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Influence of beneficiation plant pellet grade iron ore fines size on pellet Quality

JSW Steel Limited is a 10.0 Mtpa integrated steel plant and 2 corex & 4 blast furnace forms the main iron making units. Sinter and pellet are the main iron bearing feed to iron making units. JSW Steel Limited operates with a 4.2x2 Mtpa pellet plant and the production rate of each pellet plant is ~500t/hr. Pellet plant utilizes 100% beneficiation plant (BP) product for pellet making. Beneficiation plant product size (pellet grade fines) is coarser (-45micron - 40 to 45%) in nature. Optimum particle size of the raw material is required to get the desired properties of the pellets. BP plant has set up two number of ball mill to get the optimum particle size for pellet making. Pelletisation studies were carried out in laboratory by varying the ball mill discharge size from 52 to 68% -45micron size to optimize the pellet grade fines size to achieve desired physical and metallurgical properties of the fired pellets. The desired physical and metallurgical properties of the pellets were obtained with the iron ore fineness 64% -45micron size due to presence of well balanced mineralogical phases.

1.0. Introduction

JSW Steel Limited is operating a 8.4 Mtpa pellet plant (4.2x2 Mtpa) to produce pellets for 2 corex and 4 blast furnace iron making units. JSW Steel Plant receives iron ore fines from different mines of surrounding area of Bellary – Hospet region. JSW Steel Limited has set up 16.0 Mtpa beneficiation plant to reduce the alumina content in iron ore fines to the acceptable level. Pellet plant utilizes 100% beneficiation plant product for pellet making. In beneficiation plant product the -45micron size varies from ~40 to 45% and this product size is too coarser in nature for pellet making. For size reduction of beneficiation plant pellet grade fines 2 No. of ball mills were installed. Optimum particle size distribution of iron ore fines is required to get the desired properties of the green pellets and fired pellets. In iron ore pelletization, process parameters, size of the iron ore fines (% of -45micron size), fuel content of the mix, as well as pellet chemistry govern the microstructural features such as associated phases and their volume fraction, porosity which in turn influences the pellet properties and quality [1]. The laboratory pelletization studies were carried out by varying the pellet garde fines size from 49 to 68% -45micron size to decide the optimum pellet grade fines size for pellet making to achieve desired physical and metallurgical properties of the pellet.

2.0. Experimental

Basket trails were carried out by varying the iron ore fineness i.e. -45micron size from 49 to 68% with the interval of 3%. Iron ore fines were collected from beneficiation plant for detail studies. Particle size distribution of ball mill product is shown in **Table 1**. The -45micron size in the ball mill product is ~ 40.5%. Other raw materials like bentonite, limestone, and coke breeze fines were collected from pellet plant stock yard. **Table 2** shows the chemical composition of raw material. Limestone as well as coke breeze was ground in a laboratory ball mill to get -45micron > 65.0%. The received beneficiation plant product was batch wise ground in a laboratory ball mill to get the -45micron size 49, 52, 55, 57, 60, 63, 65, and 68% for each experiment. The feed mix for each experiment consist of iron ore fines, limestone as a flux to maintain basicity 0.5, bentonite binder 0.80%, and coke breeze to maintain 1.14% carbon and water to maintain optimum moisture 0.85%. **Table 3** shows the pellet green mix

Table1 Size analysis of BP2 WHIMS product

µm	%
+150	8.0
+75	12.8
+63	18.1
+45	20.5
+25	26.0
-25	14.6

Table 2 Raw material chemical analysis

Description	%			
	Iron ore	Limestone	Bentonite	Coke breeze
Fe (Tot)	63.5	1.40	15.66	3.10
Al_2O_3	3.42	2.39	47.36	9.0
SiO_2	2.66	0.59	15.96	5.50
CaO	0.08	49.19	2.62	2.02
MgO	0.01	4.14	3.36	0.36
LOI	2.59	41.6	7.85	4.08
C				71.2

proportion. Green pellets were produced in the laboratory balling discs. The details of balling disc are as follows:

Disc diameter : 450mm
Disc operating angle : 45^{o}
Disc speed : 38rpm

Each set of experiment comprises firing 20 kg green pellets (8 numbers of experiments). The green pellets were kept in rectangular stainless steel baskets (500 mm long) and fired in pellet plant induration machine. The stainless steel basket was kept in the centre of the pellet bed on the hearth layer and it covers entire bed height of the induration machine. The corresponding operating parameters of the plant are shown in **Table 4**. All experiments were carried out at the same machine parameters (Table 4). Fired pellets were subjected to evaluations of chemical, physical and metallurgical properties.

