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Effect of B_2O_3 on Slag-Metal Reaction between $CaO-Al_2O_3$ -Based Mold Flux and High Aluminum Steel

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Abstract: The effect of B_2O_3 on slag-metal reaction between $CaO-Al_2O_3$ -based mold flux and high aluminum steel was investigated. The results showed that the addition of 5 % B_2O_3 , the slag-metal reaction hardly occurred. When the content of B_2O_3 was increased, the reaction rate increased rapidly. This indicated if only considering the slag-metal reaction, it's better for high aluminum steel casting if the addition content of B_2O_3 is less than 5%. The chemical reaction was greatly influenced by the reaction time. With higher content of aluminum ($[Al] = 0.1\%$), the early stage of reaction was greatly affected by the reaction time, and furtherly, the influence was decreased. When the aluminum content was increased, the effect of $[Al]$ on the slag-metal reaction was comparatively small in the initial 10 min, and the content of $[B]$ was increased slightly. But when the reaction time increased to 1 hour, the slag-metal reaction acutely occurred, and the content of $[B]$ increased rapidly.

Keywords: B_2O_3 , slag-metal reaction, $CaO-Al_2O_3$ -based mold flux

Introduction

High aluminum steel has been received increasing attention due to their excellent combination of high strength and superior formability, which can satisfy the requirements of being light, tough and available at a reasonable cost for the modern steel materials [1–5]. The high concentration of $[Al]$ in steel is prone to react with SiO_2 from the mold flux during casting. There had many reports

about the chemical reactions between mold flux and high aluminum steel [6–8]. This chemical reaction usually leads to the huge dynamical change of the chemical composition of mold flux, which would deteriorate both the casting operation and the surface quality of cast slabs and cause many problems such as increased crack frequency, non-uniform heat transfer across the mold flux, reduced lubrication and so on.

In order to solve the problems of high aluminum steel casting, researchers have proposed the non-reactive $CaO-Al_2O_3$ -based mold flux to substitute for conventional $CaO-SiO_2$ mold flux [4–17]. Blazek et al. [11] developed $CaO-Al_2O_3$ -based mold flux and found that the interaction between flux and steel was markedly reduced and the as-cast quality was improved. However, low consumption of mold fluxes and poor lubrication problems have not been solved effectively. Cho et al. [13] found that $CaO-Al_2O_3$ -based mold flux mold fluxes could suppress the occurrence of surface depressions and cracks, but the slag film of lime-alumina mold fluxes were prone to crystallize easily, which made the mold lubrication deteriorate rapidly. Li et al. found [18] that the viscosities and break temperatures of $CaO-Al_2O_3$ -based mold fluxes were relatively high for casting. It can be concluded that $CaO-Al_2O_3$ -based mold fluxes still face many existing problems.

In our previous work, F-free $CaO-Al_2O_3-B_2O_3$ -based mold flux was developed [19], which could have similar viscosity values and melting temperatures as the traditional $CaO-SiO_2-CaF_2$ based mold fluxes showed in Fig.1. In addition, which could have lower liquidus temperature and weaker crystallization ability when compared with $CaO-Al_2O_3-CaF_2$ -based mold flux [20, 21]. However, according to Figure 2, the oxygen-potential diagram showed that B_2O_3 is prone to react with $[Al]$. B_2O_3 is likely to be reduced by $[Al]$ from the high aluminum steel during casting. The addition content of B_2O_3 ($\leq 12\%$) is much less than SiO_2 . Although a small addition of B_2O_3 , the new reaction between slag and steel may still occur, which may cause the boron pollution for steel. The content of boron in steel are directly associated with slag-metal reaction. Therefore, in order to evaluate the effect of B_2O_3 on slag-metal reaction

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Figure 1: Comparison of the melting temperatures and viscosities of the studied $CaO-Al_2O_3-B_2O_3$ -based mold flux with traditional $CaO-SiO_2-CaF_2$ -based mold flux [19].

Figure 2: The oxygen potential figure of B_2O_3 , SiO_2 and Al_2O_3 calculated by Factsage 6.4.

between $CaO-Al_2O_3$ -based mold flux and high aluminum steel, the slag-metal reaction behaviors were investigated in present work. The present results would provide the theoretical basis for development of an optimized high aluminum steel mold flux based on $CaO-Al_2O_3-B_2O_3$ system.

Experimental

Sample preparation

Analytical grade Al_2O_3 , Na_2CO_3 , Li_2CO_3 , $CaCO_3$ and H_3BO_3 were selected as raw materials of mold flux, with Na_2CO_3 , Li_2CO_3 and H_3BO_3 being substitutes for Na_2O , Li_2O and B_2O_3 , respectively. Due to the graphite crucible used in the experiments, the high content of C was designed with 4 % in all steel. Initial compositions of mold fluxes and steel for present study are listed in Table 1.

