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Agglomeration Mechanism of Rich Hematite Sinter with Lowering SiO_2 Content

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Abstract: The mini-sintering test was introduced. The experiments of specimens of rich hematite with lowering SiO_2 content were carried out by the mini-sintering test. The strength and mechanism of agglomeration were studied mainly when silica content in sintered specimens was decreased gradually. The relationships between SiO_2 volume and morphology of sinter were also investigated. It is considered that high grade sinter can be developed by raising sinter basicity so as to enhance complex calcium ferrite content or lowering sinter basicity so as to make Fe_2O_3 bonding for strength.

Key words: agglomeration; mechanism; sinter strength; SiO_2; mini-sintering test

As well known, there are close relationships between SiO_2 volume of sinter and its strength. It is the main object for metallurgists to raise Fe content of sinter and improve metallurgical properties of sinter for many years. It is puzzling whether sinter strength would be effected by reducing SiO_2 content. Nevertheless, according to metallurgists' experience, reducibility and softening, melting properties will be improved when SiO_2 volume is cut down.

Sinter strength, which is decided by not only the kind and composition of raw materials but also sintering technologies especially the temperature and atmosphere in combustion zone and cooling zone, is effected by its mineral component and microstructure. The mini-sintering test and other research methods simulating the sintering process [1–4] were often adopted in recent years. This test was introduced as the first step for the project by researchers of University of Science and Technology Beijing. A series of experiments such as increased and decreased basicity were carried out respectively to seek for whether sinter strength can be improved under low SiO_2 volume. Some valuable mechanism results were gained for the following sintering pot tests.

1 Experimental

A hematite with low SiO_2 content was selected as the base iron raw material since rich iron ore fines are used widely in sinter plants. Natural kaolinite and pure reagent SiO_2, $CaCO_3$ were used as fluxes and additives. The chemical composition and size of the iron ore fines, fluxes and additives are shown in **table 1**. The iron ore hematite was divided into two parts according to the size to simulate well and truly the sintering process in which the percentage of grains between 1–2 mm is 25% and others are fines of minus 0.105 mm.

For the project, the mini-sintering test was employed in tubular electric furnace shown in **figure 1**. The procedures were as follows: The iron ore fines, silica, limestone and kaolinite with a pre-calculated ratio and 6% water in mass fraction were mixed well distributed. After that, the disks with a size of $\phi 8$ mm×4 mm could be squashed under a pressure of 12 MPa. Six disks were put into a basket, then were hanged under the thermocouple. The thermocouple and basket were lowed into the furnace with certain velocity, staying in the high temperature zone for a certain time. Then they were elevated quickly. The atmosphere and temperature cur-

Table 1 Chemical composition and size of raw materials

Raw materials	Component mass fraction / %									Size / mm
	TFe	FeO	SiO_2	CaO	Al_2O_3	MgO	B_2O_3	Rest	Ig	
Hematite	66.3	—	0.69	—	1.00	0.10	—	—	2.22	−0.105
Silica	—	—	99.5	—	—	—	—	0.5	—	−0.098
Limestone	—	—	—	55.44	—	—	—	1.0	43.56	−0.105
Kaolinite	—	—	44.53	—	37.00	—	—	—	18.47	−0.098

ves are shown in **figure 2**. Nitrogen (N_2) was blown into the furnace from the bottom at the beginning to simulate the atmosphere of sintering combustion zone. After that, air was blown into to simulate cooling zone. A cave in the middle of the recorded curve is the cross of nitrogen replaced by air.

The experiments of specimens with basicities (CaO/SiO_2) of 1.2, 1.8, 2.3 and 2.9 were carried out in tubular electric furnace. The SiO_2 content was 1%, 2%, 3%, 4%, 5% and 6% in mass fraction respectively. The calculated chemical compositions of sintered specimens are shown in **table 2**.

