Production of High Quality Iron Pellets by Changing the Composition and Firing Conditions

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Abstract

There are no Iron ore mining activities and very few Iron extraction activities in Sri Lanka due to high electricity consumption and nonavailability of proper survey results of those ore deposits. Main components need for Iron melting are Iron ore, Limestone and Coke. The Hematite ($Fe_2O_3.XH_2O$) percentage in Dela Iron ore is 88.71%, SiO_2 percentage is 7.18% and Al_2O_3 percentage is 1.07%. Blast furnace is the most suitable method to extract Iron in Sri Lanka considering the cost and the necessary resources. Cupola furnace has the same mechanism of the blast furnace which has been used for laboratory scale Iron melting. By changing the composition and firing condition, high quality pellets were produced. While extracting Iron, huge amount slag formation is the main draw back in Iron making. By comparing degree of magnetism, degree of reduction, apparent porosity, apparent specific gravity, bulk density and water absorption, high quality pellets were produced. The optimized carbon percentage for pelletizing with optimized induration temperature were determined using above tests. Physical, chemical errors and further improvement of this procedure have been discussed in this research.

Keywords: Dela Iron, Iron Pellets, Pellet Optimization

1. Introduction

In 2015, total world crude steel production was 1,599.5 million metric tons (mt). The biggest steel producing country is currently China, which accounted for 50.3% of world steel production in 2015 [1]. In 2008 and 2009, output fell in the majority, of steel-producing countries as a result, of the global recession. In 2010, it started to rise again. China and India have an insatiable appetite for Iron ore for its rapidly growing steel industry. Therefore, Iron production will have a higher value in near future.

Currently there are no Iron ore mining activities and very few Iron extraction activities in Sri Lanka due to high power consumption. Iron ore and limestone are two of the available raw materials in Sri Lanka for Iron making. There are several Iron ore deposits in Sri Lanka such as, Panirendawa, Seruwila, Wilagedara, Eheliyagoda, Kalutara, Ambalangoda, Deniyaya etc [2]. In these deposits there are

2.2 million of tons of Iron ore. But no mining operations are started yet in Sri Lanka. Iron ores are rocks and mineral deposits from which clanging Iron can be reasonably extracted. The Iron by its own is usually found in the structure of Magnetite (Fe_3O_4), Hematite (Fe_2O_3), Goethite, Limonite or Siderite however, proven reserves of Iron ore deposits in Sri Lanka have not been scientifically estimated yet also. But availability of Limestone and possible utilization of imported coal will enhance the Gross Domestic Product of Sri Lanka. Therefore, it is important to investigate the possibility of extracting Iron using locally available resources.

Dela Iron ore in Ratnapura is used as the main material to extract metallic Iron in a Cupola furnace. The Dela Iron ore consists of $Fe_2O_3.XH_2O$, SiO_2 and Al_2O_3 88.7%, 7.18% and 1.07% respectively [3].

There are several industrial methods which are used to extract Iron such as furnace methods and electrolysis. Iron can be extracted by the blast furnace because Iron can be displaced by Carbon. This is more efficient method than electrolysis and other furnace methods because it is more cost effective. Other methods required high electricity power which is one of the most expensive energy providing system in Sri Lanka.

Blast furnace is the most suitable method to extract Iron in Sri Lanka considering the cost and the necessary resources. Cupola furnace has the same mechanism of the blast furnace. Therefore, this research work has been done to extract iron using Cupola furnace.

In this research several aspects were considered when performing Iron extraction process, such as temperature of the muffle for fired pellets, studying the fired pellets characteristics, producing optimized Iron ore pellets, extract Iron from cupola furnace, studying the extracted pig Iron characteristics. Recently induction furnace is used in steel melting worldwide. But using that method, Iron can't be extracted from Green Iron pellets because they do not have electrical conduction properties. Therefore, current is not pass through the Iron ore, so no heat is generated. Therefore, studying of Iron extraction using cupola furnace is discussed in this research.

