Influencing Factors and Effects of Assimilation Characteristic of Iron Ores in Sintering Process

Shengli WU,* Guoliang ZHANG, Shaoguo CHEN and Bo SU

School of Metallurgical and Ecological Engineering, University of Science and Technology Beijing (USTB), Xueyuan Road 30, Haidian District, Beijing, 100083 China.

(Received on August 4, 2013; accepted on November 18, 2013)

Iron ore’s assimilation characteristic reflecting the beginning formation temperature of liquid phase in sintering process plays very important role on the fluidity of liquid phase and bonding strength of sinter body. Experimental study of assimilation characteristics of 12 kinds of iron ores were conducted using micro-sinter equipment, and pure reagent simulating tests of assimilation characteristic were also carried out for the purpose of achieving the influence of chemical composition on the assimilation characteristic. In addition, effects of assimilation characteristic of iron ore on the fluidity and bonding capacity of bonding phase were also researched. This study showed that SiO₂ and LOI promoted the assimilation of iron ore, low Al₂O₃ (<1.5 mass%) was good to the assimilation, but high Al₂O₃ (≥1.5 mass%) was bad, MgO was adverse to assimilation of magnetite concentrate. In addition, lower assimilation temperature of iron ore led to higher superheat degree of liquid phase at a certain sintering temperature, then higher liquid fluidity and bonding strength.

KEY WORDS: iron ore; sinter; assimilation characteristic; influencing factor; effect.

1. Introduction

Influence of sinter quality on the running-condition of BF grows with the development of high-grade burden and large-scale of blast furnace, and the improvement of sinter quality should be based on the study of properties of sintering raw materials, especially the characteristics of iron ores. In addition to the traditional room temperature characteristics of iron ores, high temperature characteristics of iron ores get the attention of researchers gradually. WU’s research indicated that 5 kinds of high temperature characteristics of iron ores could reflect the behavior and role of iron ores in the sintering process,1) and differences of assimilation characteristics between various iron ores and the ore blending optimization based on the high temperature characteristics such as assimilation characteristic has been also studied,2,3) but the influencing factors of the assimilation characteristic of iron ores were not studied clearly. In addition, Yang4) also studied the reaction between nuclei iron ores with the initial melt formed in the adhesive powder, and the assimilation was evaluated by the composition of the mineral composition, which was different from the assimilation temperature of iron ores in the present study. Kasai5,6) studied the influence of Al₂O₃ content, particle size of iron ores and limestone on the melt-formation phenomena by DTA and achieved some useful conclusions, but the results achieved by DTA reflected the solid phase reaction temperature rather than the liquid phase beginning-formation temperature.

Okazaki7) studied the influence of iron ore characteristics on the penetrating behavior of melt into ore layer, and achieved the influence factors on the further reaction between original liquid phase with the iron ores, which was different from the assimilation characteristic reflecting the beginning-formation temperature of original liquid phase in the adhesive powder. In generally, rare study on the influence of chemical composition on the assimilation temperature of iron ores, and further influence of assimilation temperature on the fluidity of liquid phase and bonding strength of sinter body was carried out.

Therefore, in the present research, firstly, assimilation characteristics of different kinds of iron ores were carried out. Secondly, simulating tests of influence of chemical composition on assimilation characteristic were conducted. Thirdly, fluidity of liquid phase and bonding strength of sinter body tests were also carried out aiming to achieve the further influence of assimilation characteristic on the fluidity and bonding capacity of liquid phase in sintering process. Finally, Influencing mechanism of assimilation characteristic on the strength of sinter body was exploited.

2. Experiment

2.1. Raw Materials

12 kinds of iron ores including 2 kinds of limonite iron ores, 2 kinds of mixed iron ores, 3 kinds of hematite iron ores and 5 kinds of magnetite concentrates were used in this research, in addition, Fe₂O₃, CaO, SiO₂, Al₂O₃ and NH₄HCO₃ pure reagent were also used. Ore-A and Ore-B were limonite iron ores from Australia, Ore-C and Ore-D

* Corresponding author; E-mail: wushengli@ustb.edu.cn
DOI: http://dx.doi.org/10.2355/isijinternational.54.582
were mixed iron ores from Australia, Ore-E was hematite iron ores from Australia, Ore-F was hematite iron ore from Brazil, Ore-G was hematite iron ore from South Africa, and M-A to M-E were Chinese magnetite concentrates which were produced in LiaoNing province, HeBei province, ShanXi province, ShanDong province and GuangDong province respectively. Table 1 shows the chemical composition of iron ores used in this study.

