Large Scale Cold Crucible Levitation Melting Furnace for Titanium

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Katsunori Saito[1], Teppei Okumura[2] and Kazumi Yamamoto[2]

[1]Functional Material Production Sect., Hoshizaki Plant, Daido Steel Co., Ltd.

2-30 Daido, Minami, Nagoya, 457-8545, Japan

[2] Melting & Solidification Process Research Sect., Daido Steel Co., Ltd.

Research & Development Center, Daido Steel Co.,Ltd

2-30 Daido, Minami, Nagoya, 457-8545, Japan

Corresponding author :k-saito@ac.daido.co.jp

Abstract

We, Daido Steel Co., Ltd., began titanium alloy production at our first Levitation Induction melting Furnace, we named LIF, in our Hoshizaki Plant in 2007. The LIF is a cold crucible semi-levitation melting furnace (CCLM) that has bottom tapping nozzle. A 1.8 metric tons ingot has been made by a combination of LIF and Vacuum Arc Remelting. The LIF performs completely uniform melting and enables to melt high-melting point metals.Therfore, we can produce high grade titanium alloys with high melting point metals such as pure tantalum or pure niobium. We has produced many kinds of titanium alloys for 7 years by LIF. However there are some issue in melting and bottom tapping process. In this article, we show those problems.

Key words : Cold crucible

Introduction

Titanium alloys are being widely used nowadays as they have advantages of having low density, high corrosion resistance, high specific strength, and biocompatibility. They are used biological implant, automobile, aircraft, glasses, golf clubs and chemical plants. They are expected as suitable materials for engine parts of automobile such as connecting rod, and exhaust valves employing their high specific strength and good performance at elevated temperature. [1] It has been achieved to use them for parts of the aircraft in recent years.

Since titanium alloys are highly reactive metals, they react readily with oxygen during melting and casting. Their ductility and toughness decrease when contents of oxygen increase too much. Therefore, a cold crucible is used for titanium melting process instead of a refractory crucible.

CCLM furnace is a type of induction melting furnace that is replaced a conventional refractory crucible with a water-cooled copper crucible. High frequency coil current induces magnetic flux density and eddy current on the surface of the metal. Eddy current melt the metal by Joule heat.

On CCLM, Lorentz force generated by the eddy current and the magnetic flux density confine the metal and keep non-contact form the water-cooled copper crucible. That is well known as a titanium melting furnace with melting has several advantages, such as no restriction for raw material's shape and melting atmosphere compare to vacuum arc melting (VAR), electron beam melting (EB), and plasma arc melting (PAM).

Tilting tap is conventional method to tap molten metal and use well in small scale of cold crucible. However, for the cold crucible, temperature of molten metal rapidly drops when it contact to a crucible during tapping, and it caused decrease of ingot yield. In addition, when large scale of cold crucible is designed, it is difficult to design water-cooled and segmented crucible and co-axial conductor that is suitable for tilting tap. So the bottom tapping method was developed. Bottom tapping has many advantages for cold crucible because no temperature drop, do not require water-cooled cable nor co-axial conductor which has difficulty for high frequency furnace, do not require tundish and so on.[2,3]

Therefore, a new process of manufacturing several hundred kilograms ingots of titanium alloys expected to construct with utilizing large scale cold crucible with bottom tapping nozzle. The shape of the crucible and bottom-tapping nozzle was designed properly through the simulations and some experiments. Titanium alloy melting and bottom tapping were successfully performed with this process.

Features of LIF

There are two processes in the CCLM. Full levitation melting is a process to float the molten metal completely, and semi levitation melting is a process to maintain the molten metal on the solidified layer of the metal (skull). Full levitation melting can melt metals of high melting point and allows metals to be melted without contamination, but the power-consumption is very large. So, semi levitation melting was selected for the development of LIF. The skull formed at bottom of the crucible itself supports molten metal since the Lorentz force is not strong enough to levitate whole metal, including lower part of crucible. Still the Lorentz force supports metal confinement without touching the sidewall, the metal temperature is kept high.

Fig.1 shows LIF. The specification of LIF is listed in table 1. The water-cooled copper crucible is composed of 60 segments. The water-cooled bottom tapping nozzle, which is composed of copper segments, is located at the bottom of the crucible Coils are wound around the crucible and the nozzle. These are connected to different high-frequency power supplies.