Table 3 Raw material mix proportion

Description	%
	Mix 1
Iron ore	94.6
Limestone	3.6
Bentonite	0.8
Coke breeze,%	1.0

Table 4 Induration machine operating parameters

Description	
Feed rate, tph	455
Machine speed, m/min	2.28
bed height, mm	495
Hearth layer, mm	52
Firing temperature, ^{o}C	1285
Burn through temperature,^{o}C	385
Gas consumption, Nm^{3}/tonne of the feed	59

3.0. Mineralogical studies

Pellet samples of all experiments were collected for microstructural studies. For each study, the pellet sample was divided in to two pieces at the centre using the sample cutter. The pellet sample was mounted in a sample holder using epoxy resin. These sections were polished using silicon carbide paper up to 1000 grit using water as a lubricant. A final polish was made by using diamond paste. For each experiment 2 samples were prepared for microstructural analysis.

Mineralogical characterization studies were carried out using optical microscope. The visible microstructural phases identified as hematite, magnetite, silicate/slag and pores based on the color appearance and shape.

Leica Q-win Image analyser software was used to provide an objective measurement of different phases in microstructure (hematite, magnetite, silicate and pore). The polished sample was placed under a microscope for examination. A camera is mounted behind the lens to capture the image. The eye piece of 50X objective lens was selected for the current study. Images of the each sample were saved in the computer after capturing the image at different places through out the sample. For each sample 24 images were captured for phase analysis. To measure the area fraction of different phases in the pellet various tools of image analyser was used.

4.0. Results and discussion

4.1. Microstructural Investigations

Microstructural investigations were carried out by dividing the pellets into four segments as shown in **Figure 1**. They are defined as:

1. Shell: it extends from surface to 200 mm below
2. Outer mantle: just below the shell (2 mm thick)
3. Inner mantle: just below outer mantle (4 mm thick)
4. Core: innermost part of the pellet (4–5 mm in diameter).

Primary phases present in iron ore pellets are hematite (grey white) magnetite (grey white with pinkish), silicate/slag (dark grey), and pores (black).