### 2.2. Assimilation Characteristic

To clarify the influence of chemical composition on the assimilation characteristic of iron ores, assimilation reaction tests were carried out using micro-sinter equipment. The evaluation index of assimilation characteristic of iron ore in the present study was Lowest Assimilation Temperature (LAT), LAT was the lowest assimilation reaction temperature between iron ore and CaO, and according to the different research purpose, the CaO could be CaO pure reagent, quick lime or limestone.

Figure 1 shows the schematic representation of the micro-sinter equipment, Fig. 2 shows the temperature system and atmosphere of the assimilation reaction test. Figure 3 shows the schematic diagram of the assimilation reaction. All iron ores with different particle size were grinded to –0.15 mm by using a sealed crusher. Materials were shaped into tablets with different diameters by using two steel moulds under a pressure of 15 MPa. The weight of CaO tablet and iron ore (or pure reagent mixture) tablets were 2.0 g and 0.8 g respectively. Then put the iron ore tablet on the CaO tablet, and the two tablets were sintered in the micro-sinter equipment later.

LAT was entrenched by the bonding-beginning temperature between iron ore tablet and CaO tablet in the assimilation test. In the test process, through a series of heating and cooling tests, achieved the temperature range of assimilation reaction between iron ore tablet and CaO tablet firstly by the observation of bonding state between iron ore tablet and CaO tablet at different experiment temperature, then tests were continued by the heating and cooling temperature gradient of 3°C, and achieved the bonding-beginning temperature between iron ore tablet and CaO tablet, so the error of the LAT was ±1.5°C.

### 2.3. Fluidity Characteristic

To clarify the influence of assimilation temperature of iron ore on the fluidity of liquid phase in the sintering process, fluidity characteristic tests were carried out by the fluidity of liquid phase test method.2) 12 kinds of iron ores and CaO pure reagent were used. Sinter was composed by a part of melt such as calcium ferrite formed at the high temperature and a part of un-melted iron ore particles, especially the big size iron ores particles, usually, all the fluxes reacted with the iron ores, so the segregated binary basicity of the melt formed by the molten adhesive powder must be higher than the entire binary basicity of the sinter. Generally speaking, the adhesive powder accounted for about 40–50 wt% of the whole sinter materials, and the entire binary basicity of the sinter was always about 1.8–2.0, on the case of that the SiO2 content of the sinter materials was 4.0–5.0 wt%, the segregated binary basicity of the adhesive powder could be calculated, and the value was about 3.5–5.0, so the binary basicity of the fine mixture mixed by iron ore and CaO pure

