The Sintering Fundamental Characteristics of Black Iron Concentrate

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SUMMARY

In order to understand the sintering performance of Black Iron concentrate better, various physical and chemical properties, especially sintering fundamental characteristics of Black Iron concentrate, Karara concentrate, South African concentrate, Canadian concentrate and one domestic concentrate (Sijiaying concentrate) are determined and compared. The test results show that:

Chemistry and size distribution

The Fe grade of these five concentrates are in the sequence of Black Iron concentrate > Karara concentrate > Sijiaying concentrate > Canadian concentrate > South African concentrate from high to low. Black Iron concentrate have the highest Fe grade at about 67.8%. Karara concentrate, Sijiaying concentrate and Canadian concentrate have similar Fe grade which are all in 65~66%, while the Fe grade of South African concentrate is the lowest at 63.4%.

Among these five concentrates, Black Iron concentrate have medium SiO₂ content at about 4.25%, and very low other impurities. The SiO₂ content of Karara concentrate is the highest at 7.97%, and quite high alkali metals, the Na₂O content and K₂O content are 0.272% and 0.327% respectively, while the other impurities content are very low. The SiO₂ content of Sijiaying concentrate is also high at 5.97%, but lower than that of Karara concentrate. Except a little high K₂O content, the other impurities content are also very low. Canadian concentrate have medium SiO₂ content at about 4.74%, which is slightly higher than that of Black Iron concentrate. South African concentrate has the lowest SiO₂ content, while the other impurities like CaO, SiO₂, MgO, MnO and TiO₂ are all higher than that of the other four iron concentrates.

Among these five iron concentrates, the particle size of Black Iron concentrate are the finest, and which are very suitable for using as pellet feed. Next is Karara concentrate and Sijiaying concentrate. While the particle size of Canadian concentrate and South African concentrates are quite coarse, can’t be used as pellet feed. The particle size of Canadian concentrate is the coarsest, +0.154mm >86%, and most particles are in lamellar shape.

The mineral composition and microstructure

The iron minerals of Black Iron concentrate mainly are magnetite and very little of Pyrrhotite. The gangue minerals are quartz and kirschsteinite. Most magnetite exist as individual particles, very few magnetite interlock with gangue. The crystal form of magnetite mainly are xenotopic-subhedral, and most of which are very fine equiaxed grains, around 30 micron. The size of gangue particles are obviously bigger than that of magnetite.

The iron minerals of Karara concentrate mainly are magnetite. The gangue mainly are pyroxene, quartz, mica and halloysite. Most particle of Karar
concentrate are very fine equiaxed grains, smaller than 50 micron, the maximum particle size isn't over 100 micron. The size of gangue particles generally are bigger than that of magnetite.

The iron minerals of South African concentrate mainly are magnetite. The gangue mainly are hedenbergite, quartz, feldspar, carbonate minerals and halloysite. The particle of South African concentrate are quite coarse with clean-cut edges and angles, most size smaller than 200 micron, and the maximum particle size reach 400 micron.

The iron minerals of Canadian concentrate mainly are specularite, magnetite and a small amount of chromite, limonite sometimes also can be observed. The amount of specularite and magnetite are almost the same. The gangue mainly are dolomite and quartz. The particle of Canadian concentrate are quite coarse, most of which are about 200 micron, and the maximum particle size reach 500 micron.

The iron minerals of Sijiaying concentrate mainly are magnetite and hematite, in a ratio at 80:20. Pyrite and limonite sometimes also can be observed. Gangue mainly are quartz, chlorite and a small amount of amphibole and carbonate minerals. Most magnetite and hematite exist as individual particles. Interlocking particles of magnetite and hematite, or of magnetite, hematite and gangue minerals, or of magnetite and hematite, or of magnetite and gangue minerals, or of hematite and gangue minerals can be observed. The crystal form of magnetite and hematite mainly are euhedral-subhedral, and most of which are equiaxed grains, around 25-125 micron, and the maximum particle size reach 200 micron.

Moisture capacity

Among these five iron concentrates, Karara concentrate has the highest moisture capacity at 16.73%, the next is Canadian concentrate with moisture capacity of 15.69%. The moisture capacities of Sijiaying concentrate and South African concentrate are similar, at 14.81% and 14.08% respectively. While the moisture capacity of Black Iron concentrate is the lowest at 11.54%.

The water absorption speed of Canadian concentrate is the fastest, while Black Iron concentrate is the slowest. The water absorption speed of the other three concentrates are similar and in between the former two concentrates.

Fundamental sintering characteristics of iron ores

(1) Assimilation performance of iron ores

There is no assimilation reaction occurred in samples made from Black Iron concentrate, South African concentrate and Sijiaying concentrate when the calcination temperature increased from 1340°C to 1370°C. The assimilation reaction in samples made from Canadian concentrate and Karara concentrate both start from 1360°C. The assimilation reaction of Canadian concentrate
improved rapidly and fully completed at 1370°C. The assimilation temperature of iron concentrate is much higher than that of fines ores. The assimilation temperature of some fines ore is low at about 1260°C, while the assimilation temperature of these five iron concentrate in this program are all over 1350°C.

(2) The fluidity of liquid phase

For Karara concentrate, Canadian concentrate and Sijiaying concentrate, the liquid phase flow phenomenon was observed from 1260°C, and the fluidity of liquid phase increase with the increasing of temperature. The liquid phase fluidity of Karara concentrate and Sijiaying concentrate are similar, and a little higher than that of Canadian concentrate. While for South African concentrate, the liquid phase flow phenomenon was not yet observed when temperature increasing to 1330°C. For Black Iron concentrate, the liquid phase flow phenomenon was observed from 1280°C, and the fluidity of liquid phase increases with the increasing of temperature. But generally, the liquid phase fluidity of Black Iron concentrate is slightly lower than that of Karara concentrate, Canadian concentrate and Sijiaying concentrate.

(3) The strength of bonding phase

Both liquid phase strength and joined crystal stock strength of Canadian concentrate and South African concentrate are in a high level and close. The joined crystal stock strength of Karara concentrate and Sijiaying concentrate are also in a high level, while the liquid phase strength are much lower than that of Canadian concentrate and South African concentrate. The liquid phase strength of Black Iron concentrate is in a high level, and similar with that of Canadian concentrate and South African concentrate, while the joined crystal stock strength is much lower than that of the other four iron concentrates.