2. Methodology

2.1 Pelletization

Palletization of Iron ore involves the following Four stages:

1. Raw Material Preparation: This step involves:

- Grinding of Iron ore was done using Tema mill to obtain uniform particle size
- Concentration of Iron ore and separation of unwanted gangue material
- Mixing of Iron ore, Coke and Aruwakkalu limestone for preparation of agglomeration mixture.
- Crushing of raw materials mentioned above – jaw crusher followed by Tema mill.
- Sieving of crushed materials by 150 microns BS sieve set to get fine powder.

2. Green Pellet Formation: In this step, Iron ore, Coke and limestone were mixed according to following ratios.

Table 1 - Carbon mixing ratios

	Mixing ratio (parts by weight)		
Sample no	Iron ore (g)	Aruwakkalu lime (g)	Coke(g)
1	100	7	2
2	100	7	4
3	100	7	6
4	100	7	8
5	100	7	10

The pellets were made by addition of moisture. The ball formation was done in, Laboratory ceramic ball mill – Provision for water spray was made while the material to be pelletized was fed directly on to the ball mill [4].

The major forces acting on the Green balls are the capillary forces and the surface tension due to the water content. The liquid-solid interface acts cohesively to bind the particles together [5].

3. Formation of pellets

Dried pellets were fired at temperatures of 1175°C, 1225°C, 1275 °C and 1325°C in the muffle furnace [6].

2.2 Influence of Carbon Addition and Firing Temperature on Degree of Oxygen Reduction

Weight of green Iron pellets were measured before those were put in to the muffle furnace. Then fired pellets were produced according to the above steps. After fired pellets' temperatures were cooled to the room temperature then weights of the fired pellets were measured [7].

2.3 Influence of Carbon Addition and Firing Temperature on Magnetism of Fired Pellets

According to the above steps several fired pellets samples were produced at various temperatures.

Then weights of fired pellets samples were measured.

Then from the above apparatus, the weights of the fired pellets were measured.

Then weight reduction was calculated and the graphs of changing Carbon percentage against magnetism were plotted.

2.4 Standard Test Method for Apparent Porosity, Water Absorption, Apparent Specific Gravity and Bulk Density for Pellets

Following testes were done according to the ASTM c20-00 2005.

1.Pellets were heated 105-110°C degrees and dry weight was measured. (D)

2.Suspended weight was measured. (S)

- Fired pellets were boiled for 2 hours.
- Pellets were cooled to the room temperature while keeping them completely covered with water.
- After boiling, the pellets were immersed in the water minimum for 12 hours and weight of those pellets under submersion was measured. (S)

3.Saturated weight was measured. (W)

- After getting the suspended weight, the pellets were taken out and removed all the water from the surface.

•Then weight in air was measured. (W)

4.Calculations.

i. Exterior volume(V) = W-S cm^3(assume $1cm^3$ of water)

ii. Volume of open pores = W-D cm^3

iii. Volume of impervious portion = D-S cm^3

iv. Apparent porosity(P%) = (W-D/W-S) x100%

v. Water absorption(A%) = (W-D/D) x100%

vi. Apparent specific gravity(T) = D /(D-S)

vii. Bulk density(B) = D/(W-S)

2.5 Melting of Pellets in the Laboratory Type Cupola

Two kilograms of fired pellets (reduced pellets) were prepared and melted in the laboratory cupola. When placing the pellets, they were placed close to the center of the cupola because at the center of the cupola the Carbon Monoxide concentration is relatively high.

The mix proportion for the making of green pellets were kept as follows based on the optimum carbon amount found earlier.

Dela Iron ore = 100 g

Aruwakkalu lime = 7 g

Metallurgical coke = 8 g

2.6 Scanning Electron Microscope (SEM) Observation on "Metallic Pig Iron"

Sample of extracted Iron was put in the "SEM" to test the Fe percentage from fired pellets.