Electromagnetic levitation force is described with the equation (1) when eddy current flows near surface of a conductor. [4,5]

$$F = W\sqrt{\frac{\mu}{2\pi f \rho}} \qquad (1)$$

F : electromagnetic levitation force [N]
W : consumed power [W]
μ : permeability [A/m]
f : frequency [Hz]
ρ : specific resistivity [Ωm]

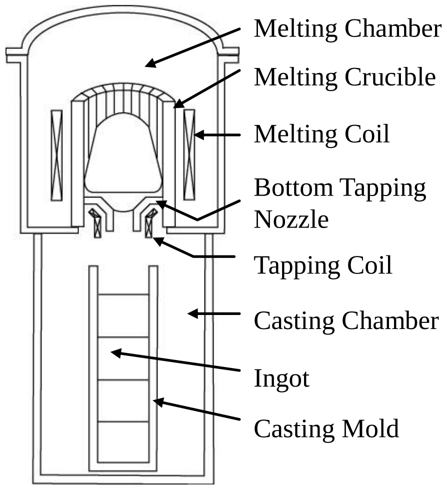

Fig.1: Schematic diagram of LIF with bottom tapping nozzle

It is derived from equation (1) that the lower the frequency is, the stronger the electromagnetic levitation force is if consumed power is constant. On the other hand, induced eddy current concentrated at the surface of the conductor leads high heating effect when frequency becomes higher. The upper coil for LIF induces strong electromagnetic force for levitating and stirring molten metal and the lower coil for bottom tapping nozzle supplies heat to metal in nozzle rather than confinement force. [6]

Table-1 Specifications of the LIF with bottom tapping nozzle

Melting power	2400kW	Melting crucible	Φ670mm×H700mm	Casting mold	Φ440mm×H3600mm
Frequency	800Hz	Number of segment	60	Melting chamber	Φ2600mm×H2000mm
Melting weight	500kg-Ti	Cooling water flux	$192m^3/h$	Casting chamber	Φ2000mm×H6000mm

Melting target

LIF has melted titanium alloy since 2007. Table-2 shows amount of commercial melting of titanium alloy by additional alloy. In most cases we use popular alloy (Al-V and Al-Nb etc.) in titanium alloy melting. But in rare cases we use high melting-point alloy (pure molybdenum and pure niobium etc.). They have not occurred high density inclusion.

Table-2 Amount of commercial melting of titanium alloy

Additional master alloy	Melting weight(MT)
Aluminum and Vanadium	2250
Aluminum and Niobium	348
Pure Molybdenum	5
Pure Niobium	2
Pure Tantalum	2

Challenges in commercial production

We have some challenges in commercial production.

Difficulty bottom tapping

We cannot be tapped molten metal from tapping nozzle in Specially titanium alloy (Ti-20%Nb-5%Cr-4%Zr) first tapping.

Turbulence flow in bottom tapping

We cannot cast ingot in a mold when turbulence occurs in bottom tapping. Photo-1 shows turbulence occurs in bottom tapping. Photo-2 shows top of mold after casting.

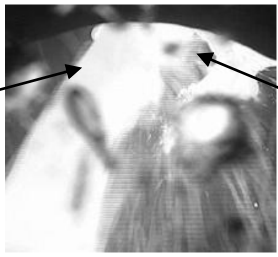

Photo-1 Turbulent in bottom tapping

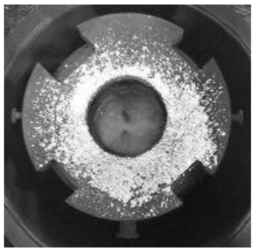

Photo.2 Top of mold after casting

Difficulty bottom tapping

In the case of Ti-20%Nb-5%Cr-4%Zr (TNCZ), we cannot be tapped from bottom tapping nozzle. We think material characteristics influence it. So we examine by using material characteristics. We cannot be tapped from bottom tapping nozzle in case of TNCZ, because the skull is thick. The reason is molten metal temperature is low. So we think that Power ratio applied to the molten metal in case of TNCZ is lower than Ti-4%Al-22%V on immediately before bottom tapping. So we compare TNCZ with Ti-4%Al-22%V on melting. Fig.2 shows power outlet and power efficiency to the metal in TNCZ. Fig.3 shows power outlet and power efficiency to the metal in Ti-4%Al-22%V.