(4) SFCA forming capability

The microstructure of the samples from these five iron concentrates are very different from that of the samples from Australian fines ores. In the samples from these five iron concentrates, the main binding minerals are glass, dicalcium silicate and hematite joined crystal stock with small amount of calcium ferrite. While in the samples from Australian fines ores, the main binding minerals are calcium ferrite, which braid in interlacement with the hematite and silicate minerals dispersed in it. All these five iron concentrate have low SFCA forming capability, the amount of SFCA generated in sintering process all below 15%. The amount of SFCA generated at the basicity of 2.0 of these five iron concentrate samples are in the sequence of South African concentrate < Canadian concentrate < Karara concentrate ~ Black Iron concentrate < Sijiaying concentrate.
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1. INTRODUCTION

1.1 Background

Iron ores are the main raw materials used in the sintering process and the properties of iron ores have huge influence on sintering performance and sinter quality. In addition to the well-known normal temperature properties of iron ores like chemistry, size distribution and granulation property, there are also some high-temperature properties closely relate to the high-temperature sintering process. Long-term research work have shown that different types of iron ores present different high-temperature physicochemical properties in the process of sintering, like the performance of reaction with CaO, the fluidity and binding strength of liquid phase generated in sintering process, and so on, which are called sintering fundamental characteristics of iron ore. The sintering fundamental characteristics of iron ore mainly include the assimilation property, fluidity of liquid phase, strength of bonding phase and SFCA forming capability, which are considered reflecting the performance of iron ores in sintering process, and used as one of the evaluation index of iron ores.

The assimilation property of iron ore reflects the reaction ability with CaO and the degree of difficulty in generating liquid phase in sintering process. In general, the higher the assimilation of iron ore, the more likely to produce liquid phase in sintering process. But, for the heterogeneous sinter, considering both the induration strength of iron ore particles and the permeability of sinter bed, the exceeding assimilation of coarser ore which act as nuclear particle are not expected. The exceeding melting of nuclear particle will decrease its skeleton role of sinter cake and deteriorate the permeability of sinter bed, thus deteriorate the quality and quantity of sinter. Therefore, the iron ore or iron ore blend with appropriate assimilation property is preferred.

The fluidity of liquid phase refers to the fluidity of liquid phase produced from the reaction of iron ore and CaO in sintering process, which reflects the "effective binding scope" of bonding phase. Although the assimilation property of iron ore reveals its generation ability of low melting point liquid phase, the assimilation temperature cannot fully reflects the amount of the effective liquid phase. In general, the higher fluidity of liquid phase, the bigger effective binding scope, so it can improve the strength of the sinter. If the liquid phase fluidity is too low, the ability of binding decrease, thus the sinter porosity increase and the strength of sinter decrease. On the other hand, if the liquid phase fluidity is too high, the sinter with thin-walled macroporous structure will be produced, thus the strength and the reducibility of sinter decrease. Therefore, the iron ore or iron ore blend with appropriate liquid phase fluidity is preferred.

The strength of bonding phase refers to the ability of the liquid phase formed in the sintering process to cement the surrounding nuclear ore. It has a crucial influence on the strength of sinter. The consolidation of nuclear ore in sintering process is mainly depend on the bonding phase. Because of the high strength of nuclear ore, it will not be the limiting factor of sinter strength. Sufficient bonding phase is the foundation of the consolidation of sinter, and the strength...
of bonding phase is also a very important factor.

Calcium ferrite (SFCA) is the optimal bonding phase of sinter, with high strength and high reducibility. More calcium ferrite (SFCA) generated in sintering process, the reducibility and strength of sinter are obviously improved.

To sum up, different types of iron ore has different sintering fundamental characteristics, presents different high-temperature performance in sintering process. While, these characteristics of iron ore are not able to be obtained based on the chemistry, size distribution, mineral composition and microstructure at normal temperature. The technical and economic indexes of sintering process depend not only on the normal temperature performance of iron ore, but also on the sintering fundamental characteristics of iron ore at high temperature.

Therefore, understanding the sintering fundmental characteristics of each ore is important to support planning of blending schemes of iron ores from different origins in order to keep the sintering process stable and obtain a high-quality sinter product. As the concept of iron ore sintering fundmental characteristics have been accepted by the people in Chinese sinter plant and the the research work on iron ore sintering fundmental characteristics are deepening continually [2~8], the iron ore sintering fundmental characteristics has gradually become one of the references for iron ore matching and optimization scheme.

Faced with various types of imported iron ores with very different physico-chemical properties, understanding the sintering fundmantal characteristics of iron ore before sinter pot test not only can choose the iron ore type and plan the proportion, but also can greatly reduce the sinter pot testwork, improve the success rate of test research.

1.2 Objectives

The aim of this test program is to understand the fundamental sintering characteristics of Black Iron concentrate in comparison with Australian Karara concentrate, a Canadian concentrate, a South African concentrate and a domestic concentrate (Sijaying concentrate). The program also includes the research and comparison on the chemistry, size distribution, moisture capacity, mineral composition and microstructure of these five iron concentrates.
2. WORK PROGRAMME AND METHODOLOGY

2.1 Raw Materials Preparation and Assessment

Each raw material sample was homogenized and enclosed in plastic bags.

The chemical analyses were carried out by National Analysis Center for Iron and Steel, while the sizing and moisture content of raw materials were determined in accordance with CISRI procedures.

2.2 Mineralogy of iron ores

The mineralogy of iron ores will be studied by XRD and optical microscop.

2.3 Moisture capacity of iron ores

The moisture capacity of iron ores is defined as the maximum water content which can be held by unit mass of the ore, calculated as follows:

\[ m_c(\%) = 100 \times \frac{M_w}{M_i} \]  

Formula 1

Where \( m_c \), \( M_w \) and \( M_i \) refer to moisture capacity, Maximum mass of water absorbed and mass of iron ore, respectively. This parameter represents the ability of holding water and can be used to predict the optimum water content in the granulation process.

Figure 2-1 shows the schematic of instrument for measurement of moisture capacity. Iron ore fines are loaded in the sample tube, provided with a filter-paper-covered sieve bottom and hung from an electric balance. The sample tube is immersed into water in a U-shaped container to absorb water into the sample, thus increasing the reading of the electric balance. Record the reading of electric balance over time and calculate the mass of water absorbed changes over time. When the difference between two consecutive measurements value is not more than 0.1g, the last value is the maximum mass of water absorbed, and the moisture capacity of iron ore can be calculated according to Formula 1.
The fundamental sintering characteristic of Black Iron concentrate

2.4 Fundamental sintering properties of iron ores

A horizontal resistance furnace (Figure 2-2) with both controlled atmosphere and imaging systems was used to determine these fundamental sintering characteristics.

To simulate the sintering process, the iron ores were tested in the furnace under specific temperature and gas composition conditions that are shown in Figure 2-3.
The fundamental sintering characteristic of Black Iron concentrate

2.4.1 Assimilation Performance of Iron Ores

The assimilation performance of iron ore is characterized by measuring the amount of assimilation that occurs over a range of temperatures.

A compressed tablet of iron ore is placed over a compressed tablet of CaO, and calcined under the temperature profile and controlled atmosphere as shown in Figure 2-3. The samples are tested at a fixed temperature and the test repeated over a range of temperatures (eg 1280°C, 1290°C, 1300°C etc) depending on the performance of iron ores.

The temperature at which the tablet of iron ore begins to assimilate with the CaO tablet is defined as the Assimilation Temperature.

The amount of Assimilation is calculated according to Formula 2.

\[
\text{Assimilation rate} = 1 - \left( \frac{A_{\text{after}}}{A_{\text{before}}} \right) \times 100\% \quad \text{Formula 2}
\]

Where \( A_{\text{before}} \) and \( A_{\text{after}} \) are the cross sectional areas of the iron ore tablet before and after the test when viewed horizontally.