3. Results and Discussion

3.1 Influence of Green Pellet Carbon Content on Pellet Degree of Weight Reduction

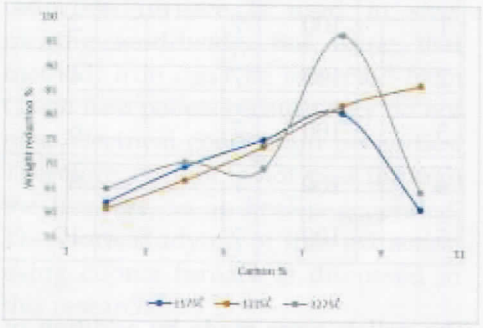

Figure 1 - Degree of weight reduction with carbon content

Degree of reduction (Figure 1) increases gradually up to 8% carbon percentage in 1175°C, 1225°C and 1275°C. After that point, the reduction begins. According to the above curves the optimum point is at 8% carbon and the 1275°C induration temperature. At that point the oxygen reduction is at its highest value in all curve. That means the occurrence of maximum possible reaction. So, Fe and FeO formation might be at its maximum amount. So, 8% Carbon percentage and 1275°C induration temperature might be the best combination for Dela Iron ore.

3.2 Influence of Green Pellet Carbon Addition on Fired Pellets FeO and Fe Content

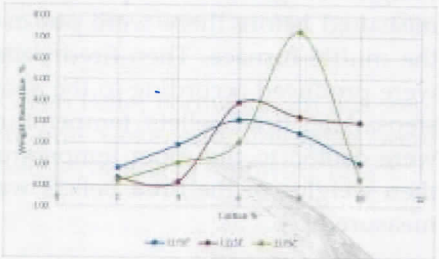

Figure 2 - Degree of oxygen reduction with carbon content

Magnetism of fired pellets (Figure 2) increases gradually up to 8% Carbon in 1275°C. After that point, the reduction begins. Magnetism of fired pellets increases gradually up to 6% Carbon percentage in 1225°C. After that point, the reduction begins in this curve as well. The 1125°C curve also show its highest magnetism value at 6% of Carbon percentage. From all the curves maximum magnetism is shown in the 1275°C curve. Only Fe and FeO show the magnetic properties. That means at the 1275°C and 8% Carbon percentage, maximum amount of Fe and FeO have been formed. So, this graph also confirms that the 8% Carbon percentage and the 1275°C induration temperature might be the best combination for Dela Iron ore.

3.3 Influence of Green Pellet Carbon Content on Apperent Porosity

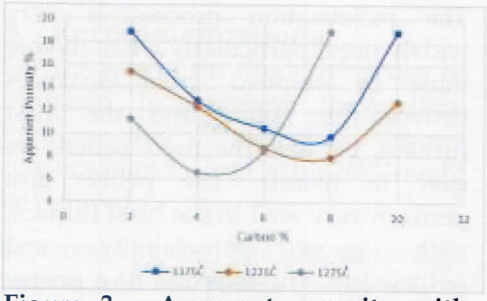

Figure 3 - Apparent porosity with carbon content

Apparent porosity (Figure 3) decreases gradually up to 8% Carbon percentage in 1175°C and 1225°C. But in 1275°C it decreases till 4% Carbon percentage. Higher temperature curves are at the bottom level of the graph. That might happen due to slag formation and filling up of the intergranular spaces at higher temperature. Beyond 8% Carbon at 1175°C and 1225°C, 4% carbon percentage in 1225°C, the apparent porosity again increases that may be due to micro cracks formation.

3.4 Influence of Green Pellet Carbon Content on Apperent Specific Gravity

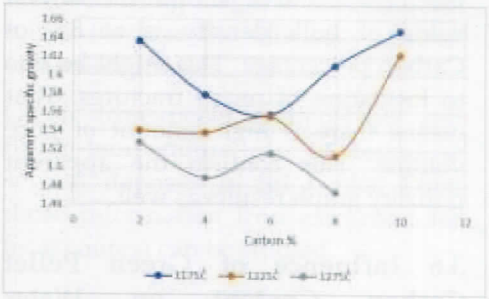

Figure 4 - Apparent specific gravity with carbon content

Apparent specific gravity of fired pellets (Figure 4) decreases when the induration temperature increases. That can be clearly obtained by the above graph. The 1275°C curve shows the lowest value of apparent specific gravity at 8% of carbon percentage. This might be happened due to removal of all the extra Carbon at high temperature values. That means at the 1275°C and 8% Carbon percentage, maximum amount of Fe and FeO have been formed as well as there might be very less amount of impurities. So, this graph also confirms that the 8% Carbon percentage and the 1275°C induration temperature might be the best combination for Dela Iron ore.

