Determining the Interactions Between Raw Sinter Blend and Sinter Product

Abstract

Sintering process is indispensable for steelmaking companies due to the main reasons which are recycling steel making wastes and producing partially-reduced iron containing material for blast furnace.

During sintering process a series of chemical reactions are taking place at high temperatures and iron ores and fluxes are combined together to form a sinter cake composed of iron oxides, silico-ferrites of calcium and aluminum (SFCA), dicalcium silicate and a glassy phase. In this study a number of chemical and mineralogical analyses have been done in order to review relationships between chemistry, structure and quality of sinter.

1. Introduction

In ironmaking industry most commonly used economical agglomeration process to prepare iron ore fines for blast furnace utilization is sintering. In today’s steelmaking technology iron ore sinter typically constitutes more than 65% of the blast furnace ferrous feed. According to managing extreme operating conditions, maintaining the productivity and energy efficiency of blast furnaces, high quality sinter and efficient production is known as fundamental requirement [1].

Erdemir Iron and Steel Group Corporation have 3 sintering machines and 6 blast furnaces in Erdemir Group, which have produced 8 million tons of hot metal and 6.1 million tons of sinter in 2015. Due to the several reasons which effect operating conditions, productivity and energy efficiency of blast furnace it is quite essential to produce high quality sinter.

Sintering reactions transform raw materials into a porous, partially reduced but physically strong cake which is generally composed of four main phases (mass percent) : iron oxides (40 % - 70 %) , ferrites (20% - 50 %) , glasses (up to 10 %) , and dicalcium silicate (up to 10%).

SFCA is the main ferrite phase in iron ore sinter and has been commonly studied in recent years. It has the capability of enhancing sinter quality with regard to mechanical strength, reducibility, reduction degradation, good intensity and low formation temperature which is suitable for developing low-temperature sintering and reducing energy consumption. [2-3].

The chemical and structural compositions are also very important for sinter as well as mineralogical structure. These concepts are expected to be stable so that primary and final slags have liquid adequate characteristics in terms of softening and melting temperatures, liquid temperature and viscosity for stable operations of the blast furnace.

Optimum basicity, low gangue and high iron content are desired specifications for sinter. In general, reducibility and quality of sinter improve with a higher level of hematite than magnetite, and structure of sinter improves with a higher level of primary or residual hematite and ferrites than secondary or precipitated hematite [4].

In this study a number of chemical and mineralogical analyses, micro-structure investigations and statistical data analyses have been done in order to review relationship between sinter chemistry, structure and quality.
2. Experimental Procedure

2.1. Raw Material

The samples used for the study are mainly obtained from the Erdemir Group Sintering Plant No:1 and No:2. Chemical composition of sinter is given in “Table 1”.

Table 1. Chemical composition (%) and property of sinter

<table>
<thead>
<tr>
<th>Sinter</th>
<th>TFe</th>
<th>FeO</th>
<th>CaO</th>
<th>SiO</th>
<th>Al₂O₃</th>
<th>MgO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>58.66</td>
<td>8.10</td>
<td>14.17</td>
<td>6.36</td>
<td>1.51</td>
<td>0.53</td>
</tr>
<tr>
<td>Plant 2</td>
<td>56.00</td>
<td>8.60</td>
<td>10.65</td>
<td>5.78</td>
<td>1.59</td>
<td>1.23</td>
</tr>
</tbody>
</table>

3. Results and Discussion

3.1. Analysis of Metallurgical Properties

A comparison of the Plant 1 and Plant 2 sinter’s metallurgical properties are given in “Table 2”. According to the results both Plant 1 and 2 RDI values are less than the limit value of %30, also TI value is good enough for desired cold strength. These specifications meet the requirement of blast furnace.

Table 2. Metallurgical properties of sinter

<table>
<thead>
<tr>
<th>Sinter</th>
<th>RDI -3.15</th>
<th>RDI -0.5</th>
<th>TI +6.3</th>
<th>TI -0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>27.58</td>
<td>5.61</td>
<td>75.02</td>
<td>4.49</td>
</tr>
<tr>
<td>Plant 2</td>
<td>29.26</td>
<td>6.01</td>
<td>79.00</td>
<td>3.81</td>
</tr>
</tbody>
</table>

3.2. Mineralogical Structure

Sinter specimens were analyzed by using Rigaku X-ray diffraction. Experiments were carried out with Co radiation and 10°-80° scanning angle. Sinter minerals were mainly formed of hematite, magnetite, SFCA, SFCA-1, larnite and wüstite. Mineralogical phases of Plant 1 and 2 sinters are given in “Table 3”.

