Investigation of blowing high silicon hot metal by double slag process

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Abstract: For integrated steel plants, hot metal with silicon content larger than 1.0% cannot be used in BOF (Basic Oxygen Furnace) process unless mixed with low silicon-content hot metal. Slopping is the major disadvantage of BOF operation with high silicon-content hot metal during blowing. This phenomenon easily occurs with excess slag amount from the results of ample CaO needed to achieve desired basicity. But for steel plants with newborn single blast furnace, such as Dragon Steel Corporation, the way of mixing hot metal cannot be delivered in exception of dumping. In order to decrease the amount of hot metal dumping, China Steel Corporation successfully developed a new BOF process for blowing hot metal with silicon content higher than 1%, with a maximum value reaching 2%. Through persistent tests in 250-ton BOF by studying slag properties and blowing models, a double-slag method was developed to blow high silicon content hot metal. The double slag process was investigated and modified for desiliconization. During blowing test of high silicon hot metal for three heats, desiliconization slag was sampled during deslagging. The slag composition and mineral phase were examined by the usual XRF chemical analysis, as well as SEM and XRD studies to provide an important reference in the slagging practice for double slag operation.

Keywords: high silicon hot metal, double slag process, deslagging

1. Introduction

In BOF process, silicon is known as an important heat source. Higher silicon content of hot metal, more profuse heat can be provided, meaning higher scrap ratio. But, there is a limitation on silicon content of liquid iron due to disadvantages resulting from excessive supply of silicon. For example, slopping easily occurred with excess slag amount from the results of ample CaO added to achieve desired basicity. Therefore, the loss of heat and molten steel ensued. In other words, the control of silicon content in hot metal is one of important factors for stable operation. The general requirement of silicon content in hot metal for BOF process is less than 1.0%.

Double slag method was applied in foreign steel plants for the conditions of silicon content in hot metal larger than 1.0%[1-2]. At first, silicon in hot metal was oxidized into silicon dioxide and dissolved in slag which overflowed out from mouth on the front side by tilting BOF vessel. Then, in the following decarbonization process, slopping rarely occurred because of less amount of slag existing. It is evident that double slag operation consists of two steps, desiliconization and decarbonization, which is different completely from conventional one-slag blowing operation.

Mixing of hot metal operation was applied to decrease silicon content of hot metal when [Si] exceeds the maximum limit of 1.0% in China Steel Corporation (CSC). But for steel plants with newborn single blast furnace yielding hot metal containing more than 2% silicon content, such as Dragon Steel Corporation (DSC), there is no way to mix the hot metal in exception of dumping. In order to decrease the amount of hot metal dumping, the double slag method will be one of new issues for steelmaking plants in CSC.

2. Experimental

Based on the conditions of silicon content higher than 2.0% and no mixing hot metal operation applied to DSC's newborn single blast furnace, the double slag process was investigated and modified for desiliconization. Initially, silicon in hot metal was oxidized into silicon dioxide and dissolved in slag which then overflowed out from mouth on the front side by tilting BOF vessel. After completely deslagging, slopping on successive decarbonization process rarely occurred because of less amount of slag existing. The entire procedure was shown step by step as following: (1)Hot metal with high silicon content and scrap were charged into BOF. (2) Desiliconization started after adding flux. (3) After silicon in hot metal was oxidized entirely into silicon dioxide, tilting BOF coerced slag flowing out from mouth on the front side. (4) Added new flux and blew again for decarbonization.

Fig. 1 Outline of double slag process for desiliconization

In order to proceed smoothly, some key points were noticed, such as deslagging proceeded as completely as possible for lessen slopping and deslagging twice if slopping still occurred. During blowing test of high silicon hot metal for three heats, slag sampling were carried out during deslagging. Composition, phase and viscosity of slag were analyzed.

3. Results and discussion

Silicon content and phosphorus content of three tested heats were shown on Table 1. It indicated that hot metal of these heats had very high content of phosphor and silicon. Normal level of silicon content is 0.09%~0.120%. The compositions of desiliconization slag in Table 2 clearly demonstrated that basicity of these heats were less than 1.5. Due to low slag basicity, it was confirmed from Table 3 that the dephosphurization effect of desiliconization process was slim. After deslagging, slopping did not occur on the succeeding decarbonization process.

