Effect of Flame Front Speed on Sinter Structure of High Alumina Iron Ores

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1. Introduction

The chemistry of iron ore and the variation in process parameters decide sinter structure. Indian iron ores are characterized by its high alumina content (~2.4 wt%), whereas the same used in other countries contains less than 1.0% alumina. This makes the sintering operation under Indian condition quite different from that being practiced all over the world. Several studies1–3) have been conducted on tablet samples using analytical materials to study the microstructure of sinter. All these are related to either low alumina levels or lower thermal levels. Ishikawa1) made studies with materials having Al2O3/SiO2 as 0.2–0.8. Pimenta and Sheshadri3) studied the structure of pot sinter having alumina 1.2–1.7 wt% and MgO 1.2–1.3 wt%, whereas Indian iron ores have Al2O3/SiO2 ~2.0 and the sinter has MgO ~2.0 wt%. Not much work has been done with this type of materials and this kind of sinter.

The movement of flame front along the bed height is one of the key process parameters which affects formation and stabilization of phases in sinter as well as sintering time and productivity.

The aim of this work has been to study the sinter structure with high alumina ores under different flame front speed (FFS).

2. Experimental

2.1. Pot Sintering Experiments

The Noamundi iron ore 64 wt% (Al2O3, 2.4 wt%; SiO2, 1.3 wt%), Lime stone 11.5 wt% (CaO, 51 wt%), Pyroxenite 2.9 wt% (MgO, 55.3 wt%; SiO2, 32.7 wt%), Return fines 17 wt% and Coke breeze 5.5 wt% (ash, 19 wt%) were used in the tests. The Sinters were made in pot of 400×400 mm2 cross section and were having Al2O3 (2.2–2.3%), MgO (1.4–1.6%), CaO (9.2–9.6%), SiO2 (4.6–4.9%) and FeO (11.6–13.8%). The raw mix was dried at 105°C for 4h to drive out the moisture to maintain constant moisture in the green mix. Bed temperatures were measured at three locations to measure the movement of maximum temperature regime.

The flame front speed was varied by varying the bed height (400 mm, 500 mm and 600 mm) and the under grate suction applied (10.8 kPa, 11.8 kPa and 12.8 kPa).

3. Results and Discussion

3.1. Measurement of Flame Front Speed (FFS)

Table 1 shows the values of FFS. F1, F2 and F3 are Flame front speed calculated by dividing the distance from the top of the bed by time taken to reach the peak temperature. The average value gives FFS across the sinter bed. F4 is the Flame front speed calculated by dividing the bed height by sintering time. The time taken to reach burn through point has been taken as sintering time. It can be seen that there is not much of a difference between the two. All analysis in this work has been done from FFS calculated by the second methodology. Samples corresponding to local FFS could not be collected. It is noticed that FFS is increased as it moves down the bed. This is because of pre-heating of the incoming (sucked) air by the upper hot sinter bed and increased permeability of the bed as the sintering process moves downwards. This accelerates burning of coke breeze and hence maximum temperature is achieved at a shorter time (i.e. faster FFS).

3.2. Sinter Structure at Different FFS

Typical microstructure at different FFS are shown in Fig. 1. The final stage of structure modification i.e. solidification of ferrite and silicate is influenced by the cooling rate during solidification. At higher flame front speed (faster cooling rate) the ferrite and silicate solidify in layers as dendritic arms (FFS, 3.0 cm/min). In case of lower flame front speed, the separation of silicate and ferrite is more distinct as they get more time to form (FFS, 2.3 cm/min).

3.3. Iron Oxide Phases

3.3.1. Effect of FFS

In Fig. 2 is shown the effect of FFS on hematite, mag-
netite and wustite phase percentage in sinter. The hematite phase increases while magnetite and wustite decreases with increasing FFS. In the heating regime, higher oxides are reduced to lower oxides and during subsequent cooling, oxidation of lower oxides takes place. The degree of reduction of iron oxides is primarily governed by the amount of coke. Where as, the oxidation kinetics is primarily controlled by the rate of oxygen input to the reaction surface. Higher FFS is due to higher suction and it implies higher air flow rate through the sinter bed. This improves the extent of oxidation of iron oxide phases. This has led to increase in hematite content and decrease in lower iron oxides in sinter.