Table 1: Initial compositions of mold fluxes and steel for present study.

Mold fluxes	Composition (mass %)				
	CaO	Al_2O_3	Na_2O	Li_2O	B_2O_3
1	39.5	39.5	8	8	5
2	38	38	8	8	8
3	37	37	8	8	10
4	36	36	8	8	12

Steel	Composition (mass %)		
	Fe	C	Al
1	95.5	4	0.5
2	95	4	1

The slag-metal reaction experimental procedure

In order to evaluate the possibility of chemical reactions between carbon and B_2O_3 , ΔG had been calculated by Factsage6.4. It can be seen that the value of ΔG is always greater than zero when the temperature is less than or equal to 1,800 K, indicating that the reactions between carbon and B_2O_3 cannot occur at 1,773 K. Compositions reported in this work are all in mass pct. A schematic figure of the experimental equipment is showed in Figure 3 [22]. The reaction temperature was set at 1,773 K. The experiments were conducted in a molybdenum silicide vertical tube furnace under argon atmosphere. Temperature inside

Figure 3: A schematic figure of the experimental equipment.

furnace was measured using a Pt-6%Rh/Pt-30%Rh (B type) thermocouple placed underneath the bottom of crucible. The ratio of slag and steel was designed as 6:1. At the end of the experiment, the sample was removed from the furnace and quenched by water. The content of [B] in steel was analyzed using inductively coupled plasma optical emission spectroscopy (ICP-OES) (Perkin Elmer, OPTIMA 7000DV).

Results and discussion

According to the melting temperature of steel, the experimental temperature was designed at 1,773 K. The slag-metal reaction was investigated at three periods of 10 min, 30 min and 60 min. The specific reaction between B_2O_3 and [Al] as showed in eq. (1), four flux compositions with varied B_2O_3 concentration and two steel composition with varied [Al] were considered.

When reaction (1) occurred, the concentrations of [B] in molten steel are analyzed. Those experimental data measured in present study are shown in Figure 4–6.

The effect of B_2O_3 in $CaO-Al_2O_3$ mold flux

Since B_2O_3 is a reactant of reaction (1), a high concentration of B_2O_3 in mold flux may increase the reaction rate of [B] accumulation and [Al] reduction in steel. Figure 4 showed that the change of [B] content of high

Figure 4: The change of [B] content of high Al steel with different B_2O_3 addition in $CaO-Al_2O_3$ -based mold flux.

Figure 5: The change of [B] content of high Al steel with different reaction time.

Al steel with different B_2O_3 in $CaO-Al_2O_3$ -based mold flux. The results showed that the addition of 5% B_2O_3 , the slag-metal reaction hardly occurred. But with the increasing content of B_2O_3 , the reaction rate increased rapidly in the steel with 0.5% [Al] and 1% [Al]. This demonstrates that if only the slag-metal reaction for high aluminum steel casting is considered, the content of B_2O_3 in $CaO-Al_2O_3$ -based mold flux should not be more than 5%. Similarly, when the concentration of $SiO_2 < 6\%$ or $B_2O_3 < 6\%$ in mold flux, the occurrence of the slag-metal reaction was really slow between high aluminum steel and low content of SiO_2 -based mold flux [23].

The effects of [Al] in steel and reaction time

[Al] is the component of the reaction between $CaO-Al_2O_3-B_2O_3$ -based mold flux and high Al steel. The effects of different [Al] of steel and the reaction time were investigated. The change of [B] content with different contents of [Al] in steel and different reaction times is shown in Figures 5–6. It can be seen that the slag-metal reaction was greatly influenced by the reaction time. With relatively high content of aluminum in steel ($[Al] = 0.1\%$), the early stage of the slag-metal reaction was greatly affected by time, and furtherly, the influence was reduced. When the aluminum content was increased, the effect of [Al] on the slag-metal reaction was comparatively small in the initial 10 min, and the content of [B] increased slightly. But when the reaction time increased to 1 h, the slag-metal reaction acutely occurred, and the content of [B] increased rapidly. It can be concluded that the content of [Al] in the steel is not restrictive step in the early period of the slag-metal reaction.

