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COMPOSITION DESIGN AND PHYSICAL PROPERTIES PREDICTION OF MOLD FLUX FOR CONTINUOUS CASTING OF HIGH Mn–HIGH AL STEEL

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The deterioration of $CaO-SiO_2$ based mold flux caused by the reaction of steel -slag interface is a bottleneck restricting the high Mn-Al steel continuous casting production efficiently. Therefore, the development of low-reactivity mold flux has become a research hotspot. In this paper, the scheme of high Al_2O_3 and low SiO_2 was adopted to suppress or reduce the occurrence of steel-slag reaction. Drawing binary phase diagram of mold flux based on the $CaO–Al_2O_3$ composition, the influence of different solvents on the melting characteristics of the mold flux were investigated and the reasonable mass ratio of CaO/Al_2O_3 and the content of SiO_2, SrO, MgO, Na_2O and B_2O_3 were determined. According to the viscosity and the melting temperature model calculation, the physical property is beneficial for the composition design of low-reactivity mold flux.

Keywords: high Mn–high Al steel, continuous casting, viscosity, melting temperature, physical property

INTRODUCTION

High Mn-high Al steel is a typical steel with low density, high strength and ductility. The chemistry of the mold flux is important, which affects heat preservation and insulation, protects the molten steel from oxidation, provides optimum lubrication, controls the heat transfer from the steel, and removes inclusion [1]. However, the high content of Al in liquid steel may easily react with SiO_2 in the traditional $CaO-SiO_2$-based mold flux during the continuous casting process, which resulting in the decreasing of the mass fraction of SiO_2 in liquid slag and the increasing of the mass fraction of Al_2O_3.

The composition of mold flux during the casting process is changed significantly due to the reaction of the element of Al in steel with the SiO_2 in the flux, which may influence the crystallization behavior as well as thermal and physical properties such as the heat transfer and viscosity of mold flux. All that destroys the lubrication and heat transfer conditions in the slag channel, leads to casting billet cracks, depressions and slag entrapment, and even breakout accidents [2].

To overcome the above difficulties caused by the $CaO-SiO_2$-based mold flux during high Mn-Al steels and other TRIP steel grades with high content of Al continuous casting process, metallurgical scholars tried to develop the $CaO-Al_2O_3$ based mold flux, and research of influence of the types and proportions of additives on the physical properties of mold flux were carried out[3 - 6]. In this paper, with analyzing $CaO-SiO_2-Al_2O_3$ phase diagram, surveying lots of literatures, analyzing the melting changing law influenced by the content of MgO and B_2O_3 through thermodynamics calculation, $CaO-Al_2O_3$ based mold flux with low SiO_2 content for the high Mn-high Al steel was proposed, the ratio of CaO/Al_2O_3 and the content SiO_2, the other additive mass ratio were determined.

DESIGN OF LOW REACTIVITY MOLD FLUX SYSTEM

Selection of base material

As shown in Figure 1 of $CaO-SiO_2-Al_2O_3$ phase diagram, there are two areas of lower melting point tem-

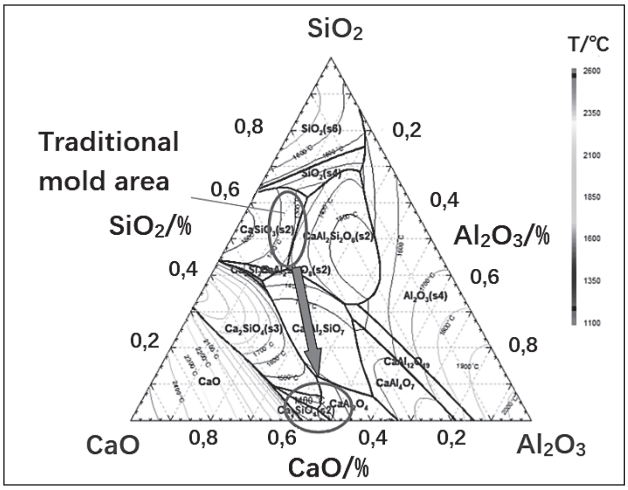

Figure 1 Phase diagram $CaO-SiO_2-Al_2O_3$ system

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perature. The upper area is the region of the Wollastonite of higher CaO-SiO_2 and less Al_2O_3 content, which is used widely for the traditional mold flux.

