Research Article

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Influence of phase distribution of converter slag microzones on the occurrence of P

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Abstract: The phase and element distribution of converter slag was analyzed with the backscattered electron (BSE) images of scanning electron microscopy and X-ray energy spectrum. The results show that the Ca and Si are attached in the slag micro-area, while the Fe is present in areas with less Ca and Si. Most of the P appear in areas with more Ca and Si. The content of SiO_2 tends to increase with an increase in the CaO content in the slag micro-area. The activity of a_{CaO} increases with an increase in the CaO content in the slag micro-area, while the activity of a_{FeO} increases first and then decreases. In the slag micro-area with an increase in the FeO content, both the mole fraction and the activity coefficient of SiO_2 decrease; so, the content of SiO_2 decreases gradually.

Keywords: converter slag, phosphorus occurrence, micro-area, calcium oxide, activity

1 Introduction

The converter slagging dephosphorization process is one of the main tasks in the steelmaking process, its importance is self-evident [1,2]. The formation of slag and the distribution of each oxide phase directly affect the slag phosphorus capacity, thereby affecting the slag phosphorus distribution ratio. The formation of slag involves a series of physical and chemical effects. The components of converter slag-making are diverse, and the formation

of slag is complex with many influencing factors. However, there are some links in the mineral distribution of slag, because the mineral composition and crystallization state are closely related to the smelting and slagging process. Hence, it is helpful to study the distribution of oxides in the slag micro-area for improving the slagging process. Also, phosphorus enrichment in the slag is more closely related to the distribution of the microregions. It can be seen that the research on the distribution of each oxide phase in the slag micro-area can not only clarify the slag formation process but also further lay the foundation for studying the occurrence of P regularity to optimize converter dephosphorization [3–5]. The formation of f-C₂S in the slag affects the content of P_2O_5 in the phosphate-rich phase nC₂S-C₃P [6,7]. The FeO content in the micro-area affects both the activity coefficient of P_2O_5 and the enrichment of P elements. It can be seen that the research on the distribution of each oxide phase in the slag micro-area can not only clarify the slag formation process but also further lay the foundation for studying the occurrence of P regularity. In this paper, the slag formation mechanism was analyzed by the backscattered electron image of cold slag, which focuses on CaO, SiO_2 , FeO oxide distribution behavior.

2 Experimental methods

Under normal smelting conditions, the earlier slag and the final slag are sampled and slowly cooled in a company's converter double slag process operation, and the treated steel slag is in a gray block shape. The main component of the earlier and final slag was analyzed by XRF. The analysis results are shown in Table 1.

The industry tests are a total of five heats, ten slags. In addition, the phase composition and elemental distribution of earlier and final slag from the different furnaces are observed by electron backscattered diffraction (EBSD). The analysis results show the contents of Ca, Si, Fe, and P in different phases [7]. Then, the content of each element in a different slag phase is summarized.

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Table 1: Slag composition (wt)/%

	TFe	CaO	SiO ₂	MgO	MnO	P ₂ O ₅	S
Earlier slag	14.4–21.2	25.7–36.9	16.2–23.7	6.0–11.3	4.3–7.8	2.6–5.0	0.03–0.05
Final slag	17.3–26.8	31.6–44.8	8.8–14.7	7.5–16.8	1.9–3.6	1.80–2.91	0.04–0.14

3 Results and discussion

The EBSD is used to analyze the earlier slag and final slag in converter smelting. The scanning image of the representative phase is shown in Figure 1. According to the principle of backscatter electron imaging, the smaller the atomic number of a substance is, the darker the image is. The atomic number of the major elements in the slag is in turn Fe, Ca, Si, Mg, and O. Hence, the color of the phase can reflect its chemical composition [8–10]. According to Figure 1, the type of steel slag is divided into three types: black, gray, and off-white.

The elemental composition can be obtained by energy spectrum analysis of different color phases in the slag zone. The elements in the microregion of the representative phase are shown in Table 2, which corresponds to Figure 1. The contents of Ca, Fe, Si, and P element are analyzed and studied emphatically. According to the results of energy spectrum analysis, the gray-white phase is mostly ferrite phase, namely ferrite phase and ferric acid dihydrate, the gray matter is mainly silicate phase, and the black matter is RO phase.

In this paper, phase analysis of different microregions of 10 slags was performed, and more than 130 sets of data similar to Table 2 were obtained. According to the content of Ca, Fe, and Si in the slag microregion,

element content was converted into the corresponding oxide content ratio, and then the distribution characteristics between the three oxides in the micro-region were researched.

3.1 Elemental distribution of slag microzone

Figure 2 shows the backscatter images and elemental distributions of 1# converter slag.

It can be seen from Figure 2 that in the microscopic area of the slag, the Ca are mostly attached to the Si elements. While Fe is present in areas with less Ca and Si, which presents an alternative trend. Most of P occurs in areas with high Ca and Si contents [8,9].

3.2 Distribution of CaO, FeO, SiO₂ in slag micro-area

To quantitatively study the distribution characteristics of Fe, Si, and Ca in the slag micro-area, the analysis data of different microregions are summarized and analyzed. Table 2 is the ratio of the quality score of each element of the management region, while the molar ratio of each element is obtained by dividing the mass fraction with the molar mass. The molar ratio of the element is the molar ratio of its simple oxide. CaO, FeO, and SiO₂ are the main compositions of the slag oxide, and the

Figure 1: Backscattered electron images of each phase in the converter slag.

