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Effects of BaO and B₂O₃ on the Absorption of Ti Inclusions for High Titanium Steel

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Abstract: In order to study the effect of BaO or B₂O₃ on the absorption of Ti inclusions, the effects of mold fluxes with different contents of BaO (0~15%) or B₂O₃ (0~15%) on the mass transfer coefficients of TiO₂ or TiN were studied with the rotating cylinder method. The experimental results show that with the addition of BaO in the mold flux, the mass transfer coefficient of TiO₂ increases from 4.58×10^{-4} m/s to 6.08×10^{-4} m/s, that of TiN increases from 3.09×10^{-4} m/s to 4.41×10^{-4} m/s, 2CaO·MgO·2SiO₂ is transformed into BaO·2CaO·MgO·2SiO₂, and the Ti inclusions combine with CaO to form CaTiO₃. With the addition of B₂O₃ in the mold flux, the mass transfer coefficient of TiO₂ increases from 4.58×10^{-4} m/s to 7.46×10^{-4} m/s, that of TiN increases from 3.09×10^{-4} m/s to 5.50×10^{-4} m/s, CaO and B₂O₃ combine to 2CaO·B₂O₃, and Ti inclusions exist in the form of TiO₂. During the experiment, TiN will be transformed into titanium oxide.

Keywords: rotating cylinder method; mass transfer; inclusion; phase

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1. Introduction

Incoloy825 alloy is a kind of austenitic Fe-Ni-Cr superalloy stabilized by Ti [1]. In the process of continuous casting, Ti inclusions float up to the slag–metal interface and the floating Ti inclusions are inevitably absorbed by mold flux. As a result, the compositions of mold flux are changed, and the properties (melting temperature, viscosity, etc.) of the mold flux are also changed [2–4]. Therefore, the performance of mold flux used in practice is different from that of the original design. Consequently, it is urgent to study the ability of mold flux to absorb Ti inclusions.

Due to the importance of absorbing inclusions, this topic has been studied by scholars, and the main research methods used are the rotating cylinder method [5–7] and the confocal scanning laser microscope (CSLM) method [8–10]. Zhong-shan Ren et al. [11] studied the dissolution and diffusion behavior of TiO₂ particles in molten slag with the CSLM method. Higher temperatures favored the dissolution and diffusion of TiO₂, whereas a greater Al₂O₃ content in the slag restrained the dissolution and diffusion. The results of Zhanquan Hao et al. [12] showed that the dissolution rate of TiO₂ in molten mold flux increased with increasing temperature and basicity, decreasing TiO₂ content, and increasing CaF₂ content. The effect of temperature and basicity was the most significant, and the diffusion process was the factor restricting TiO₂ dissolution.

Zhanjun Wang and Tae Sung Kim [13,14] believed that BaO was beneficial for the lubrication of liquid slag. Xiong Yu et al. [15] showed that, with an increase in the B₂O₃ content, the viscosity, turning point temperature, and viscous flow activation energy of mold flux decreased. Therefore, the addition of BaO or B₂O₃ into the mold flux can improve the deteriorating performance caused by the absorption of Ti inclusions.

As mentioned above, the experimental work on the effect of BaO or B₂O₃ on the absorption of Ti inclusions by mold flux is still limited. In this paper, the influence of BaO or B₂O₃ on the absorption rate of TiO₂ and TiN is studied by the rotating cylinder method. The interfaces between Ti inclusions and mold fluxes are observed and analyzed

by scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS), and the dissolution mechanism is also discussed.

2. Experimental

2.1. Materials

Analytical-grade CaO, SiO₂, Al₂O₃, MgO, Na₂CO₃, CaF₂, BaCO₃, and B₂O₃ (all of purity >99%) were taken as raw materials, with Na₂CO₃ and BaCO₃ acting as substitutes for Na₂O and BaO, respectively. CaO and MgO powders were calcined in a muffle furnace at 873 K to remove moisture. The viscosities of the different mold fluxes were measured by a high-temperature viscosity furnace at 1623 K. The chemical composition of the experimental mold fluxes and viscosities are shown in Table 1. The sintered specimens were 8 mm in diameter, 100 mm in length, and had 99% purity. The density of the TiO₂ rod was 4.1 g/cm³ and that of the TiN rod was 5.1 g/cm³.

Table 1. Chemical composition of experimental mold fluxes (mass percentage).

Sample	CaO	SiO ₂	Al ₂ O ₃	MgO	Na ₂ O	CaF ₂	BaO	B ₂ O ₃	Viscosity at 1623 K (Poise)
1#	30	30	15	5	10	10	-	-	0.465
2#	30	30	15	5	10	10	5	-	0.421
3#	30	30	15	5	10	10	10	-	0.411
4#	30	30	15	5	10	10	15	-	0.421
5#	30	30	15	5	10	10	-	5	0.399
6#	30	30	15	5	10	10	-	10	0.300
7#	30	30	15	5	10	10	-	15	0.262

2.2. Apparatus and Method

The dissolution experiment was carried out in the Vertical MoSi₂ resistance furnace, and a schematic diagram of the experimental apparatus is shown in Figure 1. The furnace body was a corundum tube with an inner diameter of 90 mm and a length of 1000 mm. The furnace temperature was measured by a type-B thermocouple (Pt-30%Rh/ Pt-6%Rh), where the deviation of temperature was maintained within ± 2 K of the center of the invariable temperature zone (10 mm).

Figure 1. Schematic diagram of the experimental apparatus.