2.4.2 The Fluidity of Liquid Phase

Firstly, iron ore and CaO are mixed in certain basicity and compressed as a single tablet. The tablet is then calcined under the temperature profile and controlled atmosphere as shown in Figure 2-3. The samples are tested at a
fixed temperature and the test repeated over a range of temperatures (eg 1240°C, 1250°C, 1260°C etc) depending on the performance of iron ores.

After the tests, the fluidity of the liquid phase is calculated according to Formula 3.

\[
\text{Fluidity} = \frac{A_{after} - A_{before}}{A_{before}} \quad \text{Formula 3}
\]

Where \( A_{before} \) and \( A_{after} \) are the cross sectional areas of the iron ore tablet before and after the test when viewed vertically.

2.4.3 The Strength of Bonding Phase

The strength of bonding phase is characterized by measuring the compressive strength of two components:

(i) the compressive strength of the products formed from the solidification of liquid phases.
(ii) the compressive strength of products formed from solid-solid reactions.

The compressive strength of the products formed from the solidification of liquid phases is measured by firstly preparing tablets of the iron ore and CaO fluxed to a specific basicity. These tablets are then calcined at 1280°C under conditions shown in Figure 2-3.

After calcining, the compressive strength of each tablet is measured and defined as the strength of products from the liquid phase.

The compressive strength of products formed from solid-solid reactions is measured by preparing tablets of iron ore only and calcining these at 1280°C under conditions shown in Figure 2-3.

After calcining, the compressive strength of each tablet is measured, and is defined as the strength of products formed from solid-solid reactions.

2.4.4 SFCA Forming Ability

Tablets of iron ore and CaO are prepared to three different basicity levels (1.8, 2.0 and 2.2) and calcined at 1280°C under conditions shown in Figure 2-3.

After calcining, polished sections of the tablets are studied under the petrological microscope to determine the rate and amounts of SFCA generated.
3. CHARACTERIZATION OF RAW MATERIALS

Table 3-1 summarises the chemical composition of the iron ores which were tested in this program, and Table 3-2 summarises the size distribution of the iron ores.

**Table 3-1 Chemical Analysis of Iron Ores, %**

<table>
<thead>
<tr>
<th>Iron Ore</th>
<th>TFe (%)</th>
<th>CaO (%)</th>
<th>SiO₂ (%)</th>
<th>MgO (%)</th>
<th>Al₂O₃ (%)</th>
<th>Mn (%)</th>
<th>TiO₂ (%)</th>
<th>S (%)</th>
<th>P (%)</th>
<th>Na₂O (%)</th>
<th>K₂O (%)</th>
<th>烧损 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>67.76</td>
<td>0.08</td>
<td>4.25</td>
<td>0.33</td>
<td>0.42</td>
<td>0.02</td>
<td>0.05</td>
<td>0.22</td>
<td>0.019</td>
<td>0.01</td>
<td>0.04</td>
<td>-2.90</td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>65.98</td>
<td>0.48</td>
<td>7.97</td>
<td>0.39</td>
<td>0.11</td>
<td>0.00</td>
<td>&lt;0.01</td>
<td>0.022</td>
<td>0.025</td>
<td>0.272</td>
<td>0.327</td>
<td>-2.81</td>
</tr>
<tr>
<td>South African concentrate</td>
<td>63.40</td>
<td>1.55</td>
<td>1.29</td>
<td>3.66</td>
<td>0.69</td>
<td>0.19</td>
<td>2.38</td>
<td>0.050</td>
<td>0.164</td>
<td>0.030</td>
<td>0.060</td>
<td>-1.19</td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>65.30</td>
<td>0.50</td>
<td>4.74</td>
<td>0.52</td>
<td>0.14</td>
<td>0.16</td>
<td>0.02</td>
<td>0.010</td>
<td>0.006</td>
<td>0.022</td>
<td>0.006</td>
<td>0.33</td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>65.75</td>
<td>0.32</td>
<td>5.97</td>
<td>0.46</td>
<td>0.43</td>
<td>0.01</td>
<td>0.06</td>
<td>0.080</td>
<td>0.020</td>
<td>0.048</td>
<td>0.157</td>
<td>-1.86</td>
</tr>
</tbody>
</table>

**Table 3-2 Moisture and Size distribution of iron ores, %**

<table>
<thead>
<tr>
<th>Iron Ore</th>
<th>+2mm</th>
<th>-2+1mm</th>
<th>-1+0.154mm</th>
<th>-0.154+0.1mm</th>
<th>-0.1+0.071mm</th>
<th>-0.071+0.045mm</th>
<th>-0.045+0.032mm</th>
<th>-0.032mm</th>
<th>合计</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.1</td>
<td>0.1</td>
<td>0.8</td>
<td>17.9</td>
<td>81.1</td>
<td>100</td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.5</td>
<td>6.0</td>
<td>36.9</td>
<td>28.5</td>
<td>28.1</td>
<td>100</td>
</tr>
<tr>
<td>South African concentrate</td>
<td>0.0</td>
<td>0.0</td>
<td>35.6</td>
<td>15.5</td>
<td>16.3</td>
<td>12.8</td>
<td>7.2</td>
<td>12.0</td>
<td>100</td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>0.0</td>
<td>0.0</td>
<td>85.0</td>
<td>11.0</td>
<td>2.1</td>
<td>0.4</td>
<td>0.0</td>
<td>0.4</td>
<td>100</td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>0.0</td>
<td>0.0</td>
<td>4.64</td>
<td>6.76</td>
<td>14.83</td>
<td>29.87</td>
<td>14.03</td>
<td>30.07</td>
<td>100</td>
</tr>
</tbody>
</table>
The Fe grade of these five concentrates are in the sequence of Black Iron concentrate > Karara concentrate > Sijiaying concentrate > Canadian concentrate > South African concentrate from high to low. Black Iron concentrate have the highest Fe grade at about 67.8%. Karara concentrate, Sijiaying concentrate and Canadian concentrate have similar Fe grade which are all in 65~66%, while the Fe grade of South African concentrate is the lowest at 63.4%.

Among these five iron concentrates, Black Iron concentrate have medium SiO$_2$ content at about 4.25%, and very low other impurities. The SiO$_2$ content of Karara concentrate is the highest at 7.97%, and quite high alkali metals, the Na$_2$O content and K$_2$O content are 0.272% and 0.327% respectively, while the other impurities content are very low. The SiO$_2$ content of Sijiaying concentrate is also high at 5.97%, but lower than that of Karara concentrate. Except a little high K$_2$O content, the other impurities content are also very low. Canadian concentrate have medium SiO$_2$ content at about 4.74%, which is slightly higher than that of Black Iron concentrate. South African concentrate has the lowest SiO$_2$ content, while the other impurities like CaO, SiO$_2$, MgO, MnO and TiO$_2$ are all higher than that of the other four iron concentrates.