For CaO-SiO_2 based flux, the precipitates are mainly $CaSiO_3$, and the melting temperature is about 1 300 °C. Due to the higher SiO_2 in the mold flux reacting with Mn and Al element in the steel and leading to the deterioration of mold flux, this slag system is not suitable for high Mn high Al steel continuous casting process. The other area of low melting point temperature is of higher CaO-Al_2O_3 and less SiO_2. For this mold flux system, the precipitates are mainly Ca_2SiO_4, and its melting point temperature is about 1 400 °C. Owing to less SiO_2, the serious steel-slag interface reaction can be avoided, so the CaO-Al_2O_3 based mold flux can be selected for the high Mn high Al steel continuous casting.

DETERMINATION OF BASE MATERIAL

The ratio of CaO/Al_2O_3

The ratio of CaO/Al_2O_3 determines the mold flux melting temperature and slag film thickness during cooling process, which influences the heat transfer of mold flux. X. J. Fu[3] found that the slag film thickness was 2,36 - 3,24mm when the ratio of CaO/Al_2O_3 is 0,7 - 2,0, and the minimum slag film thickness was 2,36mm when the ratio of CaO/Al_2O_3 was 1,5. Figure 2 is the CaO-Al_2O_3 two phase diagram, it shows that the melting temperature reaches the lowest when the value of CaO/Al_2O_3 is equal to 1, where, the precipitated phases are $Ca_3Al_2O_6$ and $CaAl_2O_4$. Considering the solidification characteristics of high Mn–high Al steel, the ratio of CaO/Al_2O_3 should be nearly 1.

The ratio of SiO_2

The existing of SiO_2 will strengthen the steel-slag reaction, but a small amount of SiO_2 is necessary. Zhu[5] proposed that the SiO_2 content less than 2 wt.% and (Al_2O_3 + CaO) > 50 wt.% would inhibit strong reducing elements from being oxidized and entering to the mold flux. The patent of a high Mn-high Al steel [6] shows that the steel-slag reaction is weak if the SiO_2 content in the mold flux is less than 7 wt.%. Overall, for the low reactivity CaO-Al_2O_3 based mold flux, the SiO_2 content should be within 7 wt.%.

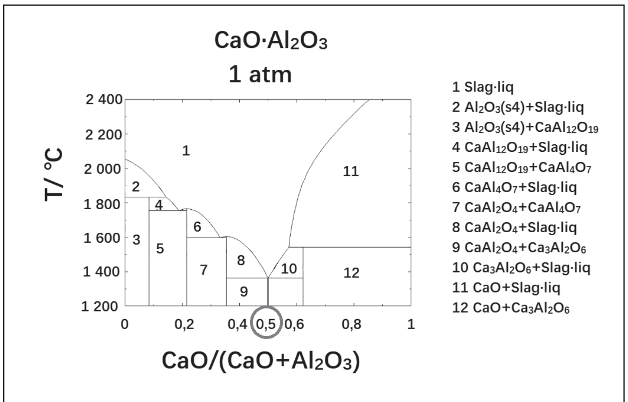


Figure 2 Phase diagram CaO-Al_2O_3 system

DETERMINATION OF LOW-REACTIVITY Mold flux additive

For the CaO-Al_2O_3 based mold flux, B_2O_3 is added into the mold flux and Borate forms, whose structure is similar to structure of silicate to compensate the decrease of the vitrification and flow performance resulting from the reduction of SiO_2 .

