Development of Pellet-Sinter Composite Agglomerate for Blast Furnace

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(Received on July 24, 2013; accepted on October 8, 2013)

Microfines of iron ore are generally utilized in Blast furnace in form of indurated pellets because sinter bed has limitation of accepting fines. Charging of acid pellets with basic sinter is the normal practice in blast furnace. However induration of pellets is very cost intensive. Further more, due to low angle of repose pellets distribution during charging with other materials in blast furnace creates inhomogeneous distribution. In order to alleviate the above problem, a composite mass of acid pellet and basic sinter has been developed, wherein; green pellets made-up of microfines were mixed with basic sinter mix and sintered the combined mass in a sinter bed of 10–12 kg scale. A composite mass of indurated pellet and sinter named as ‘Pellet-Sinter Composite Agglomerate’ was obtained. Linz Donawitz converter sludge and mill scale were used in pellet mix to provide in-situ heat in pellets that enhances incipient fusion to form bond in pellets. The developed sinter shows good shatter index (92%), tumbler index (67.5%) abrasion index (7.5%) and reducibility index (70%) and low reduction degradation index (27%), which are comparable with the conventional iron ore sinter made in the same set-up keeping other condition identical. This innovative technique help improving 30% microfines utilization in sinter bed, reduce coke breeze/energy consumption, reduce overall basicity of sinter and decrease flux composition.

KEY WORDS: microfines; sintering; pelletization; agglomeration; Pellet-Sinter Composite Agglomerate.

1. Introduction

Micro-fines are generated in steel plant as well as in mines area. Although part of the generated fines are recycled in existing agglomeration process viz. sintering, pelletization or briquetting, most of it is still unused. Further, the iron ore concentrates generated from the beneficiation of lean ore also produce a significant quantity of fines. Pelletization followed by heat hardening is an energy consuming process. On the other hand the use of micro-fines in sinter bed is very limited because it affects on the permeability of bed and reduces productivity. Therefore, utilization of micro-fine iron oxides wastes and concentrate generated from lean ore in economical way is still challenging world wide.

Investigators1,2) have tried to improve micro-fines utilization in sinter bed by pre-balling the mix with requisite quantity of water in secondary drum prior to the charging in the bed and found a good result up to a certain limit. It was further improved by addition of hydrated lime in sinter mix that helped as binder during pre-balling. However, only up to 30% microfines utilization was possible by this technique.

Micro-fines were first pelletized into 2–6 mm pellets called ‘micro-pellets’3) and then it was mixed with the sinter mix which enhanced the microfines utilization in sinter bed. Iron oxide microfines were developed through a binder-less room temperature process4) and subsequently used in sintering to get fluxed sinter. The process used a significant quantity of fines. However, strength development of micro-pellets to withstand cold handling during charging in sinter strand was very difficult.

Charging of super fluxed sinter in combination of acid pellets in blast furnace is the common technique to improve the utilization of fines in iron making. Sintering has a size limitation, while pelletization can utilize ultra-fine iron oxides or concentrates, but it is involved with high energy consumption and production cost. In order to avoid costly heat hardening and complexity of pelletization process, the hybrid pelletization5) was done for utilizing micro-fines, wherein the green pellets were coated with carbon powder and then sintered in a sinter bed to make a composite mass. HPS may disintegrate and generates high proportion of individual pellets during treatment and transportation due to insufficient contact area between fired pellets.6) However, this process is in operation with improved blast furnace productivity in Japan as shown by Niwa et al.7) The investigators6) have made the pellet with ultra-fines iron oxide and subsequently used in sinter bed to get a composite mass of pellet and sinter mix where, acid pellets were embedded in to the sinter mass. The process was named as composite agglomeration process (CAP). They reported good results for magnetite pellets in terms of shatter index, tumbler index, reducibility index and reduction degradation.
index. However, they did not report about the strength of the pellets present in CAP sinter separately or their process details. They suggested using carbon in hematite pellets for heat generation in pellet and improve its strength, but the obtained strength was not reported.

Present study has been carried out to explore the possibility of developing composite agglomerate utilizing hematite ore. For in-situ heat generation in pellet, the suitability of different materials among carbon, Linz Donawitz converter Sludge (LDS) and mill scale was assessed.

