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An Experimental Study of Improvement of Sinter Quality at High Limonite Ore Ratios

Ye Sun[1,2], Yan Liu[1,2], Ren Chen[1], Zuoliang Zhang[1,2*], Xiaoliang Li[1,2], Lingling Li[1,2], Lei Zhang[3], Yu Sun[1,2], Haibing Jiang[4], Ming Li[4]

[1]Liaoning Key Laboratory of Optimization and Utilization of Non-Associated Low-Grade Iron Ore, Liaoning Institute of Science and Technology, Benxi, China
[2]School of Metallurgy and Materials Engineering, Liaoning Institute of Science and Technology, Benxi, China
[3]Science and Technology Division, Liaoning Institute of Science and Technology, Benxi, China
[4]Yingkou Jinghua Iron & Steel Co. LTD, Yingkou, China
Email: *zhang231167@163.com

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Abstract

The sintering of limonite ore is a recent cost-effective method of iron production. In this study, the influences of sinter binary basicity and calc-flux type on the quantity, strength, and type of sintering bonding phases, as well as on sinter quality under high limonite ratios, were investigated by an experiment based on the characteristics of ore blends. Production of sinters demonstrates that, under high limonite ratios, sinter quality can be improved by increasing the binary basicity of sinters, the ratio of quicklime, and the height of the sintering bed.

Subject Areas

Chemical Engineering & Technology

Keywords

Sintering, Limonite, Basicity, Calc-Flux, Mineral Quality Index

1. Introduction

With the expansion of steel production and intensifying market competition, iron ore resources are becoming exhausted and the price of iron ore is continuously increasing [1]. In consideration of resource strategies and production costs, some ironworks have begun to adopt a sintering production process based on the use of limonite, which is cost-effective [2] [3] [4] [5]. However, limonite ore may decrease the bonding strength and yield of sinters due to its high crystal water content, large particle size, strong assimilability, special fluidity of the sintering liquid phase, and low bonding strength. These characteristics have negative effects on sintering production [6] [7] [8] [9].

Nevertheless, mineral properties, sinter basicity, calc-flux types, and the technological parameters of sintering are crucial to the quantity and quality of bonding phases produced during sintering. On one hand, these factors determine the strength of the sinter, its particle size, and the fine transmission rate of grooves. On the other hand, these factors can significantly affect the yield and productivity of sinters. Therefore, it is necessary to study the importance of these factors in processes that use a high limonite ratio.

In the present study, the influences of the binary basicity of sinters, types of calc-flux, and the technological parameters of sintering on sinter quality under a high limonite ratio are investigated via an experiment based on the characteristics of ore blends. Some technical countermeasures to improve sintering production under high limonite ratios are proposed. The research conclusions can provide a theoretical reference and technical support for the effective use of limonite in sintering production.

2. Properties of Ore Blends with High Limonite Ratios

Optimal ore blends were prepared with 45% limonite. The corresponding low-temperature properties (e.g. chemical components, bulk density, and average grain size) and high-temperature sintering properties (lowest assimilation temperature, fluidity, and bonding strength) are shown in **Table 1**.

It can be seen from **Table 1** that the optimal ore blends had a low TFe content and bulk density but high crystal water content. Moreover, the proportion of large particles (>1 mm) was high, whereas the fluidity and bonding strength were low. Subsequently, improvements in sinter productivity and quality are greatly affected.

3. Influences of Binary Basicity and Calc-Flux Type on Bonding Strength with a High Limonite Ratio

Quantity, quality, and bonding strength are key to improving sintering processes under a high limonite ratio. In addition to iron ore fines, binary basicity and calc-flux type are important factors that determine quantity, quality, and bonding strength. For this reason, two calc-fluxes (limestone and quicklime) and ore blends were used to explore the influence of binary basicity on bonding phases with different calc-fluxes.

3.1. Effects of Binary Basicity and Calc-Flux Type on the Quantity of Bonding Phases

Sinters are mainly formed by bonding phases. Hence, the quantity of effective bonding phases plays an important role in the quality of sinters. In this study, the quantity of effective bonding phases was tested by the "method based on flowing area" [10].

Table 1. Properties of uniform mixtures with a high limonite ratio.

TFe (wt%)	SiO_2 (wt%)	CaO (wt%)	LOI (wt%)	Bulk density (g/cm^3)	Average grain size (mm)	>1 mm (%)	Lowest assimilation temperature (˚C)	Fluidity (−)	Bonding strength (N)
61.13	3.75	0.74	4.39	2.24	3.77	66.23	1249	0.419	428

There are large iron fines (grain size > 1 mm) in ore blends, which are viewed as core mineral fines that won't react with the flux. Due to the segregation of calc-flux, the binary basicity of rest iron fines is higher than the target basicity of sinters. When the binary basicity values of sintering were 1.8, 1.9, 2.0, and 2.1, the binary basicity values of the bonding phase were calculated to be 4.43, 4.69, 4.95, and 5.22 by a simulation test based on the grain size distribution of ore blends. The test results of the fluidity of the bonding phases are shown in **Figure 1**.