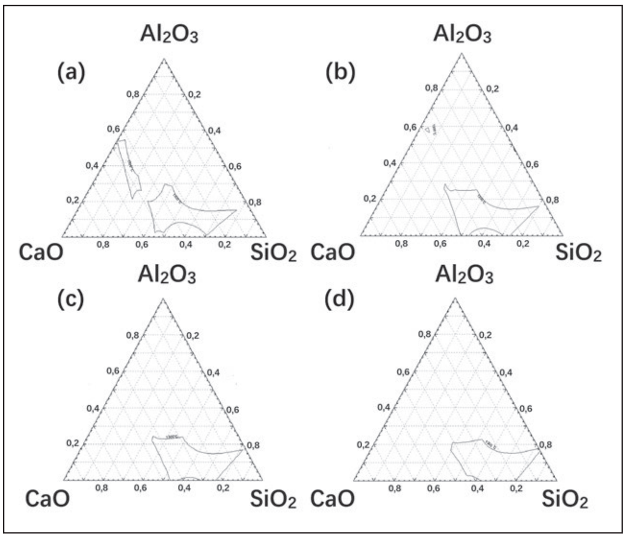
CaF_2 is a common addition of mod flux, but a large amount will cause the precipitation of high melting point substances and increase the crystallization temperature of the mold flux. In addition, fluoride is a kind of pollution element to the environment. Yu [4]' research showed that CaF_2 content should be 5 % - 8 % for the low reactivity CaO-Al_2O_3 based mold flux.

Na_2O, Li_2O, BaO, SrO and MgO may serve primarily as a fluxing agent to control viscosity and melting temperature. Wang's research [7] showed that the crystallinity of the mold flux was deteriorated if the content of Na_2O more than 2 %. Li_2O is also an important flux, which can significantly reduce the melting temperature and viscosity of the mold flux, but its price is relatively high. Dong[8]' research showed that SrO and BaO played a similar role on adjusting the mold flux viscosity and melting property, but SrO' effect was better than BaO.

In summary, the additives of CaO-Al_2O_3 based mold flux are CaF_2, Na_2O, SrO, MgO and B_2O_3, the ratio of the first three components is determined based on literatures. The following content of this article focuses on the influence of the ratio variation of MgO and B_2O_3 on liquid region of CaO-Al_2O_3-SiO_2 phase diagram, then the changing law of melting point temperature are dicussed.

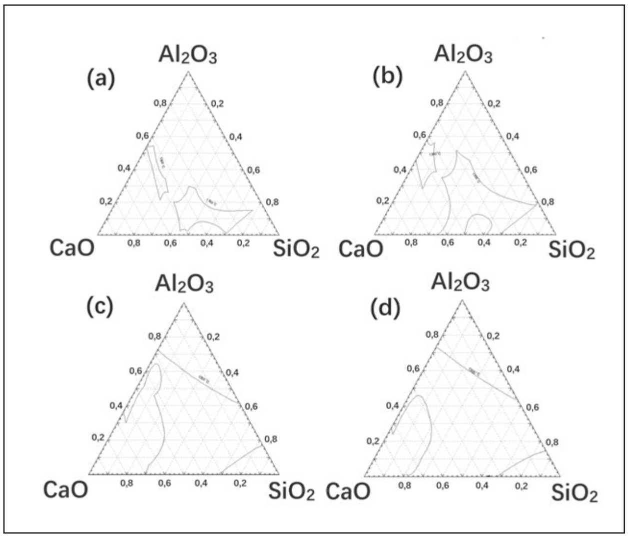
Determination of MgO content

When the ratio of MgO in the mold flux changes from 0 % - 8 %, the phase diagram at 1 300 °C was pictured respectively with the thermodynamic FACTSAGE software used. as shown in Figure 3. The region encircled by the red line in the diagram represents the liquid phase zone below 1 300 °C.There are two liquid zones below 1 300 °C when the content of MgO is 0 % or 3 %, but the area of upper region reduced when the content is 3 %, and disappeared when the content of MgO is 5 % and 8 %. The area of lower region is gradually expanding with the increasing of MgO content. This phenomenon means that the melting temperature of the mold flux increases with the content of MgO increasing. The literature [9] indicated that for non-reactive mold flux with more than 6 % MgO, a large amount of Mg^{2+} will increase the degree of polymerization of the mold flux and make the mold flux viscosity increase sharply. Therefore, the content of the MgO in CaO-Al_2O_3 based mold flux should be less than 6%.