The experimental procedures can be described as follows. Firstly, 100 g of premelted mold flux sample was placed in a graphite crucible with an inner diameter of 40 mm and a length of 80 mm, then it was heated to 1623 K in an argon atmosphere (argon purity $\geq 99.999\%$). Secondly, when the temperature reached 1623 K, the premelted mold flux should be kept stable for 30 min to ensure uniform melting. The rod with Ti inclusions

was preheated for 10 min above the mold flux surface, then immersed in the mold flux for 30 mm and rotated at a fixed speed of 200 rpm/min. At the end of the experiment, the rod with Ti inclusions was quickly withdrawn from the mold flux and cooled in air. The mold flux adhering to the side surface of the rod was removed with HCl dilute solution, as shown in Figure 2, and the rod diameter was measured by a micrometer to an accuracy of 0.02 mm. The morphology of the cross section was subjected to SEM observation with EDS analysis.

Figure 2. Treated TiO₂ and TiN rods.

3. Results and Discussion

3.1. Mass Transfer Coefficient

In the process of the rotational cylinder method, the rod (M_1) was continuously dissolved in the slag, its internal component (B) formed an intermediate reaction layer in the surrounding dissolution process, and component (B) diffused into the slag again, as shown in Figure 3. In the process of rod dissolution, the mass of component dissolved in the rod ($dM_1w(B)_1$) was equal to the sum of the mass formed by the intermediate reaction layer ($\beta A \Delta w(B) \rho_2 dt$) and the mass of the component entering the slag ($dM_1w(B)_2$) [16]:

$$dM_1w(B)_1 = \beta A \Delta w(B) \rho_2 dt + dM_1w(B)_2. \quad (1)$$

The dissolution rate of rod was obtained as:

$$-\frac{dM_1}{dt} = \frac{\beta A \rho_2 (w(B)_s - w(B)_2)}{(w(B)_1 - w(B)_2)}, \quad (2)$$

where $w(B)_1$, $w(B)_s$, and $w(B)_2$ are the concentration of each component (B); β is the mass transfer coefficient; A is the contact area between inclusion rod and slag; ρ_2 is the density of the slag.

Rod	Intermediate Reaction Layer	Slag
$w(B)_1$	$w(B)_s$	$w(B)_2$
$dM_1w(B)_1$	$\beta A \Delta w(B) \rho_2 dt$	$dM_1w(B)_2$

Figure 3. Distribution of component (B) in each phase during the dissolution of the rod with Ti inclusions.

During the dissolution process, the surface area of the rod decreased continuously and presented a cylindrical shape, as shown in Figure 2. Thus, the dissolution rate of the rod with Ti inclusions is as follows:

$$v = -\frac{dM_1}{dt} = -\frac{\rho_1 d \cdot V_1}{dt} = -\frac{2\pi r l \rho_1 dr}{dt}, \quad (3)$$

where ρ_1 is the density of the rod, r is the diameter of rod, l is the length of the rod in the slag. Equations (2) and (3) are the same, so it is concluded that:

$$\frac{\beta \rho_2 (w(B)_s - w(B)_2)}{(w(B)_1 - w(B)_2)} dt = -\frac{2l \rho_1}{r + 2l} dr. \quad (4)$$

When $t = 0 \sim t$ and $r = r_0 \sim r$, the mass transfer rate of rod dissolution is obtained as follows:

$$\beta = \frac{2L\rho_1 (w(B)_1 - w(B)_2) \ln(\frac{r_0 + 2l}{r + 2l})}{\rho_2 (w(B)_s - w(B)_2) t}. \quad (5)$$

According to Equation (5), the mass transfer coefficients of TiO_2 and TiN are calculated as shown in Figure 4. With the addition of BaO in the mold flux, the mass transfer coefficient of TiO_2 increased from $4.58 \times 10^{-4} \text{ m/s}$ to $6.08 \times 10^{-4} \text{ m/s}$, and the mass transfer coefficient increased by 32.7%. The mass transfer coefficient of TiN increased from $3.09 \times 10^{-4} \text{ m/s}$ to $4.41 \times 10^{-4} \text{ m/s}$, and the mass transfer coefficient increased by 42.7%. With the addition of B_2O_3 in the mold flux, the mass transfer coefficient of TiO_2 increased from $4.58 \times 10^{-4} \text{ m/s}$ to $7.46 \times 10^{-4} \text{ m/s}$, and the mass transfer coefficient increased by 62.9%. The mass transfer coefficient of TiN increased from $3.09 \times 10^{-4} \text{ m/s}$ to $5.50 \times 10^{-4} \text{ m/s}$, and the mass transfer coefficient increased by 78.0%.

Figure 4. The mass transfer coefficient of the rod with Ti inclusions in different mold fluxes.

The mass transfer coefficients of TiO_2 and TiN increased with the addition of BaO or B_2O_3 in the mold flux, which indicates that the addition of BaO or B_2O_3 in the mold flux is beneficial to the absorption of TiO_2 and TiN inclusions. The mass transfer coefficients of TiO_2 and TiN in mold fluxes containing B_2O_3 are higher than those of BaO , which indicates that mold flux containing B_2O_3 has a more obvious effect on the mass transfer coefficient. In addition, the mass transfer coefficient of TiO_2 in mold fluxes is greater than that of TiN under the same conditions.

This is due to the addition of BaO or B_2O_3 in the mold flux, which greatly changes the physical properties of the mold flux. With the addition of BaO into the mold flux, the ability to provide basic cations in mold flux is enhanced, and it is easier to absorb Ti inclusions and enhance mass transfer. In the process of mass transfer, the decrease in viscosity enhances the relative movement between the rod with Ti inclusions and mold flux and increases

the mass transfer rate. It can be seen from Table 1 that, with the increase in B_2O_3 in the mold flux, the viscosities of the mold flux decreased obviously more than those of BaO. Therefore, the mass transfer rate of TiO_2 and TiN in the mold fluxes containing B_2O_3 is higher than that of BaO.