Conclusion

The effects of B_2O_3 on slag-metal reaction between $CaO-Al_2O_3$ -based mold flux and high aluminum steel were investigated in the present work. The following results have been obtained:

- (1) The addition of 5% B_2O_3 , the slag-metal reaction hardly occurred. When B_2O_3 was increased, the reaction rate increased rapidly. This indicated that if only the reaction behavior was considered, it's better for high aluminum steel casting if the addition content of B_2O_3 is less than 5%.
- (2) The chemical reaction was greatly influenced by the reaction time. With higher content of aluminum ($[Al] = 0.1\%$), the early stage of reaction was greatly affected by the reaction time, and furtherly, the influence was decreased.
- (3) When aluminum content was increased, the effect of [Al] on the slag-metal reaction was comparatively small in the initial 10 min, and the content of [B] was increased slightly. But when the reaction time increased to 1 h, the slag-metal reaction acutely occurred, and the content of [B] increased rapidly.

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Figure 6: The change of $[B]$ content of high Al steel with different content of $[Al]$ in steel.

References

- [1] T. Yoshihiro and I. Takeshi, *Int. J. Mech. Sci.*, 37 (1995) 1295–1305.
- [2] O. Grässel, L. Krüger, G. Frommeyer and L.W. Meyer, *Int. J. Plasticity*, 16 (2000) 1391–1409.
- [3] S. Street, K. James, N. Minor, A. Roelant and J. Tremp, *Iron & Steel Technology*, 5 (2008) 38–49.
- [4] C. Jung-Wook, B. Kenneth, F. Michael, Y. Hongbin, P.J. Hyouk and M.S. Woon, *ISIJ Int.*, 53 (2013) 62–70.
- [5] J.L. Li, Q.F. Shu and K. Chou, *Ironmak steelmak*, 42 (2015) 154–160.
- [6] M.S. Kim, S.W. Lee, J.W. Cho, M.S. Park, H.G. Lee and Y.B. Kang, *Metall. Mater. Trans. B*, 44 (2013) 299–308.
- [7] Y.B. Kang, M.S. Kim, S.W. Lee, J.W. Cho, M.S. Park and H.G. Lee, *Metall. Mater. Trans. B*, 44 (2013) 309–316.
- [8] J. Gao, G. Wen, T. Huang, B. Bai, P. Tang and Q. Liu, *J. Non-Cryst. Solids*, 452 (2016) 119–124.
- [9] J. Li, S. Qifeng, H. Xinmei and C. Kuochih, *ISIJ Int.*, 55 (2015) 830–836.
- [10] J.L. Li, Q.F. Shu and K.C. Chou, *Can. Metall Quart*, 54 (2015) 85–91.
- [11] K. Blazek, Y. Hong-bin, G. Skoczylas, M. McClymonds, and M. Frazee: *ECCC-METEC*, Düsseldorf, Germany, (2011) 1–10.
- [12] J.S. Suk and I. Sohn, *Metall. Mater. Trans. B*, 43 (2012) 1530–1539.
- [13] C. Jung-Wook, K. Blazek, M. Frazee, H. Yin, P.J. Hyouk and M. Sang-Woon, *ISIJ Int.*, 53 (2013) 62–70.
- [14] W. Ting, W. Qian, H. Shengping, X. Jianfei, L. Xiao and L. Yongjian, *Steel Res. Int.*, 83 (2012) 1194–1202.
- [15] K. Min-Su, L. Su-Wan, C. Jung-Wook, P. Min-Seok, L. Hae-Geon and K. Youn-Bae, *Metall. Mater. Trans. B*, 44 (2013) 299–308.
- [16] K. Youn-Bae, K. Min-Su, L. Su-Wan, C. Jung-Wook, P. Min-Seok and L. Hae-Geon, *Metall. Mater. Trans. B*, 44 (2013) 309–316.
- [17] S. Cheng-Bin, S. Myung-Duk, W. Hui, C. Jung-Wook and K. Seon-Hyo, *Metall. Mater. Trans. B*, 46 (2015) 345–356.
- [18] J.L. Li, Q.F. Shu and K.C. Chou, *Can. Metall Quart*, 55 (2015) 830–836.
- [19] J. Li, B. Kong, B. Galdino, J. Xu, K. Chou, Q. Liu and Q. Shu, *Steel Res. Int.*, 88 (2017) 1600485.
- [20] C. Jung-Wook, K. Blazek, M. Frazee, H. Yin, P.J. Hyouk and M. Sang-Woon, *ISIJ Int.*, 53 (2013) 62–70.
- [21] W. Yan, W. Chen, Y. Yang, C. Lippold and A. Mclean, *ISIJ Int.*, 55 (2015) 1000.
- [22] Q. Shu, P. Li, X. Zhang and K. Chou, *Metall. Mater. Trans. B*, (2016) 1–6.
- [23] Y. Xiong, *High-aluminum steel casting mold slag basic research* [D], Chongqing University, Chongqing (2011).