Table 1 Properties of hot metal

Heat No.	[Si](%)	[P](%)	Temperature(℃)
A	1.36	0.175	1241
B	1.75	0.189	1375
C	1.09	0.149	1266

Table 2 Composition of BOF-desiliconization Slag

	Composition of Slag (wt%)			Basicity
Heat No.	CaO	SiO_2	T-Fe	
A	32.58	31.21	23.81	1.04
B	34.87	28.82	24.38	1.20
C	36.93	25.44	25.94	1.45

Table 3 Composition of hot metal after desiliconization

	Composition of hot metal		
Heat No.	C (wt%)	Si (wt%)	P (wt%)
A	3.32	0.50	0.202
B	3.34	0.46	0.167
C	3.0	0.27	0.141

3.1 Micrograph and XRD analysis

The X-ray diffraction patterns of desiliconization slag from three heats(A、B and C) are shown in Fig.2, where mineral phases of kirschsteinite(CaO-FeO-SiO_2) is identified. The kirschsteinite is the preferred phase in slag from the observation of peak height intensity, which indicates kirschsteinite phase is the main constitution in desiliconization slag. Beside kirschsteinite phase, dicalcium silicate(C_2S) phase is also observed on XRD spectra in heat no. C slag with high basicity.

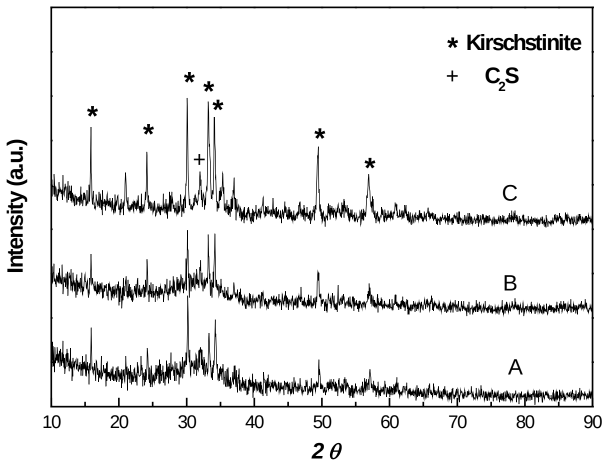

Fig.2 X-ray diffraction pattern of slag samples from heat no. A, B and C

The micrograph and Energy Dispersive Spectroscopy (EDS) of no.A slag are shown in Fig.3, where black ground is composed of CaO-FeO-SiO_2. In Fig.4, C_2S structure appears in the form of black granular among slag of heat no. C. This result is consistent with XRD analysis.

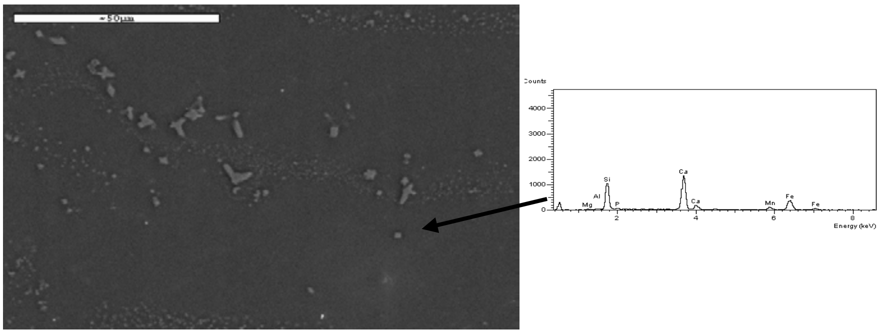

Fig.3 Micrograph and Energy Dispersive Spectroscopy of heat no. A slag

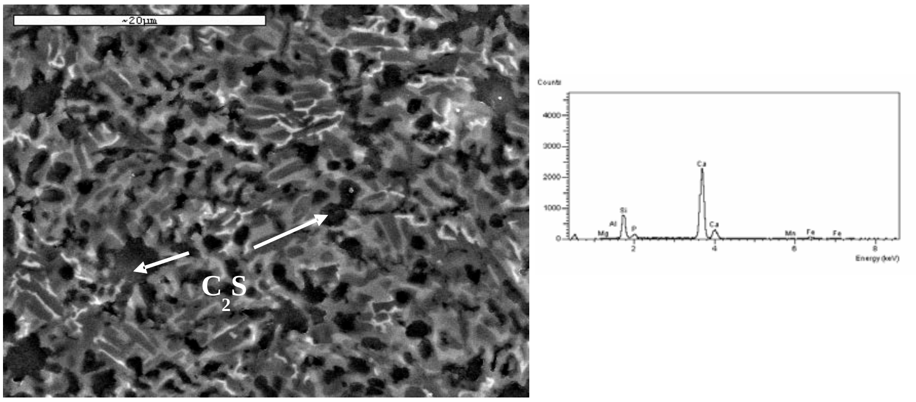

Fig.4 Micrograph and Energy Dispersive Spectroscopy of heat no. C slag

3.2 Slag viscosity and deslagging

The relationships of slag viscosity with temperature are shown in Fig.5. It shows apparently from the data curve tendency that heat no.A and B have similar behavior of viscosity. As the facts of high basicity, heat no.C shows more viscous behavior.