3.2. Phase of Mold Flux

XRD analyses were carried out on the mold flux after adsorbing Ti inclusions, and the results are shown in Figure 5. As shown in Figure 5a, when mold fluxes containing BaO absorb Ti inclusions, the corresponding phase is $CaTiO_3$. The peak value of $2CaO \cdot MgO \cdot 2SiO_2$ is decreased and the peak value of $BaO \cdot 2CaO \cdot MgO \cdot 2SiO_2$ increased. With the addition of BaO in the mold flux, BaO combined with $2CaO \cdot MgO \cdot 2SiO_2$ to form $BaO \cdot 2CaO \cdot MgO \cdot 2SiO_2$. As shown in Figure 5b, with the addition of B_2O_3 in the mold flux, the properties of the mold fluxes changed greatly. When the content of B_2O_3 in the mold flux increases to 10%, 6# and 7# mold fluxes change from crystalline to glass. This is due to the combination of B_2O_3 and CaO to form a large amount of $2CaO \cdot B_2O_3$ with a low melting point, which promotes the vitrification of the mold flux and reduces the viscosity of the mold flux. The addition of B_2O_3 to the mold flux reduces the activity of CaO and inhibits the binding ability of CaO and TiO_2 . Therefore, when mold fluxes containing B_2O_3 absorb TiO_2 and TiN, the corresponding phase is still TiO_2 .

Figure 5. XRD pattern of mold fluxes after absorbing Ti inclusions: (a) BaO; (b) B_2O_3 .

3.3. Activity Model of $a(CaO)$

In order to understand the form of absorbing Ti inclusions in the slag, the activity of CaO was calculated by the ion and molecule coexistence theory (IMCT) [17]. On the basis of IMCT, the mole fraction of each oxide could be assigned as $m_1 = n_{CaO}^0$, $m_2 = n_{SiO_2}^0$, $m_3 = n_{Al_2O_3}^0$, $m_4 = n_{Na_2O}^0$, $m_5 = n_{MgO}^0$, $m_6 = n_{CaF_2}^0$, and $m_7 = n_{BaO}^0$ to represent the chemical composition of the slag, and each of n_i^0 could be expressed by Equation (6). At 1623 K, the relevant compounds and chemical reactions of the present slag are list in Tables 2 and 3, respectively [18–21].

$$n_i^0 = n_i / \sum n_i. \quad (6)$$

Table 2. Expression of structural units as ion couples or complex molecules, their mole numbers, and their mass action concentrations in 100 g of CaO-SiO₂-Al₂O₃-Na₂O-MgO-CaF₂-BaO slags based on IMCT.