3.3.2. Composition of Iron Oxide

The average composition of oxides of iron in our sinter is shown Table 2. Hematite is present as primary and secondary. In the present study these two were not distinguished. Nevertheless, from the chemistry of iron oxide phases it can be seen that hematite contains Ca and Mg, much higher than the original material. This indicates that hematite is of secondary type. Also, the Al/Si ratio in iron oxides varies widely and is completely different from the original raw materials. In the recent studies carried out by Nicola, it has been reported that during heating of Iron oxide and calcium oxide with high alumina, SFCA is formed and almost all of calcium ferrite is consumed at 1200°C. Therefore, at the end of heating regime, the melt is primarily SFCA. Thus it can be inferred that the hematite has formed from dissociation of SFCA during cooling/oxidation regime. Present studies has shown that amount of hematite and its chemistry is dependent on FFS. Increasing FFS leads to increase in hematite content of sinter.

Table 2. Composition of phases in sinter.

<table>
<thead>
<tr>
<th>Phases present in sinter</th>
<th>FFS (cm/min)</th>
<th>Fe (%)</th>
<th>Ca (%)</th>
<th>P (%)</th>
<th>Si (%)</th>
<th>Al (%)</th>
<th>Mg (%)</th>
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<tbody>
<tr>
<td>Hematite</td>
<td>2.3</td>
<td>67.4</td>
<td>0.85</td>
<td>0.16</td>
<td>0.98</td>
<td>6.40</td>
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<td>2.6</td>
<td>72.6</td>
<td>1.24</td>
<td>0.08</td>
<td>0.29</td>
<td>0.81</td>
<td>1.3</td>
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<tr>
<td></td>
<td>2.9</td>
<td>72.5</td>
<td>2.63</td>
<td>0.09</td>
<td>0.85</td>
<td>1.10</td>
<td>1.08</td>
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<tr>
<td>Magnetite</td>
<td>2.3</td>
<td>72.0</td>
<td>0.67</td>
<td>0.16</td>
<td>0.24</td>
<td>2.46</td>
<td>0.24</td>
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<tr>
<td></td>
<td>2.6</td>
<td>72.6</td>
<td>1.24</td>
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<td>0.09</td>
<td>0.85</td>
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<tr>
<td>Wustite</td>
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<td>76.0</td>
<td>0.86</td>
<td>0.05</td>
<td>0.30</td>
<td>0.62</td>
<td>0.46</td>
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<td>2.6</td>
<td>73.9</td>
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<td>0.08</td>
<td>0.29</td>
<td>0.64</td>
<td>1.2</td>
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<td></td>
<td>2.9</td>
<td>75.2</td>
<td>0.96</td>
<td>0.05</td>
<td>0.26</td>
<td>0.94</td>
<td>1.64</td>
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<td>Silicate</td>
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<td>19.2</td>
<td>21.60</td>
<td>1.80</td>
<td>19.5</td>
<td>4.27</td>
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<td>SFCA</td>
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<td>11.8</td>
<td>0.33</td>
<td>7.20</td>
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<td></td>
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<td>49.1</td>
<td>14.1</td>
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3.4. SFCA Phase in Sinter

The variation of SFCA with FFS is shown in Fig. 2. No clear trend could be seen.

The average composition of SFCA as observed in sinter is shown in Table 2.

Under Indian sintering conditions of our study, the possible mechanism of SFCA formation can be explained as follows. Formation of initial calcium ferrite undergoes significant changes by diffusion of Al and Si species. Thus SFCA is formed towards the end of heating/reduction regime itself. With our iron ore having high Al₂O₃ and SiO₂, there is little chance that ferrite is present as calcium ferrite. At a sintering temperature as high as ours (>1300°C), increased mobility of Al and Si into ferrite melt is a more likely proposition. Based on above considerations, we propose a flow chart (Fig. 3), a schematic representation of formation of phases in high alumina sinter, which is a modified form of that suggested by Matsuno.
the flow chart presented by Matsuno, the formation SFCA has not been shown. The present figure (Fig. 3) shows the formation of SFCA from calcium ferrite and gangue, which on cooling decomposes to give secondary hematite.

3.5. Silicate Phase in Sinter

The variation of silicate with FFS is shown in Fig. 1. The silicate phase increases with increase in FFS. The average composition of silicate at different FFS is given in Table 2. It can be seen that increased diffusion of Ca is taking place in silicate melt substituting Fe. This is more pronounced at higher FFS.

4. Conclusion

- A trend can be seen in the phases present in sinter at different FFS. The hematite content increases at higher FFS. This is an evidence of faster oxidation of the melt.
- The hematite phase in sinter contains much higher Ca and Mg than the original materials. This indicates that this hematite has formed by dissociation of SFCA and is of secondary type. Evidence were found of higher diffusion of Al and Si into hematite.
- The composition of SFCA were affected by FFS. At higher FFS, SFCA was having higher Fe and lower Si and at lower FFS, it contained lower Fe and higher Si.
- Based on our results, a modified flow chart of formation of phases in high alumina sinter is proposed.

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REFERENCES