### Table 1. Chemical composition of iron ores/mass%.

<table>
<thead>
<tr>
<th></th>
<th>T. Fe</th>
<th>FeO</th>
<th>SiO₂</th>
<th>CaO</th>
<th>Al₂O₃</th>
<th>MgO</th>
<th>LOI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore-A</td>
<td>58.07</td>
<td>0.18</td>
<td>5.30</td>
<td>0.03</td>
<td>1.55</td>
<td>0.05</td>
<td>9.82</td>
</tr>
<tr>
<td>Ore-B</td>
<td>58.64</td>
<td>0.19</td>
<td>4.65</td>
<td>0.04</td>
<td>1.63</td>
<td>0.05</td>
<td>9.89</td>
</tr>
<tr>
<td>Ore-C</td>
<td>61.40</td>
<td>0.28</td>
<td>3.69</td>
<td>0.06</td>
<td>2.31</td>
<td>0.06</td>
<td>5.68</td>
</tr>
<tr>
<td>Ore-D</td>
<td>60.84</td>
<td>0.29</td>
<td>3.96</td>
<td>0.03</td>
<td>2.26</td>
<td>0.05</td>
<td>6.38</td>
</tr>
<tr>
<td>Ore-E</td>
<td>62.44</td>
<td>0.26</td>
<td>4.43</td>
<td>0.03</td>
<td>2.37</td>
<td>0.05</td>
<td>3.52</td>
</tr>
<tr>
<td>Ore-F</td>
<td>65.26</td>
<td>0.15</td>
<td>1.92</td>
<td>0.03</td>
<td>1.27</td>
<td>0.03</td>
<td>2.16</td>
</tr>
<tr>
<td>Ore-G</td>
<td>65.10</td>
<td>0.21</td>
<td>5.36</td>
<td>0.14</td>
<td>1.80</td>
<td>0.03</td>
<td>0.61</td>
</tr>
<tr>
<td>M-A</td>
<td>65.55</td>
<td>25.15</td>
<td>7.39</td>
<td>0.23</td>
<td>0.20</td>
<td>0.19</td>
<td>–2.42</td>
</tr>
<tr>
<td>M-B</td>
<td>61.14</td>
<td>21.13</td>
<td>13.26</td>
<td>0.52</td>
<td>0.95</td>
<td>0.56</td>
<td>–1.09</td>
</tr>
<tr>
<td>M-C</td>
<td>65.48</td>
<td>28.73</td>
<td>6.83</td>
<td>0.36</td>
<td>0.34</td>
<td>0.17</td>
<td>–2.68</td>
</tr>
<tr>
<td>M-D</td>
<td>64.40</td>
<td>25.92</td>
<td>4.16</td>
<td>1.69</td>
<td>0.85</td>
<td>1.75</td>
<td>–1.78</td>
</tr>
<tr>
<td>M-E</td>
<td>61.55</td>
<td>25.16</td>
<td>3.98</td>
<td>0.40</td>
<td>0.27</td>
<td>3.95</td>
<td>1.15</td>
</tr>
</tbody>
</table>
was calculated. Phase before and after sinter tests. As shown in Eq. (1), IFL (IFL) was achieved by comparing the area of the liquid phase of iron ore on the bonding strength of sinter body clearly, the reagent. To achieve the influence of assimilation temperature of these tests were made in a disc pelletizer. About 200 quasi-particles made in a disc pelletizer were consisted of each kind of iron ore and pure reagent in the present study was set to 4.0. Fine mixture about 0.8 g was shaped into tablet by using steel mould under a pressure of 15 MPa. The equipment, temperature and atmosphere of fluidity characteristic tests were almost the same to the assimilation reaction tests, except that the experiment temperature of fluidity tests was 1 280°C, and the air atmosphere was changed to N2 after 600°C, and the gas flow rate was 3 L/min. Figure 4 shows the schematic diagram of fluidity of liquid phase. Index of Fluidity of Liquid phase (IFL) was achieved by comparing the area of the liquid phase before and after sinter tests. As shown in Eq. (1), IFL was calculated.

\[
IFL = \frac{(FA - OA)}{OA} \quad \text{................. (1)}
\]

In which, IFL is Index of Fluidity of Liquid phase, FA is Flowing Area after sinter test, mm², and OA is Original Area before sinter test, mm².

2.4. Bonding Strength Characteristic

To clarify the influence of assimilation temperature of iron ore on the strength of sinter, bonding strength tests were carried out. 7 kinds of iron ores were used, and Fe₂O₃, SiO₂, Al₂O₃ and CaO pure reagent were also used. Figure 5 shows the schematic diagram of sinter body in bonding strength tests. About 200 quasi-particles made in a disc pelletizer were put into a quartz crucible. The nuclei-particles used in these tests were Ore-F from Brazil, and the adhesive powders were consisted of each kind of iron ore and pure reagent. To achieve the influence of assimilation temperature of iron ore on the bonding strength of sinter body clearly, the chemical composition of quasi-particles were maintained constant, i.e. Fe₂O₃ = 60.8 mass%, SiO₂ = 3.5 mass%, CaO = 7.1 mass%, Al₂O₃ = 1.6 mass%, basicity was 2.0, by adjusting the proportion of pure reagent. The equipment, temperature and atmosphere of bonding strength tests were same to the fluidity tests. After sinter, measured the weight (original weight) of the sinter body, and then free fell the sinter body from 2 m high, and screened the pieces with 5 mm perforated screen, first shatter index was achieved by calculating the ratio of the weight of pieces above 5 mm and the original weight of the sinter body. Then sequentially free fell the above 5 mm pieces from 2 m high and screened, second shatter index was achieved by calculating the ratio of the weight of pieces above 5 mm and the original weight of the sinter body. The third to ten shatter indexes were achieved similarly. Moreover, observation of the sinter body using scanning electron microscope was performed.