Item	Structural Units as Ion Couples or Molecules	Mole Number of Structural Unit n_i /mol	Mass Action Concentration of Structural Unit or Ion Couple N_i (—)
Simple cation	$\text{Ca}^{2+} + \text{O}^{2-}$	$n_1 = n_{\text{Ca}^{2+}} = n_{\text{O}^{2-}}$	$N_1 = N_{\text{CaO}} = 2n_1 / \sum n_i$
-	$\text{Na}^{2+} + \text{O}^{2-}$	$n_4 = 2n_{\text{Na}^{+}} = n_{\text{O}^{2-}}$	$N_4 = N_{\text{Na}_2\text{O}} = 3n_4 / \sum n_i$
-	$\text{Mg}^{2+} + \text{O}^{2-}$	$n_5 = n_{\text{Mg}^{2+}} = n_{\text{O}^{2-}}$	$N_5 = N_{\text{MgO}} = 2n_5 / \sum n_i$
-	$\text{Ca}^{2+} + 2\text{F}^{-}$	$n_6 = n_{\text{Ca}^{2+}} = 2n_{\text{F}^{-}}$	$N_6 = N_{\text{CaF}_2} = 3n_6 / \sum n_i$
-	$\text{Ba}^{2+} + \text{O}^{2-}$	$n_8 = n_{\text{Ba}^{2+}} = n_{\text{O}^{2-}}$	$N_8 = N_{\text{BaO}} = 2n_8 / \sum n_i$
Simple molecule	SiO_2	$n_2 = n_{\text{SiO}_2}$	$N_2 = N_{\text{SiO}_2} = n_2 / \sum n_i$
-	Al_2O_3	$n_3 = n_{\text{Al}_2\text{O}_3}$	$N_3 = N_{\text{Al}_2\text{O}_3} = n_3 / \sum n_i$
Complex molecule	$\text{CaO} \cdot \text{SiO}_2$	$n_{c1} = n_{\text{CaO} \cdot \text{SiO}_2}$	$N_{c1} = N_{\text{CaO} \cdot \text{SiO}_2} = n_{c1} / \sum n_i$
-	$2\text{CaO} \cdot \text{SiO}_2$	$n_{c2} = n_{2\text{CaO} \cdot \text{SiO}_2}$	$N_{c2} = N_{2\text{CaO} \cdot \text{SiO}_2} = n_{c2} / \sum n_i$
-	$3\text{CaO} \cdot \text{SiO}_2$	$n_{c3} = n_{3\text{CaO} \cdot \text{SiO}_2}$	$N_{c3} = N_{3\text{CaO} \cdot \text{SiO}_2} = n_{c3} / \sum n_i$
-	$3\text{CaO} \cdot 2\text{SiO}_2$	$n_{c4} = n_{3\text{CaO} \cdot 2\text{SiO}_2}$	$N_{c4} = N_{3\text{CaO} \cdot 2\text{SiO}_2} = n_{c4} / \sum n_i$
-	$\text{CaO} \cdot \text{Al}_2\text{O}_3$	$n_{c5} = n_{\text{CaO} \cdot \text{Al}_2\text{O}_3}$	$N_{c5} = N_{\text{CaO} \cdot \text{Al}_2\text{O}_3} = n_{c5} / \sum n_i$
-	$\text{CaO} \cdot 2\text{Al}_2\text{O}_3$	$n_{c6} = n_{\text{CaO} \cdot 2\text{Al}_2\text{O}_3}$	$N_{c6} = N_{\text{CaO} \cdot 2\text{Al}_2\text{O}_3} = n_{c6} / \sum n_i$
-	$\text{CaO} \cdot 6\text{Al}_2\text{O}_3$	$n_{c7} = n_{\text{CaO} \cdot 6\text{Al}_2\text{O}_3}$	$N_{c7} = N_{\text{CaO} \cdot 6\text{Al}_2\text{O}_3} = n_{c7} / \sum n_i$
-	$3\text{CaO} \cdot \text{Al}_2\text{O}_3$	$n_{c8} = n_{3\text{CaO} \cdot \text{Al}_2\text{O}_3}$	$N_{c8} = N_{3\text{CaO} \cdot \text{Al}_2\text{O}_3} = n_{c8} / \sum n_i$
-	$12\text{CaO} \cdot 7\text{Al}_2\text{O}_3$	$n_{c9} = n_{12\text{CaO} \cdot 7\text{Al}_2\text{O}_3}$	$N_{c9} = N_{12\text{CaO} \cdot 7\text{Al}_2\text{O}_3} = n_{c9} / \sum n_i$
-	$3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$	$n_{c17} = n_{3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2}$	$N_{c10} = N_{3\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2} = n_{c10} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{SiO}_2$	$n_{c11} = n_{\text{Na}_2\text{O} \cdot \text{SiO}_2}$	$N_{c11} = N_{\text{Na}_2\text{O} \cdot \text{SiO}_2} = n_{c11} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 2\text{SiO}_2$	$n_{c12} = n_{\text{Na}_2\text{O} \cdot 2\text{SiO}_2}$	$N_{c12} = N_{\text{Na}_2\text{O} \cdot 2\text{SiO}_2} = n_{c12} / \sum n_i$
-	$2\text{Na}_2\text{O} \cdot \text{SiO}_2$	$n_{c13} = n_{2\text{Na}_2\text{O} \cdot \text{SiO}_2}$	$N_{c13} = N_{2\text{Na}_2\text{O} \cdot \text{SiO}_2} = n_{c13} / \sum n_i$
-	$\text{MgO} \cdot \text{SiO}_2$	$n_{c14} = n_{\text{MgO} \cdot \text{SiO}_2}$	$N_{c14} = N_{\text{MgO} \cdot \text{SiO}_2} = n_{c14} / \sum n_i$
-	$2\text{MgO} \cdot \text{SiO}_2$	$n_{c15} = n_{2\text{MgO} \cdot \text{SiO}_2}$	$N_{c15} = N_{2\text{MgO} \cdot \text{SiO}_2} = n_{c15} / \sum n_i$
-	$\text{BaO} \cdot \text{SiO}_2$	$n_{c16} = n_{\text{BaO} \cdot \text{SiO}_2}$	$N_{c16} = N_{\text{BaO} \cdot \text{SiO}_2} = n_{c16} / \sum n_i$
-	$\text{BaO} \cdot 2\text{SiO}_2$	$n_{c17} = n_{\text{BaO} \cdot 2\text{SiO}_2}$	$N_{c17} = N_{\text{BaO} \cdot 2\text{SiO}_2} = n_{c17} / \sum n_i$
-	$2\text{BaO} \cdot \text{SiO}_2$	$n_{c18} = n_{2\text{BaO} \cdot \text{SiO}_2}$	$N_{c18} = N_{2\text{BaO} \cdot \text{SiO}_2} = n_{c18} / \sum n_i$
-	$2\text{BaO} \cdot 3\text{SiO}_2$	$n_{c19} = n_{2\text{BaO} \cdot 3\text{SiO}_2}$	$N_{c19} = N_{2\text{BaO} \cdot 3\text{SiO}_2} = n_{c19} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3$	$n_{c20} = n_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3}$	$N_{c20} = N_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3} = n_{c20} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3$	$n_{c21} = n_{\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3}$	$N_{c21} = N_{\text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3} = n_{c21} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 9\text{Al}_2\text{O}_3$	$n_{c22} = n_{\text{Na}_2\text{O} \cdot 9\text{Al}_2\text{O}_3}$	$N_{c22} = N_{\text{Na}_2\text{O} \cdot 9\text{Al}_2\text{O}_3} = n_{c22} / \sum n_i$