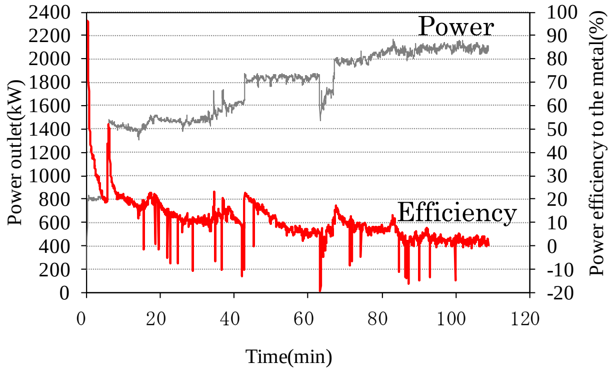

Fig.2 TNCZ Melting

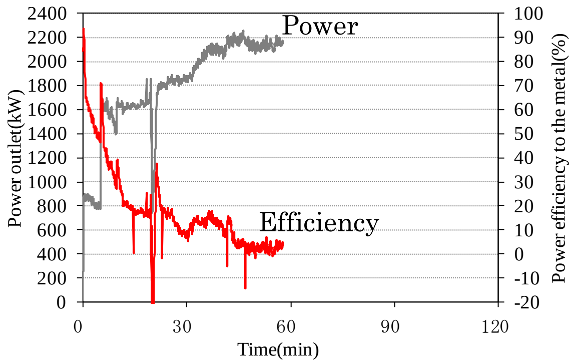

Fig.3 Ti-4%Al-22%V Melting

Power distribution to the metal drop to a lower level as melting goes on and it becomes 0% on immediately before bottom tapping. But, Result of comparison between TNCZ and Ti-4%Al-22%V, there is no difference. Fig.4 shows total power efficiency on melting. It means crucible loss energy is larger in TNCZ than Ti-4%Al-22%V. So it is shown that area in contact with the crucible on TNCZ is larger than Ti-4%Al-22%V. Therefore we derived a contact area with the crucible from protuberance height. Fig.5 shows molten metal shape in LIF.

Gravity acting on the molten metal=Force to lift the molten

$$\gamma g h = \frac{W\eta\sqrt{\dfrac{\mu}{2\pi\rho f}}}{S} \qquad (1)$$

γ:specific gravity, g:gravitational acceleration, h: protuberance height
W: Power outlet, η:Power distribution ratio to the metal
μ:Magnetic permeability, ρ:Specific resistance, f:Power supply frequency, S:Surface area on protuberance, d:diameter of crucible

We put the case that protuberance shape is spheroid.

$$S = 2\pi\left\{\left(\frac{d}{2}\right)^2 + \frac{h^2\tanh^{-1}e}{e}\right\} \qquad (2)$$

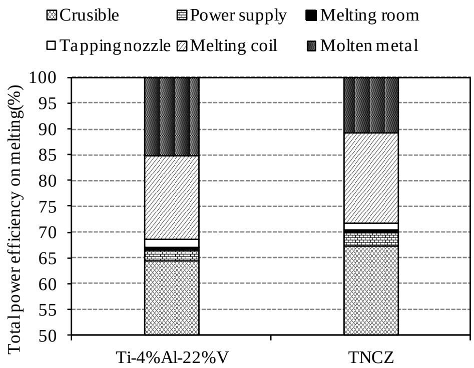

Fig.4 Total power efficiency on melting

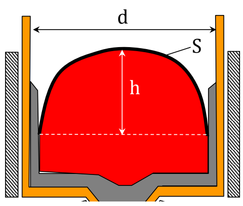

Fig.5 Molten metal shape in LIF

$$e = \sqrt{1 - \left(\frac{h}{2d}\right)^2} \quad (3)$$

It will assign (2) and (3) to (1).

$$\gamma gh = W\eta\sqrt{\frac{\mu}{2\pi\rho f}} \times \frac{2\sqrt{4d^2 - h^2}}{\frac{\pi}{2}d^2\sqrt{4d^2 - h^2} + 4dh^2 \tanh^{-1}\frac{\sqrt{4d^2 - h^2}}{2d}} \quad (4)$$

Obtained the answer by that it will assign parameter in case of table-3 to (4).

Table-3 Calculation condition

Listing	TNCZ	Ti-4%Al -22%V	Listing	TNCZ	Ti-4%Al -22%V
specific gravity γ(kg/m^3)	5200	4690	Magnetic permeability μ(H/m)	1.0	1.0
gravitational acceleration g(kg・m/s^2)	9.8	9.8	Specific resistance $\rho \times 10^{-6}$(Ωm)	1.29	1.48
Power outlet W(kW)	2250	2250	Power supply frequency f(Hz)	820	820
Power distribution ratio to the metal η(%)	10.8	15.3	diameter of crucible (mm)	600	600

The calculated results were obtained answers in Table-4. It shows that when protuberance height is small, the contact area grows. So we think molten metal temperature is lowered by heat removal amount increases, it estimated that the skull thickness is increased.

Table-4 Calculation result

Listing	TNCZ	Ti-4%Al -22%V
protuberance height (mm)	168	220
Contact area with crucible ratio (%)	47.4	44.3

Conclusion

LIF can melt high melting point metal (pure niobium, pure tantalum etc.).
There are many technical issues in bottom tapping, so we need to any research.
We think protuberance height and power distribution to the metal have a great influence.

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