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Study and Implementation of Quality Improvement Techniques to Improve the Consistency in Cold Crushing Strength of Iron Ore Pellets

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Abstract - Iron ore pellets plays vital role in the success of the steel industry across the globe. Maintaining consistent quality of pellets is very important to achieve good reducibility and productivity at both blast furnace and direct reduction processes. Physical parameters like cold crushing strength and shatter index of iron ore pellets are very critical for their handling and use. Cold crushing strength (CCS) of iron ore pellets varies widely from as low as 80 Kgf / pellets to as high as 350 Kgf /pellets depending upon the input material quality and the process variables. The most preferred range of CCS of iron ore pellets is 180-240 Kg f / pellets which were normally found in the proportion of 35-40% at the plant. The current investigation focuses on study and implementation of various quality improvement techniques to increase the proportion to the level of 60-70% and improve the cold crushing strength of iron ore pellets.

Keywords: Abrasion Index, Porosity, Tumbler Index, Blaine Number

I. INTRODUCTION

Iron orepelletization is a process of agglomerating iron ore concentrate produced by beneficiating low grade iron ore. Looking at the current scenario of iron ore availability in India, pellets are expected to replace iron ore lumps in the long run. Indian steel industry has to look forward to utilize the excess availability of iron ore fines. Hence, pelletization is going to be the necessity to sustain in the coming years and it will be a cheaper route to manufacture steel. The evolution of iron ore pellets will gradually decrease dependence on iron ore lumps. But, since the demand of iron ore fines is expected to rise with the additional capacity of pellet production, its prices are definitely going up. Plants without captive mines will be at disadvantage and for such plants quality of pellets will be a key factor to sustain. Thus the study focus on implementation of quality improvement techniques to improve the consistency in Cold Crushing Strength (CCS) in the acceptable range of 200-240 Kgf/Pellets from the present proportion of 35-40% to 60- 70%.

II. NEED FOR PELLETIZATION

The following are the factors which influence the need for pelletization of the iron ore:

1. Steep rise in the prices of raw materials for DRI & Pig Iron production
2. Good productivity, product quality and reasonable campaign life is very important amongst fierce competition and low grade iron ore availability.
3. To meet ever increasing demand for iron ore with growth in Steel i.e. 110 million tones by 2020
4. Improved productivity and efficiency of the rotary kiln & Blast Furnace with superior reducibility behavior of pellets compared to lump ore.
5. Catering to the iron ore demands of all the DR/ Steel plants in the country.
6. Good reducibility
7. Less consumption of coal
8. High Tumbler Index
9. Uniform chemical composition
10. High uniform porosity
11. Increased campaign life
12. Less fines generation at the time of reducing
13. Easy handling and transportation

Pelletizing is the process of converting iron ore fines into "Uniformed Sized Iron Ore Pellets" that can be charged into the blast furnaces or for Production of Direct Reduced Iron (DRI) [1].

1. Process objective is to transform fine iron ore concentrate into pellets suitable to feed Blast Furnace or Direct Reduction plant or COREX.
2. Pelletization was invented to make use of Blue dust and ultra-fine concentrate generated in the Iron ore beneficiation plants.
3. Pellets have the benefit of lower gangue on account ofbeneficiated ore.

TABLE I SPECIFIC CONSUMPTION OF RAW MATERIALS (PER TON OF PELLETS)

Raw Material	Quantity
Iron ore fines	1.25 MT.
Coal	40kg
Fuel Oil	12 ltr
Bentonite	0.4 to 1.0 kg
Lime stone power	0.4 to 0.7 kg

III. PROCESS TECHNOLOGY

Pellets are normally produced in the form of Globules from very fine iron ore (normally –100 mesh) (Ground Ore with additives and water are mixed together to be balled in to pellets) and mostly used for production of sponge iron in gas based plants, though they are also used in blast furnaces in place of sized iron ore.Stages of pelletization process:

Stage I- Raw material preparation

Stage II- Formation of green balls

Stage III- Induration of green balls & screening

A. Grinding of iron ore fines to liberate gangue

Wet Grinding requires less power per ton of material ground than dry grinding.Wet grinding requires less space than dry grinding if classifiers are required.Wet grinding does not require elaborate dust control equipment

B. Hydro Cyclone

Hydro-cyclones use the principle of centrifugal separation to remove or classify solid particles from a fluid, based on particle size, shape and density. It utilizes centrifugal forces to increase the settling rates of the particles, the coarser of which reaches the cone's wall is discharged through the underflow and the fine particles with major portions of feed water reports to the overflow of the cyclone.