-	$\text{MgO} \cdot \text{Al}_2\text{O}_3$	$n_{c23} = n_{\text{MgO} \cdot \text{Al}_2\text{O}_3}$	$N_{c23} = N_{\text{MgO} \cdot \text{Al}_2\text{O}_3} = n_{c23} / \sum n_i$
-	$\text{BaO} \cdot \text{Al}_2\text{O}_3$	$n_{c24} = n_{\text{BaO} \cdot \text{Al}_2\text{O}_3}$	$N_{c24} = N_{\text{BaO} \cdot \text{Al}_2\text{O}_3} = n_{c24} / \sum n_i$
-	$3\text{BaO} \cdot \text{Al}_2\text{O}_3$	$n_{c25} = n_{3\text{BaO} \cdot \text{Al}_2\text{O}_3}$	$N_{c25} = N_{3\text{BaO} \cdot \text{Al}_2\text{O}_3} = n_{c25} / \sum n_i$
-	$\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$	$n_{c26} = n_{\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2}$	$N_{c26} = N_{\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2} = n_{c26} / \sum n_i$
-	$2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2$	$n_{c27} = n_{2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2}$	$N_{c27} = N_{2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot \text{SiO}_2} = n_{c27} / \sum n_i$
-	$2\text{Na}_2\text{O} \cdot \text{CaO} \cdot 3\text{SiO}_2$	$n_{c28} = n_{2\text{Na}_2\text{O} \cdot \text{CaO} \cdot 3\text{SiO}_2}$	$N_{c28} = N_{2\text{Na}_2\text{O} \cdot \text{CaO} \cdot 3\text{SiO}_2} = n_{c28} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{CaO} \cdot 5\text{SiO}_2$	$n_{c29} = n_{\text{Na}_2\text{O} \cdot \text{CaO} \cdot 5\text{SiO}_2}$	$N_{c29} = N_{\text{Na}_2\text{O} \cdot \text{CaO} \cdot 5\text{SiO}_2} = n_{c29} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{SiO}_2$	$n_{c30} = n_{\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{SiO}_2}$	$N_{c30} = N_{\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 3\text{SiO}_2} = n_{c30} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 3\text{CaO} \cdot 6\text{SiO}_2$	$n_{c31} = n_{\text{Na}_2\text{O} \cdot 3\text{CaO} \cdot 6\text{SiO}_2}$	$N_{c31} = N_{\text{Na}_2\text{O} \cdot 3\text{CaO} \cdot 6\text{SiO}_2} = n_{c31} / \sum n_i$
-	$\text{CaO} \cdot \text{MgO} \cdot \text{SiO}_2$	$n_{c32} = n_{\text{CaO} \cdot \text{MgO} \cdot \text{SiO}_2}$	$N_{c32} = N_{\text{CaO} \cdot \text{MgO} \cdot \text{SiO}_2} = n_{c32} / \sum n_i$
-	$\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$	$n_{c33} = n_{\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2}$	$N_{c33} = N_{\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2} = n_{c33} / \sum n_i$
-	$2\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$	$n_{c34} = n_{2\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2}$	$N_{c34} = N_{2\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2} = n_{c34} / \sum n_i$
-	$3\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2$	$n_{c35} = n_{3\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2}$	$N_{c35} = N_{3\text{CaO} \cdot \text{MgO} \cdot 2\text{SiO}_2} = n_{c35} / \sum n_i$
-	$3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2$	$n_{c36} = n_{3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2}$	$N_{c36} = N_{3\text{CaO} \cdot 2\text{SiO}_2 \cdot \text{CaF}_2} = n_{c36} / \sum n_i$
-	$3\text{CaO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{CaF}_2$	$n_{c37} = n_{3\text{CaO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{CaF}_2}$	$N_{c37} = N_{3\text{CaO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{CaF}_2} = n_{c37} / \sum n_i$
-	$11\text{CaO} \cdot 7\text{Al}_2\text{O}_3 \cdot \text{CaF}_2$	$n_{c38} = n_{11\text{CaO} \cdot 7\text{Al}_2\text{O}_3 \cdot \text{CaF}_2}$	$N_{c38} = N_{11\text{CaO} \cdot 7\text{Al}_2\text{O}_3 \cdot \text{CaF}_2} = n_{c38} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2$	$n_{c39} = n_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2}$	$N_{c39} = N_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 4\text{SiO}_2} = n_{c39} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$	$n_{c40} = n_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2}$	$N_{c40} = N_{\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2} = n_{c40} / \sum n_i$
-	$2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{SiO}_2$	$n_{c41} = n_{2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{SiO}_2}$	$N_{c41} = N_{2\text{MgO} \cdot 2\text{Al}_2\text{O}_3 \cdot \text{SiO}_2} = n_{c41} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot \text{MgO} \cdot 4\text{SiO}_2$	$n_{c42} = n_{\text{Na}_2\text{O} \cdot \text{MgO} \cdot 4\text{SiO}_2}$	$N_{c42} = N_{\text{Na}_2\text{O} \cdot \text{MgO} \cdot 4\text{SiO}_2} = n_{c42} / \sum n_i$
-	$\text{Na}_2\text{O} \cdot 2\text{MgO} \cdot 6\text{SiO}_2$	$n_{c43} = n_{\text{Na}_2\text{O} \cdot 2\text{MgO} \cdot 6\text{SiO}_2}$	$N_{c43} = N_{\text{Na}_2\text{O} \cdot 2\text{MgO} \cdot 6\text{SiO}_2} = n_{c43} / \sum n_i$

