Proper MgO Addition in Blast Furnace Operation

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Based on laboratory experiment, the effects of MgO on sintering process and metallurgical properties of sintered ore are examined. The experiment results show that, adding no or small amount of MgO in sintering, the sintering productivity can be improved, and the sintered ore can have high cold strength and small temperature range of cohesive zone and as a result the permeability of cohesive zone can be improved and the total pressure drop of blast furnace (BF) can be decreased. In this paper a new process of proper MgO addition into BF operation is proposed and in this process MgO content in BF slag can meet the requirement and at the same time RDI of sintered ore is low.

KEY WORDS: MgO; sintered ore; blast furnace; cohesive zone.

1. Introduction

As the grade of BF charge is increasingly improved, the relative content of Al_2O_3 in slag is increased and as a result the slag fluidity and desulphurization ability are decreased. In order to solve this problem, the common solution is to add dolomite *etc.* into sintering raw materials, to increase MgO content and then improve the fluidity and desulphurization ability of slag. The effect of MgO on sintering process and on sintered ore (strength, RDI and softening/melting behaviour at high temperature) has been reported widely.^{1–9)} However, the previous reports did not examine the effect of MgO on the whole sintering-BF process systematically. In this paper, based on laboratory experimental study, the positive and negative effects of MgO on sintering process and metallurgical properties of sintered ore are examined and a new process of appropriate MgO addition into BF is proposed.

2. Effect of MgO on Sintering Process

2.1. Sintering Experiment

Under laboratory condition, various iron concentrates are used as raw materials to examine the effect of MgO content on sintering process under two basicity conditions ($R = \% \text{CaO} / \% \text{SiO}_2 = 1.36$ and $R = 1.76$), by using the $\Phi 150$ mm sintering test system. In the experiment, MgO is added in the form of dolomite. The MgO content in sintered ore are 1.3%, 1.7%, 2.1%, 2.5% and 3.0% respectively. The chemical compositions of the sinter raw materials are listed in **Table 1** and other sintering test conditions are listed in **Table 2**.

2.2. Results and Discussion

(1) Effect on Sintering Productivity: **Figure 1** shows

the effect of MgO content on productivity of sintering. It can be seen in the figure that, as MgO content increases, the productivity of sintering shows a decreasing trend. This is because that, during the sintering process, the decomposition and mineralization of dolomite will consume heat. Under the same chemical composition of raw material and flux and the same experimental condition, heat consumption will control the sintering productivity. Therefore, under the experimental condition, more MgO will need more heat consumption and then the productivity of sintering will be decreased.

(2) Effect on Strength of Sintered Ore: **Figure 2** shows the effect of MgO content on Drum Index (DI) of sintered ore. It shows that, when $R = 1.36$, MgO content does not have significant effect on the strength of sintered ore; whereas when $R = 1.76$, the DI of sintered ore is decreased as MgO content increases. This is because, under low basicity ($R = 1.36$) the glass phase acts as the dominant binding phase. MgO does not have much effect on glass phase, whereas under higher basicity, it is difficult for MgO in raw materials to form binding phase of low-melting point and at the same time the generation of calcium ferrite will decrease. Therefore the DI of sintered ore is decreased as MgO content increases.

(3) Effect on Other Sintering Index: According to industrial practice experience, dolomite does not have strong stickiness, therefore excessive addition of dolomite will affect pelletization performance. In addition, as dolomite content increases, unit energy consumption in sintering process will be increased. This is because that, carbonate decomposition is an endothermic reaction. When more dolomite is added into the sintered raw materials, much more energy will be required to meet endothermic reaction of carbonate decomposition. Therefore, more MgO addition in sintering will be not favorable to unit energy consumption

Table 1. Chemical composition of sinter raw materials.

Test	TFe(wt%)	MgO(wt%)	CaO(wt%)	SiO ₂ (wt%)	R(CaO/SiO ₂)
L-1.3	58.64	1.30	7.11	5.23	1.36
L-1.7	57.42	1.70	6.92	5.09	1.36
L-2.1	56.99	2.10	6.91	5.08	1.36
L-2.5	56.63	2.50	6.88	5.06	1.36
L-3.0	56.49	3.00	6.80	5.00	1.36
H-1.3	55.62	1.30	9.19	5.22	1.76
H-1.7	55.25	1.70	9.06	5.15	1.76
H-2.1	55.02	2.10	9.06	5.15	1.76
H-2.5	54.81	2.50	9.03	5.13	1.76
H-3.0	54.51	3.00	8.89	5.05	1.76

Table 2. Experimental condition of sintering test.