3. Results

Figure 6 shows the results of assimilation reaction tests of different kinds of iron ores. Among 7 kinds of hematite and limonite iron ores, Australian limonite iron ores (Ore-A and Ore-B) had lowest LATs, then Australian mixed fines (Ore-C and Ore-D), Australian hematite iron ore (Ore-E), South African hematite iron ore (Ore-G) and Brazilian hematite iron ore (Ore-F). On contrast, among 5 kinds of magnetite concentrates, M-E from Guangdong province had highest LAT, then M-C and M-D, M-A and M-B had lower LATs. The LATs of magnetite concentrates were higher than that of hematite and limonite iron ores. According to the research of Clout8 that compared to the hematite used in the sintering process as iron-bearing material, more magnetite and glass phase and less complex calcium ferrite such as SFCA were formed in the sinter when magnetite was used as iron-bearing material. So it could be speculated that compare to hematite, less molten point materials were formed when magnetite was used as iron-bearing material in the sintering process, and that might be the reason why LATs of magnetite concentrates were usually higher than that of hematite iron ores.

Assimilation temperature also influenced the fluidity of liquid phase of iron ores, which was due to the high degree of superheat of liquid phase using low assimilation temperature iron ores as ferrous materials. Figure 7 shows the results of fluidity of liquid phase tests. On the whole, magnetite concentrates had higher IFLs than limonite and hematite iron ores, which was due to the higher SiO₂ content of magnetite concentrates. Meanwhile, among 5 kinds of magnetite concentrates, M-B and M-A had higher IFLs, then M-C and M-D, and M-E had lowest IFL. In addition, among 7 kinds of limonite and hematite iron ores, Limonite Ore-A, Ore-B and hematite Ore-G had higher IFLs, then Ore-E and Ore-D, Ore-C and Ore-F had lowest IFLs.

Assimilation of iron ores influenced the fluidity of liquid phase, which could also influence the bonding strength of sinter body further, and the results of bonding strength tests were shown as Figs. 8 and 9. Each sinter body was com-

© 2014 ISIJ

584
posed of a lot of sinter body units which was quasi-particles before sinter. For the sinter body using limonite Ore-A, Ore-B and hematite Ore-G as adhesive powder, sinter body unites were bonded together well under the cohesive effect of bonding phase, more bonding phase was also observed between the sinter body units, and the sinter bodies also had higher bonding strength. On contrast, sinter body using Ore-C as adhesive powder had lowest bonding strength. Bonding strength of sinter bodies using Ore-D, Ore-E and Ore-F as adhesive powder were in the middle level.

4. Discussion

4.1. Influence of Chemical Composition on Assimilation Temperature of Iron Ores

To clarify the influence of SiO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3} and LOI on the assimilation characteristic of iron ore, Fe\textsubscript{2}O\textsubscript{3}, SiO\textsubscript{2}, Al\textsubscript{2}O\textsubscript{3} and NH\textsubscript{4}HCO\textsubscript{3} (simulating the LOI, and the thermal decomposition temperature of NH\textsubscript{4}HCO\textsubscript{3} is below 100°C, and the thermal decomposition temperature of crystal water of iron ore is about 300°C) pure reagents were mixed according to certain proportion which was shown in Table 2.

Figure 10 shows the results of pure reagent simulating tests of assimilation characteristic. With the increase of SiO\textsubscript{2} in the Fe\textsubscript{2}O\textsubscript{3}–SiO\textsubscript{2} mixture, LATs decreased linearly. On contrast, with the increase of Al\textsubscript{2}O\textsubscript{3} in the Fe\textsubscript{2}O\textsubscript{3}–Al\textsubscript{2}O\textsubscript{3} mixture, LATs decreased at the Al\textsubscript{2}O\textsubscript{3} content of 2 mass%, but increased rapidly later.

