Reduction of Solid Fuel Consumption in Sintering of Indian Iron Ore

R. P. Bhagat
Mineral Processing Division
CSIR-National Metallurgical Laboratory
Jamshedpur 831007 India

Abstract:

The present investigation deals with the sinterability of Goa (India) iron ore having high Fe (65.2%) content. The sinter basicity (CaO/SiO$_2$) and its MgO were varied in the 2.0 to 2.5 and 1.5 to 3.0 range. The effect of process variables on the quality parameters of sinter namely, tumbler index (TI), reduction–degradation index (RDI) and reducibility index (RI) as well as the productivity of sinter was studied.

The studies have shown that the consumption of coke (C: 74%) was inter-influenced by the sinter basicity and its MgO content. Increasing the solid fuel consumption was not a viable solution to improve TI and RI simultaneously. The content of coke in the mix could be reduced to as low as 4% through ‘low temperature sintering’ at the balanced return fines recirculation (~ 33 wt. percent). The sintering indices in terms of productivity of sinter and its quality improve quite significantly at a higher sinter basicity (CaO/SiO$_2$ ~ 2.5) and its lower MgO content (1.5%).

Keywords: Reducibility, Reduction-degradation index, Speed of sintering, Yield of sinter, Tumbler index, Sinter basicity;

1. Introduction

Importance of the proper selection of process and operation variables is generally accepted in order to achieve better quality of sinter and greater productivity simultaneously [1-5]. The sinter-ability of ore could depend, besides other process parameters, on the sinter chemistry. Sinter basicity does influence the reduction-degradation index (RDI) and reducibility index (RI) through the changes in the mineralogical and morphological characteristics of sinter [6, 7]. The fact that calcium-rich ferrites with increase in basicity [8] impart beneficial properties of strength and reducibility to fluxed sinter has been accepted [9].

A majority of installation in India, guided by the blast furnace slag requirement, operate around sinter basicity(CaO /SiO$_2$) 2 which is possibly not conducive with regards to degradation of sinter during reduction [10]. Structure–property correlations of sinter are available which suggest that the structure of the sinter could be heterogeneous around this basicity level with a mixture of some basic and some acidic phases in it [7] which causes short cracks while it is getting reduced.

A major problem with the Indian sinter plants and elsewhere is their high solid fuel requirement compared to those abroad which leads to a greater scope for reduction of the
coke consumption in the process. Previous authors have made important contribution in this direction by studying the effect of granulation of coke breeze fines [11,12] and divided coke addition during the mixing process [13]. Addition of flue dust, having ~30 wt.% fixed carbon, though could substitute a part of carbon requirement, decreases vertical speed of sintering and hence the strand productivity [14].

Another possible approach, which has been adopted in the present work, is to control the sinter chemistry leading to a more favourable sinter mineralogy. Research suggests that the replacement of CaO by MgO at different sinter basicity leads to an increase in the liquidus temperature of the melt phase [15] and different reaction mechanisms, hence the sinter with different micro-texture are produced [7]. However, such effect is material specific, i.e. the nature of ore being sintered etc. [16] and inter-influenced by the factors such as, sinter basicity and the quantity of solid fuel in the mix. It is reasonably fair to accept the fact that the above mentioned interactional effect could be exploited to improve the sinter quality parameters and to lower the solid fuel consumption. The process could be termed as ‘low temperature sintering’ [17,18].

In principle, it is possible to enforce the bonding by diffusion more during the sintering process resulting in the sinter with its (more) favourable mineralogical and morphological characteristics. This has been attempted in the present work. A continual search strategy for optimisation of the process parameter has been adopted within the limiting condition of sinter chemistry required by the blast furnace.

2. Materials and methods
2.1. Raw Materials

Typical ore fines from Goa Mines, India was used in the sintering studies. Fig. 1(a) and 1(b) and Tab. I, respectively, show the sieve and chemical analyses of blended iron ore fines and other mix ingredients used in the studies. The ore fines had very low content of gangues, SiO$_2$ and Al$_2$O$_3$ being 1.95% and 1.70%, respectively having Fe 65.20%. X-ray diffraction analysis of the ore samples shows that hematite was the major iron bearing mineral phase. The minerals, which were present in ore fines in minor to trace quantity, are goethite, hydrated iron oxide, gibbsite, kalonite and quartz. Calcite was the major mineral phase present in limestone while dolomite and quartz were present in minor amount. Freshly calcined lime was used during the experiments.