2. Experimental

Noamundi iron ore (Noa) was used as basic raw material for this study and coke powder, LDS or mill scale was used as an additive. In some experiments, Joda iron ore (Joda) was also used mixing with Noamundi ore. The chemical composition of iron ores and LDS are presented in Table 1. Chemical analysis of lime stone and pyroxenite, used as flux materials are presented in Table 2. Composition of coke breeze from Tata Steel used as fuel is presented in Table 3.

The Table 4 shows the size distribution of iron ore and coke used.

2.1. Pelletization

Schematic of the experimental is presented in Fig. 1. A part of dry Noamundi iron ore fines was ground for 18 minutes to ~45 μm (56% approx). The size distribution and Blaine fineness of it is shown in Table 5. The iron ore fines along with 0.5% bentonite binder were mixed with pyroxenite fines and other additives like coke fines, LDS etc. in varying quantity. The mixture was pelletized with requisite quantity of water. The properties of green pellets viz. green compressive strength, green drop strength, and dry compressive strength were measured for representative samples. It involved at least 20 pellets of 10–11 mm diameter to achieve an average value of strength properties in each case. In some experiments, coke powder was used in core of the pellet mixing with 50% of iron ore fine having a coating of rest 50% iron ore fines with bentonite as a binder.

2.2. Sintering

Sinter mix was made with varying amount of fluxes viz. calcined lime (2%), lime stone, MgO containing flux (pyroxenite) and coke breeze along with 6–7% of water. The moist mixture was granulated in a rotating disc. Prepared green pellets were also mixed in the granulated mixture in rotating disc.

Composite mass of pellet and sinter mix were sintered in a 10–12 kg scale pot sintering facility. At the bottom, there is a perforated magnesite refractory plate (grid), to hold the burden and provide passage for outgoing (sucked) gas.
Below this grid, there is a dust catcher for arresting the dust carried by the outlet gas. A suction blower of maximum capacity of 1 200 lpm flow rate is connected with the bottom pipe of pot through a water cooling jacket surrounding the pipe. There is provision for measuring outlet gas temperature, and suction pressure.

The bed was ignited at the top by burning jute with a mild suction of air. After ignition, the air suction at the top was increased to 230 lpm at around –0.05 to –0.06 kg/cm² suction pressure at bottom in all experiments. The heat front propagated from the top towards the bottom was monitored through temperature measurement by thermocouples positioned at different heights. The maximum temperature of heat front was recorded to be in the range of 1 250–1 375°C for different experiments. The operation was stopped when the bottom thermocouple started to cool after indicating maximum temperature. After cooling, the sinter cake was removed from the pot through the front door. Thus, sintering studies were done in varying conditions and the necessary reproducibility was checked. The cake was crushed to the desired size and the composite mass obtained was termed as Pellet-Sinter Composite Agglomerate (P-SCA). The sinter was characterized chemically, physically and physico-chemically. Kinds of sinter made and their details are presented in Table 6.

### 2.3. Characterization

The pellets inside sinter were separated manually and the Breaking load was tested by a universal testing machine (HOUNSFIELD). Load necessary for breaking the pellet was termed as cold crushing strength (CCS) of pellets. It involved at least 20 pellets of 10–11 mm diameter to achieve an average value of CCS.

With a view to examine the cold handling property of produced sinter, the shatter test was conducted as per standard: IS9963-1981-2003 by dropping 2 kg of agglomerate sample of size range, +10 to –40 mm from the height of 2.0 m for four times over a 10 mm thick mild steel (MS) plate. The different size fraction of broken material after shatter was quantified. Percentage of +5 mm size was termed as shatter index. Further, the shatter test of finally developed product, P-SCA was done in 20 kg scale as per above standard to check its industrial suitability.

Tumbler test was done taking 0.5 kg of dry sinter of size range, +10 to –40 mm and allowing 1 500 revolution (@30 rpm) in a 130 mm diameter and 200 mm long mild steel drum. It was done only for comparison of strength between different laboratory scale experiments in varying conditions. Further the tumbler test of finally developed P-SCA was done as per standard: IS6495-1984-2003 taking 15 kg of dry sinter of size range, +10 to –40 mm and allowing 200 revolutions (@25 rpm) in a 1 000 mm diameter and 500 mm long mild steel drum. After revolution, the percentage of +6.3 mm was taken as measure of the Tumbler index. Abrasion Index (AI) was measured as follows:

\[
AI = \frac{M - (M_1 + M_2)}{M} \times 100\%
\]

Where, M: Mass of sample before test, M1: mass of sample retained in 6.3 mm screen after test, M2: mass of sample passing through 6.3 mm screen and retained in 0.5 mm screen after test.

