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The Electron Beam Cold Hearth Melting Technology

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The electron beam cold hearth is a advanced melting technology compared with vacuum arc remelting. In this article, electron beam cold hearth's structure, work principle and the characteristic of melting are mainly commented and process control is discussed

Keywords: Electron beam cold hearth, Electron gun, Energy distribution

1. Preface

Titanium and titanium alloys melting methods contain vacuum arc remelting(VAR) , vacuum induction furnaces, the rotation electrode stove, the electroslag furnace,etc. At present, VAR is the leading process in titanium and titanium alloys melting. Pure titanium and non-aerospace titanium alloys generally adopt twice melting, aerospace titanium alloys and other important positions are triple melting to get the ingots of homogeneity composition and lower defective rate. But practice show: VAR cannot eliminate the defect of high density and low density inclusion, and segregation of composition occurs. These affect the reliability of using the material seriously and cause serious economical loss. To improve the melting standard of titanium and titanium alloys and the quality of titanium and titanium alloys used in aerospace, electron beam cold hearth melting(EBCHM) technology was developed and by its method, ingots were purified and separated solidification completely. Though there are much density difference between high density inclusion and titanium melts, the high density inclusion will descend to the bottom of electron beam cold hearth and be caught by skull and the low density inclusion will try its best to melting or float by the molten pool over-heat and long soaking time. ENCHM achieved the purposes, i.e. getting rid of the high or low density inclusion, realizing high quality alloying and improving the quality of the ingots. In this article, electron beam cold hearth's structure, work principle and the characteristic of melting are mainly commented and process control is discussed.

2. The composition of the electron beam cold hearth

The electron beam cold hearth is mainly composed of electron gun system, feeding system, melting system, vacuum system, cooling system, controlling system and power system. Figure 1 shows schematic representation of electronic beam cold hearth.

2.1 Electron Gun

The electron gun system is an important part of the electron beam cold hearth, at present, type of the electron gun is "pierce" generally. It has a long using life. By accurate controlling, it's easy to change the size and position of the electron beam by focus and deflection system. Electron gun has high deflected frequency and big deflected angle. The biggest deflected angle of electron beam gun at the direction of X, Y is able to reach ±45°. The biggest deflected frequency of each direction is 1250HZ. The biggest power is 750KW. The voltage between cathode and positive is 3KV. The voltage between cathode and the heated metal can reach 45KV. The large electron beam cold hearth usually has 4~6 electron guns. The total power usually is 2.0MW~4.0MW.

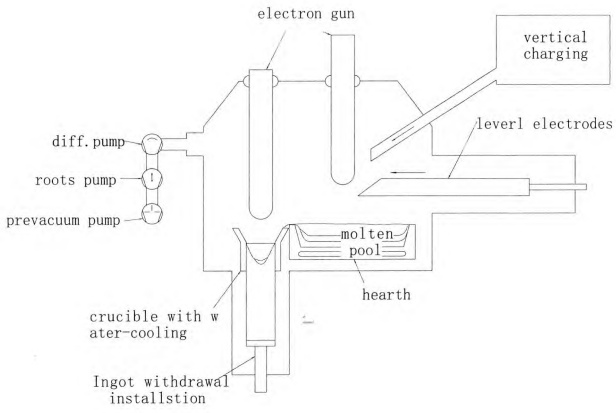

Figure 1. the sketch figure of electronic beam cold hearth

2.2 Feeding System

Feeding system usually adopts two ways as vertical and level feeding. The vertical feeding system suits the raw material of grain and the level feeding system suits the raw material of large-block scrap for recycling or electrode.

The material store-chamber of vertical feeding system is a vacuum chamber. The raw material of grain in the material store-chamber (the titanium sponges, scrap for recycling, master alloy) is put into hearth by vibra feeder. By introducing the divorce valve, it was achieved to put material into material store-chamber without affecting the vacuum of melting chamber. The feeding speed can be controlled by vibra feeder based on the request of process.