Tab. I Chemical analysis of raw mix ingredients.

<table>
<thead>
<tr>
<th>Radical</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Iron Ore</td>
</tr>
<tr>
<td>CaO</td>
<td>53.50</td>
</tr>
<tr>
<td>MgO</td>
<td>0.18</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>1.95</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>1.70</td>
</tr>
<tr>
<td>Fe$_2$O$_3$</td>
<td>93.14</td>
</tr>
<tr>
<td>FeO</td>
<td>2.19</td>
</tr>
<tr>
<td>LOI</td>
<td>3.10</td>
</tr>
<tr>
<td>FC</td>
<td></td>
</tr>
<tr>
<td>VM</td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td></td>
</tr>
</tbody>
</table>
2.2. Sintering

Sintering tests were carried out in a batch square shaped sintering unit of 30*30 sq. cm cross sectional area with 500 mm high sinter box having removable grate bar at the bottom. The sinter mix, prepared in a balling drum, was put into the pot up to the top layer level and ignited for 2 minutes. Heat input for ignition was: 24 thousand Kcal /m²* min. (100*10⁶ J/m²*min).

Vacuum was maintained by operating the exhaust fan till the completion of sintering which was known from the temperature of the wind box (burn through point). The sinter was allowed to cool under suction till the temperature of exhaust gas reaches 100°C. The sinter cake was then dislodged and subjected to stabilisation / shatter test.

2.3. Physico-Chemical Tests of Sinter

IS 9963:1981 and IS 6495:1984, respectively, were followed for the shatter and tumbler tests of the sinter samples. Representative sinter sample after the stabilisation was ground to ~200 mesh size for the chemical and X-ray diffraction analyses, while ~15+10 mm sized sinter was withdrawn from the representative one for RDI and RI investigations.

3. Results and discussion

3.1. Response Variables

The response variables are as follows:
Yield of sinter (Y<sub>10</sub>): % +10 mm of sinter after stabilization of the sinter mass (20 kg) following shatter test. 3 drops with 2 m height.

Tumbling index (TI): The percentage of +6.3 mm remained after tumbling the 11.4 Kg mass of sinter (+10 mm) in a standard tumbler test apparatus (ASTM E279-97) for a total of 200 revolutions.

Strand productivity (P<sub>10</sub>):
\[
\text{Charge weight} \times \text{Yield of sinter} \times 100 \times \text{Time of sintering (h)}
\]

RDI: Percentage of –3.15 mm size fraction generated after tumbling in a standard tumbler for 900 revolutions following reduction under standard condition [19]

RI: Percentage of loss in weight of the sinter sample after reduction under (30%+70%) CO+N<sub>2</sub> atmosphere for 3 h at 900°C to the total weight of available O<sub>2</sub> in the sample [19]

3.2. Sintering of High Fe Ore and MgO requirement

The ore fines had very low content of gangues, SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> being 1.95% and 1.70%, respectively having Fe 65.20%. The blast furnace requirement for sinter basicity, CaO/SiO<sub>2</sub> and its MgO (%) was in the range of 1.8-2.0 and 2.5-3.0 respectively. At MgO level around 3, more of dolomite was required than limestone, as flux which is normally otherwise in the process of sintering. Dolomite, it is reported that, beyond 4 wt.% in the mix reduces the strength and reducibility, because of the formation of the minerals magnesium ferrite and magnesio-wustide [15] [20] both have poor reducibility [21]. Tab. II shows the selected results of experiments at various composition of sinter basicity and MgO content.

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Input parameter</th>
<th>Output parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sinter Basicity</td>
<td>MgO in Sinter, %</td>
</tr>
<tr>
<td>A</td>
<td>2.0</td>
<td>3.0</td>
</tr>
<tr>
<td>B</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>D</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>E</td>
<td>2.5</td>
<td>1.5</td>
</tr>
<tr>
<td>F</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>G</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>H</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>I</td>
<td>2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