### Table 6. Kinds of sinter made.

<table>
<thead>
<tr>
<th>Kinds of Sinter (Code)</th>
<th>Ratio of sinter mix: pellet</th>
<th>Pellet description</th>
<th>Sinter description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C in pellet mix (%)</td>
<td>C in pellet core (%)</td>
<td>LDS in pellet mix (%)</td>
</tr>
<tr>
<td>A 70:30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B 70:30</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>C 70:30</td>
<td>0</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>D1 70:30</td>
<td>0</td>
<td>0</td>
<td>7–12</td>
</tr>
<tr>
<td>D2 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>D3 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>D4 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>E1 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>E2 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>E3 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>E4 70:30</td>
<td>0</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>F No pellets were used (Usual sinter)</td>
<td>2.1</td>
<td>2.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>

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3. Results and Discussion

After making green pellets, the strength properties of the green pellets were measured to assess its suitability for handling during charging and mixing in sinter mix. Maximum compressive load for breaking a green pellet is termed as green compressive strength (GCS) and the same for a dry pellet is termed as dry compressive strength (DCS). These were also measured by universal testing machine (HOUNSFIELD) like CCS measurement for the indurated pellet in P-SCA. The drop strength of green pellets was conventionally measured by repeatedly dropping an individual pellet upon a mild steel plate from a height of 450 mm. The number of drops required to break the pellet is a measure of its drop strength. The average value of 20 such test is termed as the green drop strength number (GDSN).

Table 7 shows that the strength properties of green/dry pellets of A, B, D and E groups are beyond the acceptable limit as required in pelletization practice. However, it is not so good in C group pellet that may be due to the presence of carbon in pellet core.

3.1. Sintering with Pellets

Sintering was conducted with green pellets in sinter mix. The cold crushing strength of the pellets separated manually from sinter mass was measured. The Table 8 indicates that CCS of the pellet was varying in the wide range of 15–110 kg/pellet while average was 60 kg/pellet. In order to minimize the variation in CCS the overall coke rate was increased to 5.5% from 5%. However, the most of the pellets were found to be melted. The strength variation in pellets is presumably due to the inhomogeneous temperature at the different point of sinter bed, which is unavoidable in sintering practice. In-situ heat supply in pellets may help in minimizing this problem.

3.2. Sintering Using Coke Powder in Pellet

In order to generate in-situ heat inside pellet, carbon in form of coke powder has been added in pellet and the sintering test results are shown in Table 9. But, use of only 2% C in pellet mix showed fusion of pellets because; carbon inside pellet produces a significant heat to melt the pellets as per reactions in Eqs. (1) and (2).

\[
\begin{align*}
C + \frac{1}{2}O_2 &= CO(g) ; \Delta H^0 = -110.5 \text{ kJ} \quad \text{(1)} \\
C + O_2 &= CO_2 ; \Delta H^0 = -393 \text{ kJ} \quad \text{(2)}
\end{align*}
\]

When, C content of pellet was decreased to 1.0% and 1.5% keeping all other parameters constant, good sintering was observed, however, average pellet strength was only up to 30 and 25 kg/pellet (Table 9), respectively. Shatter index of sinter was also very low. A significant quantity of broken pellets has also been found. During sintering the heat transfer occurs from gas to pellet core at the beginning and after reaching to elevated temperature, the C inside pellet reacts with oxygen as per Eqs. (1) and (2). The calculated heat (used Factsage 6.1) generation in pellet is 0.163, 0.245 and 0.327 kJ/g, respectively for 1, 1.5 and 2% C in pellet. Thus, after reaching to elevated temperature by transferred heat from sinter bed to pellet, 2% C in pellet generated high amount of heat inside resulting increase in temperature so high to melt the pellet, whereas, 1.5% C generates lower

Table 7. Properties of green pellets used.