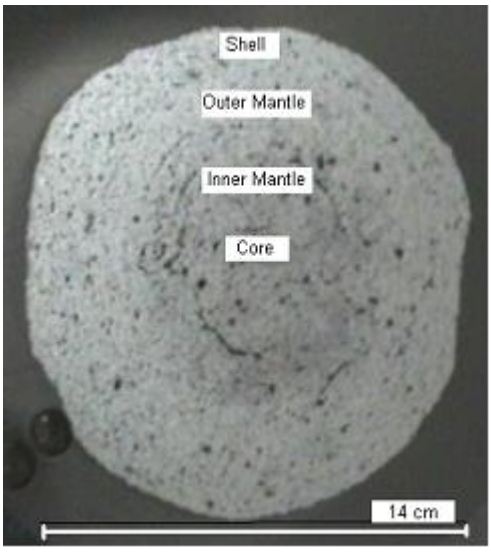


Figure 1 Segments of pellets

Figure 2(a-d) Macrographs of pellet with fineness -45micron 68 & 49%

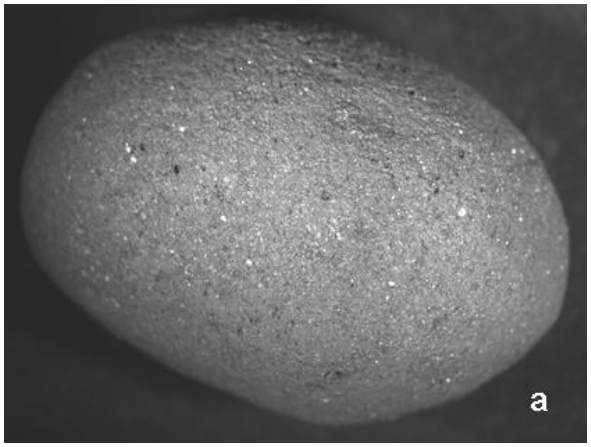


Figure 2a Macrographs of pellet with fineness -45micron 68%

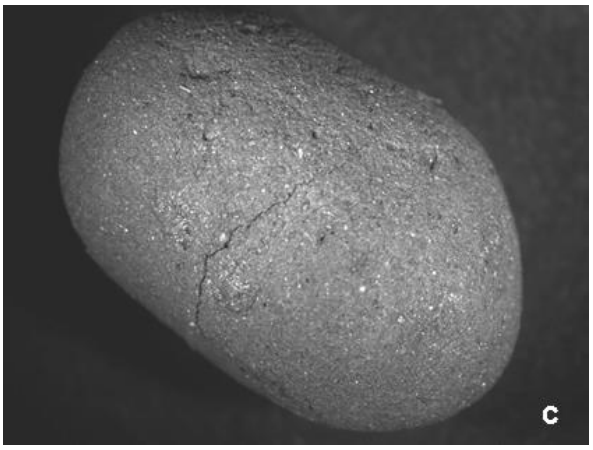


Figure 2c Macrographs of pellet with fineness -45micron 68%

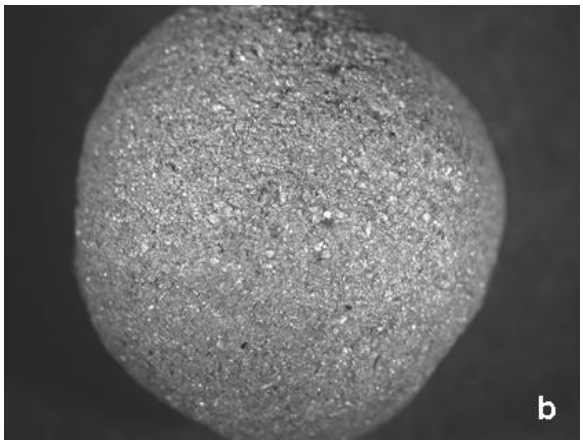


Figure 2b Macrographs of pellet with fineness -45micron 49%

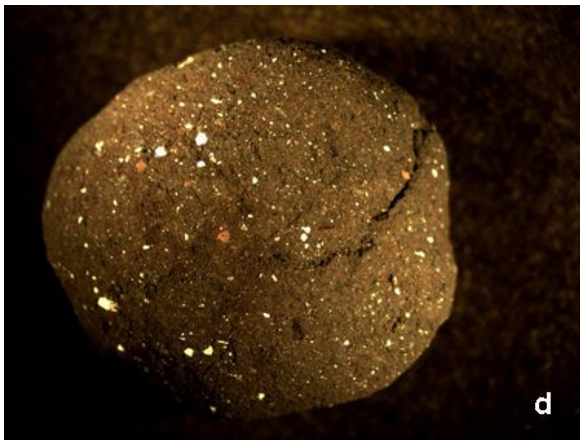


Figure 2d Macrographs of unfired pellet with fineness -45micron 49%

Figure 3(a-g) shows the micrographs of pellet and **Figure 4** shows the phase analysis of the pellet at different fineness i.e. -45micron 49% to 68%.

The macrographs of the pellets at fineness -45micron 68% and 49% are shown in Figure 2a & Figure 2c and Figure 2b & Figure 2d respectively. The surface of the pellet is very smooth and compacted when the fineness of the iron ore was 68% -45micron size (Figure 2a). The some of the pellets were not fired properly due to less porosity of the pellet and insufficient supply of air to the core and inner mantle. The pellet prepared with the iron ore fineness 49% -45micron was exactly opposite to that of the previous one. In this condition the pellet surface is too rough and the particles are not compacted fully. From macroscopic figures it was clear that the porosity of the coarser fine size pellet was higher side compared to finer size iron ore fines. The pellets with fineness 68% -45micron size showed thinner crack on the surface (Figure 2c). In this test more quantity of unfired pellets were observed. The pellet with 49% -45micron size produced more broken pellets and this affects the induration machine bed permeability and generated more quantity of unfired pellets. Some of the unfired pellets showed the thick crack on the surface due to poor bed permeability and weight of the bed.

The micrographs of the pellets at fineness -45micron 49% to 68% are shown in Figure 6a to Figure 6g. With increase in iron ore fineness from -45micron 49 to 68% the pellet porosity decreased and bonding between solid-solid and solid – slag increased.

The micrograph of pellet at optimum iron ore fineness size -45micron 61 and 64% showed balanced mineral phases like hematite, silicate, pore phase and magnetite phase. These pellets consist of crystallized hematite particles with proper slag bonding.

The micrograph of pellet with 68% -45micron size consists of magnetite phase in core and inner mantle. Pellet with iron ore fineness 49% -45micron size consist of higher porosity, less magnetite phase and bonding of hematite particles with slag phase was poor.

With increase in iron ore fineness the magnetite phase increased and pore phase decreased. With increase in iron ore fineness the slag phase increased up to iron ore fineness 64% -45 micron size and afterwards decreased slightly with increase in iron ore fineness.

