reduction vehicles, return of which in a production process presents economic interest, and titanium sponge with increased (to 0.110% O) content of oxygen were exposed to the refining. The return of this waste in the production process presents an economic interest. The pressed electrodes from the residues of the reaction mass and the titanium sponge were to the remelting in the chamber electro-slag furnace.

Table 1. A table of contents of nitrogen and oxygen in titanium ChESR

№ of melting	Electrode	Slag	Table of contents, %	
			N	O
1	Residues of the reaction mass	CaF_2	0.110* 0.110	0.75 0.76
2	Residues of the reaction mass	CaF_2+ Ca (3.4%)	0.110 0.093	0.75 0.61
3	Titanium sponge, polluted by oxygen	CaF_2	0.026 0.023	0.110 0.110
4	Titanium sponge, polluted by oxygen	CaF_2+ Ca (2.5%)	0.026 0.022	0.110 0.083

*- numerator – an initial content, denominator – after remelting

As it is seen from the table 1, the electro-slag melting in the protective atmosphere of argon even under a «standard» flux (*CaF_2*) allows to compact the titanium sponge and residues of the reaction mass in ingots without additional contamination of metal by nitrogen and oxygen. Introduction to the slag of ChESR of metallic calcium provides the refining of titanium from nitrogen and oxygen by 10-15 and 20-25%, accordingly [19].

The following result of fulfilled complex of work – the complex technology is developed, allowing to receive cast ingots of the titan with the content of impurity at level: oxygen – 0.03-0.06 % weight., nitrogen – 0.005-0.006 % weight., hydrogen – 0.003-0.005 % weight., carbon – 0.01 % weight, from a titanium sponge and a waste (a pipe, a shaving). Obtained metal was investigated by chemical, macro- and microstructre analysis. Results, showed that chamber electro-slag remelting under the slag systems with metallic calcium may be the basis for technology for producing of the quality ingots from titanium and its alloys [20-22]. These may be directly applied to electronic applications (coatings), as getters in super high-vacuum pumps and for super-conductive and magnetic alloys. Another advantage of ChESR produced Ti, is its low cost when compared to iodide titanium (5-6 times lower in conditions of Ukraine). Further opportunities exist to produce square and rectangular ingot cross-section of ingots, this technology again resulting in a net systems cost saving by permitting fewer steps between ingot and semi-finished product. Finally it is expected that the ChESR equipment can be easily installed as a modification to presently existing VAR furnaces.

The developed technology of high-quality ingots producing from titanium, chromium and its alloys may be the alternative to vacuum remelting processes.

Oxygen in titanium is possible to consider as a perspective alloying element for the obtaining of new economically-alloyed materials. However, for today the main problem of producing titanium alloys, alloyed by oxygen, is related to the complication of obtaining the established content of oxygen and its homogeneous distributing in an ingot. For solving this problem the chamber electro-slag remelting was applied as a base process. It allows to provide a high purity, and also structural and chemical homogeneity of material due to the uniform melting of the consumable electrode and simultaneous crystallization of an ingot, which flow in the conditions of chemical vacuum due to the presence of active components of flux (in particular, metallic calcium). For alloying of titanium by oxygen the residues from the lids of vehicles of titanium sponge reduction [23], and also gaseous oxygen [24] are used as the sources of oxygen. According to the developed technology the set of titanium ingots is melted with the content of oxygen in the range from 0,035 to 0,40%.

The range of ChESR application may be essentially expanded as a result of its using for refining and producing of steels and ferrous-based alloys. Influence of this method on the structure and chemical composition of steels with different degree of alloying and carbon content was investigated.

For example, remelting of autensitic stainless steel by ChESR results in the reduction of content of oxygen, nitrogen, sulfur and phosphorus. Additionally application of this process results in a 5 fold reduction of both the volume fraction, number and size of non-metallic inclusions [25]. It was established the existence of optimum for remelting under flux that contains from 3 to 10% (by weight) of metallic calcium. Thus at 3% of Ca the sharp decrease of number of nonmetallic inclusions and increasing of degree of their dispersity is observed. Increasing of calcium content in flux from 7 to 10% leads to increasing of pollution of metal by nonmetallic inclusions due to appearance of calciumcontaining silicates and increasing of number of crystalline nitrides. Modifying effect of calcium was evaluated over changing of primary dendrite structure. It was established that the presence of calcium in low- and medium carbon steels in small quantities (up to 0.006 %) provides the substantial modifying effect. It appears in refining of primary austenite grain size, decreasing of ferrite grain size and increasing of dispersity of peartlite. With increasing of calcium content the effect of “overmodification” may be observed. It leads to formation of coarse cast structure and increasing of degree of dendrite nonunifomity. Revealed rules are representative for ChESR of another studied grades of steel.

Additionally it is established that ChESR may be used to produce high purity intermetallic alloys through adaptation and refinement of initially impure, low cost feed stock [26-28].

Lastly it is possible that ChESR can be used to introduce and control the nitrogen level with steels. It is expected that this may be achieved by controlling the partial pressure of oxygen above the oxide-fluoride slag thereby controlling the impurities content, in particular, due to the so called “pumping effect”. Possibility of increase of the maintenance of nitrogen by 4 times in comparison with initial (from 0.006 to 0.027%) was experimentally shown [26-28]. On the developed technology series of ingots is melted from a stainless steel 15-15 HS Max for a company «CARPENTER» (USA).

Conclusions

Fulfilled complex of investigations allows developing the equipment and new technology of melting and refining of metals and alloys, in this number metals with high reaction ability, by the method of chamber electroslag remelting methods. Mentioned results show the perspectives of ChESR for development of the new electroslag technologies. The process is characterized by relative simplicity of realization, reliability and ecological safety. In the world there is large number of ESR and VAR furnaces out of operation. After moderate revision and modernization they may be used for producing of highquality ingots from various metals and alloys.

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