In general, assimilation temperature was influenced by the mineral composition and micro-structure of the samples, and the former influenced the assimilation temperature through their melting point, the latter influenced the assimilation temperature through changes of the dynamic condition. In the present study, all the samples were mixed by pure reagents, and the differences of the dynamic condition between various samples were negligible. So in the pure reagent simulating tests of assimilation characteristic, thermodynamic factors were mainly considered. According to the thermodynamics,\textsuperscript{9,10} the melting point of CF (Fe\textsubscript{2}O\textsubscript{3}·CaO) was 1 216°C. With increase of SiO\textsubscript{2}, eutectic mixture CaO·SiO\textsubscript{2}–CaO·Fe\textsubscript{2}O\textsubscript{3} with melting point of 1 192°C, and 2FeO·SiO\textsubscript{2}–Fe\textsubscript{2}O\textsubscript{3} with melting point of 1 142°C were also could be formed, all of

Table 2. Mix condition of pure reagent mixture used in assimilation tests/mass%.

<table>
<thead>
<tr>
<th>Base</th>
<th>Sch 1</th>
<th>Sch 2</th>
<th>Sch 3</th>
<th>Sch 4</th>
<th>Sch 5</th>
<th>Sch 6</th>
<th>Sch 7</th>
<th>Sch 8</th>
<th>Sch 9</th>
<th>Sch 10</th>
<th>Sch 11</th>
<th>Sch 12</th>
<th>Sch 13</th>
<th>Sch 14</th>
<th>Sch 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe\textsubscript{2}O\textsubscript{3}</td>
<td>100</td>
<td>98</td>
<td>96</td>
<td>94</td>
<td>92</td>
<td>90</td>
<td>96</td>
<td>94</td>
<td>92</td>
<td>90</td>
<td>98</td>
<td>96</td>
<td>94</td>
<td>92</td>
<td>90</td>
</tr>
<tr>
<td>SiO\textsubscript{2}</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>8</td>
<td>10</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Al\textsubscript{2}O\textsubscript{3}</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>LOI (NH\textsubscript{4}HCO\textsubscript{3})</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
which lowered the assimilation temperature of Fe$_2$O$_3$–SiO$_2$ mixture. So SiO$_2$ contributed to reduce the assimilation temperature of Fe$_2$O$_3$.

Meanwhile, according to the previous research,\textsuperscript{11,12} with increase of Al$_2$O$_3$ in the Fe$_2$O$_3$–Al$_2$O$_3$ mixture, on one hand, the Al$_2$O$_3$ will block the diffusion of Fe$_2$O$_3$ and CaO, which decreasing the formation speed of calcium ferrite. On the other hand, the affinity between CaO and Al$_2$O$_3$ is higher than that between CaO and Fe$_2$O$_3$ because the lower $\Delta G^\theta$ of CaO·2Al$_2$O$_3$,\textsuperscript{13} which decreasing the formation rate of calcium ferrite. So Al$_2$O$_3$ went against the assimilation reaction between CaO and Fe$_2$O$_3$.

It was needed to be pointed out that the lowest assimilation temperature of Fe$_2$O$_3$–Al$_2$O$_3$ mixture with Al$_2$O$_3$ content of 2 mass% was lower than that of Fe$_2$O$_3$ and other Fe$_2$O$_3$–Al$_2$O$_3$ mixtures with higher Al$_2$O$_3$ content, the reason might be the formation of some ternary calcium ferrite which was also needed to be studied further.

In addition, with increase of LOI (simulated by NH$_4$HCO$_3$ in this study), the dynamic condition would be improved with the volatilization of combined water or carbonate in the sintering process, which could promote the assimilation reaction between Fe$_2$O$_3$ and CaO forming CF, and finally decreased the lowest assimilation temperature. According to the research results of Bergman and Sandwijk,\textsuperscript{14,15} in the reaction process between Fe$_2$O$_3$ and CaO, a little CF will be formed at the contact interface of Fe$_2$O$_3$ and CaO above 600$^\circ$C, then CF will react with Fe$_2$O$_3$ further and formed CF$_2$, and then Ca$^{2+}$ diffuses through CF into CF$_2$ and reacts with CF$_2$ forming more CF. So it could be speculated that LOI in the Fe$_2$O$_3$ not only improves the dynamic condition of the reaction between Fe$_2$O$_3$ and CaO, but also increases the contact interface between Fe$_2$O$_3$ and CF, which leading to more formation of CF finally. Certainly, the CaO will also reacts with CF forming C$_2$F, but it is not related to the LOI of Fe$_2$O$_3$, so it is not discussed in this study.