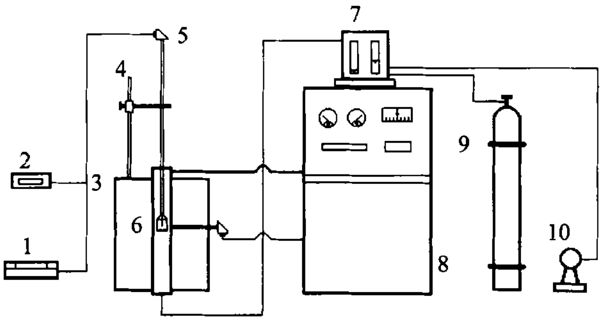

Figure 1 Mini-sintering test system. 1—YEW Type 3066 pen-recorder; 2—PZ26b millivoltmeter; 3—Tubular electric furnace; 4—Elevator; 5—Pt-Rh10 thermocouple; 6—Basket; 7—LZB-6 flowmeter; 8—JWK-702 temperature controller; 9—Nitrogen; 10—Air pump.

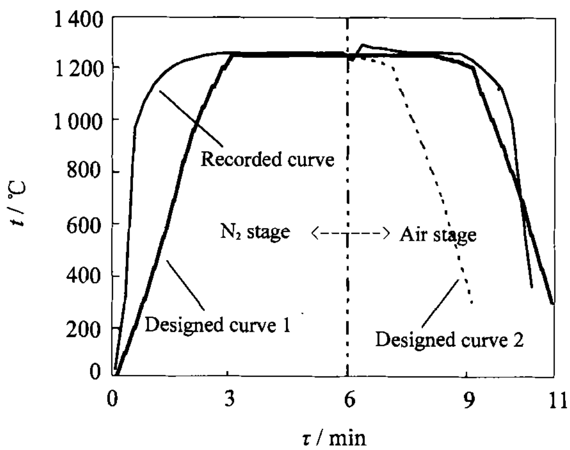

Figure 2 Temperature and atmosphere system in the mini-sintering test.

The basicity of the first series tests of specimens was decided in 1.8 for it is a typical parameter in sinter plants. The atmosphere and temperature system was adjusted based on the results of microstructure similar to sinter from production line.

The tests of variable SiO_2 with a basicity of 1.2 were investigated to seek how sinter strength varies when the basicity varies.

The tests in which the basicity is 2.3 were carried out for the reason that the basicity of sinter must be increased to maintain the balance of CaO in blast furnace burden when SiO_2 volume in sinter was decreased.

The tests for theoretical research and comparison with a basicity of 2.9 were also carried out. However, the tests at SiO_2 of 5% and 6% in mass fraction were not completed for melting overmuch.

The appearance of specimens was observed one by one. The strength and size of green and sintered disks were measured and then calculated with a modified equation [4] ($\sigma_f = \frac{2F}{\pi D\delta}$) to avoid the dependence of shape and size of the specimens. A compressive load was applied diametrically until the specimen failed. Where F is the load on the specimen in N, and D and δ are average diameter and thickness of the specimen in mm.

2 Results and Discussion

2.1 Volume change and compression strength

The compression strength and volume change of the

Table 2 Chemical composition of specimens in mass fraction %

CaO/SiO_2	SiO_2	TFe	MgO	Al_2O_3	CaO/SiO_2	SiO_2	TFe	MgO	Al_2O_3
	1.000	66.769	0.101	1.007		1.000	66.004	0.100	0.996
	2.000	65.248	0.098	0.984		2.000	63.719	0.096	0.961
1.2	3.000	63.728	0.096	0.961	2.3	3.000	61.434	0.093	0.927
	4.000	62.028	0.094	1.200		4.000	58.937	0.089	1.200
	5.000	60.286	0.091	1.500		5.000	56.422	0.085	1.500
	6.000	58.544	0.088	1.800		6.000	53.908	0.081	1.800
	1.000	66.352	0.100	1.001		1.000	65.584	0.100	0.998
	2.000	64.414	0.097	0.972		2.000	62.906	0.097	0.475
1.8	3.000	62.476	0.094	0.974	2.9	3.000	60.221	0.094	0.304
	4.000	60.342	0.091	1.200		4.000	57.308	0.086	0.300
	5.000	58.179	0.088	1.500		5.000	54.386	0.082	0.300
	6.000	56.015	0.084	1.800		6.000	51.463	0.078	0.300

specimens with different SiO_2 content in the designed basicity are shown in **figure 3**. Moreover, the mineral component of the specimens with different basicity at SiO_2 of 4% in mass fraction is shown in **figure 4**.