C. Spirals

A spiral concentrator is a flowing film separation device. General operating principle of spiral is continuous gravitational laminar flow.

D. Thickeners

The major principle involved in thickening is the gravity sedimentation. Industrial sedimentation is conducted as a continuous process in thickener. It receives the slurry at the center, permits the overflow of the supernatant liquid through over weirs in periphery and discharge thick slurry from the bottom. The tank bottom is made conical to facilitate the discharge of the underflow slurry. The tank is fitted with rakes, which are rotating railings with fixed vertical plates and positioned slightly above the tank bottom.These rakes scrap the concentrate slurry towards the central discharge. When the particles are more in fine nature or charge particles, settling rate is extremely slow. By adding flocculent, the rate of settling of particles can be enhanced.

E. Filtration

Filtrationis the final part of iron ore beneficiation process. After Filtration, the moisture of iron ore slurry is reduced to 9 -10%. The water discharged during filtration is recycled and the filter cakes are sent for pelletization.The settling of particles in different zones in thickener:

a) Clear liquid zone
b) Thickening zone
c) Transition zone
d) Compact zone

F. Fineness of filter cake (Blaine Number)

It is the measure of the total exposed surface area of a ground material. Units of surface area are expressed in square centimeters per gram. It is an important parameter of iron ore concentrate affecting porosity and strength of pellets.

IV. FORMATION OF GREEN BALLS

A. Proportionate mixing of input materials (iron ore concentrate with additives like coal, limestone and bentonite powder)

The ore being pelletized must have a sufficiently fine particle size distribution/Blaine surface area. (Optimum Blaine is between 1900 to 2000 cm^2/gm.) -45 micron fraction in the grind must be above 70%. Sufficient moisture is needed to make the ore sticky enough to pelletize around 8.5 to 9.5% moisture is considered optimum. A binder is necessary to hold the particle grains together after the pellet is dried and before it is finally heat hardened.

B.Disc Pelletization

It is essentially a disc, with an outwardly sloping peripheral wall, which is rotated, around its own centre, in an inclined position to horizontal as shown in Figure 1. This disc assembled flying saucers are normally 6.0 meter in diameter and are inclined at about 45 degree to the horizontal. The material to be pelletized is generally fed directly on to the disc and the moisture is made up with the help of water sprays. Scrapper is provided to prevent buildup of moisture material on the disc. It can also control the material flow pattern on the disc.

In the region where water is added seeds are easily formed. With the growth of these seeds there frictional drag against the disc decreases and the centrifugal force acquired by them increases and, consequently they move out of nucleation zone. They also tend to rise on the inclined surface of the pelletizer in the direction of rotation and fall down against the toe section of the disc. The height and width of trajectory of the ball movements increases with the size of the ball until eventually the balls are deflected downwards by the scrapper. During this movement the ball encountered fresh feed and growth takes place more by layering while compaction- assimilation plays a relatively minor role. In a continuous operation the discharge of desired size ball is balanced by an equivalent of addition of feed.

Fig. 1 Disc Pelletizer

V. INDURATION OF GREEN BALLS AND SCREENING

Induration is a process in which pellets are subjected to drying, preheating, firing and cooling.Pellets are hardened by the above thermal treatment in the following stages:

a) Drying of green balls.

b) Heating of dried pellets and oxidation of magnetite pellets up to induration temperature.

c) Firing at induration temperature.

A. Drying & Pre-heating

I. Travel Grate Process

Travelling grate machine is having completely closed hood with many interconnected thermal zones for recirculation of gas leading to maximum heat recovery.The machine consists of three main parts,

a. Upper part comprises the heat energy and air supply system in astationary hood abovethe entire grate length with burner system in thefiring zone.

b. Bottom part is composed of the stationary wind boxes connected withgas mains.

c. Central part is movable and consists of pallets, composed of a frameand a supportingstructure into which grate bars are inserted. Thepallets are connected to the wind boxes bymeans of sliding seal bars ina gas tight manner.