\textbf{Figure 11} shows the influencing schematic diagram of LOI on assimilation reaction. With the increase of sintering temperature, thermal decomposition of crystal water is happened which leaving a lot of pores in the Fe$_2$O$_3$. Then CaO diffuses into the pores at the contact interface between Fe$_2$O$_3$ and CaO, which increasing the contact area of Fe$_2$O$_3$ and CaO and improving the dynamic condition of the reaction between Fe$_2$O$_3$ and CaO, and more CF is formed. At the same time, the CF reacts with Fe$_2$O$_3$ further and CF$_2$ is formed.

But in the actual sintering process, high LOI of iron ore could also lead to high ignition loss rate of sinter and then low productivity, so the effect of LOI in the actual sinter process should be evaluated synthetically.

Influence of MgO on the assimilation temperature of Fe$_2$O$_3$ was not carried out in the pure reagent simulating tests because the low content of MgO in the limonite and hematite iron ore, and influence of MgO on the assimilation temperature of magnetite concentrates was analyzed later.

\textbf{Figure 12} shows the analysis results of correlativity of SiO$_2$ with LATs of iron ores. With increase of SiO$_2$, LATs of hematite and limonite or magnetite all decreased, which was similar to the results of pure reagent simulating tests. The not very good correlativity of LATs with SiO$_2$ of magnetite was maybe due to the large differences of MgO content in the magnetite concentrates, which would be discussed later.

\textbf{Figure 13} shows the analysis results of correlativity of Al$_2$O$_3$ with LATs of iron ores. LATs decreased with the increase of Al$_2$O$_3$ when the Al$_2$O$_3$ content below 1.5 mass%, on contrast, LATs increased with the increase of Al$_2$O$_3$ when the Al$_2$O$_3$ content above 1.5 mass%. Maybe it was because SFCA with lower melting point could be formed with the coexistence of SiO$_2$, Al$_2$O$_3$, CaO and Fe$_2$O$_3$ in the case of low Al$_2$O$_3$ content in iron ores, so the LATs decreased with the increase of Al$_2$O$_3$ below 1.5 mass%, but with the further increase of Al$_2$O$_3$ over 1.5 mass%, the iron ore’s LATs increased as a result of influence of superfluous high melting point Al$_2$O$_3$ in the SFCA which was discussed in the pure reagent simulating tests.

\textbf{Figure 14} shows the analysis results of correlativity of LOI with LATs of 7 kinds of limonite and hematite iron ores. Similar to the results of pure reagent simulating tests,
LATs of limonite and hematite iron ores decreased with the increase of LOI by the reason of improvement of dynamic condition of assimilation reaction. The relationship between LATs with LOI of magnetite concentrates was not analyzed in this study by the reason of the loss of ignition of magnetite concentrates was influenced by the de-carbonation and oxidation of Fe3O4 collectively, which was needed to be studied further.

Figure 15 shows the analysis results of correlativity of MgO with LATs of magnetite concentrates. And to some extent, LATs increased with the increase of MgO content in magnetite concentrates. With the increase of MgO in the magnetite concentrates, magnesium wustite and magnesioferrite with melting point above 1700°C could be formed, which increased the beginning formation temperature of liquid phase. It was needed to be pointed out that the correlativity of MgO with LATs of magnetite concentrates was not very good, which was maybe because the comprehensive influence of SiO2, Al2O3 and MgO on the LATs of magnetite concentrates.