Figure 3(a-g) Micrographs of pellet with iron ore fineness -45mic 49 to 68%

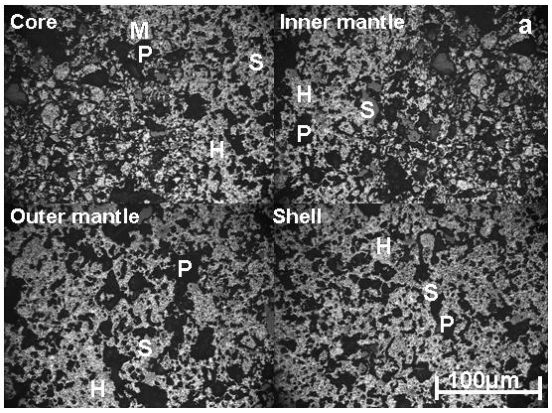


Figure 3a Micrographs of pellet with iron ore fineness -45mic 49%

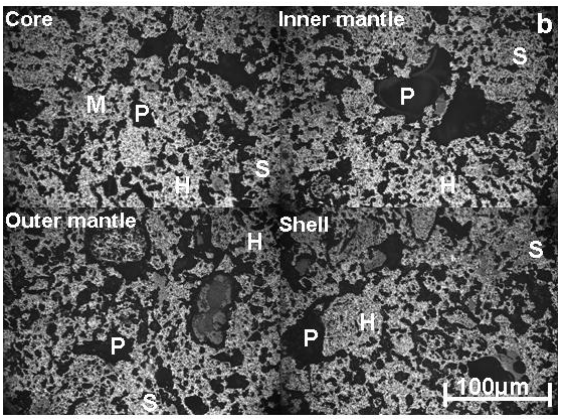


Figure 3b Micrographs of pellet with iron ore fineness -45mic 52%

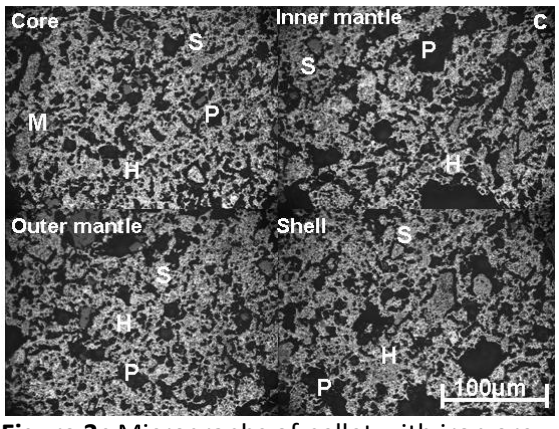


Figure 3c Micrographs of pellet with iron ore fineness -45mic 55%

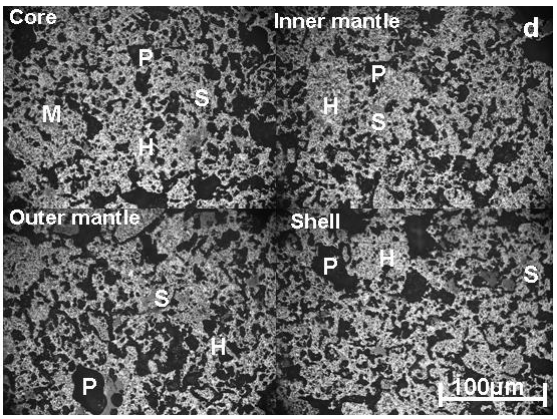


Figure 3d Micrographs of pellet with iron ore fineness -45mic 58%

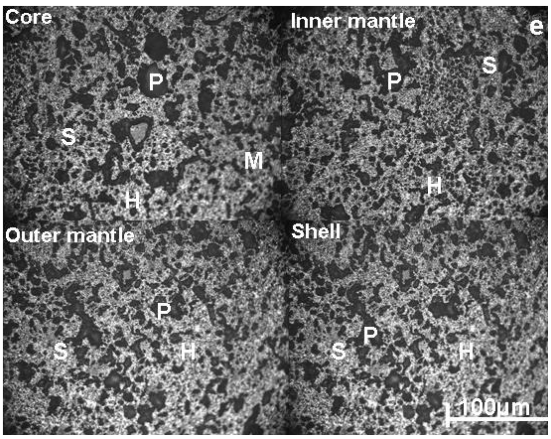


Figure 3e Micrographs of pellet with iron ore fineness -45mic 61%

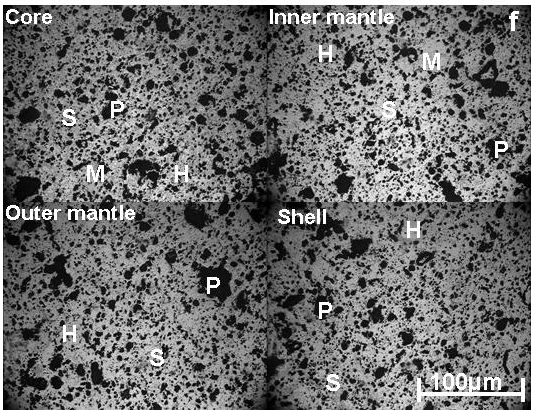


Figure 3f Micrographs of pellet with iron ore fineness -45mic 64%

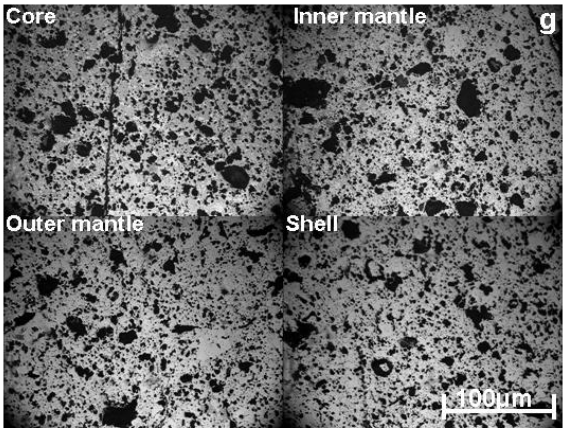


Figure 3g Micrographs of pellet with iron ore

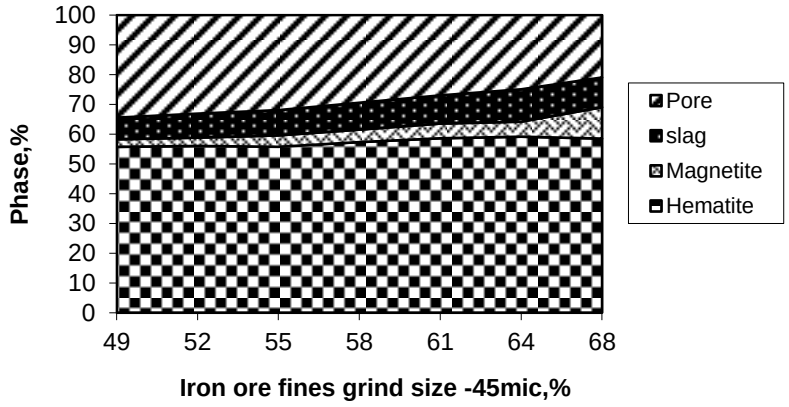


Figure 4 Phase analysis of the pellet at different iron ore fineness

4.2. Influence of iron ore fineness -45micron size on FeO content of the pellet

Figure 5 shows the influence of iron ore fines size (-45micron size) on FeO content of the fired pellets. The FeO content of the pellet increased with increase in iron ore fineness.

At 1100^{o}C the generated CO_2 and CO gas from coke

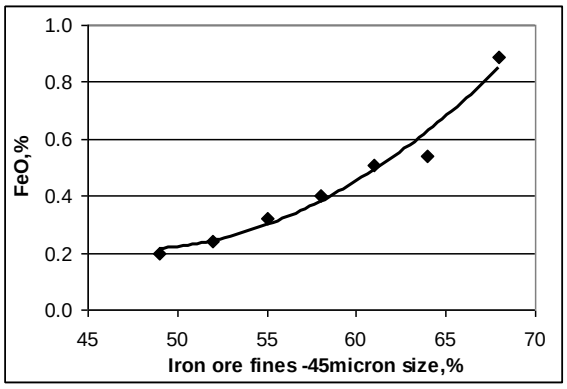


Figure 5 Influence of iron ore fines -45micron size on FeO content of the pellet

breeze combustion lead to builds up carbon monoxide cloud in the internal zone (core and inner mantle) and because of this reason the hematite of the internal part and a significant fraction of the inner mantle reduced to magnetite. With increase in iron ore fineness the porosity of the pellet decreases (Figure7). Due to poor porosity of the pellet the supply of oxygen to core and inner mantle hinders the oxidation of magnetite to hematite. The FeO content of the pellet is directly related to magnetite phase. **Figure 6** shows the influence of magnetite phase on FeO content of the pellet. FeO content of the pellet increased with increase in magnetite content of the pellet. For Iron making units the desired FeO content of the pellet should be less than 0.60%. The iron ore fineness 64% and below 64% of -45micron size consist of optimum FeO content i.e. <0.60%. The control of FeO content in iron ore pellet is rated as a key point of pellet quality [2].