Among these five iron concentrates, the particle size of Black Iron concentrate are the finest, and which are very suitable for using as pellet feed. Next is Karara concentrate and Sijiaying concentrate. While the particle size of Canadian concentrate and South African concentrates are quite coarse, can not be used as pellet feed. The particle size of Canadian concentrate is the coarsest, +0.154mm >86%, and most particles are in lamellar shape.
4. THE MINERAL COMPOSITION AND MICROSTRUCTURE

The mineral composition and microstructure of Black Iron concentrate, Karara concentrate, South African concentrate, Canadian concentrate and Sijiaying concentrate are studied by optical microscope assisted with XRD.

Due to the limitation of XRD method itself, the result can only prove one mineral exists, can not prove one mineral is in existent. So the result of XRD only can be the reference for optical microscope.

(1) Black Iron concentrate

The iron minerals of Black Iron concentrate mainly are magnetite refering to picture a of Figure 4-1. Pyrrhotite and pyrite sometimes also can be observed. The yellow particle in the middle of picture b is pyrrhotite. A small amount of gangue mainly are quartz and kirschsteinite.

Most magnetite exist as individual particles, very few magnetite interlock with gangue. The crystal form of magnetite mainly are xenotopic-subhedral, and most of which are very fine equiaxed grains, around 30 micron. The size of gangue particles are obviously bigger than that of magnetite.

(2) Karara concentrate

The iron minerals of Karara concentrate mainly are magnetite refering to Figure 4-2. The gangue mainly are pyroxene, quartz, mica and halloysite.

Most particle of Karara concentrate are very fine equiaxed grains, smaller than 50 micron, the maximum particle size isn't over 100 micron. The size of gangue particles generally are bigger than that of magnetite.

(3) South African concentrate

The iron minerals of South African concentrate mainly are magnetite refering to Figure 4-3. The gangue mainly are hedenbergite, quartz, feldspar, carbonate minerals and halloysite. Copper pyrite sometimes also can be observed, the yellow particle in the middle of picture c is copper pyrite.

The particle of South African concentrate are quite coarse with clean-cut edges and angles, most size smaller than 200 micron, and the maximum particle size reach 400 micron.

(4) Canadian concentrate

The iron minerals of Canadian concentrate mainly are specularite, magnetite and a small amount of chromite, limonite sometimes also can be observed, refering to Figure 4-4. The amount of specularite and magnetite are almost the same. The gangue mainly are dolomite and quartz.
The particle of Canadian concentrate are quite coarse, most of which are about 200 micron, and the maximum particle size reach 500 micron.

(5) Sijiaying concentrate

The iron minerals of Sijiaying concentrate mainly are magnetite and hematite, in a ratio at 80:20. Pyrite and limonite sometimes also can be observed, refering to picture d of Figure 4-5. Gangue mainly are quartz, chlorite and a small amount of amphibole and carbonate minerals. Most magnetite and hematite exist as individual particles, referring to picture a of Figure 4-5.

Interlocking particles of magnetite and hematite, or of magnetite, hematite and gangue minerals can be observed, which are shown in picture b. Interlocking particles of magnetite and hematite, or of magnetite and gangue minerals, or of hematite and gangue minerals can be observed, which are shown in picture c.

The crystal form of magnetite and hematite mainly are euhedral-subhedral, and most of which are equiaxed grains, around 25-125 micron, and the maximum particle size reach 200 micron.

Figure 4-1 Mineralogical micrograph of Black Iron concentrate
The fundamental sintering characteristic of Black Iron concentrate

**Figure 4-2** Mineralogical micrograph of Karara concentrate

a

b

c (The yellow mineral in the middle of the picture is chalcopyrite)

**Figure 4-3** Mineralogical micrograph of South African concentrate

a (The upper right particle is chromite)

b (Several particles in the middle are gangue)
The fundamental sintering characteristic of Black Iron concentrate

**Figure 4- 4** Mineralogical micrograph of Kooly fines

(a) Monomer

(c) The central granule is chromite

(d) The central blue-gray mineral is limonite

**Figure 4- 5** Mineralogical micrograph of Sijiaying concentrate

(a) Monomer

(c)

(b)

(d)
5. THE MOISTURE CAPACITY OF IRON ORE

Water acts as binder during the granulation process of sintering. The water absorption ability of iron ores influences the growth and strength of the green granules. Moisture capacity of iron ore defined as its ability to hold water, has been found to be affected by its patical size and chemical composition.

The moisture capacity of iron ores had a strong positive relation to the optimal water content during the granulation process. The higher the moisture capacity of iron ore, the higher the optimal moisture content during granulation content. The determination of the moisture capacity provides guidance on the adjustment of mix moisture when it is introduce into the mixture of sintering process. It was also found that the moisture capacity increased with decreasing size of the iron ore particals and the content of SiO₂, and with increasing content of Al₂O₃ and LOI.

The moisture capacity of Black Iron concentrate, Canadian concentrate, South African concentrate, Karara concentrate, and Sijiaying concentrate are determined in this program and the result was shown in Table 5-1 and Figure 5-1.

<table>
<thead>
<tr>
<th>Iron ore</th>
<th>Moisture capacity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>11.54</td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>15.69</td>
</tr>
<tr>
<td>South African concentrate</td>
<td>14.08</td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>16.73</td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>14.81</td>
</tr>
</tbody>
</table>

Figure 5-1 The moisture capacity of five iron concentrates
Among these five iron concentrates, Karara concentrate has the highest moisture capacity at 16.73%, the next is Canadian concentrate with moisture capacity of 15.69%. The moisture capacities of Sijiaying concentrate and South African concentrate are similar, at 14.81% and 14.08% respectively. While the moisture capacity of Black Iron concentrate is the lowest at 11.54%.

The water absorption speed of Canadian concentrate is the fastest, while Black Iron concentrate is the slowest. The water absorption speed of the other three concentrates are similar and in between the former two concentrates.

**Figure 5- 2 Moisture capacity of iron ores increasing with time**
6. FUNDAMENTAL SINTERING CHARACTERISTICS OF IRON ORE

The Assimilation Performance, Fluidity of Liquid Phase, Strength of Binding Phase and SFCA forming capability are used to evaluate the fundamental sintering characteristics of iron ores. In this program, the fundamental sintering characteristics of Black Iron concentrate, Karara concentrate, South African concentrate, Canadian concentrate and Sijiaying concentrate are determined and compared.

6.1 Assimilation performance of iron ores

The assimilation performance of iron ore is characterized by measuring the assimilation temperation and the assimilation rate that occurs over a range of temperatures.

6.1.1 Black Iron concentrate

The assimilation test of Black Iron concentrate was started from 1260°C, and the calcination temperature was increased gradually, but the assimilation still was not observed when it was increased to 1370°C.