Table 3. Mineralogical phase distribution of sinter

<table>
<thead>
<tr>
<th>Sinter</th>
<th>C₅S</th>
<th>Fe₂O₃</th>
<th>Fe₃O₄</th>
<th>SFCA</th>
<th>SFCA-1</th>
<th>TSFCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant 1</td>
<td>5.26</td>
<td>21.85</td>
<td>24.39</td>
<td>27.27</td>
<td>20.10</td>
<td>47.36</td>
</tr>
<tr>
<td>Plant 2</td>
<td>3.66</td>
<td>26.95</td>
<td>38.22</td>
<td>22.36</td>
<td>8.17</td>
<td>30.54</td>
</tr>
</tbody>
</table>

3.3. Statistical Analysis

The relationships between sinter chemistry, structure and quality were investigated by statistical data analysis program “Minitab 17”.

The primary tools of that program which has been used for analyze are descriptive statistics, boxplot, regression and correlation. Monthly average SFCA values are demonstrated in “Figure 1” below. As seen in the figure, the average total SFCA level of Plant 1 is 48 while Plant 2 is 30.

Figure 1 Plant 1 and Plant 2 Total SFCA Ratio vs Date

Relations Between SFCA and Raw Materials

BOF Slag

Firstly BOF slag was analyzed for relation between SFCA phases. According to Umadevi’s research, the utilization of BOF slag should be limited. Non availability of free CaO in BOF slag reduces the formation of calcium ferrite phases and more Fe₂O₃ remains as free phase due to less reaction with CaO. The weakening and degradation of sinter is associated with volume increase due to the phase transformation of hematite to magnetite present in sinter [5]. This result strengthens the idea of negative effect of BOF slag for final sinter strength. The “Figure 2” shows the results of both plants. SFCA mineralogical phase results were divided into two parts as high and low for both sinter plants. Thus it can be seen that SFCA ratio rises when BOF slag amount is low.

Figure 2 Total SFCA vs BOF Slag Ratio
Coke Breeze

Coke breeze consumption is a critical parameter for evaluating the raw material and thermal conditions. It also affects sinter machine productivity, mechanical strength and reducibility. As far as Umadevi is concerned that an increase in FeO (coke breeze rate) decreases the amount of acicular SFCA and hematite with a concomitant increase in magnetite content [6]. Correspondingly “Figure 3” shows the high and low SFCA amounts against coke breeze ratio.

Relation Between SFCA and Sinter Characteristics

Basicity

Basicity is one of the most important and essential notion for sintering from the point of forming compounds like calcium ferrites, slags and agglomeration. Also both Ca and Si take part in the SFCA structure with vital roles. An increasing in basicity level of sinter was found to increase the amount of SFCA-I, formation of more bonding phases and better pore structure with thick necks and a more regular shape [1, 7]. In parallel with, “Figure 4” shows that SFCA amounts also rose.

Reduction Degradation Index (RDI)

RDI (determination of low-temperature reduction-disintegration indices by static method) is used as a quality parameter to simulate the upper part of the blast furnace at 500°C-600°C under the influence of reducing gases. Correlation between RDI -3,15mm and SFCA values of Erdemir and Isdemir can be seen in “Figure 5”.

Microstructural Observations

Sinter specimens were mounted in epoxy resin and left under vacuum. The specimens were examined using a Nikon Epiphot 200 optical microscope, Clemex Vision Lite software, Jeol JSM 7100F Field Emission Scanning Electron Microscope and Oxford software. “Figure 7” Scanning electron (x3300) (a) and optical (x200) (b) photomicrographs of Plant 2 sinter: Hematite (H), Magnetite (Mt) and Columnar SFCA.
The mineral structures of sintering samples are shown in “Fig. 7-8” and Table 3. Columnar and platy SFCA forms can be seen obviously in Plant 2 sinter’s scanning electron photomicrograph in Figure 8. The interwoven texture is formed with the columnar SFCA among with hematite, magnetite and larnite.

Similarly same phases also can be seen in Plant 1 sinter’s optical microscope photomicrograph associated with acicular SFCA in Fig. 8 [8].

The microstructure and phase distribution of sinter mainly depends on its composition (basicity, Al₂O₃, MgO, SiO₂), sintering process, sintering time, temperature, raw materials origin and quality. Consequently it is natural and expected to differ Plant 1 results from Plant 2.

4. Conclusion

1. In number 1 and 2 plants total SFCA amounts decrease with the increase of BOF slag usage. In Plant 1 the utilization of BOF slag is 3 times more than Plant 2.
2. A high proportion of total SFCA is obtained with lower amount of coke both Plant 1 and 2.
3. High amounts of total SFCA is obtained with higher basicity for both plants.
4. RDI and TI which are indicators of sinter’s mechanical strength were improved with higher total SFCA rates.
5. RDI and Tumbler Index level of Plant 2 is higher than Plant 1, SFCA level of Plant 1 is higher than Plant 2.
6. According to the data analyses the two significant factors affecting the SFCA parameter in sinter blend are BOF slag and coke breeze. The relationship of sinter blend composition, machine parameters and sinter characteristics and the optimum SFCA level of the plants will be clarified with plant trials.

References

[8] Iron Ore, Mineralogy Processing and Environmental Sustainability, L. Lu