<table>
<thead>
<tr>
<th>Types of green pellet</th>
<th>Iron ore fines</th>
<th>Pellets Size obtained</th>
<th>GCS, kg/pellet</th>
<th>GDSN, (Numbers)</th>
<th>DCS, kg/pellet</th>
</tr>
</thead>
<tbody>
<tr>
<td>A &amp; B Group</td>
<td>Noamundi ore</td>
<td>10–16 mm</td>
<td>1.2</td>
<td>12</td>
<td>3.5</td>
</tr>
<tr>
<td>C Group</td>
<td>Noamundi ore</td>
<td>10–16 mm</td>
<td>0.7</td>
<td>5</td>
<td>2.7</td>
</tr>
<tr>
<td>D &amp; E Group</td>
<td>Noamundi ore/Joda ore</td>
<td>10–16 mm</td>
<td>1.2</td>
<td>12</td>
<td>3.5</td>
</tr>
</tbody>
</table>

Table 8. Sintering with only Noamundi iron ore pellets.

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Type of sinter group</th>
<th>Overall coke rate, %</th>
<th>Basicity</th>
<th>%MgO</th>
<th>Maximum temp °C</th>
<th>CCS, kg/pellet</th>
<th>observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sinter</td>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A</td>
<td>5</td>
<td>2.1</td>
<td>1.2</td>
<td>1325</td>
<td>60 avg. (range: 15–110 kg)</td>
<td>A significant quantity of broken pellets. Wide variation in strength.</td>
</tr>
<tr>
<td>2</td>
<td>A</td>
<td>5.5</td>
<td>2.1</td>
<td>1.2</td>
<td>1370</td>
<td>–</td>
<td>Most of the pellets were melted.</td>
</tr>
</tbody>
</table>

Table 9. Sintering test with C containing pellets in sinter mix.

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Sinter Group</th>
<th>Overall coke rate, %</th>
<th>C in pellets, %</th>
<th>Basicity</th>
<th>Pellet strength kg/pellet</th>
<th>Shatter index of P-SCA, %</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sinter</td>
<td>Overall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>B</td>
<td>6.3</td>
<td>1.0</td>
<td>2.1</td>
<td>1.49</td>
<td>75</td>
<td>Good sintering but pellet strength was very low. A significant quantity of broken pellets.</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>6.3</td>
<td>1.5</td>
<td>2.05</td>
<td>1.48</td>
<td>74</td>
<td>Pellets did not melt but porous structure was physically seen.</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>6.3</td>
<td>2.0</td>
<td>2.12</td>
<td>1.49</td>
<td>75</td>
<td>Only around 10% pellets remained unmelted and rest was melted.</td>
</tr>
</tbody>
</table>
amount of heat (0.245 kJ) that does not melt the pellet but provides good fusion. However, the lower compressive strength of the pellets was observed. This may be due to the formation of gas inside pellet at high temperature as per reactions in Eqs. (1) and (2). At the latter stage it was thought that the strength improvement in carbon containing pellet is possible if the pellet is partially reduced to the magnetite or metallic iron. In order to minimize C burning in pellet the passage of free oxygen inside the pellets required to be minimized. For this purpose carbon (coke powder) was used at the core of the pellet and then coated with iron ore fines without carbon as shown in Fig. 2. Core of the pellet contains iron ore fines with varying percentage of coke powder with 1% bentonite as binder. After making 8–10 mm pellet with requisite quantity of water, the pellets were coated with 50% of total iron ore fines using 0.5% bentonite in iron ore. Pellets were rolled in disc with simultaneous addition of water and bentonite containing iron ore fines. Thus, pure iron ore coating was made surroundings of the pellet. This iron oxide coating may provide hindrance to the passage of oxygen and reduce the burning of carbon in pellet as per reactions (1) and (2).

The photograph of the pellet samples (manually separated) and composite mass obtained from the experiment is shown in Figs. 3(a) and 3(b). It was observed that melting happens in a significant quantity of pellets. When coke in sinter mix was reduced the majority of the pellets became hollow or perforated. This is presumably due to the burning of internal carbon in the pellet core with oxygen passed through the coating and generation of heat inside on reaching the pellet to elevated temperature by the transfer of heat from sinter bed. The result of the sintering test is presented in the Table 10. The sintered mass was available, but pellets were affected. The shatter index of sintered mass was found to be very low. The result indicates that presence of carbon beyond certain limit create internal temperature so high that fusion of pellets happens and the coating of iron ore is not sufficient to prevent it. Further, for lower amount of C, either peak temperature inside pellet is not sufficient or the time of prevailing peak temperature to form bonding phases is not sufficient. Therefore, difficulties were observed in creating appropriate melt phase in hematite pellet by adding carbon. Though carbon helps in induration of conventional pelletization process by supplying in-situ heat, here it becomes very difficult because of highly oxidizing atmosphere and short retention of pellet at sintering temperature (flame front temperature).