(a) 0 % MgO, (b) 3 % MgO, (c) 5 % MgO, (d) 8 % MgO

Figure 3 Isothermal section diagram of different MgO content at 1 300 °C



(a) 0 % B_2O_3, (b) 4 % B_2O_3, (c) 8 % B_2O_3, (d) 12 % B_2O_3

Figure 4 Isothermal section diagram of different B_2O_3 content at 1 300 °C

Determination of B_2O_3 content

B_2O_3 is commonly used to adjust the viscosity of CaO-Al_2O_3 based mold flux. However, B_2O_3 reacts with Al element in the steel easily. Therefore, it is necessary to obtain the critical content of B_2O_3 in mold flux to avoid steel-slag reaction. Yu[4] studied CaO-Al_2O_3 based mold flux containing 4 % - 10 % B_2O_3, and found that mold flux with 6 % B_2O_3 had a weak slag-steel reaction. Here, When the ratio of B_2O_3 in the mold flux changes from 0 % - 12%, the phase diagram at 1 300 °C was pictured respectivelywith the thermodynamic Factsage software used, as shown in Figure 4. There are two liquid zones below 1 300 °C when the content of B_2O_3 is 0 % or 8 %, but the area of lower region increases with the content of B_2O_3 increasing, and integrates with the upper region gradually. That means that the increasing of B_2O_3 can improve the melting performance of the mold flux. Considering the reactivity and physical property requirements of high Mn-high Al steel mold flux, the content of B_2O_3 should be about 6 %.

PHYSICAL PROPERTY PREDICTION OF MOLD FLUX

Based on the above analysis, the composition of mold flux for high Mn high Al steel mold flux and the content range of the each component are listed in Table 1. In order to evaluate the melting and viscosity performance of the this mold flux system, the melting temperature and the viscosity calculated with equation (1) and (2) [4] respectively. The melting temperature is 1 133,95 °C - 1 199,35 °C, viscosity value is 0,038 Pa·s - 0,137 Pa·s.

$$T_s = 1293 - 8\times w(B_2O_3) - 13\times w(Li_2O) - 6\times w(Na_2O)$$
$$-5\times w(SrO) - 1,5\times w(BaO) - 1,8\times w(F^-) + 2\times w(MgO)$$
$$+(w(Al_2O_3)/w(CaO) - 0,966)^2 \times 300 \qquad (1)$$

Table 1 **Composition of mold flux designed / %**

Component	CaO/Al_2O_3	SiO_2	Na_2O	SrO	CaF_2	MgO	B_2O_3
Content	1	7	2	5 - 15	5 - 8	0 - 5	6

$$\eta = MTexp(\frac{N}{T}) \qquad (2)$$

where

$$M = exp(-6,431 + 2,361X_{Al_2O_3} - 8,136X_{CaO} - 0,01X_{Na_2O}$$
$$-0,003X_{CaF_2})$$

$$N = -398X_{CaO} - 6032,239X_{CaF_2} - 3645,393X_{Na_2O}$$
$$+485X_{Al_2O_3}$$

where

$$X_{Al_2O_3} = X_{MgO} + X_{BaO} + X_{SrO} + X_{Al_2O_3}$$
$$X_{Na_2O} = X_{Na_2O} + X_{Li_2O}$$
$$X_{CaO} = X_{CaO} + X_{B_2O_3}$$

X percentage of moles of different components in the liquid slag

T temperature

CONCLUSION

In this paper, the composition region of CaO-Al_2O_3 based mold flux system is determined based on the literature and phase diagram analysis, the melting and viscosity performance evaluated with empirical formula used, the final conclusions are as follows,

(1) To avoid SiO_2 in the mold flux reacting with the Al element during in mold flux , CaO-Al_2O_3 based mold flux with 6 % SiO_2 and the ratio of CaO/Al_2O_3 equal to 1 is suitable for the high Mn-high Al steel continuous casting process.

(2) The ratio of SrO, Na_2O, MgO, B_2O_3 and CaF_2 is 5 - 15 %, 2 %, 0 - 5 %, 6 % and 5 - 8 %. The melting

temperature and the viscosity value of the designed mold flux is 133,95 °C - 1 199,35 °C and 0,038 Pa·s - 0,137 Pa·s, which can meet the requirement of the high Mn-high Al steel continuous casting process.

Acknowledgements

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Note: D. Nie is the master degree candidate and responsible for English language.