II. Down Draft Drying zone- 1

Where the initial green pellets feed moisture (free moisture) is removed. Hot gases recuperated from pre-heating zone are used for drying purpose.Before subjecting the green pellets to high temperature, they must be dried to prevent rapid release of steam. Too rapid release of steam results in cracking, spalling, or explosion of the green pellets.

III. Down Draft Drying Zone- 2

Because the moisture is not completely removed from the bed of pellets in drying zone-1, another downdraft drying zone is required. In downdraft drying-2, the removal of the free moisture of all of the pellet bed is essentially completed. A gain in compressive strength of the pellets throughout the bed is noted once the drying phases are completed.

IV. Pre-heating:Zone-1 &2

In this zone removal of combined moisture, conversion of iron oxide to hematite and gasification of solid fuel takes place.Hot gases recuperated from cooling zone-1 are utilized for this purpose. Preheating zone serves to heat the pellets to an intermediate temperature before subjecting them to indurating temperatures and thus avoiding the development of undue stresses within the pellet bodies.

V. Bed Height

At all times the total material depth on the grate should be kept at ~160-170 mm. Uniform bed height is a criteria for better furnace control. This in turn is obtained by making the feed consistent. But too much increase in bed level will affect the bed permeability (a tight bed) and will cause higher energy consumption by fans.

Fig. 2 Travelling Grate

Fig. 3 Pellets after Screening to T.G

B. Firing

The strength of the pellet is developed initially at the shell and progresses towards the centre with time at the firing temperature. The bond strength is essentially developed at the firing temperatures but the heating cycle should be decided in relation to the chemistry of the pellets so as to finally develop optimum quality of hardened pellets. The heat evolved during the oxidation of magnetite ore or sulphides is by far the largest source of energy which must be carefully utilized in the promotion of grain growth and liquid bond formation. The calcinations of minerals, on the contrary requires heat and which must be accomplished without disintegration of the pellets. It should also be completed ahead of the time when maximum firing temp is reached. Optimum fuel economy should be achieved by carefully planning the firing cycle.

It should be clear that heat requirement for hardening hematite pellets are more than those for magnetite and similarly those for Geothite, limonite etc. are more than those for hematite.In general firing temperatures in the range of 1250-1350 degreeC, are sufficient to produce pellets of the required qualities. Higher temperatures lead to excessive slag formation and less porous pellets a quality detrimental to DRI use. The actual firing temperature is decided in terms of the basic feed material, the additives, the holding time at the maximum temperature, the size of the pellets and the ultimate quality of pellets required.

I. Firing time

A given strength can be achieved either by lower temperature & longer firing time or higher temperature and shorter firing time.

Fig. 4 Central Burner

II. Cooling

a. Annular Cooling

Cooling of pellets is necessary for recovery and recirculation of sensible heat, so that the heat requirement for induration is minimum and saves energy. Crystalline and Glassy compounds arising during Induration are damaged by a too rapid cooling.

b. Cooling zone-1 & 2

Hot pellets are cooled gradually with ambient air before being stacked. Process air is supplied from cooling zone-1.In the first cooling zone, the gases recuperated will be used in the Kiln firing zones, while the gases recuperated from the second cooling zone will be used in Pre-Heating zone-1.

Fig. 5 Annular Cooler

C. Quality assurance at Pellet Production

The quality assurance at pellet production starts with careful selection of raw materials like iron ore fines as per the laid down specification. The Fe(Total) content, Gangue like SiO2 & Al2O3 and impurities like Phosphorous are the determining factors for the output quality.The process control parameters are being measured and monitored at each processing stages to assure quality for the next stage.Finally, the product quality is assured by monitoring and control of key quality parameters of the product. The products with quality deviations are segregated and suitably identified to ensure quality of the bulk product during production.The key quality parameters have been identified in the specification sheet.