3.3. Sintering with LDS in Pellet

Owing to the problem of using carbon in pellet core, another alternative material LDS was used in pellet mix. The Photograph of the produced P-SCA is presented in Fig. 4(a) and the manually separated pellets from the same sinter (P-SCA) are presented in Fig. 4(b). Both the pellets and sintered mass are physically appeared to be very good. Sinter properties with 10% LDS in pellet is presented in Table 11. The table shows average 80 kg/pellet compressive strength and a good tumbler and shatters properties. When LDS in pellets has been increased to 12%, no further improvement in strength has been found. It may be recalled that when neither LDS nor carbon was used (Table 8) in pellets, the average compressive strength was 60 kg/pellet, however, there was a wide variation between 15–110 kg/pellet. It is evident from the Table 11 that due to the use of LDS, the variation of strength has been decreased (60–120 kg/pellet) and the average strength of pellets has been improved to 80 kg/pellet. This is due to the formation of in-situ heat in pellet for oxidation of metallic iron and its lower oxides (Fe, FeO and Fe₃O₄ present in LDS) during sintering as per reactions in Eqs. (3)–(6).
Fe + 1/2O₂ = FeO; ΔH₀ = –266.9 kJ mole⁻¹ ...... (3)

3FeO + 1/2O₂ = Fe₃O₄; ΔH₀ = –319.7 kJ mole⁻¹ ... (4)

2/3Fe₃O₄ + 1/6O₂ = Fe₂O₃; ΔH₀ = –76.4 kJ mole⁻¹

.......................................... (5)

2Fe + 3/2O₂ = Fe₂O₃; ΔH₀ = –823.4 kJ mole⁻¹.... (6)

Here also the heat transfer happens to proceed through gas to pellet core and after reaching to elevated temperature, the oxidation reactions (Eqs. (3)–(6)) become faster and a significant quantity of heat (0.236 kJ/g of pellet) is generated inside the pellet. The in-situ heat in pellet exhibits the bond formation in pellet. As above reactions do not produce any gas unlike reactions in Eqs. (1) and (2), the bonding seemingly becomes stronger to provide good CCS in pellet.

XRD patterns of pellet produced in sintering with 4% C in pellets and 10% LDS are presented in Figs. 5(a) and 5(b), respectively. Both patterns show a significant quantity of magnetite phase. Carbon in the pellet does not show satisfactory results due the excessive heat generation in oxidation.

RI of the P-SCA looks very good however, RDI is very poor. On RDI test of Sl No-1 (Table 11), the total weight loss was only 10 g out of 500 g sample (Initial charge weight). The photographs of obtained sample after RDI test separating –3.15 and +3.15 mm are presented in Figs. 6(a) and 6(b), respectively. It is evident from the figures that in +3.15 mm part, most of the pellets remains unbroken, that weigh about 130 g out of 228 g of total weight. Since, P-SCA (Group-D1) contains 30% pellet and 70% sinter mass the pellet quantity is estimated to be around 150 g out of total weight. Therefore, an appreciable quantity of obtained unbroken pellet (130 g) clearly indicates that pellets remain strong and do not have any significant disintegration after RDI test. This appears that the poor RDI is due to poor quality of sinter mass only, while pellets are very superior from RDI point of view.

3.3.1. Improvement of RDI in LDS Added Pellet

In order to improve (decrease) RDI up to the acceptable limit, the following steps were taken.