4.2. Influence of Assimilation Characteristic on the Strength of Sinter Body

Figure 16 shows the analysis results of correlativity of assimilation temperature with fluidity of liquid phase of iron ores. IFLs increased with the decrease of LATs. Low LAT meant low liquid phase formation temperature, which led to high degree of superheat in certain sintering temperature, then high fluidity of liquid phase, and these results were similar to the research results of Machida.16)

Figure 17 shows the correlativity of fluidity of liquid phase with bonding strength of sinter body. Bonding phase which had high fluidity of liquid phase could bond the unmelted nuclei ores together better, which led to high bonding strength of sinter body. Certainly, in the sintering process, high fluidity of liquid phase maybe also led to low permeability of sinter bed, then low productivity, so suitable fluidity of liquid phase should be achieved in the actual sintering process. In the actual sintering process, suitable assimilation temperature of iron ores which could lead to suitable fluidity of liquid phase, and high bonding strength and suitable permeability of sinter bed was also needed to be achieved.

Figure 18 shows the microstructure of sinter body of some typical iron ores. Each sinter body was composed of pores and sinter body units which was quasi-particles before sinter. Little large-pores were existed in sinter body-Ore-A and sinter body-Ore-G which also had lower LATs, higher fluidity and bonding strength. Moreover, compared to sinter body-Ore-G, a lot of small pores were existed in sinter body-Ore-A, which might be caused by the high LOI of Ore-A. On contrast, a large amount of large-pores were existed in sinter body-Ore-C and sinter body-Ore-E, especially in sinter body-Ore-C which had higher LAT, lowest fluidity of liquid and bonding strength. So it could be speculated that, in general, melt with higher fluidity was caused largely by the lower LAT of iron ores, which led to higher bonding strength finally.

Figure 19 shows the influencing schematic diagram of assimilation temperature on the strength of sinter body. In sintering process, melt was formed at a temperature by the reaction between iron ore fines and fluxes in the adhesive powders, then melt parcelled outside the nuclei particles.
flowed at a higher temperature and filled the pores between quasi-particles, finally, quasi-particles were boned together by the melt and the sinter was formed. For the high-LAT ores used as adhesive powder, melt formed at high temperature had small superheat degree and low fluidity, and could not filled the pores between quasi-particles sufficiently, and the macro-porous sinter which had low bonding strength was formed finally. On contrast, for the low-LAT iron ores used as adhesive powder, melt formed at low temperature had large superheat degree and high fluidity, and could filled the pores between quasi-particles sufficiently, and the micro-porous sinter which had high bonding strength was formed finally.

Certainly, sinter using low-LAT iron ores has high fluidity and bonding strength, but it does not mean the low-LAT iron ores are better than the high-LAT ores because the sinter bed permeability which related the productivity of sinter is also a very important index of sinter, and obviously, the low-LAT and high-IFL iron ore maybe leads to low permeability of sinter bed.

5. Conclusions

In order to understand the influence of chemical composition of iron ores on the beginning formation temperature of liquid phase, and the further effect of beginning formation temperature of liquid phase on the fluidity and bonding capacity of bonding phase, lowest assimilation reaction tests, fluidity of liquid phase tests, bonding strength of sinter body tests were conducted, in addition, relationship between chemical composition with lowest assimilation temperature of iron ores, relationship between lowest assimilation temperature of iron ores with fluidity of liquid phase, relationship between fluidity of liquid phase with bonding strength of sinter body were all analyzed. The following conclusions were obtained.

(1) Limonite iron ores had lower LATS by the reason of higher SiO2 and LOI contents. On contrast, Magnetite concentrates had higher LATS by because of the higher MgO content and the Fe-existing state of Fe3O4.

(2) SiO2 and low Al2O3 content (<1.5 mass%) promoted the assimilation reaction between iron ores with CaO owing to the formation of low melting point eutectic mixture and SFCA, but high Al2O3 content (>1.5 mass%) was bad to assimilation reaction.

(3) LOI was conducive to assimilation reaction between iron ores and CaO by reason of higher contact area and better dynamic condition of assimilation reaction.

(4) Lower assimilation temperature of iron ore could lead to higher superheat degree of the liquid phase at certain sintering temperature, which led to higher fluidity and bonding capacity of bonding phase further, and then the higher bonding strength of sinter body.

Acknowledgement

The financial support of the Fundamental Research Funds for the Central Universities (FRF-MP-12-003B) is gratefully acknowledged.

REFERENCES