4.3. Influence of iron ore fineness on physical properties of the pellet

Tumbler index is the measure of resistance to generate fines during handling and transportation from pellet plant to iron making units. Cold crushing strength of the pellet is the strength of the pellet to withstand the handling loads during shipping and the load of the burden of iron making units. The desired tumbler index, abrasion index and cold crushing strength of the pellet for iron making unit are 94.0%, 5.0% and 220kg/p respectively. **Figure 7** shows the influence of iron ore fineness on tumbler and abrasion index of the pellet. **Figure 8** shows the influence of iron ore fineness on CCS of the pellet. With increase in iron ore fineness (-45micron size) the tumbler index and CCS of the pellet increased up to -45micron size 64% and after wards both decreased with increase in fineness. The abrasion index of the pellet decreased with increase in iron ore fineness up to -45micron 64% and after that increased with increase in fineness. In iron ore pellet physical properties like tumbler index and cold crushing strength (CCS) of the pellet mainly depends on FeO content, porosity, proper bonding of iron ore particles with slag phase, and re-crystallization of hematite particles (after conversion of hematite into magnetite). At iron ore fineness i.e. -45micron less than 62% showed poor tumbler index and abrasion index due to poor green pellet properties like wet and dry pellet crushing strength, higher porosity, and poor bonding of the hematite particles with silicate/slag phase. The more cracked and broken pellets were observed due to poor green pellet strength and higher porosity with more moisture. **Figure 9** shows the influence of porosity on tumbler and abrasion index of the pellet. **Figure 10** shows the influence of iron ore fineness on broken pellets percentage. With increase in iron ore fineness the generation of broken pellets decreased. Lesser the fineness higher the proportion of broken pellets and this affects the induration bed permeability and poor firing of the pellets. Lesser the

iron ore fines fineness higher the porosity (Figure 7) leads to poor physical properties of the pellet. Strength of the pellet depends on the bonding phases as well as pore phase [3].