3.3.1.1. Effect of Varying Basicity

With increase in basicity the shatter index of the sinter increases as shown in Fig. 7. Sinter RDI with varying basicity indicated high RDI. Increasing MgO content leads to more magnetite and less hematite in sinter.10 It may cause less strain in pellet during reduction. The beneficial effect of MgO has also been observed by Das et al.11 They used magnesium silicates with low silica containing iron ore. Noamundi ore contains very low SiO₂ (1.21%). It was therefore explored to use magnesium bearing pyroxenite as flux in pellet. It was observed that even up to the level of pyroxenite, equivalent to 1.5% MgO, in 1.9 basicity level, RDI was found to be 41.5% (Sl No-2 in Table 11) that is also not suitable for blast furnace (BF).
basisity at constant MgO content is presented in Fig. 8. With increase in basicity, RDI decreases. i.e. increasing basicity promotes sinter properties. But, even up to high basicity of sinter, RDI could be reduced down to only around 41%. This sinter with high RDI is not usable for blast furnace operation.

3.3.1.2. Mixing of Joda Iron Ore

Further improvement of RDI was tried with mixing of 50% Joda ore that proportionately reduce the average alumina content of ore and results are shown in Fig. 8. The figure depicts that use of Joda ore reduces RDI to a great extent up to 34.5% at basicity of 2.1. But still it is beyond the acceptable limit in blast furnace. The primary reason of decreasing RDI with Joda ore may be due to its lower alumina content than Noamundi ore.

3.3.1.3. Increase in MgO Content of Sinter

MgO content of sinter was further increased with increasing pyroxenite to reduce the RDI. Table 12 shows the sinter properties at different level of MgO when all other parameters are identical. Shatter and tumbler properties remain almost constant and RDI decreases to a very low level of 27% that would be suitable for use in blast furnace. Thus, the combined effect of above three parameters yields in improving RDI of composite agglomerate to the acceptable value.

3.4. Properties of the Developed P-SCA and Comparison with Usual Sinter

The properties of developed sinter are shown in Table 13 which depict that with RDI other properties such as RI, shatter index and tumbler index are also good. Sintering without any pellet i.e. usual sintering was conducted keeping all other parameters constant. The comparative results are shown in Table 13.

The table shows in usual sintering (Sl. No 2), when the equivalent amount of coke breeze (overall coke rate) is used in sinter mix equal to the proportion used in P-SCA, the sinter yield is found to be very low. RDI is also poor in P-SCA. When the coke rate is increased to 6.5% (equal to the coke percentage with respect to the sinter mix in P-SCA) the sinter yield increases and tumbler index remains same. The yield, shatter index and RDI of P-SCA are as good as usual sinter when 6.5% coke is used (Sl. No 3) but, RI of P-SCA is slightly higher than usual sinter. Since almost all the properties are comparable with usual sintering, it may be a potential material for the down stream process.

In P-SCA, 30% of green pellet is used. This in turn indicates the increase of 30% microfines utilization in this new sintering process. It is further envisaged from the Table 13 that for the similar energy ( coke) consumption, composite agglomerate shows improved sinter properties and a better result (compared between Sl. No. 1 and 2). On the other hand to achieve similar properties in both the cases higher amount of coke addition is necessary in usual sintering (Sl. No-3). Thus, the pellet-sinter composite agglomeration process may also be advantageous for energy saving and reduction in CO₂ emission. Sl. No-1 consumes lower amount of pyroxenite also, because, pellets in it contain only 1.2% MgO, while there is no pellet in Sl. No-3 and sinter mass contains 1.7% MgO.

3.5. Possibility of Using Mill Scale

The sintering experiment was also conducted with mill scale for in-situ heat generation in pellet replacing LDS.

<table>
<thead>
<tr>
<th>SI No</th>
<th>Sinter Group</th>
<th>Pellet Used, %</th>
<th>Ore used</th>
<th>Sinter Basicity</th>
<th>MgO content, %</th>
<th>Overall coke rate, %</th>
<th>Yield ( %)</th>
<th>Shatter index ( %</th>
<th>Tumbler index ( %)</th>
<th>RI %</th>
<th>RDI %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E1 (P-SCA)</td>
<td>30</td>
<td>Joda : Noa50:50</td>
<td>2.1</td>
<td>1.7</td>
<td>5.1</td>
<td>68.2</td>
<td>55</td>
<td>91</td>
<td>74.2</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>F (Usual Sinter)</td>
<td>0</td>
<td>Joda : Noa50:50</td>
<td>2.1</td>
<td>1.7</td>
<td>5.1</td>
<td>57</td>
<td>43</td>
<td>–</td>
<td>83.2</td>
<td>–</td>
</tr>
<tr>
<td>3</td>
<td>F (Usual Sinter)</td>
<td>0</td>
<td>Joda : Noa50:50</td>
<td>2.1</td>
<td>1.7</td>
<td>6.5</td>
<td>66.3</td>
<td>57</td>
<td>90</td>
<td>83.1</td>
<td>66</td>
</tr>
</tbody>
</table>