Table 3. Chemical reaction formulas of possibly formed complex molecules.

Reactions	$\Delta G^\ominus/\text{J}\cdot\text{mol}^{-1}$	N_i
$(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (\text{CaO}\cdot\text{SiO}_2)$	$-21,757 - 36.82T$	$N_{c1} = K_{c1}N_1N_2$
$2(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (2\text{CaO}\cdot\text{SiO}_2)$	$-102,090 - 24.27T$	$N_{c2} = K_{c2}N_1^2N_2$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (3\text{CaO}\cdot\text{SiO}_2)$	$-118,826 - 6.69T$	$N_{c3} = K_{c3}N_1^3N_2$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) = (3\text{CaO}\cdot 2\text{SiO}_2)$	$-236,814 + 9.62T$	$N_{c4} = K_{c4}N_1^3N_2^2$
$(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (\text{CaO}\cdot\text{Al}_2\text{O}_3)$	$59,413 - 59.41T$	$N_{c5} = K_{c5}N_1N_3$
$(\text{Ca}^{2+} + \text{O}^{2-}) + 2(\text{Al}_2\text{O}_3) = (\text{CaO}\cdot 2\text{Al}_2\text{O}_3)$	$-16,700 - 25.52T$	$N_{c6} = K_{c6}N_1N_3^2$
$(\text{Ca}^{2+} + \text{O}^{2-}) + 6(\text{Al}_2\text{O}_3) = (\text{CaO}\cdot 6\text{Al}_2\text{O}_3)$	$-22,594 - 31.80T$	$N_{c7} = K_{c7}N_1N_3^6$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (3\text{CaO}\cdot\text{Al}_2\text{O}_3)$	$-21,757 - 29.29T$	$N_{c8} = K_{c8}N_1^3N_3$
$12(\text{Ca}^{2+} + \text{O}^{2-}) + 7(\text{Al}_2\text{O}_3) = (12\text{CaO}\cdot 7\text{Al}_2\text{O}_3)$	$617,977 - 612.12T$	$N_{c9} = K_{c9}N_1^{12}N_3^7$
$3(\text{Al}_2\text{O}_3) + 2(\text{SiO}_2) = (3\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2)$	$-4354.27 - 10.47T$	$N_{c10} = K_{c10}N_2^2N_3^3$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{SiO}_2) = (\text{Na}_2\text{O}\cdot\text{SiO}_2)$	$-299,348.7 + 55.32T$	$N_{c11} = K_{c11}N_2N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + 2(\text{SiO}_2) = (\text{Na}_2\text{O}\cdot 2\text{SiO}_2)$	$-279,093.8 + 23.19T$	$N_{c12} = K_{c12}N_2^2N_4$
$2(2\text{Na}^+ + \text{O}^{2-}) + (\text{SiO}_2) = (2\text{Na}_2\text{O}\cdot\text{SiO}_2)$	$-517,220.2 + 124.22T$	$N_{c13} = K_{c13}N_2^2N_4^2$
$(\text{Mg}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (\text{MgO}\cdot\text{SiO}_2)$	$23,849 - 29.71T$	$N_{c14} = K_{c14}N_2N_5$
$2(\text{Mg}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (2\text{MgO}\cdot\text{SiO}_2)$	$-56,902 - 3.35T$	$N_{c15} = K_{c15}N_2^2N_5^2$
$(\text{Ba}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (\text{BaO}\cdot\text{SiO}_2)$	$-145,604.8 + 10.5T$	$N_{c16} = K_{c16}N_2N_7$
$(\text{Ba}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) = (\text{BaO}\cdot 2\text{SiO}_2)$	$-145,585.8 + 34.2T$	$N_{c17} = K_{c17}N_2^2N_7$
$2(\text{Ba}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (2\text{BaO}\cdot\text{SiO}_2)$	$-257,581.1 + 9.11T$	$N_{c18} = K_{c18}N_2^2N_7^2$
$2(\text{Ba}^{2+} + \text{O}^{2-}) + 3(\text{SiO}_2) = (2\text{BaO}\cdot 3\text{SiO}_2)$	$-303,755.9 + 29.1T$	$N_{c19} = K_{c19}N_2^3N_7^2$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3)$	$-247,970.8 + 44.6T$	$N_{c20} = K_{c20}N_3N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + 3(\text{Al}_2\text{O}_3) = (\text{Na}_2\text{O}\cdot 3\text{Al}_2\text{O}_3)$	$-282,626.4 + 35.28T$	$N_{c21} = K_{c21}N_3^3N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + 9(\text{Al}_2\text{O}_3) = (\text{Na}_2\text{O}\cdot 9\text{Al}_2\text{O}_3)$	$-295,918 + 25.18T$	$N_{c22} = K_{c22}N_3^9N_4$
$(\text{Mg}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (\text{MgO}\cdot\text{Al}_2\text{O}_3)$	$-18,828 - 6.28T$	$N_{c23} = K_{c23}N_3N_5$
$(\text{Ba}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (\text{BaO}\cdot\text{Al}_2\text{O}_3)$	$-124,300 + 6.69T$	$N_{c24} = K_{c24}N_3N_7$
$3(\text{Ba}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) = (3\text{BaO}\cdot\text{Al}_2\text{O}_3)$	$-212,100 + 18.83T$	$N_{c25} = K_{c25}N_3^3N_7^3$