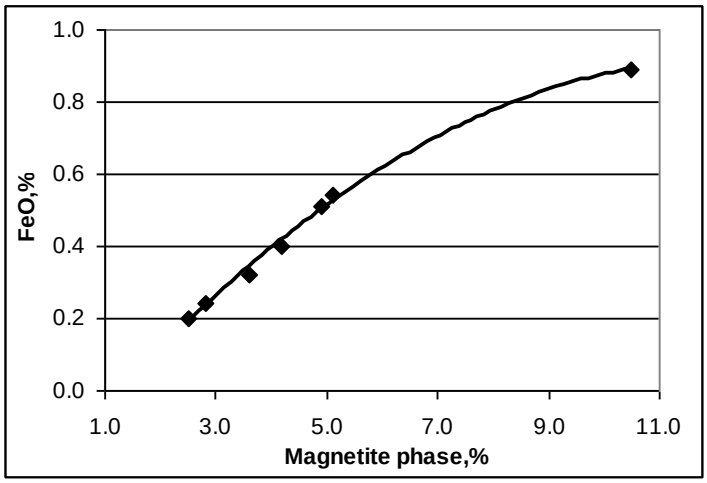


Figure 6 Influence of magnetite phase on FeO content of the pellet

Pellet with higher fineness i.e. more than 64% shows the poor physical properties. This is mainly because of higher FeO content of the pellet and more unfired proportion of the pellet due to lower porosity. FeO % increased in the pellet at iron ore fineness -45micron 68% because of increase in magnetite phase and decrease in pore phase. The process of oxidation of magnetite into hematite is the most important aspect since it has a decisive influence on the strength of the pellets. Due to non-availability of sufficient oxygen, core and inner mantle of the pellet is not oxidised, so full strength is not attained and hence pellets with high-retained Fe_3O_4 show lower strength. The unfired pellets proportion also increased due to lower porosity and this porosity affected the firing of the pellets as well as induration machine bed permeability. Due to unfired pellets the tumbler and abrasion index of the pellet was at lower side due to generation of fines.

At optimum iron ore fineness size i.e. -45micron 61 to 64% achieved optimum physical properties due to formation of pellet with well balanced mineralogical phases with proper bonding of hematite particles with slag phase.

4.4. Influence of iron ore fineness on Metallurgical properties of the pellet

Reduction degradation index of pellets is an adverse phenomenon that occurs at lower temperature i.e. 850°C during their reduction in iron making units like blast furnace. During reduction process the conversion of hematite to magnetite is followed by a volume increase. This initiates the coarser pores and cracks due to mechanical stress [4]. These pellets under the influence of mechanical load degrade. Poor strength pellets can not sustain mechanical loading during reduction hence adversely affects the reduction degradation index of the pellets. **Figure 11** shows the influence of iron ore fineness on reduction degradation index of the pellet. With increase in iron ore fineness the reduction degradation index of the pellet decreased up to -45micron size 64% and after that increased slightly with increase in fineness. The desired RDI (-6.3mm) of the pellet required for blast furnace and corex iron making units are <12.0%. **Figure 12** shows the influence of pore phase on pellet reduction degradation of the pellet. With increase in pellet porosity the RDI of the pellet increased. Kenichi Higuchi also observed that with increase in pellet porosity the RDI also increases [5].

The pellet formed with iron ore fineness less than 64% the RDI of the pellet was at higher side due to poor bonding of hematite particles with silicate phase, higher hematite phase and porosity. In iron ore pellet hematite bonds are common and strong, but they are not stable during the reduction process. During reduction when hematite bonds are reduced to magnetite, silicate bonds remain unaltered.

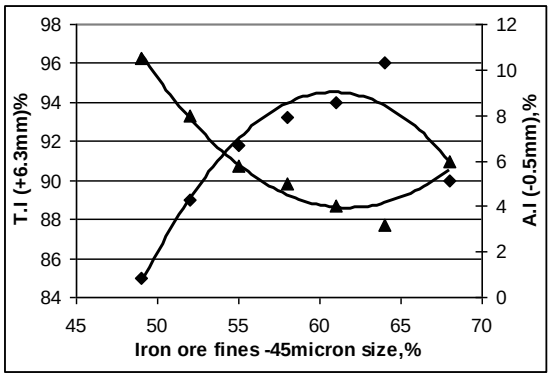


Figure 7 Influence of iron ore fineness on tumbler and abrasion index of the pellet

During reduction process at lower temperature 800 to 1000°C the silicate slag in the form

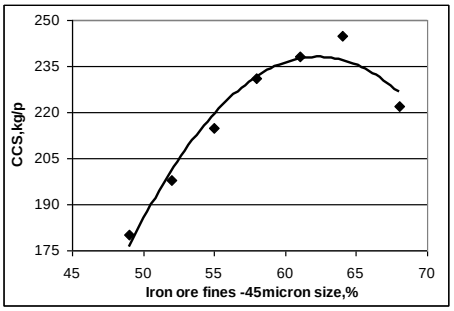


Figure 8 Influence of iron ore fineness on cold crushing strength of the pellet

of plastic state reduce the stress and above 1000°C the metallic frame provides the strength to the pellet. Due to

higher porosity and moisture content in the voids, poor compaction of the iron ore particles, the thicker cracks