Table 12. P-SCA properties with increasing MgO and use of Joda & Noa ore (50:50).
Amount of mill scale was calculated from the heat balance, i.e., the amount of mill scale added was equivalent to the amount of LDS to generate same amount of heat. The results are presented in the Table 14. The table depicts that similar quality of P-SCA can be produced with mill scale also. Comparatively lower quantity of mill scale is necessary to get similar quality P-SCA. Therefore, any one of the above wastes oxide fines can be used for this purpose based on the availability in plant.

### 3.6. Characterization of Final Sinter in Larger Scale

It may be recalled that all shatter and tumbler properties were done in 2 kg and 0.5 kg scale respectively due to the limitation of sample quantity obtained in laboratory scale sintering experiments. In order to carry out tumbler and shatter test in larger scale, a large quantity of P-SCA (total 40 kg +10 to –40 sizes) was prepared by repeating the same sintering batch (Group E1) six times. The finally developed sinter was tested for the tumbler and shatter as per standard, i.e. taking 15 kg and 20 kg material in a batch, respectively. The results are presented in Table 15.

Shatter index, is nearly equal to the small scale tests as reported earlier while, there is a little deterioration in tumbler index. All these strength properties are well within the acceptable limit. Physico-chemical properties, viz. RI and RDI are also comparable with normal sinter as discussed earlier. Therefore, the product sinter appears to be useful in blast furnace iron making.

### 4. Conclusions

Pellet in P-SCA without any carbon shows average strength of 60 kg/pellet but with a wide range of variation. Strength of P-SCA pellet was tried to improve through in-situ heat generation by use of carbon in pellet but no improvements was found. Rather, sintering with pellets containing 4% carbon in core gives either perforated pellets or fused pellet. Therefore, the use of C in P-SCA pellet is not recommended.

Use of LDS shows comparatively better strength of pellets in P-SCA because of in-situ heat generation by the oxidation of metallic Fe and its lower oxides and no gas generation occurs inside pellet for the oxidation reactions. Shatter and tumbler index in developed P-SCA are also good. For the same reason mill scale also shows similar performance.

RDI of P-SCA developed from the Noamundi ore has been improved by increasing basicity, blending Joda ore and increasing MgO (pyroxenite) content of sinter mix. Finally, P-SCA of acceptable quality has been obtained and is comparable with good quality sinter made through usual practice. The developed process for P-SCA increase 30% micro-fines use in sinter bed, consumes less coke breeze and less flux.

### Acknowledgement

Authors thankfully acknowledge the financial assistance offered by M/s Tata Steel Ltd., Jamshedpur to carry out this investigation and they wish to express their sincere gratitude to the Director CSIR-NML for his kind permission to publish this paper.

### REFERENCES


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**Table 14.** Properties of P-SCA made using mill scale.

<table>
<thead>
<tr>
<th>Pellet Used, %</th>
<th>Ore used Joda: Noa</th>
<th>Basicity</th>
<th>Overall Overall</th>
<th>Yield (%)</th>
<th>Shatter</th>
<th>Tumbler</th>
<th>RI</th>
<th>RDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>50:50</td>
<td>2.1</td>
<td>1.7</td>
<td>1.55</td>
<td>68</td>
<td>53</td>
<td>92</td>
<td>74.2</td>
</tr>
</tbody>
</table>

**Table 15.** Tumbler and shatter properties with larger quantity of sample.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Lager quantity as per BIS Standard</th>
<th>Smaller quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tumbler Index, %+6.35 mm</td>
<td>67.5</td>
<td>74.2</td>
</tr>
<tr>
<td>Abrasion Index, %–0.5 mm</td>
<td>7.5</td>
<td>6.4</td>
</tr>
<tr>
<td>Shatter Index, %+5 mm</td>
<td>92</td>
<td>91</td>
</tr>
</tbody>
</table>

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