Table 2: EDS of each phase in converter slag

Spectrum	O	Mg	Si	P	Ca	Fe	CaO/SiO ₂
Spectrum 1	42.52	30.84	1.12	—	6.10	17.00	3.56
Spectrum 2	42.60	28.52	1.10	—	6.54	18.88	3.88
Spectrum 3	41.98	30.84	1.10	—	5.81	17.54	3.45
Spectrum 4	44.54	1.24	10.21	2.36	33.30	7.22	2.13
Spectrum 5	45.29	1.51	10.29	2.58	32.85	7.09	2.09
Spectrum 6	39.46	2.60	2.20	—	20.58	30.96	6.11
Spectrum 7	39.49	3.10	2.85	0.41	21.32	28.94	4.89

Figure 2: Backscattered electron image and elements distribution of 1# converter slag.

proportion of the three added together is above 60%. Therefore, the slag formation process can be understood by studying the distribution characteristics of CaO, FeO, and SiO₂ in the slag micro-area. First, CaO was used as the matrix to study the distribution relationship of CaO, FeO, and SiO₂ in earlier slag and final slag. Figure 3 shows the distribution characteristics of CaO and SiO₂ in the earlier slag and the final slag.

As can be seen from Figure 3, the content of CaO is small in the micro-area of earlier slag. With an increase in the CaO content, SiO₂ becomes larger, and the trend of

change is uniform. Compared with the earlier slag, the content of CaO in the final slag is large, and with an increase in the CaO content, SiO₂ in the micro-area increases.

According to the slag molecular theory, CaO belongs to basic oxide, SiO₂ belongs to acidic oxide, and both can react to form calcium silicate. At the steel-making temperature, silicates may exist in the form of CaSiO₃, Ca₂SiO₄, and Ca₃SiO₅. Figure 4 shows that the SiO₂ content gradually increases with an increase in CaO in the micro-area. Figure 2 shows that the Ca and Si are attached to each other. The steelmaking slag is mainly CaO–SiO₂–FeO–MgO four-component slag system; the analysis result indicates that the CaO activity (a_{CaO}) increases with the addition of CaO content, while the activity of SiO₂ (a_{SiO_2}) in the micro-area also increases.

Figure 4 shows the distribution characteristics of CaO and FeO in the earlier slag and the final slag.

Figure 4 shows that in the earlier slag and final slag micro-areas, although the FeO and CaO contents are different, the changing trends of the two are consistent. With an increase in the CaO content, FeO in the micro-area first increases and then decreases. According to the changing trend, it is known that a_{CaO} increases with an increase of CaO content in the slag micro-area, while the activity of a_{FeO} increases first and then decreases in the micro-area. Because CaO content is small in the slag micro-area, CaO is more alkaline than FeO; hence, CaO is combined with acidic substances such as SiO₂ in the

Figure 3: Distribution characteristics of CaO and SiO₂ in the slag micro-area phase.

Figure 4: Distribution characteristics of CaO and FeO in the slag micro-area phase.

slag, which results in an increase of free FeO content in the slag and an increase of a_{FeO} in the slag. However, when the content of CaO is higher than a certain value, the increase of CaO will result in a decrease in the FeO mole fraction. However, the addition of CaO content increases the FeO activity coefficient [10]. But, the combined effect of two is the decrease in a_{FeO} .

Figure 5 shows the distribution characteristics of SiO_2 and FeO in the earlier slag and the final slag.

Figure 5 shows that with an increase in the FeO content, the SiO_2 gradually decreases in the earlier and final slag. They exhibit anti-correlation properties because FeO is a basic oxide and SiO_2 is an acidic oxide, both of which react to form complex compounds. With an increase in the FeO content in the slag micro-area, the

Figure 5: Distribution characteristics of SiO_2 and FeO in the slag micro-area phase.

melting point and viscosity of the slag are reduced, and the fluidity of the slag becomes better, which is conducive to mass transfer. The mole fraction of SiO_2 and the activity coefficient of SiO_2 decreased, so that the content of SiO_2 in the slag decreased [11–13]. Figure 5 shows that both CaO and SiO_2 oxides appear to be substitutable in the slag micro-area; that is, the existence of oxide is bound to reduce the activity of another oxide.

4 Conclusions

In the present work, the oxides' distribution behavior of $\text{CaO-SiO}_2\text{-FeO-P}_2\text{O}_5$ in converter slag micro-area was investigated. The main conclusions are described as follows:

- (1) Most of Ca are attached to the Si in the slag micro-area, while the Fe is present in the areas with less Ca and Si, which shows an alternative trend. The P is mostly found in areas where there are more Ca and Si. And, O shows an average distribution in the micro-area.
- (2) With an increase in the CaO content, the a_{CaO} increased and the content of SiO_2 in the micro-area increased. In the micro-area, the influence of CaO content on the FeO content is consistent, and the a_{CaO} increases with an increase in the CaO content, while the a_{FeO} first increases and then decreases.
- (3) In the earlier and the final slag micro-area, with an increase in the FeO content, the mole fraction and the activity coefficient of SiO_2 decrease.

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