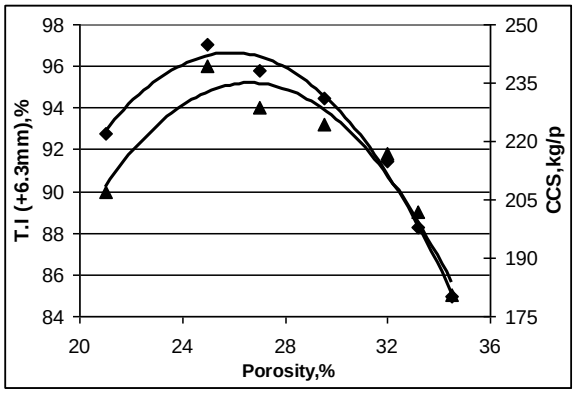


Figure 9 Influence of porosity on tumbler and cold crushing strength of the pellet

were observed on the pellet surface due to generation of internal stress (Figure 5d). Higher porosity pellets shows poor strength and degrades very easily during the reduction process.

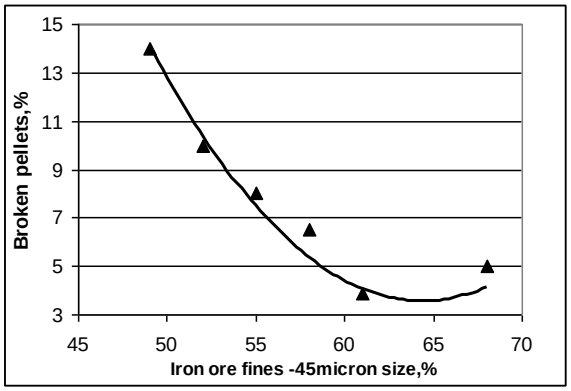


Figure 10 Influence of iron ore fineness on broken pellets percentage

The pellet with iron ore fineness -45micron 64% showed better reduction degradation properties due to the amount of distribution of silicate melt with hematite particles and optimum porosity. These pellets consist of higher hematite phase even though RDI of the pellet was at lower side to due to the proper silicate bonding around the hematite particles. The strength of these pellets was at higher side. Stronger the pellet lower the RDI. The pellets with high amount of silicate melt wets the solid hematite particles facilitate the diffusion and grain growth.

The pellet with iron ore fines -45micron >64.0% showed higher RDI compared to pellet with iron ore fineness 64.0% -45micron size. These pellets consist of lower porosity and observed cracks inside the pellets and poor crystal bonding with silicate melt due to poor firing of the pellets. In this test the unfired proportion was ~6.8% and these pellets generates lot of fines during the RDI test i.e the AI (-0.5mm) was ~7.0%.

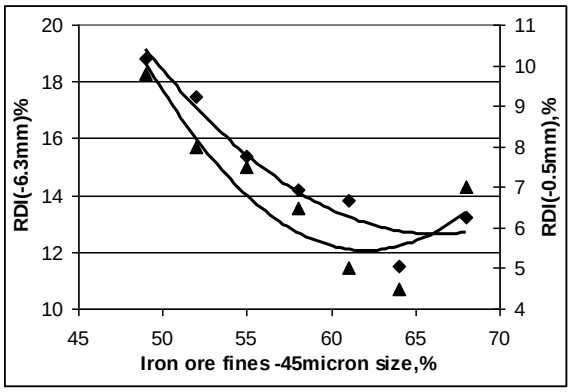


Figure 11 Influence of iron ore fineness on reduction degradation index of the pellet

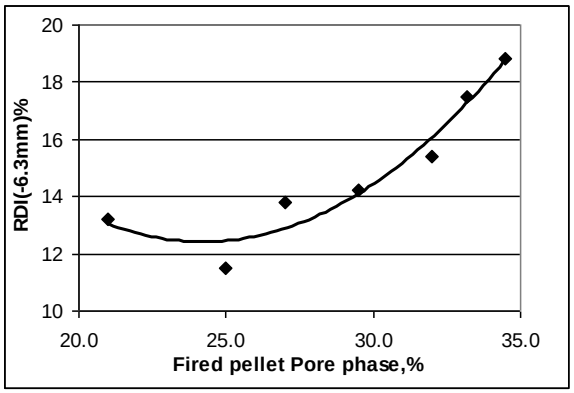


Figure 12 Influence of pellet pore phase on reduction degradation index of the pellet

Figure 13 shows the influence of iron ore fineness on pellet reducibility. The iron ore pellet reducibility decreased with increase in iron ore fineness. Reducibility of the pellet mainly depends on the pore phase and magnetite phase. As the iron ore fineness increases the pellet pore phase decreases and magnetite phase increases. **Figure 14** and **Figure 15** shows the influence of pore phase and magnetite phase on pellet reducibility respectively. The reducibility of the pellet increased with increase in pore phase and reducibility decreased with increase in magnetite phase. The