2.2 Mineral component

The mineral composition with different SiO_2 content and basicity at different atmosphere are shown in **figure 5**.

At first, some conclusions can be derived from the experimental results with a basicity of 1.8. It is shown in figure 3(a) that the strength of sintered specimens is higher enough when SiO_2 content is about 5%–6% in mass fraction. The mineral component, microstructure observed under microscope and appearance are similar to normal sinter. It is shown from **figure 6**(a) that calcium-ferrite was formed largely, the main bond phase

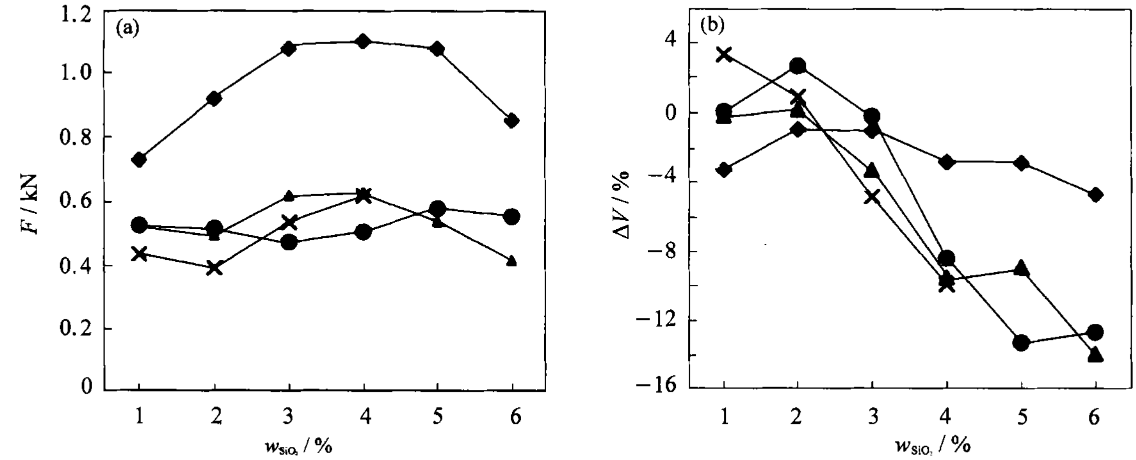

Figure 3 Relationships of volume change (ΔV) and compression force (F) of the specimens with SiO_2 content in mass fraction (w_{SiO_2}). Basicity (B) ◆ 1.2; ● 1.8; ▲ 2.3; × 2.9.