The level feeding system consist of loading chamber

and feeding chamber which is divided by the sluice'valve in the middle, and also can realize to put material into loading chamber without affecting the vacuum of melting chamber. The material can be put into hearth by propeller. By this method, it is achieved to melt continuously. Feeding speed can be adjusted by changing propeller speed based on factors such as melting power, ingot withdrawal speed and so on.

The electronic beam cold hearth has the function as preheating and removal atmosphere in advance and makes preheat at a temperature between 400 and 500°C before melt, dislodging the gas-adsorbent.

2.3 Melting System

Melting system consists of cold hearth, crucible, ingot withdrawal installation mainly. Hearth is one rectangle copper slot with water-cooling. The hearth depth is general 100mm, whose length and width is determined by the time of melting metal requiring. The melting area and refining area are separated by a screen, with prevents the spilling thing enter into refining area, affects purification effect , ingot withdrawn installation. By control of the ingot withdrawal speed by pilgrim step according to the melting speed, the surface quality of ingot is ensured.

2.4 Vacuum System

The vacuum system of the electron beam cold hearth is more complicated. Generally, vacuum system has three groups; one group is the electron gun vacuum system, the electron gun could work under the high vacuum normally. Generally, the advanced turbine molecule pump is adopted. The pre-vacuum pump is his front level pumps. Other group is feeding vacuum system, adopting tradition pre-vacuum pump, roots pump and booster pump vacuum maintains and keeping vacuum. Another group is the melting chamber vacuum system. It was composed by the pre-vacuum pump, roots pump and diffusion pump. The melting chamber pressure generally maintains at 10^{-1}~ 10^{-2}Pa. The vacuum degree of the electron gun is generally 10^{-2}~ 10^{-4}Pa.

3. Operation principle

Compared with VAR, the crucible is separated from the copper hearth with water-cooling in the design of electron beam cold hearth. It has realized melting and solidifying the separation. The cold hearth is divided into three works areas: melting area, refining area and crystallization area. Raw materials turn from solid state into melt in melting area by the electron beam scanning and then flow into the refining area. At the area the metal melt is refining. There are much density difference between high density inclusion and titanium melts. The high density inclusion will descend to the bottom of electron beam cold hearth and be caught by skull. The low density inclusion will try its best to melting or float by the molten pool over-heat and long soaking time. By this method, the high and low density inclusion were removed, molten metals were alloyed completely and then pour into the crucible and form ingots.

Unlike traditional VAR, the raw materials of EBCHM have gain raw materials or the electrode, first melted ingots, etc. We controlled separately the electron beam scanning method, frequency, power in melting area,, refining area, crystallization district.

4. EBCHM characteristic

Compared with VAR , EBCHM has a lot of characteristics, among them the advantage is as follows:

(1) There are much density difference between high density inclusion and titanium melts. The high density inclusion will descend to the bottom of electron beam cold hearth and be caught by skull. The low density inclusion will try its best to melting or float by the molten pool over-heat and long soaking time, the high and low density inclusion were removed and molten metals were alloyed completely.

(2) The molten titanium is maintained by the vacuum for a long time. During this treatment, inclusions are removed effectively and reach the lowest impurity, e.g. H, Cl, Ca, Mg, K, etc. make impurity elements such as

(3) Under the same melting speed condition , temperature gradient EBCHM ingot is less half than ingot of the VAR in the same volume. Macrostructure of the ingot is much homogeneity. It is easier to control hot topping process.

(4) In the course of melting, the sample can be taken from the crucible regularly , and then its chemical composition can be analyzed. Consequentially, the high quality of ingot was ensured.

(5) The following can be done by using "ESCOSYS" software control system; It makes the electron beam scanning pattern and crucible to match. It can produce the ingot in many kinds of specifications such as round ingot, slab ingot, hollow ingot and other specifications ingot. among them slab ingot, hollow ingot can reduce follow-up for producing process of slab and tube, save the lots and increase the output.

(6) The scraps of various form are 100% recyclable, charge proportion reach at 100%, but Charging-ratio of VAR is reached to only 30%. Therefore by **EBCHM** the production lots can be reduced effectively. Meanwhile VAR is difficult to recycle alloying materials. The electron beam cold hearth can mix the raw materials reasonable based on their chemical composition and achieve a controllable level for recycling.