D. Factors affecting the Cold Crushing Strength of Iron Ore Pellets

The principal factors responsible for the variation in cold crushing strength (CCS) of pellets are as under:

1. Porosity of the pellets
2. Temperature of induration
3. Degree of fineness of iron ore concentrates
4. Quality & quantity of binder additive
5. Green ball Strength
6. Granulometry of iron ore fines
7. Moisture content of green ball
8. Size of green ball pellets

VI. METHODOLOGY

The Quality Improvement tools like Root Cause analysis, Brainstorming, Pareto analysis, scatter diagrams etc. of the actual plant data supported by the required technical inputs related to production process technology. The study may include few experimental trials to achieve the desire improvement.

A. Laboratory set up for test results

The experimental set up to go ahead with the project is to conduct trails by adjusting the following during the process:

1. Physical parameters of the input materials
2. Chemical parameters and the % of additives, and
3. Process control parameters within the practical limits of the process technology

B. Laboratory Test method for Cold Crushing Strength [8]

Principle: This standard prescribes the method measuring the crushing strength of indurated iron ore pellet at ambient temperature.

Sampling tools required: Sampling scoop, steel bucket & refill decider.

Apparatus: CCS machine & load cell capacity 1000kg.

Sample: Collect 20 pellet sample between 12.5 mm and 10 mm size then dried it 105+/-5 ^{0}C.

Test Procedure:

1. Place a single pellet at the center of the lower platen of the testing machine.
2. Apply load at a speed of 10mm/minute of compression platen on each pellet throughout the test period.
3. Record the maximum load at which the pellet undergoes complete breakage to nearest 5kg for each pellet.

Result: The final crushing strength, expressed in kilograms, of the test sample shall be reported as the arithmetic mean value of all the readings to a whole number.

C. Other Tests

1) Particle Size Analyzer

The analyzer is fully automated where the laser intensity has to be a minimum of 60% and laser obscuration and the range of 10%-20%. The sample is mixed with distilled water where the camera takes 2000 pictures in a minute to determine the fractions of the particle size.

2) Cold Crushing Strength

It is used to determine the strength of the pellet. A easy process where the end product is placed on a base plate.The force is then acted upon by the pressure plate. Readings are obtained digitally and noted as and when the pellet breaks.Unit =kg/ pellet.

3) Blaine Number

Again a simple process where weights are calculated and are put in the formula to calculate the Blaine number.

Specific gravity= W_4-W_1/W_3-W_2 x100

Blaine No.= 60000/reading x sp. gravity cm^2/gm

4) Drop Number

Repeated drop of 9-16 mm green pellets onto a steel plate from a height of 46 cm without any cracks on the green balls, measures the ability of the wet pellets to retain their shape during transfer operations. A pellet should with stand at least 10 drops, which also depends on the number of transfer points between the balling equipment and the induration machine.

5) Green Ball Crushing Strength (GCS)

Green balls on conveyor belts and grates should with stand a certain load. Wet compressive strength is a measure of how much load a pellet can bear and determined by applying a certain load onto a pellet until it cracks. It should ideally be greater than 1.0 kg/pellet.

6) Dry Crushing Strength(DCS)

In travelling grate minimum dry pellet strength is necessary so that the pellets withstand the load of layers located above or the pressure of gases flowing through the charge. A dried pellet is crushed and the maximum load is recorded. It measures the ability of dried pellets to survive handling during the firing process. Should be a mean value of at least 2.24 kg/pellet.

7) Pre-Heated Pellet Strength

Especially, when pellets are produced with the grate-kiln cooler technology, they are pre-heated in the travelling grate prior to firing in the kiln. The pre-heated pellets from the grate are discharged by cascading into the kiln. Therefore, such pellets should be strong enough not to disintegrate during cascading and tumbling in the rotary kiln. In the case of weak pellets, dust and chips generated as a result of disintegration will cause losses in plant efficiency, in terms of both productivity and quality.(30 to 40 kg/p)

8)Cold Crushing Strength (CCS)

Fired (indurated) pellet is crushed and the maximum load is recorded. It measures the ability of product pellets to survive handling during shipment and reduction. Pellets should have a mean product pellet compressive strength value of minimum 200 kg/pellet with the <80 kg/pellet fraction less than 5%.