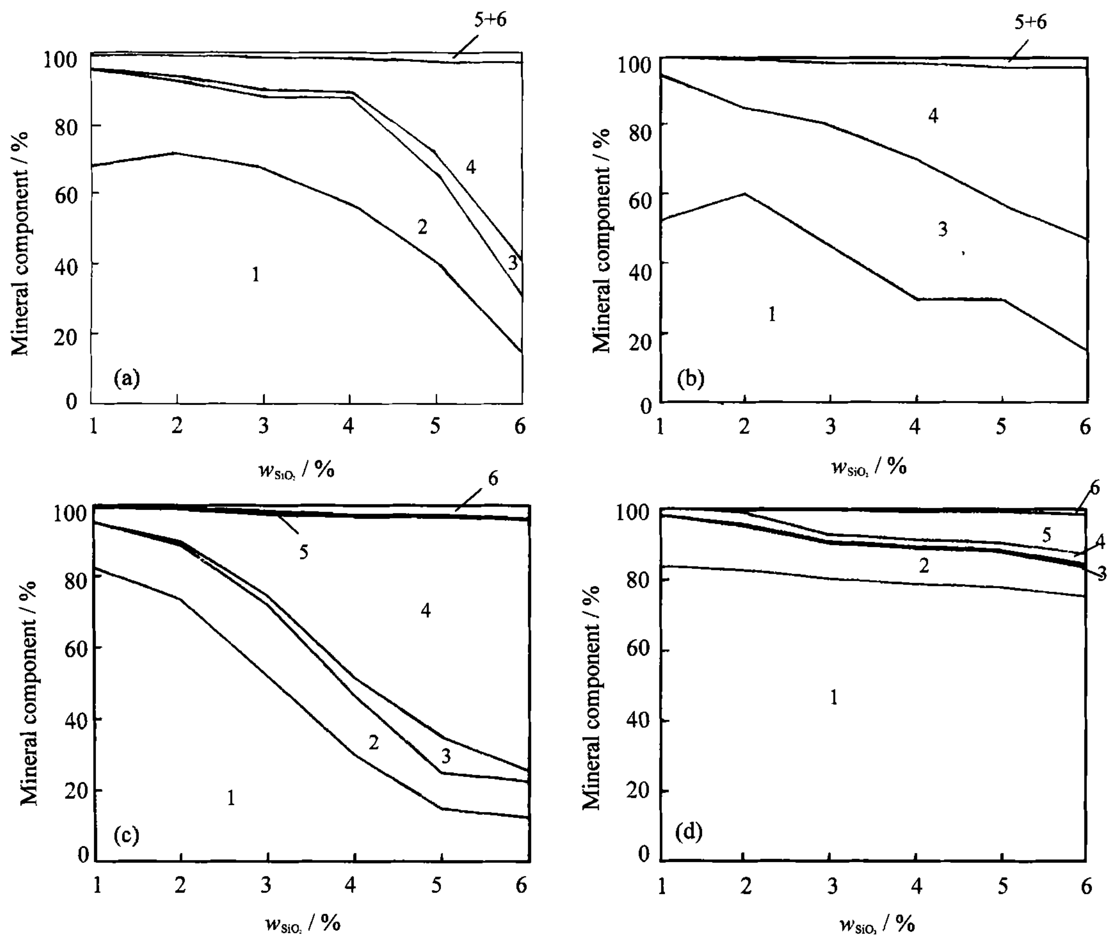

Figure 4 Changes of mineral component in mass fraction. The basicity values are 1.8 (a), 1.8 at nitrogen (b) and 2.3 (c) 1.2 (d). 1—Primary hematite (PH); 2—Secondary hematite (SH); 3—Magnetite (M); 4—Silico ferrite of calcium and aluminium (F); 5—Vitreous phases (C);

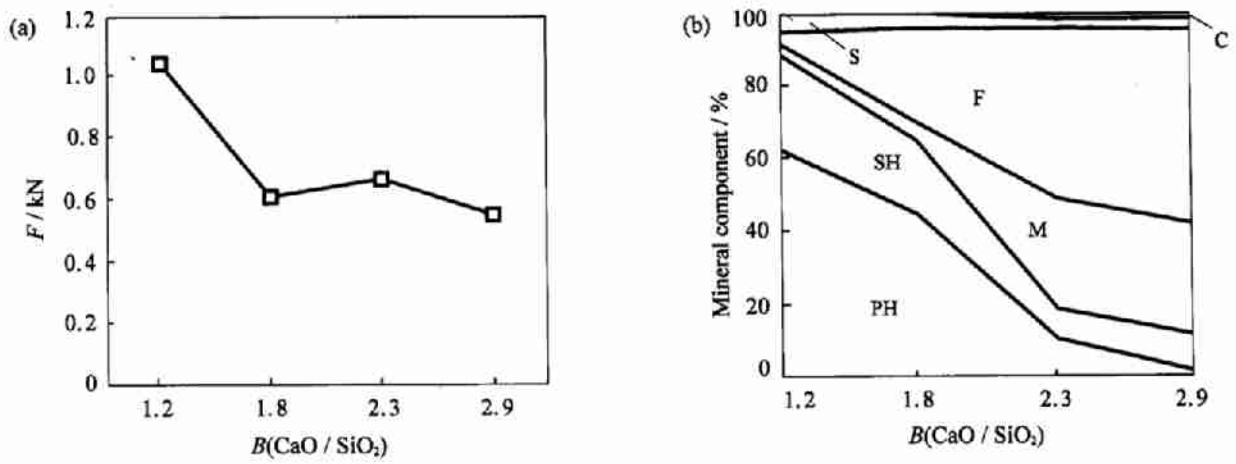

Figure 5 Compression force F (a) and mineral component (b) at different basicity. The mass fraction of SiO_2 w_{SiO_2}=4.0%.