(7) In general, civilian and non- aerospace material can carry on single times of EB melting, reduce melting times and improve production efficiency.

EBCHM weakness:

(1) EBCHM is a complicated technology, i.e. needing the vacuum technology, electron and physical knowledge than melting craft other. Operators have to carry on with high-level training. train experienced operator and technician.

(2) The high vacuum degree and high energy density make metal losses greater. Metal losses reach about 3~ 8% generally. By high saturation steam pigeonhole Al of alloying element volatilization, losses reach 1%. Chemical composition homogeneity and accuracy control are difficultly.

(3) EBCHM requires high vacuum. The using proportion of titanium sponges must be restricted.

(4) Melting material commixture is difficult and the metal inside the hearth amounts are limited.

(5) The structure of the electron beam cold hearth is completed(such as vacuum system. Electron gun system and so on) and using and maintenance cost are highly.

(6) Because of the electron beam cold hearth adopting the high-acceleration electron which produces X-ray to be bad for body, we must adopt special measure to protect.

5. EBCHM process control

The titanium alloy used in aerospace usually takes the method of "EB+VAR", pure titanium and non- aerospace titanium alloy usually takes the method of single "EB".

The core process of electron beam cold hearth is the controlling of the electron gun's parameter. In order to simultaneously control the power distribution of many high powers electron guns , it uses the "ESCOSYS" software system which can automatic control the electron beam power distribution. It through draws a chart and the sign note on the computer to obtain the simulation of the melting region's geometry size and the position, chooses the suitable deflection pattern which's active power can be control by the dwell time.

The electron beam cold hearth main process parameter has the loading speed , the electron beam scanning pattern, the scanning bath, the resolution, the frequency, the dwell time, the ingot withdrawn speed and so on. This process parameter formulation must based on the production's type, the using material type, the feeding way , the crucible specification factor and so on. Through using the advanced "ESCOSYS" software control system to carry on the energy distribution, the energy density adjustment is carrying on according to the molten pool condition, and by the union using survey surface temperature distribution thermal imagery system and in the survey the gas element density instrument, its molten pool temperature achieves the ideal condition, various process parameter achieves the reasonable matching and finally both the enhancement of melting speed and the prevention of the partial over-heat of molten metal are achieved. We can effective control the alloying element's volatilization losses, and enhances the ingot chemical composition uniformity and the accuracy.

6. Chinese electron beam cold hearth technological development

In recent years, China is developing the electron beam cold hearth's process and technology research in industrialization production titanium and the titanium alloy. At present China has realized the industrialization scale and produces can reach the 3000t/ year.

The BAOTI group LTD. has introduced an electron beam cold hearth from German ALD company, the type is EBCHR4/200/2400(Figure. 2). It altogether has 4 electron gun which powers is the 600KW , the total output is 2.4MW, the produces can reach the 2500t/ year and the production specification is diameter Φ 736mm ingot, the specification is 270 mmx1085 mm, 370×1340 mm slab ingot, the ingot greatest length is 5000mm, the ingot maximum weight may reach 11t. The BAOTAI LTD. has become the flag of Chinese electron beam cold hearth technology research and industrialization production.

The BAOTAI group LTD., in the electron beam cold hearth process control aspect , through using the advanced "ESCOSYS" software control system to carry on the energy distribution, carrying on the energy density adjustment according to the molten pool condition, and the union using survey surface temperature distribution thermal imagery system. Its molten pool temperature achieves the ideal condition and various process parameters achieve the reasonable matching.

In the melting stage input electron beam energy concentrates on the raw material at the melting. the cold hearth molten pool and ingot outside, compensates because the water cooling hearth and the crystallizer create thermal loss. In hot topping stage to establishment decrease progressively the temperature field from the ingot outside to the central certain, causes the ingot casting to pipe position to raise, even does not have the pipe.