Table 6-1 Assimilation rate of Black Iron concentrate at different calcination temperatures

<table>
<thead>
<tr>
<th>Calcination temperature</th>
<th>1340°C</th>
<th>1350°C</th>
<th>1360°C</th>
<th>1370°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation rate</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

(a) 1350°C, unassimilated;  (b) 1360°C, unassimilated;  (c) 1370°C, unassimilated

Figure 6-1 Assimilation process of Black Iron concentrate

6.1.2 Karara concentrate

Figure 6-2 shows the assimilation process of Karara concentrate, and the assimilation rate of Karara concentrate at different temperatures are shown in Table 6-2.
The assimilation process of Karara concentrate started from 1350°C, and the assimilation rate increased gradually with the increasing of calcination temperature. The assimilation process of Karara concentrate well improved at 1370°C.

**Table 6-2** Assimilation rate of Karara concentrate at different calcination temperatures

<table>
<thead>
<tr>
<th>Calcination temperature</th>
<th>1340°C</th>
<th>1350°C</th>
<th>1360°C</th>
<th>1370°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation rate</td>
<td>0%</td>
<td>0%</td>
<td>15.33%</td>
<td>64.33%</td>
</tr>
</tbody>
</table>

(a) 1350°C, unassimilated; (b) 1360°C, started; (c) 1370°C, improved

**Figure 6-2** Assimilation process of Karara concentrate

6.1.3 South African concentrate

The assimilation test of South African concentrate was started from 1260°C, and the calcination temperature was increased gradually, but the assimilation still was not observed when it was increased to 1370°C.

**Table 6-3** Assimilation rate of South African concentrate at different calcination temperatures

<table>
<thead>
<tr>
<th>Calcination temperature</th>
<th>1340°C</th>
<th>1350°C</th>
<th>1360°C</th>
<th>1370°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation rate</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

(a) 1350°C, unassimilated; (b) 1360°C, unassimilated; (c) 1370°C, unassimilated

**Figure 6-3** Assimilation process of South African concentrate
6.1.4 Canadian concentrate

Figure 6-4 shows the assimilation process of Canadian concentrate, and the assimilation rate of Canadian concentrate at different temperatures are shown in Table 6-4.

The assimilation process of Canadian concentrate started and improved at 1360°C, the assimilation rate reach to 56.33% at 1360°C. The assimilation rate increased rapidly with the increasing of calcination temperature and fully completed at 1370°C.

Table 6-4 Assimilation rate of Canadian concentrate at different calcination temperatures

<table>
<thead>
<tr>
<th>Calcination temperature</th>
<th>1340°C</th>
<th>1350°C</th>
<th>1360°C</th>
<th>1370°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation rate</td>
<td>0%</td>
<td>0%</td>
<td>56.33%</td>
<td>100%</td>
</tr>
</tbody>
</table>

(a) 1350°C, unassimilated; (b) 1360°C, started and improved; (c) 1370°C, full assimilated

Figure 6-4 Assimilation process of Canadian concentrate

6.1.5 Sijiaying concentrate

The assimilation test of Sijiaying concentrate was started from 1260°C, and the calcination temperature was increased gradually, but the assimilation still was not observed when it was increased to 1370°C.

Table 6-5 Assimilation rate of Sijiaying concentrate at different calcination temperatures

<table>
<thead>
<tr>
<th>Calcination temperature</th>
<th>1350°C</th>
<th>1360°C</th>
<th>1370°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assimilation rate</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

The fundamental sintering characteristic of Black Iron concentrate
Figure 6-5 Assimilation process of Sijiaying concentrate

6.1.6 Brief summary

Table 6-6 Assimilation rate of Black Iron concentrate and the other four concentrates at different temperatures, %

<table>
<thead>
<tr>
<th>Iron ore</th>
<th>Temperature</th>
<th>Assimilation rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1340°C</td>
<td>1350°C</td>
</tr>
<tr>
<td>Black Iron concentrate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>South African concentrate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

From Figure 6-6, it can be seen that the calcination temperature increased from 1340°C to 1370°C, there is no assimilation reaction occurred in samples made from Black Iron concentrate, South African concentrate and Sijiaying concentrate.

The fundamental sintering characteristic of Black Iron concentrate
The fundamental sintering characteristic of Black Iron concentrate in samples made from Canadian concentrate and Karara concentrate both start from 1360°C. The assimilation reaction of Canadian concentrate improved rapidly and fully completed at 1370°C.

The assimilation performance of iron concentrate is much different from that of fines ore. The assimilation temperature of iron concentrate is much higher than that of fines ores. The assimilation temperature of some fines ore is low at about 1260°C, while the assimilation temperature of these five iron concentrate in this program are all over 1350°C.

6.2 The fluidity of liquid phase

6.2.1 Black Iron concentrate

Figure 6-7 shows the process of liquid phase generating and flowing of Black Iron concentrate, and the fluidity of Black Iron concentrate at different temperatures are shown in Table 6-7. For Black Iron concentrate, the liquid phase generated at 1280°C, and the fluidity of liquid phase increase with the increasing of temperature, and get pretty well at 1340°C.

<table>
<thead>
<tr>
<th>Temperature (℃)</th>
<th>1280</th>
<th>1300</th>
<th>1310</th>
<th>1320</th>
<th>1330</th>
<th>1340</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>0.08</td>
<td>0.16</td>
<td>0.40</td>
<td>0.68</td>
<td>1.06</td>
<td>1.81</td>
</tr>
</tbody>
</table>

6.2.2 Karara concentrate

Figure 6-8 shows the process of liquid phase generating and flowing of Karara concentrate, and the fluidity of Karara concentrate at different temperatures are shown in Table 6-8. For Karara concentrate, the liquid phase generated at
1260°C, and the fluidity of liquid phase increase with the increasing of temperature, and get pretty well at 1310°C.

**Table 6- 8** The fluidity of Karara concentrate at different temperatures

<table>
<thead>
<tr>
<th>Temperature</th>
<th>1260°C</th>
<th>1270°C</th>
<th>1280°C</th>
<th>1300°C</th>
<th>1310°C</th>
<th>1330°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>0.08</td>
<td>0.23</td>
<td>1.44</td>
<td>2.35</td>
<td>2.61</td>
<td>-</td>
</tr>
</tbody>
</table>

**Figure 6- 8** The process of liquid phase generating and flowing of Karara concentrate

6.2.3 South African concentrate

**Figure 6-9** shows the process of liquid phase generating and flowing of South African concentrate, and the fluidity of South African concentrate at different temperatures are shown in **Table 6-9**.

But the liquid phase still did not generate at 1330°C.

**Table 6- 9** The fluidity of South African concentrate at different temperatures

<table>
<thead>
<tr>
<th>Temperature</th>
<th>1270°C</th>
<th>1280°C</th>
<th>1300°C</th>
<th>1310°C</th>
<th>1330°C</th>
<th>1350°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South African concentrate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>
6.2.4 Canadian concentrate

Figure 6-10 shows the process of liquid phase generating and flowing of Canadian concentrate, and the fluidity of Canadian concentrate at different temperatures are shown in Table 6-10. For Canadian concentrate, the liquid phase generated at 1260°C, and the fluidity of liquid phase increase with the increasing of temperature, and get pretty well at 1320°C.