Bed height: 500mm	Sintering pot diameter: 150mm
Ignition pressure: 4.9kPa	Exhausting pressure: 9.8kPa
Ignition temperature: 1000°C	Ignition time: 1.5min
Carbon content in blend: 4%	Water content in blend: (8.0±0.5)%
Return fines content: 30%	Height of grate layer: 20mm
Basicity (R=CaO/SiO ₂): 1.36 or 1.76	Pelletizing time: 10min

Fig. 1. Effect of MgO content on productivity of sintering.

Fig. 2. Effect of MgO content on drum index of sinter.

and pelletization performance.

To sum up above, the addition of dolomite *i.e.* (MgO) will have negative effect on sintering process.

3. Effect of MgO on Softening/Melting Behaviour of Sintered Ore

3.1. Experiment

A $\Phi 75$ mm (inner diameter) graphite crucible, with a $\Phi 10$ mm dripping hole on the bottom, is used in the experiment. 500 g sintered ore sample (size: 10–12.5 mm) is charged into graphite crucible to 65 mm high. Coke is laid under the bottom and on the top of sample column to ensure molten materials and gas flow can pass through bed easily. The details of this experimental apparatus and condition can be found in reference.¹⁰⁾ In order to simulate the heating up and reduction process of sinter in BF, the experimental conditions are determined as **Table 3**. After experiment, the dripping slag and residual slag in crucible are taken out for further analysis.

The temperature when shrinkage ratio comes to 10% is defined as the upper temperature (T_{10}) of cohesive zone and likewise the temperature when dripping starts is defined as the bottom temperature (T_D) of cohesive zone, and then the temperature range of cohesive zone (ΔT) is defined as

$$\Delta T = T_D - T_{10} \dots \dots \dots (1)$$

The maximum resistance of material bed to gas flow during softening/melting process is defined as the maximum pressure drop ($\Delta P_{\max}$).

3.2. Results and Discussion

Figure 3 shows the effect of MgO content on upper temperature (T_{10}), temperature range of cohesive zone (ΔT) and maximum pressure drop ($\Delta P_{\max}$). When MgO content increases from 1.3 to 3.0%, T_{10} has a small fluctuation (Fig. 3(a)), while ΔT has a great increase (Fig. 3(b)) and as a result, $\Delta P_{\max}$ has a significant increase (Fig. 3(c)). Under lower basicity ($R=1.36$), MgO content has a great effect on thickness of cohesive zone, but the absolute value of temperature range of cohesive zone with 3.0% MgO addition is still low, only 325.5°C. Under higher basicity ($R=1.76$), the temperature range of cohesive zone is increased from 310.5 to 389.3°C. Therefore, under the same operational condition, the temperature range of cohesive zone is much wider when using sintered ore of high basicity with high MgO content than using self-fluxing sintered ore with high MgO.

In order to clarify the effect of MgO on softening/melt-

Table 3. Experimental conditions for softening/melting examination of sintered ore.

Heating up time, min	40	50	40	>120
Load, kg/cm ²	0.5 kg/cm ²		1.0 kg/cm ²	
Gas composition and flow rate	N ₂ 100% 3NL/min	N ₂ 60% 9.0NL/min CO 26% 3.9NL/min CO ₂ 14% 2.1NL/min	N ₂ 70% 10.5NL/min CO 30% 4.5NL/min	
Heating up rate	10°C/min, to 900°C		3°C/min, to 1020°C	5°C/min, to dripping

Fig. 3. Effect of MgO content on T_{10} , ΔT and $\Delta P_{\max}$.

Fig. 4. X-ray diffraction of dripping slag and residuals slag.

ing behavior, X-ray diffraction is used to analyse the dripping slag and residual slag of sintered ore with various MgO contents (Fig. 4).

The results of X-ray diffraction show that: the main components of dripping slag are merwinite [$\text{Ca}_3\text{Mg}(\text{SiO}_4)_2$] and larnite [Ca_2SiO_4], and those of residual slag are akermannite [$\text{Ca}_2\text{MgSi}_2\text{O}_7$], merwinite [$\text{Ca}_3\text{Mg}(\text{SiO}_4)_2$] and monticellite [CaMgSiO_4]. The chemical composition of slag is listed in Table 4. It shows that, (a) the MgO content in dripping slag has no relation with the initial MgO addition, (b) the MgO content in dripping slag is double of that in residual slag. It can be deduced that, the slag containing high MgO cannot come to dripping easily and therefore the temperature range of cohesive zone will be increased much, and then the permeability of BF burden will be worse and this is not favorable for BF operation.

Table 4. Chemical composition of dripping and residual slags of sintered ore (wt%).

Sample	Initial MgO content	TFe	MgO	CaO	SiO ₂
Residual slag	1.7	2.77	11.45	36.71	33.55
Dripping slag	1.7	1.64	6.94	39.35	35.74
Dripping slag	2.1	1.66	5.99	39.72	35.89

Fig. 5. Relationship between MgO content and $\text{RDI}_{-3.15}$.