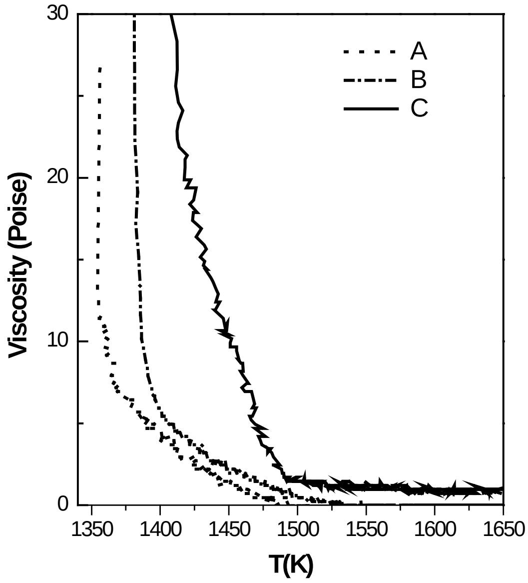

Fig.5 Slag viscosity and temperature for different heats

In our previous study, the melting point and viscosity of BOF slag with basicity in the range of 0.8-2 has been investigated [3]. FactSage thermodynamic software was also used to calculate the liquidus temperature of slag in comparison with the results of experimental measurement. The composition of slag used for thermodynamic calculation is listed in Table 4. Based on the study, the mass fractions of solid phase were estimated with FactSage, and the relative mass fraction of liquid was also evaluated as a function of temperature, as shown in Fig.6**.** It indicates that the mass fraction of liquid phase is decreased with the increase of basicity in the same temperature range. Therefore, the mass fraction of solid phase in heat no.C is higher than heat no.A and B in the deslagging operation temperature(1300℃ -1350℃) due to its high basicity. The amount of existence solid phase might affect the viscosity of slag.

Table4 Composition of slag used for thermodynamic calculation

Sample	CaO	SiO_2	MgO	Al_2O_3	MnO	T-Fe	CaO/SiO_2
LBS1	27.8	34.2	4.7	2.5	12.5	18.4	0.82
LBS2	31.1	29.0	4.1	2.4	11.0	22.4	1.07
LBS3	37.3	21.8	4.6	2.3	9.3	24.8	1.34
LBS4	39.0	20.0	4.5	2.0	8.2	26.5	1.95

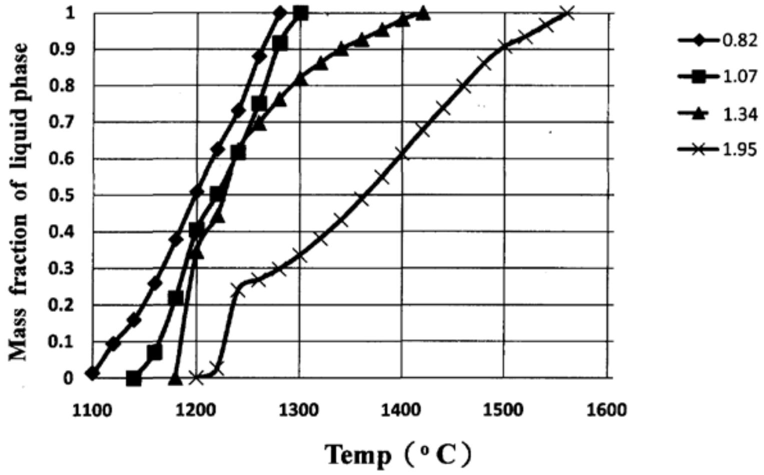

Fig.6 Mass fraction of liquid as function of temperature with different basicity

For blowing operation of high silicon hot metal, low basicity of slag in favor of good fluidity is primary concern for easy deslagging after desiliconization. Based on the comparison of slag properties, shown in Fig. 7, desiliconization slag of high silicon content hot metal has lower melting point than normal double slag method. Additionally, lower FeO content is one of reasons why [P] is still high after desiliconization.