VII. RESULTS

Factors induced in order to meticulously control CCS variation.

1) Tumble Index

To know resistivity of pellets/resistance to de-gradation. 15 kg representative sample of the material to be tumbled is prepared from +6.3mm to –20 mm size. The sample is put into a tumbler drum and rotates for 200 revolutions @25 rpm. The tumbled material is screened at +6.3mm and +0.5mm size. The weight of the material at +6.3mm size is weighed and itsweight % is calculated, which determines the tumblerindex of the material.

2) Abrasion Index

The weight of the material passing –0.5mm size is weighed and weight % is calculated which determines the abrasion index of the material. Tumbling and abrasion procedure consists of subjecting product pellets (-18+6.3 mm) to 200 revolutions at 25rev/ min in a drum. The Tumble index (TI) is given by the percentage weight of +6.3 mm material surviving the test, and Abrasion index (AI) by the percentage of -0.5 mm material produced. Product pellets should have a TI of 92 - 97% and an AI of 2.5 - 5.0%

3) Porosity

Porosity of typical wet and dry pellets is in the range of31 - 36% whilst it should be 20- 28% for fired pellets. Pellets must have a substantially higher strength primarily to withstand their transportation and stresses occurring in metallurgical operation. Such strength can be achieved by thermal treatment (Induration) under controlled atmosphere.

TABLE II DATA ANALYSIS OF CCS WITH POROSITY

Plant Data Analysis-Tables & Graphs

Table no 4.2- Data analysis of CCS with Porosity

Month of February'14		
Date	CCS % (180-240)	Porosity
1-Feb-14	35.34	25.68
2-Feb-14	31.25	23.93
3-Feb-14	33.12	25.52
4-Feb-14	29.38	25.28
5-Feb-14	31.45	25.00
6-Feb-14	28.75	25.01
7-Feb-14	35.41	22.75
8-Feb-14	24.36	23.76
14-Feb-14	28.54	25.20
15-Feb-14	34.58	24.29
16-Feb-14	28.16	24.38
18-Feb-14	18.54	25.63
19-Feb-14	31.25	25.74
20-Feb-14	21.04	26.39
21-Feb-14	17.29	21.75
22-Feb-14	8.54	18.85
23-Feb-14	6.66	17.96
24-Feb-14	3.75	16.81
27-Feb-14	18.12	23.32
28-Feb-14	22.29	22.96

Month of March'14		
Date	CCS % (180-240)	Porosity
1-Mar-14	35.52	22.90
12-Mar-14	32.29	21.86
13-Mar-14	37.92	23.67
14-Mar-14	41.04	26.28
15-Mar-14	34.30	25.80
16-Mar-14	31.46	25.04
17-Mar-14	36.46	25.00
18-Mar-14	32.29	24.64
19-Mar-14	26.46	24.18
20-Mar-14	25.63	24.74
21-Mar-14	32.92	25.01
22-Mar-14	28.75	25.09
23-Mar-14	32.50	25.21
24-Mar-14	34.17	22.64
25-Mar-14	31.94	23.21
26-Mar-14	32.69	24.11
27-Mar-14	27.51	24.38
28-Mar-14	32.48	24.59
29-Mar-14	38.96	23.92
30-Mar-14	37.82	25.05
31-Mar-14	37.82	23.43

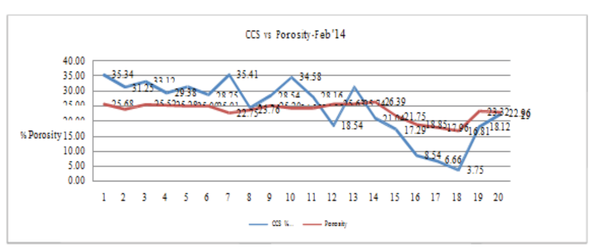

Fig. 6 CCS versus Porosity Feb'14

The Figure 7 shows the CCS versus Porosity for the month March 2014 in the plant as per the data in Table II.