4. Effect of MgO on RDI of Sintered Ore

Under laboratory condition, the effect of MgO on RDI of sintered ore is examined according to ISO standard.

4.1. Results and Discussion

Figure 5 shows the effect of MgO on RDI. It shows that as MgO content increases $\text{RDI}_{-3.15}$ is decreased significantly. That is to say, increasing MgO content is favourable to decrease the RDI.

Concerning the mechanism of MgO can decrease RDI of sintered ore, according to EPMA analysis for test H-2.5, Fig. 6(c) shows the MgO distribution inside sintered ore with dolomite ($\text{CaCO}_3 \cdot \text{MgCO}_3$) addition. It shows that most of MgO particles will react with ferrous oxide and form solid solution, and then are dispersed in sintered ore. Therefore it can be deduced that, under high roasting temperature, the MgO particles diffused into ferrous oxide can prevent both the secondary Fe_2O_3 formation when sintered ore is cooling down¹¹⁾ and the low temperature reduction of ferrous oxide inside the sintered ore. Therefore the RDI of sintered ore can be decreased by MgO addition.

4.2 Counter-measure for Reduction Disintegration of Sintered ore under Low Temperature

As discussed above, no or less MgO addition in sintering process can increase its productivity and improve cold strength and high temperature metallurgical properties of sintered ore. However, if MgO content in sintered ore is too low, the sintered ore will be disintegrated easily when reduced at low temperature. In order to solve this problem, the solution is proposed that CaCl_2 solution is sprayed on the surface of sintered ore based on previous study.^{12,13)}

Studies show that, the mechanism that CaCl_2 can decrease RDI of sintered ore is, CaCl_2 solution sprayed on surface of sintered ore will be absorbed and form a thin film on the surface of sintered ore. This film can then prevent the contact between reducing gas and surface of sintered ore and stop reducing gas from entering the sintered ore, and therefore the film can stop the potential reduction

Fig. 6. Distribution of main elements (Fe, Mg, Ca, Si) inside sintered ore (H-2.5).

reaction inside the ore. As a result, the reduction rate will be lowered and the RDI can be decreased.

5. Proposal of New Process of Proper MgO Addition into BF

To ensure the BF slag contains certain amount of MgO, in the conventional industrial operation, dolomite or magnesite is added into raw materials for sintering and then the sintered ore will be charged into BF from the top. These processes have the advantages of 1) maintaining MgO content in slag; 2) low RDI of sintered ore *etc.* However, they have also disadvantages: 1) low productivity of sintering; 2) bad cold strength of sintered ore; 3) leading to big temperature range of cohesive zone and big cohesive zone thickness, which will then make total pressure drop of BF increase much. Therefore, in order to ensure proper MgO content in BF slag and avoid the disadvantages of MgO addition during sintering, it is necessary to propose a new process of appropriate MgO addition into BF.

From above results and discussion, a new process of proper MgO addition into BF is proposed: 1) adding no or less MgO into raw materials of sintering; 2) spraying CaCl_2 solution on surface of sintered ore to control RDI of sintered ore; 3) instead of adding MgO in sintering in the conventional process, the required amount of MgO is added into BF by injection through tuyere together with PC. The features of this new process are as follows: 1) MgO adding method is modified: all or part of MgO is injected into BF through tuyere together with PC, instead of adding all of them during sintering. Thus sintered ore with no or low content of MgO will be produced and as a result the pro-

ductivity of sintering will be improved, and product yield and cold strength of sintered ore will be increased, which will greatly improve high temperature softening/melting performance of sintered ore, compared with high MgO (especially high basicity) sintered ore. Then the thickness of cohesive zone in BF can be decreased and the total pressure drop will be decreased. 2) Raw coal and additive containing MgO are pulverized together by coal grinding mill, then PC containing MgO will be injected into BF through tuyeres, to ensure slag containing required content of MgO, improve slag fluidity and desulphurization performance, and increase PC combustion at the same time.¹⁴⁾ 3) Due to adding no or low MgO into sintering, RDI of sintered ore will be deteriorated. This problem can be solved by spraying CaCl_2 solution on surface of sintered ore.

6. Conclusions

Based on experimental study and theoretical analysis, it can be concluded that

(1) Decreasing MgO addition in sintering can increase sintering productivity, cold strength of sintered ore, and decrease the temperature range of cohesive zone.

(2) RDI problem of low-MgO sintered ore can be solved by spraying CaCl_2 solution on the surface of sintered ore.

(3) A new process for MgO addition is proposed. It has many advantages for both sintering process and BF operations, such as, 1) high productivity of sintering; 2) low RDI and high cold strength of sintered ore; 3) small temperature range of cohesive zone and better permeability in lumpy zone and cohesive zone; 4) higher PC combustion efficien-

cy in raceway; 5) better slag fluidity and desulphurization performance.

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