According to the experimental results: 1) The quantity of bonding phases in samples with limestone or quicklime was positively correlated with binary basicity and sintering temperature. This is mainly because the quantity of materials with low melting points increases with binary basicity, but the bonding phase is weakened as the temperature rises. 2) Given a fixed sintering temperature and binary basicity, the quantity of bonding phases in samples with quicklime was significantly higher than that in a sample with limestone, which is attributed to the higher reactivity of quicklime. 3) With increases in binary basicity, the quantity of bonding phases in samples with quicklime increased more than that in samples with limestone. This is also related to the higher reactivity of quicklime.

Based on the above research results, it can be speculated that in order to increase the quantity of bonding phases, the content of quicklime should be increased while the limestone content should be decreased or the binary basicity of sintering increased. On the contrary, it is suggested to replace limestone with quicklime or decrease the binary basicity to control the quantity of the bonding phases.

In fact, the fluidity of the bonding phases in the optimal ore blends was not very high under a high limonite ratio (**Table 1**). Therefore, it is necessary to increase the quantity of bonding phases appropriately by increasing the quicklime content or binary basicity.

3.2. Effects of Binary Basicity and Calc-Flux Type on Bonding Strength

Generally, sinters are products formed by the solidification of non-melted core ores through bonding phases. Since core minerals have relatively high strength, they do not restrain the bonding strength of sinters. Hence, bonding strength depends highly on sinter strength when there are enough sintering phases.

In this study, the lowest temperature at which bonding phases were generated

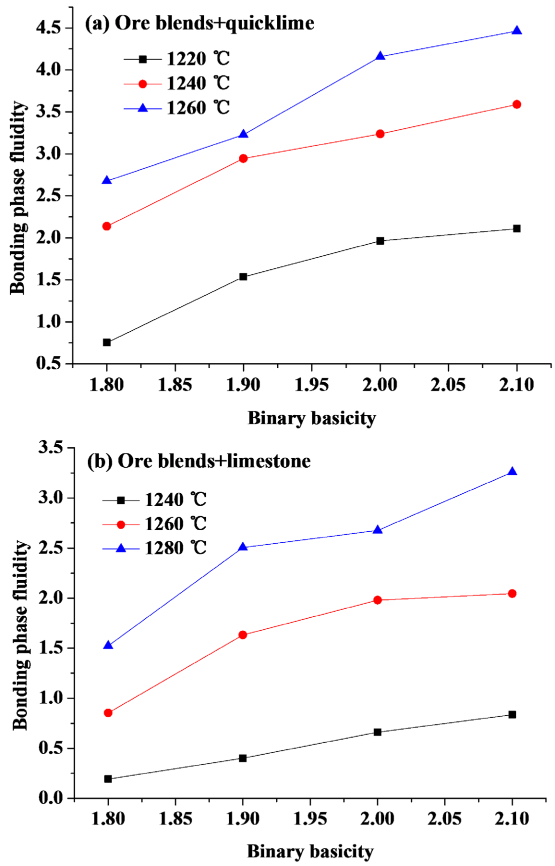

Figure 1. Influence of binary basicity on the bonding phase fluidity, (a) ore blends + quicklime, (b) ore blends + limestone.

was defined as the temperature at which samples contracted by 10% after sintering. The lowest bonding phase generation temperatures at various segregated binary basicity values were tested. Firstly, the temperature at which the fluidity index was zero was identified in combination with a liquid fluidity test. Later, the diameters and heights of samples after sintering at five temperatures were measured. Contraction of samples was then calculated relative to their diameters and heights before sintering. A sintering temperature-contraction curve was drawn and a regression equation fitted. The temperature at which 10% contraction occurred was calculated from the regression equation. Subsequently, the compressive strengths of samples at the lowest bonding phase generation temperature were tested and used to evaluate bonding strength. [11] The experimental results are listed in Figure 2.

Figure 2 shows that: 1) The generation bonding phase temperatures of both samples decreased with increases in binary basicity, which is attributed to the improvement in the conditions for generating compounds with low melting points. 2) When the binary basicity ranged between 1.8 - 2.1, the bonding phase generation temperature in the sample with quicklime was lower than that of the sample with limestone, but the bonding strength was higher. This is mainly because quicklime has higher reactivity and structural density than limestone.