Table 6-10 The fluidity of Canadian concentrate at different temperatures

<table>
<thead>
<tr>
<th>Iron ore</th>
<th>1260°C</th>
<th>1270°C</th>
<th>1280°C</th>
<th>1300°C</th>
<th>1310°C</th>
<th>1330°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canadian concentrate</td>
<td>0.02</td>
<td>0.46</td>
<td>0.57</td>
<td>0.75</td>
<td>1.6</td>
<td>2.0</td>
</tr>
</tbody>
</table>

6.2.5 Sijiaying concentrate

The fundamental sintering characteristic of Black Iron concentrate
Figure 6-11 shows the process of liquid phase generating and flowing of Sijiaying concentrate, and the fluidity of Sijiaying concentrate at different temperatures are shown in Table 6-11. For Sijiaying concentrate, the liquid phase generated at 1260°C, and the fluidity of liquid phase increase with the increasing of temperature, and get pretty well at 1310°C.

Table 6-11 The fluidity of Sijiaying concentrate at different temperatures

<table>
<thead>
<tr>
<th>Temperature</th>
<th>1260°C</th>
<th>1270°C</th>
<th>1280°C</th>
<th>1300°C</th>
<th>1310°C</th>
<th>1330°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sijiaying concentrate</td>
<td>0.19</td>
<td>0.95</td>
<td>1.07</td>
<td>1.86</td>
<td>2.53</td>
<td>2.61</td>
</tr>
</tbody>
</table>

Figure 6-11 The process of liquid phase generating and flowing of Sijiaying concentrate

6.2.6 Brief summary

The fluidity of liquid phase of Black Iron concentrate and the other four iron concentrate (Karara concentrate, South African concentrate, Canadian concentrate, and Sijiaying concentrate) are summarized and compared in Table 6-12 and Figure 6-12.

Table 6-12 Fluidity of liquid phase at different temperatures

<table>
<thead>
<tr>
<th>Iron ore</th>
<th>Temperature</th>
<th>1260°C</th>
<th>1270°C</th>
<th>1280°C</th>
<th>1300°C</th>
<th>1310°C</th>
<th>1320°C</th>
<th>1330°C</th>
<th>1340°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>-</td>
<td>-</td>
<td>0.08</td>
<td>0.16</td>
<td>0.40</td>
<td>0.68</td>
<td>1.06</td>
<td>1.81</td>
<td></td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>0.08</td>
<td>0.23</td>
<td>1.44</td>
<td>2.35</td>
<td>2.61</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>South African concentrate</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>0.02</td>
<td>0.46</td>
<td>0.57</td>
<td>0.75</td>
<td>1.6</td>
<td>-</td>
<td>2.0</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>0.19</td>
<td>0.95</td>
<td>1.07</td>
<td>1.86</td>
<td>2.53</td>
<td>-</td>
<td>2.61</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>
For Karara concentrate, Canadian concentrate and Sijiaying concentrate, the liquid phase flow phenomenon was observed from 1260°C, and the fluidity of liquid phase increase with the increasing of temperature. The liquid phase fluidity of Karara concentrate and Sijiaying concentrate are similar, and a little higher than that of Canadian concentrate. While for South African concentrate, the liquid phase flow phenomenon was not yet observed when temperature increasing to 1330°C.

For Black Iron concentrate, the liquid phase flow phenomenon was observed from 1280°C, and the fluidity of liquid phase increases with the increasing of temperature. But generally, the liquid phase fluidity of Black Iron concentrate is slightly lower than that of Karara concentrate, Canadian concentrate and Sijiaying concentrate.

It can be seen that there is a good positive correlation between liquid phase fluidity and SiO$_2$ content of iron ore. This is because the higher the SiO$_2$ content in the iron ore, the more the amount of CaO is allocated, and the more slag is produced, which can improve the generating amount and the fluidity of liquid phase. While for South African concentrate, the SiO$_2$ content is very low, plus with high levels of MgO and TiO$_2$ which can form high melting point compounds, that is possibly the cause of low assimilation characteristic and low liquid phase fluidity.

If the proportion of ores that generate a high fluidity liquid phase (eg Yandi fines) is too high, the strength and yield of the sinter product could decrease. This could happen if the vertical speed of the flame front is too high and not...
allow enough time for the sinter to consolidate and generate adequate strength. Conversely, if the proportion of ores that generate a low fluidity liquid phase is too high, the vertical speed of the flame front could be too low and reduce productivity.

Therefore, a sinter ore blend needs to have a balance of iron ores that generate a liquid phase of high fluidity and ores that generate a liquid phase of low fluidity.

6.3 The strength of bonding phase

The strength of the products formed from the solidification of liquid phases and the strength of joined crystal stock are used to evaluate the strength of bonding phase. A high strength for both these two components is good for sintering.

The binding phase strength of Black Iron concentrate and the other four concentrates are summarized in Table 6-13 and Figure 6-13.

Table 6-13 Strength of bonding phase

<table>
<thead>
<tr>
<th>Iron ores</th>
<th>Liquid phase MPa</th>
<th>Joined crystal stock MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron concentrate</td>
<td>75.83</td>
<td>44.71</td>
</tr>
<tr>
<td>Karara concentrate</td>
<td>39.03</td>
<td>85.01</td>
</tr>
<tr>
<td>Canadian concentrate</td>
<td>78.55</td>
<td>77.24</td>
</tr>
<tr>
<td>South African concentrate</td>
<td>81.67</td>
<td>82.23</td>
</tr>
<tr>
<td>Sijiaying concentrate</td>
<td>52.56</td>
<td>84.51</td>
</tr>
</tbody>
</table>

Figure 6-13 Strength of bonding phase
The fundamental sintering characteristic of Black Iron concentrate and South African concentrate are in a high level and close. The joined crystal stock strength of Karara concentrate and Sijiaying concentrate are also in a high level, while the liquid phase strength of Karara concentrate and Sijiaying concentrate are much lower than that of Canadian concentrate and South African concentrate.

The liquid phase strength of Black Iron concentrate is in a high level, and similar with that of Canadian concentrate and South African concentrate, while the joined crystal stock strength is much lower than that of the other four iron concentrates.

There are several factors influencing the binding strength of iron ore. Firstly, the binding strength of liquid phase and their SiO₂ content show positive correlation. Similar with the influencing on the fluidity of liquid phase, higher SiO₂ content need more CaO reagent added, and more slag generated, which normally can improve the binding strength of liquid phase. Secondly, high Fe grade and high reactivity are beneficial to the formation of joined crystal stock and its strength.

6.4 SFCA forming capability

After calcining, polished sections of the tablets are studied under the petrological microscope to determine the rate and amounts of SFCA which generated in sintering process.

Each iron ore samples were blended with CaO reagent at three basicities e.g. 1.8, 2.0, 2.2 respectively and sintered at 1280°C. The mineral composition of the sintered samples are shown in Table 6-14 and Figure 6-14. The microstructure of the sintered samples are shown in Figure 6-15 to Figure 6-19.

For each sample, two different magnification photomicrographs were given below: Photomicrograph left was magnified 50 times for presenting the consolidation structure; Photomicrograph right was magnified 200 times for presenting the detail of calcium ferrite.