3.3. Inter-influence of Sinter Basicity and MgO

The inter-influence of sinter basicity and MgO content is apparent at 8 % coke in the mix (Table 2). At sinter basicity 2.0 by lowering the sinter MgO to 2% from 3% (Expt. A vs B), the TI decreased significantly (from 68.8% to 63.6%) while the sintering and cooling was faster. We have got similar results In our previous studies with Joda ores [22]. Pangrahy et al. [15] have also observed that in case of basic sinter the period of both sintering and cooling increases with higher MgO. It is reported that an increase in sinter MgO, introduced by the addition of dolomite, decreases the amount of calcium ferrite slightly. The sinter porosity under some conditions increases with increase in MgO content [23].
The yield was marginally higher at 3% MgO level [Exp. A]. This is because of the formation of a higher amount of glassy phase in the sinter product. It is reported that the liquidus temperature of the melt phase increases when the MgO, contributed by dolomite addition, replaces the CaO in sinter [15]. A very high FeO (27.8%) in the sinter sample pertaining to Exp. A reflects that the sintering process [Exp. A] had a highly reducing condition contributed by a higher amount of coke during the sintering process.

At 8 wt.% coke in the mix when the sinter basicity was raised to 2.5 and MgO content was reduced to 1.5% (Expt. B vs C) significant improvement in the TI (63.6% to 70.1%) could be achieved, besides the sintering time was lower (13.5 min vs 11.5 min.) (Fig. 2). An improvement in TI was possibly due to higher ferrite formation. This fact suggests that there could be limitation in the digestion of magnesium bearing minerals in the sintering process. An increase in the productivity from 1.14 T/(sq.m*h) to 1.54 T/(sq.m*h) (Exp. A vs C) was primarily due to decrease in the sintering time with decrease in sinter MgO similar to the results observed previously [15]

3.4. Decrease in Coke Content

In the present study an attempt was also made to reduce the consumption of coke breeze in the sintering process by choosing the process parameters such that the sintering process is forced to adopt a greater amount of diffusion at relatively lower temperature. At 2.5 sinter basicity and 1.5% MgO content, with successive decrease in coke content from 8 wt.% in the mix (Exp. C) to 4 wt.% (Exp. E), the yield improved quite significantly from 39.7% to 46.3% which has been reflected in significant improvement in productivity from 1.54 to 1.87 T/(sq.m*h) (Fig. 2). The TI also improved marginally (70.1% to 73.9%) (Fig. 2).

A marginal increase in the sintering time (11.5 in to 12.5 min) could be observed, when the coke in mix was decreased from 8 wt.% to 4 wt.% (Exp. C and E); whereas the cooling time decreased significantly from 10.5 min to 7.5 min which was possibly due to combined effect of a lower temperature of the sintered mass (at lower coke) and more porous structure of the sinter having high heat transfer rate. In these cases (CaO/SiO_2 : 2.5) the sinter MgO was lower, 1.5%. The requirement of solid fuel decreases with the decrease in the liquidus temperature of the melt phase with the addition of lower amount of dolomite [24]. It was also observed that the sinter mass at 8% coke was over fused and had highly glassy structure which took much more time to cool to the normal temperature after the sinter was dislodged.

![Fig. 2. Effect on Solid Fuel on TI and Productivity (sinter basicity=2.5, MgO=1.5%).](image-url)
3.5. MgO Practice at Lower Coke

Fig. 3 shows the effect of sinter MgO on the sintering indices at reduced rate of solid fuel (4 wt. %) and 2.5 sinter basicity. It is apparent that while the TI of sinter decreased with increasing MgO, the effect of MgO on the productivity of sinter was marginal. The best test results could be achieved when sinter MgO was significantly reduced to 1.5% (Exp. E).

![Fig. 3. Effect of MgO on TI and Productivity.](image)

The next step of the present study was to increase the MgO content of sinter from 1.5% level to 2.5% level (in Exp. F) so as to meet the technical requirement of the blast furnace. The sinter with desired quality parameters namely, (a) high cold strength (TI ≈ 72%), (b) reasonable reduction properties (RDI ≈ 29%, RI ≈ 70 %), (c) low FeO (~ 11%) and (d) acceptable porosity (~17%) could be produced. The productivity at this level was: 1.64 T/(sq.m*h).

3.6. Reduction Properties

A significant increase in reducibility index (RI) could be observed with the sintering under low heat flux (using 4 wt.% coke) [Exp. F]. An increase in RI, in this case, was contributed by an increase sinter porosity and decrease in FeO content (Fig. 4). In contrast, at 8 wt.% coke breeze in the mix an extremely low RDI (~ 13%) [Exp. A] which was due to the fact that the sinter product was too glassy to be reduced which has been reflected through a significantly lower reducibility index (RI ≈ 51%).