$(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) + 2(\text{SiO}_2) = (\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot 2\text{SiO}_2)$	$-13,816.44 - 55.26T$	$N_{c26} = K_{c26}N_1N_2^2N_3$
$2(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) + (\text{SiO}_2) = (2\text{CaO}\cdot\text{Al}_2\text{O}_3\cdot\text{SiO}_2)$	$-61,961 - 60.29T$	$N_{c27} = K_{c27}N_1^2N_2N_3$
$2(2\text{Na}^+ + \text{O}^{2-}) + (\text{Ca}^{2+} + \text{O}^{2-}) + 3(\text{SiO}_2) =$ $(2\text{Na}_2\text{O}\cdot\text{CaO}\cdot 3\text{SiO}_2)$	$-672,019.9 + 62.8T$	$N_{c28} = K_{c28}N_1N_2^3N_4^2$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{Ca}^{2+} + \text{O}^{2-}) + 5(\text{SiO}_2) = (\text{Na}_2\text{O}\cdot\text{CaO}\cdot 5\text{SiO}_2)$	$-443,841.2 + 63.84T$	$N_{c29} = K_{c29}N_1N_2^5N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + 2(\text{Ca}^{2+} + \text{O}^{2-}) + 3(\text{SiO}_2) =$ $(\text{Na}_2\text{O}\cdot 2\text{CaO}\cdot 3\text{SiO}_2)$	$-607,292.6 + 125.68T$	$N_{c30} = K_{c30}N_1^2N_3^2N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + 3(\text{Ca}^{2+} + \text{O}^{2-}) + 6(\text{SiO}_2) =$ $(\text{Na}_2\text{O}\cdot 3\text{CaO}\cdot 6\text{SiO}_2)$	$-837,543.4 + 219.73T$	$N_{c31} = K_{c31}N_1^3N_2^6N_4$
$(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Mg}^{2+} + \text{O}^{2-}) + (\text{SiO}_2) = (\text{CaO}\cdot\text{MgO}\cdot\text{SiO}_2)$	$-124,683 + 0.766T$	$N_{c32} = K_{c32}N_1N_2N_5$
$(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Mg}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) = (\text{CaO}\cdot\text{MgO}\cdot 2\text{SiO}_2)$	$-80.333 - 51.882T$	$N_{c33} = K_{c33}N_1N_2^2N_5$
$2(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Mg}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) =$ $(2\text{CaO}\cdot\text{MgO}\cdot 2\text{SiO}_2)$	$-73,638 - 63.597T$	$N_{c34} = K_{c34}N_1^2N_2^2N_5$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + (\text{Mg}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) =$ $(3\text{CaO}\cdot\text{MgO}\cdot 2\text{SiO}_2)$	$-205,016 - 31.798T$	$N_{c35} = K_{c35}N_1^3N_2^2N_5$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + 2(\text{SiO}_2) + (\text{Ca}^{2+} + 2\text{F}^-) =$ $(3\text{CaO}\cdot 2\text{SiO}_2\cdot\text{CaF}_2)$	$-255,180 - 8.2T$	$N_{c36} = K_{c36}N_1^3N_2^2N_6$
$3(\text{Ca}^{2+} + \text{O}^{2-}) + 3(\text{Al}_2\text{O}_3) + (\text{Ca}^{2+} + 2\text{F}^-) =$ $(3\text{CaO}\cdot 2\text{Al}_2\text{O}_3\cdot\text{CaF}_2)$	$-44,492 - 73.15T$	$N_{c37} = K_{c37}N_1^3N_3^2N_6$
$11(\text{Ca}^{2+} + \text{O}^{2-}) + 7(\text{Al}_2\text{O}_3) + (\text{Ca}^{2+} + 2\text{F}^-) =$ $(11\text{CaO}\cdot 7\text{Al}_2\text{O}_3\cdot\text{CaF}_2)$	$-228,760 - 155.8T$	$N_{c38} = K_{c38}N_1^{11}N_3^7N_6$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) + 4(\text{SiO}_2) = (\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 4\text{SiO}_2)$	$-440,859.8 + 101.36T$	$N_{c39} = K_{c39}N_2^4N_3N_4$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{Al}_2\text{O}_3) + 6(\text{SiO}_2) = (\text{Na}_2\text{O}\cdot\text{Al}_2\text{O}_3\cdot 6\text{SiO}_2)$	$-425,604 + 19.38T$	$N_{c40} = K_{c40}N_2^6N_3N_4$
$2(\text{Mg}^{2+} + \text{O}^{2-}) + 2(\text{Al}_2\text{O}_3) + 5(\text{SiO}_2) =$ $(2\text{MgO}\cdot 2\text{Al}_2\text{O}_3\cdot 5\text{SiO}_2)$	$-14,422 - 14.81T$	$N_{c41} = K_{c41}N_2^5N_3^2N_5^2$
$(2\text{Na}^+ + \text{O}^{2-}) + (\text{Mg}^{2+} + \text{O}^{2-}) + 4(\text{SiO}_2) =$ $(\text{Na}_2\text{O}\cdot\text{MgO}\cdot 4\text{SiO}_2)$	$-306,210.4 - 1.2T$	$N_{c42} = K_{c42}N_2^4N_4N_5$
$(2\text{Na}^+ + \text{O}^{2-}) + 2(\text{Mg}^{2+} + \text{O}^{2-}) + 6(\text{SiO}_2) =$ $(\text{Na}_2\text{O}\cdot 2\text{MgO}\cdot 6\text{SiO}_2)$	$-312,061.3 - 33.06T$	$N_{c43} = K_{c43}N_2^6N_4N_5^2$