Micrograph note: White granular: Hematite; Light grey granular: Magnetite; Grey acicular or platelike: Calcium ferrate (SFCA); Dark gray: Glass and granular residual gangue; Black: pores and cracks; The gray strip in crack is resin used for bonding sample.

Table 6-14 SFCA amount generated in different basicity (Black Iron concentrate and the other four iron concentrates), %

<table>
<thead>
<tr>
<th>Samples</th>
<th>Hematite</th>
<th>Magnetite</th>
<th>SFCA</th>
<th>Silicate and others</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Iron con. R=1.8</td>
<td>55.0</td>
<td>-</td>
<td>0.8</td>
<td>14.2</td>
<td>30.0</td>
</tr>
<tr>
<td>Black Iron con. R=2.0</td>
<td>52.5</td>
<td>-</td>
<td>7.5</td>
<td>11.7</td>
<td>28.3</td>
</tr>
<tr>
<td>Concentrate</td>
<td>R = 1.8</td>
<td>R = 2.0</td>
<td>R = 2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black Iron con.</td>
<td>53.7</td>
<td>10.2</td>
<td>9.5</td>
<td>26.6</td>
<td></td>
</tr>
<tr>
<td>Karara con. R = 1.8</td>
<td>50.5</td>
<td>5.3</td>
<td>20.8</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>Karara con. R = 2.0</td>
<td>47.2</td>
<td>0.8</td>
<td>7.3</td>
<td>15.5</td>
<td>29.2</td>
</tr>
<tr>
<td>Karara con. R = 2.2</td>
<td>48.0</td>
<td>-</td>
<td>13.2</td>
<td>6.8</td>
<td>32.0</td>
</tr>
<tr>
<td>Canadian con. R = 1.8</td>
<td>51.5</td>
<td>-</td>
<td>1.0</td>
<td>19.2</td>
<td>28.3</td>
</tr>
<tr>
<td>Canadian con. R = 2.0</td>
<td>50.0</td>
<td>-</td>
<td>4.5</td>
<td>21.3</td>
<td>24.2</td>
</tr>
<tr>
<td>Canadian con. R = 2.2</td>
<td>56.3</td>
<td>-</td>
<td>6.5</td>
<td>18.8</td>
<td>18.4</td>
</tr>
<tr>
<td>South African con. R = 1.8</td>
<td>65.3</td>
<td>5.3</td>
<td>0.7</td>
<td>1.2</td>
<td>27.5</td>
</tr>
<tr>
<td>South African con. R = 2.0</td>
<td>62.7</td>
<td>7.2</td>
<td>3.5</td>
<td>1.6</td>
<td>25.0</td>
</tr>
<tr>
<td>South African con. R = 2.2</td>
<td>62.3</td>
<td>5.3</td>
<td>6.3</td>
<td>1.8</td>
<td>24.0</td>
</tr>
<tr>
<td>Sijiaying con. R = 1.8</td>
<td>52.8</td>
<td>-</td>
<td>3.0</td>
<td>17.5</td>
<td>26.7</td>
</tr>
<tr>
<td>Sijiaying con. R = 2.0</td>
<td>51.7</td>
<td>0.8</td>
<td>11.5</td>
<td>11.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Sijiaying con. R = 2.2</td>
<td>42.5</td>
<td>2.5</td>
<td>14.2</td>
<td>10.8</td>
<td>30.0</td>
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**Figure 6-14** SFCA amount generated in different basicity (Black Iron concentrate and the other four iron concentrates), %
Figure 6-15 The typical microstructure of SFCA in Black Iron concentrate sample
The fundamental sintering characteristic of Black Iron concentrate

Figure 6-16 The typical microstructure of SFCA in Karara concentrate sample
The fundamental sintering characteristic of Black Iron concentrate

Figure 6-17 The typical microstructure of SFCA in Canadian concentrate sample
The fundamental sintering characteristic of Black Iron concentrate

**Figure 6-18** The typical microstructure of SFCA in South African concentrate sample
Figure 6-19 The typical microstructure of SFCA in Sijiaying concentrate sample

Three samples in different basicity from Black Iron concentrate have similar mineral composition and microstructure, mainly composed of hematite, glass and dicalcium silicate. With the increasing of basicity from 1.8 to 2.2, the amount of calcium ferrite increase and the amount of glass and dicalcium silicate decrease gradually. The pores present as nearly round which distribute
evenly in the samples. The size of hematite is very small as the size of Black Iron concentrate.

Karara concentrate: With the increasing of basicity from 1.8 to 2.0, the amount of calcium ferrite are very low, but increase. The amount of calcium ferrite got an obvious increase at the basicity of 2.2. However, in general, the amount of calcium ferrite are still low and present in microcrystalline, distribute among dicalcium silicate microcrystalline and hematite. With the increasing of basicity, the amount of dicalcium silicate decrease and the porosity increase gradually. The pores present as nearly round with size about 100-200 micron, which distribute evenly in the samples.

Canadian concentrate: With the increasing of basicity, the amount of calcium ferrite increase, and got an obvious increase at the basicity of 2.0. However, in general, the amount of calcium ferrite are still low and present in microcrystalline, distribute among dicalcium silicate microcrystalline and hematite. With the increasing of basicity, the porosity decrease gradually. The pores present as nearly round with size about 100-200 micron, which distribute evenly in the samples.

South African concentrate: With the increasing of basicity, the amount of calcium ferrite increase gradually. However, in general, the amount of calcium ferrite are still low and present in schistose, distribute among dicalcium silicate and hematite. With the increasing of basicity, the hematite content and porosity decrease gradually. The pores present as irregular shape and distribute evenly in the samples. Residual gangue is common.

Sijiaying concentrate: The amount of calcium ferrite are very low at basicity of 1.8, with the increasing of basicity, the amount of calcium ferrite increase and got an obvious increase at the basicity of 2.0 and 2.2. The calcium ferrite present in columnar shape, distribute among dicalcium silicate and glass. With the increasing of basicity, the amount of hematite and glass decrease and the porosity increase at the basicity of 2.2. The pores present as nearly round with size about 100-200 micron, which distribute evenly in the samples.

The microstructure of the samples from South African concentrate is similar with the microstructure of acid pellet with hematite whisker connection. The microstructure of the samples from Canadian concentrate, Karara concentrate, Black Iron concentrate and Sijiaying concentrate are very close, mainly composed of hematite, glass and dicalcium silicate with nearly round pores distribute evenly in the samples. Comparing with Australian limonite fines ores, the amount of calcium ferrite formed is very low.

On the whole, the microstructure of the samples from these five iron concentrates are very different from that of the samples from Australian fines ores. In the samples from these five iron concentrates, the main binding minerals are glass, dicalcium silicate and hematite joined crystal stock with small amount of calcium ferrite. While in the samples from Australian fines ores, the main binding minerals are calcium ferrite, which braid in interlacement with the hematite and silicate minerals dispersed in it.
All these five iron concentrate have low SFCA forming capability, the amount of SFCA generated in sintering process all below 15%.