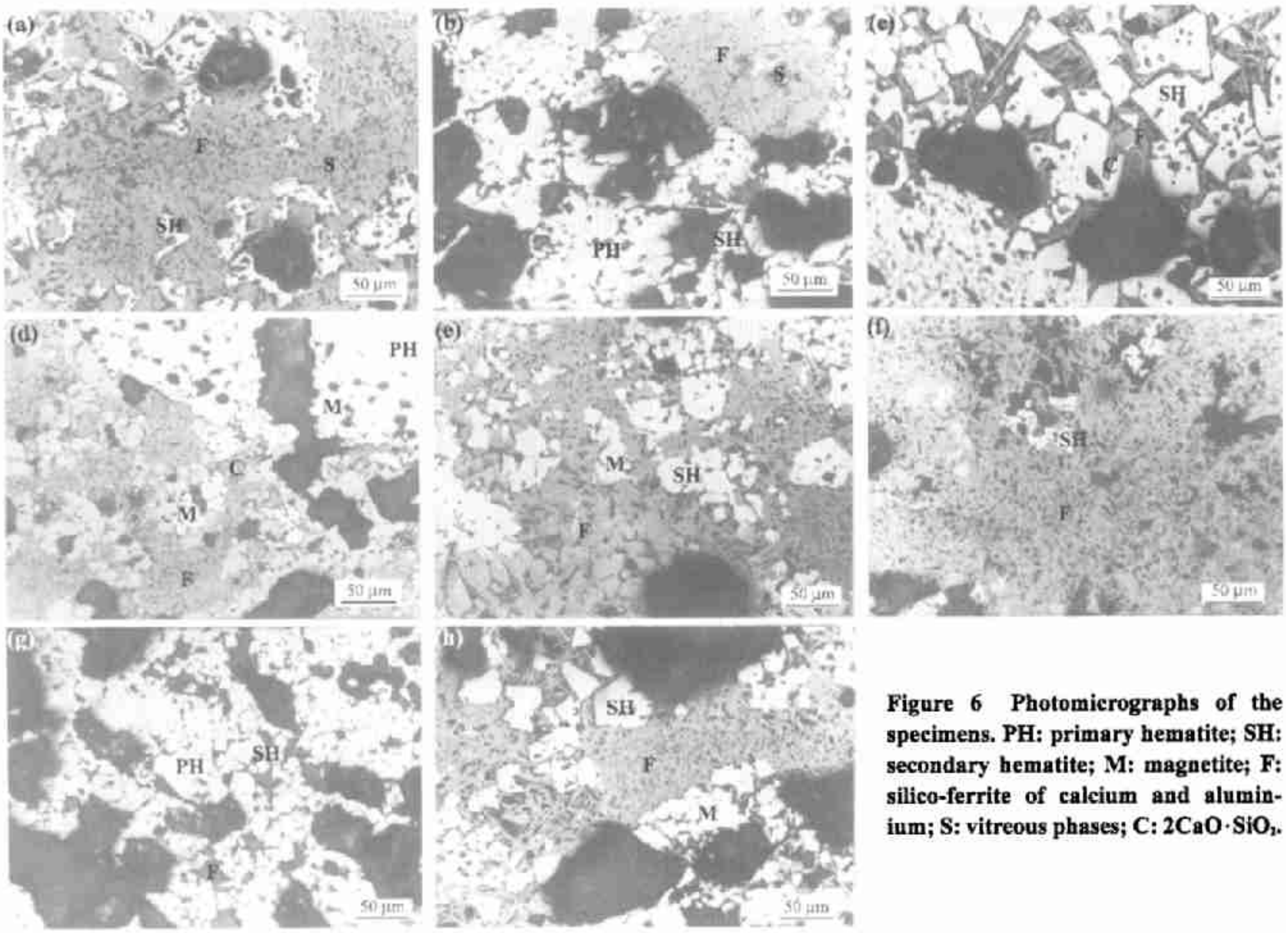

Figure 6 Photomicrographs of the specimens. PH: primary hematite; SH: secondary hematite; M: magnetite; F: silico-ferrite of calcium and aluminium; S: vitreous phases; C: $2CaO \cdot SiO_2$.

is F and its mass fraction could be more than 50%. The intermixture was formed by hematite (Fe_2O_3) as frame surrounded by F separately.