The equilibrium constant equation of the reaction is established by the structural unit of the slag, and then the activity calculation model of the slag is established according to the mass balance. Finally, the mathematical model is constructed.

According to the material balance, it can be concluded that:

$$\sum_{i=1}^{50} N_i = 1, \quad (7)$$

$$m_1 = \sum n(1/2N_1 + N_{c1} + 2N_{c2} + 3N_{c3} + 3N_{c4} + N_{c5} + N_{c6} + N_{c7} + 3N_{c8} + 12N_{c9} + N_{c26} + 2N_{c27} + N_{c28} + N_{c29} + 2N_{c30} + 3N_{c31} + N_{c32} + N_{c33} + 2N_{c34} + 3N_{c35} + 3N_{c36} + 3N_{c37} + 11N_{c38}) \quad (8)$$

$$m_2 = \sum n(N_2 + N_{c1} + N_{c2} + N_{c3} + 2N_{c4} + 2N_{c10} + N_{c11} + 2N_{c12} + N_{c13} + N_{c14} + N_{c15} + N_{c16} + 2N_{c17} + N_{c18} + 3N_{c19} + 2N_{c26} + N_{c27} + 3N_{c28} + 5N_{c29} + 3N_{c30} + 6N_{c31} + N_{c32} + 2N_{c33} + 2N_{c34} + 2N_{c35} + 2N_{c36} + 2N_{c37} + 7N_{c38} + 4N_{c39} + 6N_{c40} + 5N_{c41} + 4N_{c42} + 6N_{c43}) \quad (9)$$

$$m_3 = \sum n(N_3 + N_{c5} + 2N_{c6} + 6N_{c7} + N_{c8} + 7N_{c9} + 3N_{c10} + N_{c20} + 3N_{c21} + 9N_{c22} + N_{c23} + N_{c24} + N_{c25} + N_{c26} + 2N_{c37} + 7N_{c38} + 3N_{c39} + 6N_{c40} + 2N_{c41}) \quad (10)$$

$$m_4 = \sum n(1/3N_4 + N_{c11} + N_{c12} + 2N_{c13} + N_{c20} + N_{c21} + N_{c22} + 2N_{c28} + N_{c29} + N_{c30} + N_{c31} + N_{c39} + N_{c40} + N_{c42} + N_{c43}) \quad (11)$$

$$m_5 = \sum n(1/2N_5 + N_{c14} + 2N_{c15} + N_{c23} + N_{c32} + N_{c33} + N_{c34} + N_{c35} + 2N_{c41} + N_{c42} + 2N_{c43}), \quad (12)$$

$$m_6 = \sum n(1/3N_6 + N_{c36} + N_{c37} + N_{c38}), \quad (13)$$

$$m_7 = \sum n(1/2N_7 + N_{c16} + N_{c17} + 2N_{c18} + N_{c19} + N_{c24} + 3N_{c25}). \quad (14)$$

$N_1, N_2, N_3, N_4, N_5, N_6, N_7$ could be calculated by solving the algebraic equation groups of Equation (7) to Equation (14) with Matlab, and N_1 represents $a(\text{CaO})$. The activity of CaO in the mold flux containing BaO increased from 0.022 to 0.039.

Similarly, the $a(\text{CaO})$ of the mold flux containing B_2O_3 was calculated, and activity of CaO in different mold fluxes is shown in Figure 6. The activity of CaO in the mold flux containing B_2O_3 decreased from 0.022 to 0.003.

Figure 6. Activity of CaO in different mold fluxes.

With the increase in BaO in the mold flux, the activity of CaO increased, which promoted the combination of CaO and TiO_2 to form CaTiO_3 , thus increasing the mass transfer capacity of TiO_2 , as shown in Equation (15).

The increase in B_2O_3 in the mold flux reduces the activity of basic oxides and inhibits the binding ability of TiO_2 and CaO.

3.4. Intermediate Reaction Layer

Through line scanning Ti element, it is determined that there is an intermediate reaction layer between the mold flux and the rod in the process of absorbing inclusions by the mold flux (2#), as shown in Figure 7. According to EDS analysis of absorbing Ti inclusions by the mold flux (2#), the main phase is CaTiO_3 , as shown in Table 4. Under the same conditions, the thickness of the intermediate reaction layer for absorbing TiO_2 is about 120 μm , and that for absorbing TiN is about 35 μm , which indicates that the mass transfer coefficient of TiO_2 to the mold flux is greater than that of TiN . This is due to the reaction of TiN and O_2 to produce N_2 , which takes away heat, reduces local temperature, increases viscosity, and slows down the mass transfer process, as shown in Equation (16) [22].

Figure 7. SEM microphotograph image of the intermediate reaction layer between the mold flux (2#) and rod: (a) TiO_2 ; (b) TiN .

Table 4. EDS analysis of absorbing Ti inclusions by mold flux (2#).

Element	Ca	Si	Al	Mg	Na	Ti	O	F	Ba
(a)	18.19	0.26	0.27	0.08	1.50	20.27	57.65	1.77	0
(b)	17.18	0.13	0.09	0.05	3.08	21.21	56.26	1.98	0.02

4. Conclusions

The dissolution of TiO_2 and TiN inclusions in mold fluxes containing BaO or B_2O_3 for steel continuous casting has been investigated by employing the rotating cylinder method. The results are presented as follows:

- (1) With the addition of BaO in the mold flux, the mass transfer coefficient of TiO_2 increased by 32.7% and the mass transfer coefficient of TiN increased by 42.7%. With the addition of B_2O_3 in the mold flux, the mass transfer coefficient of TiO_2 increased by 62.9% and the mass transfer coefficient of TiN increased by 78.0%. The addition of BaO or B_2O_3 in the mold flux is beneficial to the absorption of TiO_2 and TiN inclusions.

- (2) The mass transfer rate of TiO_2 and TiN in the mold flux with B_2O_3 is higher than that of BaO . The mass transfer coefficient of TiO_2 in the mold flux is greater than that of TiN .
- (3) The way of absorbing inclusions is different for mold fluxes containing BaO or B_2O_3 . TiO_2 and CaO combine to form CaTiO_3 in the mold flux containing BaO , while titanium inclusions still exist in the form of TiO_2 in the mold flux containing B_2O_3 .

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