The amount of SFCA generated at the basicity of 2.0 of these five iron concentrate samples are in the sequence of South African concentrate < Canadian concentrate < Karara concentrate ~ Black Iron concentrate < Sijiaying concentrate.
7. CONCLUSION

7.1 Chemistry and size distribution

The Fe grade of these five concentrates are in the sequence of Black Iron concentrate > Karara concentrate > Sijiaying concentrate > Canadian concentrate > South African concentrate from high to low. Black Iron concentrate have the highest Fe grade at about 67.8%. Karara concentrate, Sijiaying concentrate and Canadian concentrate have similar Fe grade which are all in 65~66%, while the Fe grade of South African concentrate is the lowest at 63.4%.

Among these five concentrates, Black Iron concentrate have medium SiO$_2$ content at about 4.25%, and very low other impurities. The SiO$_2$ content of Karara concentrate is the highest at 7.97%, and quite high alkali metals, the Na$_2$O content and K$_2$O content are 0.272% and 0.327% respectively, while the other impurities content are very low. The SiO$_2$ content of Sijiaying concentrate is also high at 5.97%, but lower than that of Karara concentrate. Except a little high K$_2$O content, the other impurities content are also very low. Canadian concentrate have medium SiO$_2$ content at about 4.74%, which is slightly higher than that of Black Iron concentrate. South African concentrate has the lowest SiO$_2$ content, while the other impurities like CaO, SiO$_2$, MgO, MnO and TiO$_2$ are all higher than that of the other four iron concentrates.

Among these five iron concentrates, the particle size of Black Iron concentrate are the finest, and which are very suitable for using as pellet feed. Next is Karara concentrate and Sijiaying concentrate. While the particle size of Canadian concentrate and South African concentrates are quite coarse, can’t be used as pellet feed. The particle size of Canadian concentrate is the coarsest, +0.154mm >86%, and most particles are in lamellar shape.

7.2 The mineral composition and microstructure

The iron minerals of Black Iron concentrate mainly are magnetite and very little of Pyrrhotite. The gangue minerals are quartz and kirschsteinite. Most magnetite exist as individual particles, very few magnetite interlock with gangue. The crystal form of magnetite mainly are xenotopic-subhedral, and most of which are very fine equiaxed grains, around 30 micron. The size of gangue particles are obviously bigger than that of magnetite.

The iron minerals of Karara concentrate mainly are magnetite. The gangue mainly are pyroxene, quartz, mica and halloysite. Most particle of Karara concentrate are very fine equiaxed grains, smaller than 50 micron, the maximum particle size isn’t over 100 micron. The size of gangue particles generally are bigger than that of magnetite.

The iron minerals of South African concentrate mainly are magnetite. The gangue mainly are hedenbergite, quartz, feldspar, carbonate minerals and
The fundamental sintering characteristic of Black Iron concentrate. The particle of South African concentrate are quite coarse with clean-cut edges and angles, most size smaller than 200 micron, and the maximum particle size reach 400 micron.

The iron minerals of Canadian concentrate mainly are specularite, magnetite and a small amount of chromite, limonite sometimes also can be observed. The amount of specularite and magnetite are almost the same. The gangue mainly are dolomite and quartz. The particle of Canadian concentrate are quite coarse, most of which are about 200 micron, and the maximum particle size reach 500 micron.

The iron minerals of Sijiaying concentrate mainly are magnetite and hematite, in a ratio at 80:20. Pyrite and limonite sometimes also can be observed. Gangue mainly are quartz, chlorite and a small amount of amphibole and carbonate minerals. Most magnetite and hematite exist as individual particles. Interlocking particles of magnetite and hematite, or of magnetite, hematite and gangue minerals, or of magnetite and hematite, or of magnetite and gangue minerals, or of hematite and gangue minerals can be observed. The crystal form of magnetite and hematite mainly are euhedral-subhedral, and most of which are equiaxed grains, around 25-125 micron, and the maximum particle size reach 200 micron.

7.3 Moisture capacity

Among these five iron concentrates, Karara concentrate has the highest moisture capacity at 16.73%, the next is Canadian concentrate with moisture capacity of 15.69%. The moisture capacities of Sijiaying concentrate and South African concentrate are similar, at 14.81% and 14.08% respectively. While the moisture capacity of Black Iron concentrate is the lowest at 11.54%.

The water absorption speed of Canadian concentrate is the fastest, while Black Iron concentrate is the slowest. The water absorption speed of the other three concentrates are similar and in between the former two concentrates.

7.4 Fundamental sintering characteristics of iron ores

(1) Assimilation performance of iron ores

There is no assimilation reaction occurred in samples made from Black Iron concentrate, South African concentrate and Sijiaying concentrate when the calcination temperature increased from 1340°C to 1370°C. The assimilation reaction in samples made from Canadian concentrate and Karara concentrate both start from 1360°C. The assimilation reaction of Canadian concentrate improved rapidly and fully completed at 1370°C. The assimilation temperature of iron concentrate is much higher than that of fines ores. The assimilation temperature of some fines ore is low at about 1260°C, while the assimilation temperature of these five iron concentrate in this program are all over 1350°C.
(2) The fluidity of liquid phase

For Karara concentrate, Canadian concentrate and Sijiaying concentrate, the liquid phase flow phenomenon was observed from 1260°C, and the fluidity of liquid phase increase with the increasing of temperature. The liquid phase fluidity of Karara concentrate and Sijiaying concentrate are similar, and a little higher than that of Canadian concentrate. While for South African concentrate, the liquid phase flow phenomenon was not yet observed when temperature increasing to 1330°C. For Black Iron concentrate, the liquid phase flow phenomenon was observed from 1280°C, and the fluidity of liquid phase increases with the increasing of temperature. But generally, the liquid phase fluidity of Black Iron concentrate is slightly lower than that of Karara concentrate, Canadian concentrate and Sijiaying concentrate.

(3) The strength of bonding phase

Both liquid phase strength and joined crystal stock strength of Canadian concentrate and South African concentrate are in a high level and close. The joined crystal stock strength of Karara concentrate and Sijiaying concentrate are also in a high level, while the liquid phase strength are much lower than that of Canadian concentrate and South African concentrate. The liquid phase strength of Black Iron concentrate is in a high level, and similar with that of Canadian concentrate and South African concentrate, while the joined crystal stock strength is much lower than that of the other four iron concentrates.

(4) SFCA forming capability

The microstructure of the samples from these five iron concentrates are very different from that of the samples from Australian fines ores. In the samples from these five iron concentrates, the main binding minerals are glass, dicalcium silicate and hematite joined crystal stock with small amount of calcium ferrite. While in the samples from Australian fines ores, the main binding minerals are calcium ferrite, which braid in interlacement with the hematite and silicate minerals dispersed in it. All these five iron concentrate have low SFCA forming capability, the amount of SFCA generated in sintering process all below 15%. The amount of SFCA generated at the basicity of 2.0 of these five iron concentrate samples are in the sequence of South African concentrate < Canadian concentrate < Karara concentrate ~ Black Iron concentrate < Sijiaying concentrate.