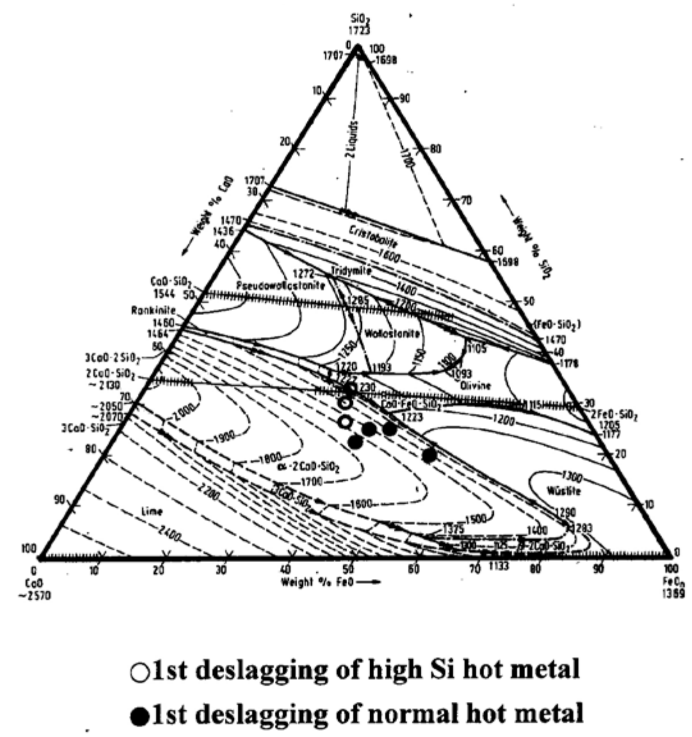

Fig. 7 The phase diagram of the CaO-'FeO'-SiO2 system reproduced from Slag Atlas [4] and slag composition after desiliconization

3.3 Blowing pattern for high silicon content hot metal

The purpose of the trial blowing high silicon content hot metal aims at diminishing slopping instead of dephosphorization. Compared with normal double slag method, basicity during desiliconization stage is maintained low in order to reduce slag amount. Otherwise, intense oxygen gas flow rate is preferred to avoid protracted blowing time. Although blowing time can be shorten, promoting gas flow rate always results into un-melting completely of added scrap and iron ore. In such condition, elevating temperature during blowing may be a good choice. However, the drawback is that low [P] content can not be obtained after desiliconization.

BOF blowing pattern is very important and has its specific characteristics. For high silicon content hot metal, severe slopping easily occurs during blowing. Not only equipments are damaged but also personal safety is deteriorated. So, the primary concern for blowing high silicon content hot metal is preventing slopping.

The slopping phenomenon mainly takes place at the final stage of desiliconization[5]. Due to weak mixing energy and low temperature of hot metal, C-O reaction postpones and FeO content of slag accumulates. After the oxidation of silicon, liquid acid slag forms with low melting point. Then, carbon is oxidized rigorously during decarbonization stage accompanied with temperature escalation. A large amount of tiny droplets of molten steel permeate into slag and react with FeO to generate CO gas in profusion. If excess amount of lime are added for balancing high silicon content of hot metal at that time, the slag amount will become too much. Therefore, CO gas will be depressed and garnered until slag slopping out of mouth caused by huge expansion energy. Deslagging to reduce slag amount after desiliconization was carried out in order to alleviate the peril of slopping. In the meanwhile, smaller top blowing oxygen flow rate and higher bottom blowing gas flow rate are applied during desiliconization.

3.4 The metallurgic consideration of blowing high silicon hot metal

The process of blowing high silicon hot metal is divided into two stages, desiliconization and decarbonization. Keeping basicity of slag around 1.0~1.2 is preferable for a good fluidity in order to deslag smoothly after desiliconization. It is important to maintain temperature of desiliconization stage in a reasonable range. Higher temperature is good for slag fluidity, but brings about severe slopping as a result of excessive CO gas from vast premature decarbonization reaction. According to normal double slag blowing pattern, phosphorous partition ratio between slag and molten steel decreases as temperature elevates. Lower temperature is beneficial to achieve good dephosphorization ability at low basicity. The temperature of hot metal during deslagging less than the range of 1350~1400℃ is consequently favorable for dephosphorization. However, the temperature is better set at ～1400℃ after taking into account of the dissolution of scrap and iron ore.

4. Conclusion

For DSC’s newborn blast furnace, blowing technology of high silicon content hot metal was indeed needed in order to reduce dumping amount of hot metal. After plant trials in CSC coupled with slag analysis and blowing pattern study for simulation of blowing high silicon content hot metal, it was confirmed that double slag method in BOF was capable for blowing hot metal with silicon content higher than 1.0%.Silicon content of primordial hot metal from DCS blast furnace was 4.0%. After silicon content abated to 2.0%, double slag operation was applied to blow high silicon hot metal. BOF operation retrieved conventional single slag practice until silicon content was less than 1.0%. This new process saved 4000 tons of high silicon hot metal for steelmaking after technology transfer to Dragon Steel shop at the nascent phase.

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