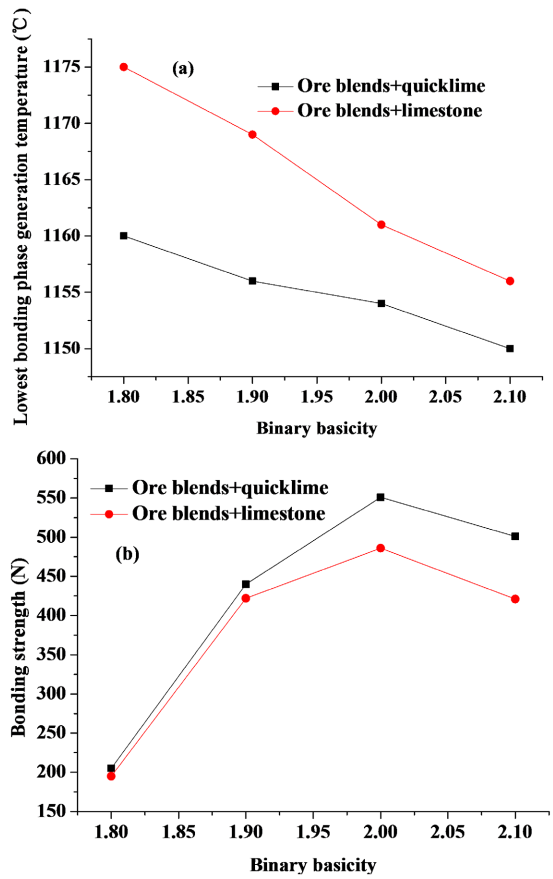

Figure 2. Lowest bonding phase generation temperatures and compressive strengths under different binary basicity values.

3) Given a low binary basicity, the bonding strength was positively related to binary basicity and reached a peak of 2.0. Later, the bonding strength decreased with further increases in binary basicity. According to the analysis results, sintering strength is poor at low binary basicity due to the inadequate liquid phase. Hence, binary basicity improves the strength of bonding phases. However, excessive binary basicity may increase the number of pores in the bonding phase and thereby lead to structural brittleness.

For sintering production with a high limonite ratio, bonding strength has to be increased to solve problems concerning the strength of sinters, such as a decreased yield and drum index, and increased proportion of fine particles. Hence, it is a feasible and effective technological countermeasure to increase the binary basicity of sinters and the content of quicklime appropriately. Moreover, the binary basicity range of the sinters should be controlled within 1.9 - 2.0.

3.3. Effects of Binary Basicity and Calc-Flux on Bonding Phase Type

The calcium ferrite bonding phase is the best one for iron ore sintering. Increasing the quantity of calcium ferrite bonding phases in sinters increases their strength and improves their reducibility. The mineral phase analyses of samples containing quicklime or limestone were carried out to explore the influence of binary basicity on bonding phase type (mineral composition) under different types of calc-flux. Binary basicity values were variable while the sintering temperature was fixed at 1260˚C in the experiments.

According to the mineral phase analyses as shown in Figure 3: 1) the calcium ferrite content in samples with quicklime or limestone presented an inverse V-shaped variation with increases in binary basicity, reaching a peak at 2.0. The variation in calcium ferrite content with binary basicity agreed with the variation in bonding phase strength reported in Section 3.2. This demonstrates the internal influence of binary basicity on bonding strength and further confirms the contribution of calcium ferrite. 2) Compared with the limestone samples, quicklime samples had higher bonding strength due to their higher calcium ferrite content.

We suggest increasing the quantity of bonding phases with high calcium ferrite contents when conducting sintering production with high limonite ratios. Hence, the quality of sinters can be improved by increasing the quicklime content or increasing the binary basicity of the sinters to about 2.0.

4. Sintering Pot Experiment to Improve Sinter Quality

Based on the results so far, the influences of sinter binary basicity, calcium flux proportion, and sintering parameters on sinter quality with high limonite ratios were investigated by a sintering pot experiment. On this basis, appropriate technological countermeasures were determined.

4.1. Effects of Binary Basicity on Sinter Quality

The parameters and quality indexes of raw materials under different binary basicity values (1.8, 1.9, 2.0, and 2.1) were investigated via an experiment. In addition, the effects of sinter binary basicity on strength and productivity are discussed. The experimental results are listed in Table 2.

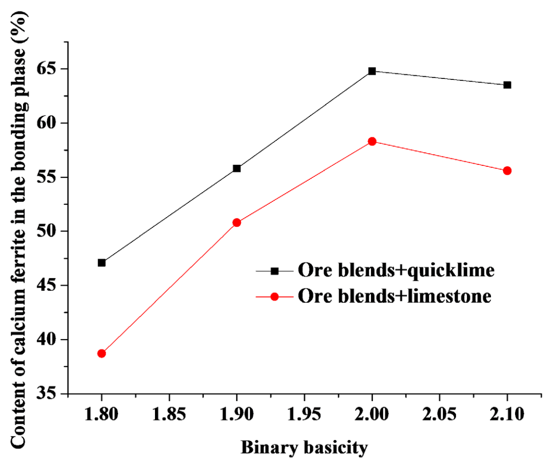

Figure 3. Comparison of calcium ferrite in the bonding phase of samples with different calc-flux.