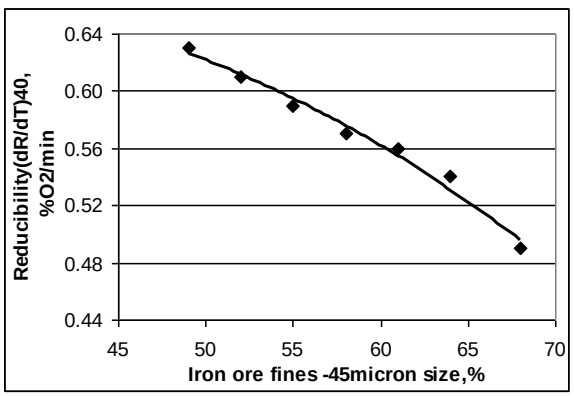


Figure 13 Influence of iron ore fineness on pellet reducibility

reducibility of the pellet largely governed by its porosity and mineralogical phases present. Low magnetite/FeO

content has long been used as an index of good reducibility. The hematite phases are generally easier to reduce. The pellet with lesser iron ore fines size i.e. -45micron <64.0% consists of higher porosity and hematite as major iron bearing phase. The hematite mineral is known to be easily reducible than magnetite.

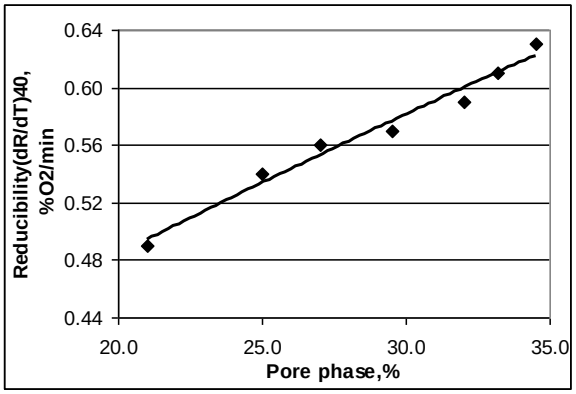


Figure 14 Influence of pore phase on pellet reducibility

The pellet with higher iron ore fineness i.e. -45 micron >64.0% consist of higher magnetite phase and lower pore phase. Reducibility of these pellets shows lesser values compared to pellet with lower iron ore finness.

The slag phase/silicate phase increased with increase in iron ore fineness. The presence of slag as a bonding constituent tends to cause shrinkage of the pellets and reduce the micro porosity, which, in turn increases the time required for reduction. The effects are brought out by Merklin and De Vancy [6].

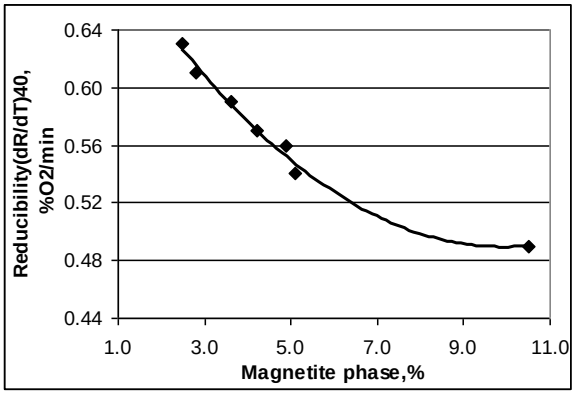


Figure 15 Influence of magnetite phase on pellet reducibility

5.0. Conclusions

1. The magnetite phase increased and pore phase decreased with increase in iron ore fineness -45micron size.
2. The slag phase increased with increase in iron ore fineness from 49 to 64% -45 micron size and afterwards decreased with increase in iron ore fineness from 64 to 68% -45 micron size.
3. The hematite phase decreased with increase in iron ore fineness from 49 to 64% -45 micron size and afterwards increased with increase in iron ore fineness from 64 to 68% -45 micron size.
4. FeO content of the pellet increased with increase in iron ore fineness of -45micron size from 49 to 68%. This may be due to decrease in pore phase and poor supply of oxygen to core and inner mantle for oxidation of magnetite.
5. The tumbler index and cold crushing strength of the pellet increased with increase in iron ore fineness from 49 to 64% -45 micron size and afterwards decreased with increase in iron ore fineness from 64 to 68% -45 micron size. At optimum iron ore fineness size i.e. -45micron 61 to 64% achieved optimum physical properties due to formation of pellet with well balanced mineralogical phases with proper bonding of hematite particles with slag phase.
6. The reduction degradation index of the pellet decreased with increase in iron ore fineness up to -45micron size 64% and after that increased slightly with increase in fineness. The pellet with iron ore fineness -45micron 64% showed better reduction degradation properties due to the amount of distribution of silicate melt with hematite particles and optimum porosity.
7. The iron ore pellet reducibility decreased with increase in iron ore fineness due to increase in magnetite phase and decrease in pore phase.
8. The desired physical and metallurgical properties of the pellets were obtained with the iron ore fineness 64% -45micron size due to presence of well balanced mineralogical phases

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