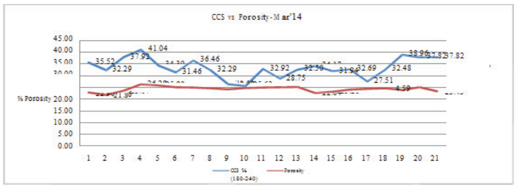

Fig. 7 CCS versus PorosityMarch'14

The Figure 7 shows the CCS versus Porosity for the month March 2014 in the plant as per the data in Table III.

TABLE III DATA ANALYSIS OF CCS WITH BINDER

Table no 4.5- Data analysis of CCS with Binder

Month of February'14			Month of March'14		
Date	CCS % (180-240)	Binder %	Date	CCS % (180-240)	Binder %
1-Feb-14	35.34	14.00	1-Mar-14	35.52	7.72
2-Feb-14	31.25	16.01	12-Mar-14	32.29	12.13
3-Feb-14	33.12	18.78	13-Mar-14	37.92	8.51
4-Feb-14	29.38	21.34	14-Mar-14	41.04	9.36
5-Feb-14	31.45	15.14	15-Mar-14	34.30	8.27
6-Feb-14	28.75	17.30	16-Mar-14	31.46	8.90
7-Feb-14	35.41	11.67	17-Mar-14	36.46	7.82
8-Feb-14	24.36	4.20	18-Mar-14	32.29	8.03
14-Feb-14	28.54	9.82	19-Mar-14	26.46	7.51
15-Feb-14	34.58	4.76	20-Mar-14	25.63	7.72
16-Feb-14	28.16	6.29	21-Mar-14	32.92	10.85
18-Feb-14	18.54	9.25	22-Mar-14	28.75	7.29
19-Feb-14	31.25	8.99	23-Mar-14	32.50	8.81
20-Feb-14	21.04	11.31	24-Mar-14	34.17	8.55
21-Feb-14	17.29	10.01	25-Mar-14	31.94	8.16
22-Feb-14	8.54	6.97	26-Mar-14	32.69	9.06
23-Feb-14	6.66	10.78	27-Mar-14	27.51	11.21
24-Feb-14	3.75	9.79	28-Mar-14	32.48	10.23
27-Feb-14	18.12	8.25	29-Mar-14	38.96	10.25
28-Feb-14	22.29	17.01	30-Mar-14	37.82	9.64
			31-Mar-14	37.82	6.53

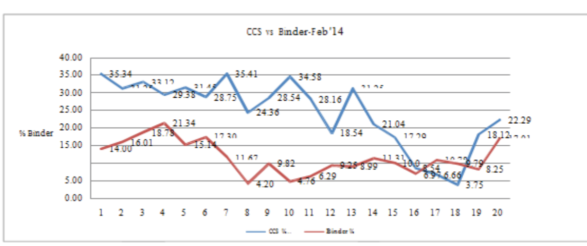

Fig. 8 CCS versus Binder Feb'14

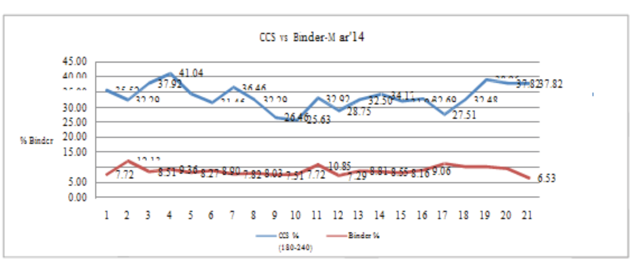

Fig. 9 CCS versus Binder March'14

The Figure 8 and Figure 9 shows the CCS versus Binder for the month February and March 2014 in the plant as per the data in Table 4.

VIII. CONCLUSIONS

The study of various process variables for their effect on preferred range of cold crushing strength of iron ore pellets based on the process study and the process parameters lead to the following conclusions:

1. Porosity in the range of 22-28% is preferred for improving the results when in range gives a 67% rise in efficiency of DRI plants.
2. MPS in the range of 10.5 to 11.5 mm may give better desired results.
3. The other variable whose effects are not evident can be maintained within their acceptable ranges.
4. 4.Product pellets should have a TI of 92 - 97%and an AI of 2.5-5.0%. Maintaining TI and AI would increase the consistency of CCS making it as the idea raw material for sponge iron plant.

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