Table 2. Sintering pot experimental results under different binary basicity values.

Scheme	Vertical sintering speed	Productivity	Yield	Drum index	Grain size of finished products (%)			Solid fuel consumption
	mm/min	T/(m²·h)	%	%	>25 mm	25 - 10 mm	10 - 5 mm	kg/T
R = 1.8	21.88	1.612	76.83	61.55	46.01	30.11	20.27	51.58
R = 1.9	22.03	1.653	76.92	62.80	44.22	31.79	20.11	52.14
R = 2.0	23.51	1.752	78.68	65.10	41.08	34.28	20.78	51.48
R = 2.1	24.15	1.793	79.66	64.33	35.33	37.52	23.04	51.36

Table 3. Sintering pot experimental results under different calc-flux contents.

Experimental scheme	Vertical sintering speed	Productivity	Yield	Drum index	Grain size of finished products (%)			Solid fuel consumption
	mm/min	T/(m²·h)	%	%	>25 mm	25 - 10 mm	10 - 5 mm	kg/T
1.9 (normal)	22.03	1.653	76.92	62.80	44.22	31.79	20.11	52.14
1.9 quicklime 6 wt%	21.44	1.617	80.51	63.35	45.72	31.05	20.08	51.01
1.9 quicklime 4 wt%	21.13	1.610	80.23	63.01	43.22	30.79	21.95	52.11
2.1 (normal)	24.15	1.793	79.66	64.33	35.33	37.52	23.04	51.36
2.1 quicklime 6 wt%	25.32	1.803	82.21	65.62	35.88	38.39	21.62	50.01
2.1 quicklime 4 wt%	23.44	1.764	80.84	63.02	34.22	38.01	23.67	51.00

According to the experimental results, the vertical sintering speed, yield, and sintering productivity increased significantly (by about 10%, 3.6%, and 11% at most) as the binary basicity increased from 1.8 to 1.9, 2.0, and 2.1, respectively. Meanwhile, solid fuel consumption declined and the grain size compositions of the sinters deteriorated. Specifically, the proportion of particles larger than 25 mm decreased, whereas the proportion of particles sized 10 - 25 mm increased significantly and the proportion sized 5 - 10 mm increased slightly. However, the drum index of sinters presented an inverted V-shaped trend and reached a peak at 2.0. This conforms to the research conclusions in Section 3.2. Therefore, bonding strength is an important factor influencing the drum index of sinters.

To sum up, the binary basicity of sinters should be increased to 2.0 to improve the quality of sinters produced at high limonite ratios.

4.2. Effects of Calc-Flux Content on Sinter Quality

The effects of calc-flux content on sintering parameters and quality under high limonite ratios were investigated via experiments with the binary basicity fixed at 1.9 or 2.1. Quicklime proportions of 6.0 wt% and 4.0 wt% were used. The experimental results are shown in Table 3.

It can be seen from results that, on one hand, high yield and productivity with lower solid fuel consumption can be achieved by increasing the quicklime content and decreasing the limestone content in calc-flux. On the other hand, it can improve the drum index and grain size composition of the sinters. These effects are attributed to the high reactivity of quicklime, good granulation of the sintering materials, and the decomposition-induced pores of limestone. It is worth noting that the proportion of quicklime in calc-flux can only significantly improve sinter productivity at high basicity.

To improve sinter quality, it is necessary to increase the sintering binary basicity to about 2.0 and increase the proportion of quicklime appropriately according to the high limonite ratio.

5. Conclusions

1) The optimal ore blend for production with a high limonite ratio has low TFe content, bulk density, liquid phase fluidity, and bonding strength, and high crystal water content. These are disadvantageous for sintering production.

2) The lowest bonding phase production temperature for quicklime or limestone samples is negatively related to binary basicity, while the quantity of bonding phase is positively related. The bonding strength and quantity of calcium ferrite in the bonding phase present inverted V-shaped variations with binary basicity. Both reach a peak at about 2.0.

3) Given a fixed binary basicity, limestone samples are inferior to quicklime samples in terms of quantity, strength, and type of bonding phases.

4) With a high limonite ratio, sinter quality can be improved by increasing the binary basicity to about 2.0, increasing proportion of quicklime, and increasing the sintering bed thickness appropriately.

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Conflicts of Interest

The authors declare no conflicts of interest.

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