At the same time, the strength of specimens is maintained high enough mainly by hematite bond but not a bit of scattered calcium-ferrite and some slag phases when the SiO_2 content is low to 1%–2% in mass fraction with a basicity of 1.8. The bonding reason is shown in figure 6(b).

Figure 6 (c) shows that when SiO_2 is some low (3%–4%), calcium-ferrite and silicate slag phases are developed in some degree but not more enough to be the main bonding phase. Moreover, the bonding of hematite is not developed well in such region where hematite aggregates but interrupted by calcium-ferrite and silicate slag phases. While it is not good enough to be the bonding phases when hematite is scatter.

It was studied that complex calcium ferrite might be formed basically in little slice and acicular shape at the early of combustion zone. The amount of F was relating to sinter basicity. Based on observation, the typical results of the specimens at the end of nitrogen at mosphere with a basicity of 1.8 similar to 1.2 and 2.3 were shown in figures 4(b) and 6(d).

2.3 Approaches to enhancing strength

There are great differences in agglomeration mechanism between 1%–2% and 5%–6% silica in mass fraction with a basicity of 1.8 while strength values of both the specimens are high equally. It can be maintained mainly by bonding hematite or complex calcium-ferrite submerged Fe_2O_3.

It is shown in figure 4 and figure 6(e,f) that the amount of calcium-ferrite increases when the basicity increases. The volume shrinkage increases while the amount of calcium-ferrite and other liquid slag phases generated at high temperature increase. When the SiO_2 content is as high as 3%–4% in mass fraction, the strength of specimen with a basicity of 2.3 reaches its peak, and after this point the strength decreases when the SiO_2 content increases. The hematite content as a frame is as high as calcium-ferrite when the SiO_2 content is 3%–4% in mass fraction. Furthermore, the intermixture formed by not only hematite but also magnetite with acicular calcium-ferrite. The magnetite increases when the amount of calcium-ferrite increases.

The experimental results with a basicity of 1.2 show that the strength of the specimens in this series is high evenly especially when the SiO_2 content is about 3%–4% in mass fraction. The bond of hematite adhered to opportune liquid phases is well developed (see figure 6 (g)). It was also proved by productions in Finland [5] and in Sweden [6] that the sinter strength could be kept at high level by developing the bond between ferrous oxide (Fe_3O_4) when the slag volume is low.

It could be concluded that high grade sinter with low silica content can be developed by lowering its basicity to make the bonding of hematite or raising the basicity to enhance the content of complex calcium ferrite for strength. It could make up for the strength decrease caused by shortage of traditional bonding phases. The metallurgical properties of sinter would be improved when its SiO_2 content is lowered.

It was proved by another temperature and atmosphere system (Designed Curve 2) that the strength with a basicity of 1.8 is lower than that with basicities of 2.3 and 1.2 at 4% SiO_2 content in mass fraction. The results similar to figure 3 were shown in figure 4. The appearance (figure 6 (h)) of microstructure with system 2 presents the same regulation.

It would be bad reducibility and softening for over melting caused by excessive amount of calcium-ferrite when the basicity is as high as 2.9. It's an approach to improve strength and structure of two-component sinter [7] by increasing basicity.

3 Conclusions

It is shown in the mini-sintering test that lowing SiO_2 content and decreasing liquid phases are disadvantageous to the sinter strength relied on traditional bonding phases.

It can be concluded from specimens' morphologies that the development of the hematite bond, as well as the amount and the distribution of calcium-ferrite is important to the sinter strength. However, overmuch calcium-ferrite and liquid phase do not contribute to the strength.

The way to developing the high-grade sinter maintaining strength highly enough with shortage of traditional bonding phases is to increase the basicity so as to enhance the content of complex calcium-ferrite or lower the basicity so as to make bonding of hematite.

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