![Fig. 4. Chemical analysis & Property of sinter.](image)
The above results may be indicative as the process had been studied at two different levels of sinter basicity. Nevertheless, the results suggest the possible approach through adopting ‘low temperature sintering’ in producing the sinter with improved quality parameters at lower fuel rate to a level of 4.0 wt.% of the mix which was much lower than the figure envisaged.

3.7. Return Fines Balance

Exp. A to Exp. H were carried out with return fines input at 25 wt.% of the mix. The quantity of return fines output was higher than the return fines input in these cases. A ‘balanced return fines regime’ was obtained when the sintering was carried out at 33 wt.% of the mix (Exp I). However, with the increase in return fines input from 25 % to 33 %, the sinter productivity decreased marginally, whereas the TI of sinter increased significantly from 67.7% to 72.3 %, also the cooling time decreased from 8.5 min to 6.5 min. These indices had improved due to the improvement in permeability resulting in more evenly distribution and transfer of heat with the lower shrinkage of sinter mix [25] (with the increased return fines to 33%). However, it has been observed that a return fines input beyond this level (~40 wt.% of the mix) decreased the speed of sintering which could be attributed to the poor thermal efficiency resulting from poor absorption of heat from incoming hot gases to the sintering mix [1,26].

4. Conclusions

- The present paper describes an approach to reduce the coke breeze consumption in the sintering process while improving the quality parameters of sinter namely, cold strength (TI) and reduction properties (RDI and RI) in case of iron ore with high Fe (~65%). The strand productivity also improved.
- At higher basicity ratio, CaO/SiO$_2$:2.5, and 4 wt.% coke (C : 75.4%) in the mix an increase in sinter MgO, contributed by dolomite, has increased the cooling time significantly. Besides, decreased the TI and productivity marginally.
- The study has shown that the amount of coke in the mix was inter-influenced by the basicity and MgO content of sinter. This could be exploited to reduce the coke consumption through ‘low temperature sintering process’, while improving the sinter qualities (reduction properties and strength of sinter) and other sintering indices at the same time.
- At 2.5 basicity ratio (CaO/SiO$_2$) and 1.5% sinter MgO the TI and productivity of sinter increased with decrease in coke breeze content from 8 wt.% to 4 wt.. The change in variation of these parameters has been significant in the 6 wt.% to 4 wt.% range while it has been marginal in the 8 wt.% to 6 wt.% range. Besides, the cooling time of sinter also decreased. The optimal values are: TI~ 74% and Productivity : 1.87 T/(sq.m* h).
- At 2.5 sinter basicity (CaO/SiO$_2$) and 2.5.% MgO in sinter, It is also possible to reduce the content of coke breeze (C : 75.4%) in the mix to 4 wt.%. The TI of sinter (~72.%) and sinter productivity (1.64 T/(sq.m).h) are marginally lower than those at 1.5% sinter MgO

Acknowledgements

The author expresses his deep sense of gratitude and appreciation to the Management of Sesa Goa as well as Director, CSIR-NML for the support to the present research. The present work has been immensely benefited through the cooperation from Mr. D. P. Singh
and Mr. M. C. Goswami of NML. The author is grateful to them. The experimental assistance from his colleagues, Mr. (Late) S. K. Sil, Dr. Vinod Kumar, Mr. P. Saha, Mr. U.S. Chattoraj and Mr. S. C. Maulik is duly acknowledged.

5. References

22. R. P Bhagat, S. K. Pradhan,, M. C. Goswami, B. Nandi and T. Venugopalan

Садржај: У овом раду представљена је синтерабилност Гоа (Индија) челичне руде са високим садржајем гвожђа (65,2%). Однос (CaO/SiO₂) и MgO је варирао од 2,0 до 2,5 и
1,5 до 3,0. Утицај варијабли на квалитативне параметре синтеровања, наиме, индекс преноса (ИП), редукционо–разградиви индекс (РРИ) и редукцијски индекс (РИ) као и продуктивност синтеровања су проучавани.

Истраживања су показала да на потрошњу кокса (C: 74%) утичу однос (CaO/SiO$_2$) и MgO. Повећање потрошње чврстог горива не побољшава индексе ИП и РИ. Садржај кокса у мешавини може бити редукован до 4% кроз ниско температурско синтеровање. Квалитет синтеровања је побољшан при односу (CaO/SiO$_2$ ~ 2,5) и нисег садржаја MgO (1,5%).

Кључне речи: редукција, редукционо-разградиви индекс, брзина синтеровања, принос синтеровања, преносни индекс