The metal losses about 3%~ 6%. It concerns with the raw material type, the melting vacuum, the melting powers, the dwell time, the scanning frequency, melting speed and so on. Using 100% scrap for recycling production the ingot surface quality is fine(Figure.3). The chemical composition is homogeneity in ingot length direction distribution.(Table1). The structure in the ingot cross section was examined and the ingot structure is evener than VAR. The ingredient content satisfies the standard request. The defects such as the blowhole, flaw, non-metallic inclusion and so on has not appeared. Bar completely satisfies the standard request.

Unceasingly thoroughly studies along with the electron beam cold hearth technology, its production titanium and the titanium alloy ingot application prospect is extremely broad.

Table. 1: composition of TA2 ingot by EBCHM (wt, %)

Position	Fe	O	C	N	Al	H
top1	0.08	0.12	0.02	0.02	0.02	<0.001
top2	0.06	0.13	0.02	0.02	0.02	<0.001
middle	0.08	0.12	0.02	0.02	0.02	<0.001
Bottom2	0.07	0.13	0.02	0.01	0.02	<0.001
Bottom1	0.08	0.13	0.02	0.01	0.02	<0.001

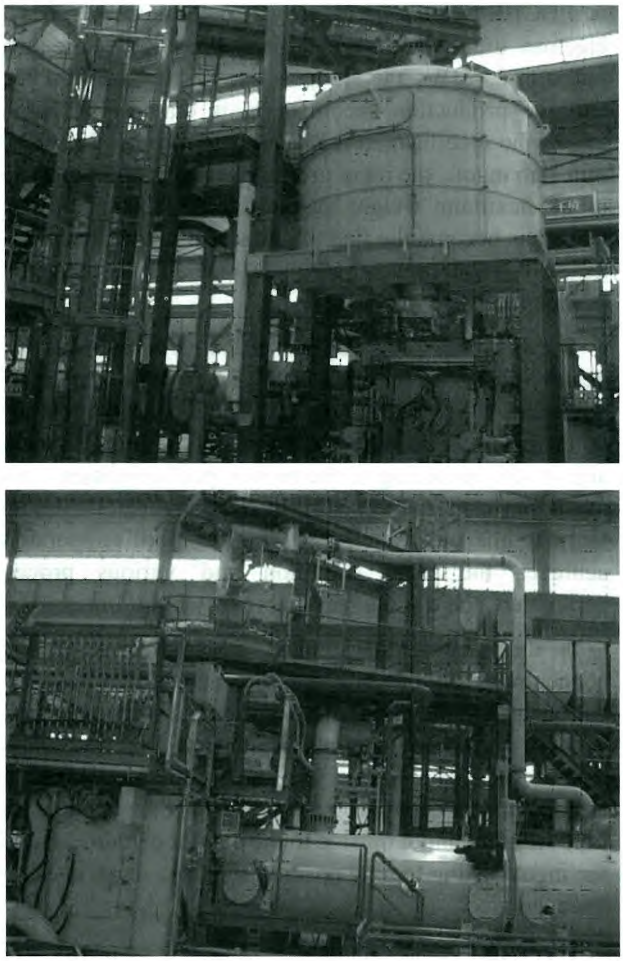

Figure 2. EBCHR4/200/2400 electron beam cold hearth

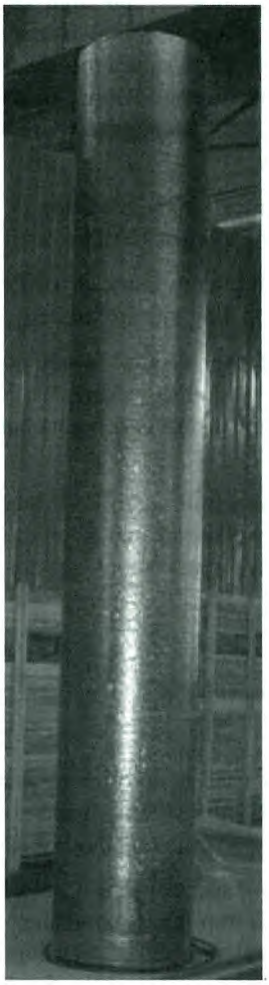

Figure 3. Φ736×5000mm TA2 ingot by EBCHM