3.5 Influence of Green Pellet Carbon Content on Bulk Density

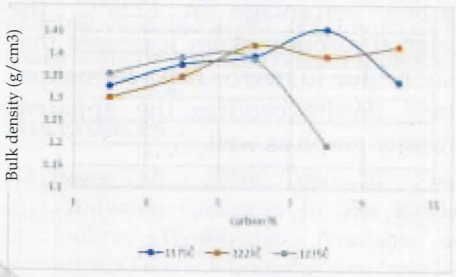

Figure 5 - Bulk density with carbon percentage

Bulk density of fired pellets (Figure 5) does not show much variation according to the above graph. But in the 1275°C curve shows the lowest value of bulk density is at 8% of Carbon percentage. This might be due to formation of micro fractures. That means there is high amount of pore volume. This confirm the apparent porosity graph results as well.

3.6 Influence of Green Pellet Carbon Content on Water Absorption

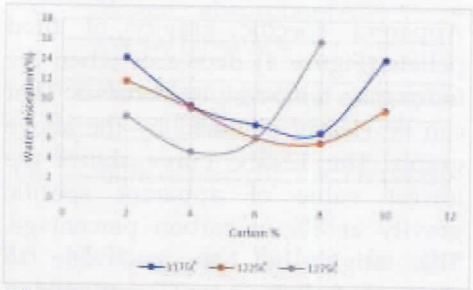

Figure 6 - water absorption with carbon content

Water absorption (Figure 6) decreases gradually up to 8% Carbon percentage in 1175°C and 1225°C. But in 1275°C it decreases till 4% Carbon. Higher temperature curves are at the bottom level of the graph. That might happen due to slag formation and filling up of the intergranular spaces at higher temperature. Beyond 8% Carbon percentage in 1175°C and 1225°C, 4% Carbon percentage in 1225°C, the water absorption again increases that may be due to micro cracks formation. These results confirm the apparent porosity graph as well.

3.7 Results For Scanning Electron Microscope View on "Metallic Pig Iron"

Table 2 - Results of SEM analysis

Element	Weight %	Atomic %
C	3.04	7.46
O	25.16	46.42
Na	2.72	3.49
Mg	0.62	0.75
Al	3.39	3.71
Si	5.5	5.78
P	0.74	0.71
Ca	2.78	2.05
Mn	1.53	0.82
Fe	54.51	28.81

By interpreting the above results, it is confirmed that the "Fe" has formed. But the issue is since Fe has formed, it is less than the expected value. The Iron to slag ratio was less than expected.

The palletization process is very widely used, particularly when the ore must be shipped great distances between the mine and the blast furnace, because the fired pellets are easy to handle. The pellets also perform very well in the blast furnace, with good permeability and reducibility. The selection of a proper binder type and dosage is of critical importance in producing good quality pellets at a reasonable price as palletiztion process consumes high amount of primary binders. So, it is utmost important to study the characteristics of fired pellets as well as their final performance in Iron making.

4. Conclusions

The possibility of Iron extraction is a function of geological, technical, environmental, social, political, and economic factors. In this research

production of high quality Iron pellets by changing composition and firing conditions is discussed.

Iron ore is potential raw material in Sri Lanka which can contribute to the country if it was fully explored. Limestone also available in Sri Lanka. Coal is the only raw material Sri Lanka need to import, but as it is a cheap material, it won't have a higher impct on Iron industry severely.

In pelletizing procedure there are some conclusions such as,

i. Green Iron pellets should be air dried and it should be dried around 110 °C, otherwise fractures occur in the pellets while producing fired pellets.
ii. Optimum Carbon percentage should be around 8% to Dela Iron ore.
iii. When producing fired pellets, muffle furnace temperature should be around 1275°C.

5. Recommendations

Surface area of the fired pellets can be increased by crushing the pellets. From this method energy consumption in Iron extraction might be reduced.

By increasing the Hematite percentage in Dela Iron ore, pellets quality will be increased as well as the formation slag might be reduced in Iron extraction. Froth floatation can be used to increase the Hematite percentage in Iron ore.

At pelletizing procedure some P_2O_5 can be added. It provides 5 mols of CO to the process. Almost every process happen in Iron extraction process involves CO. Exploring potential of using P_2O_5 with the intention of reducing induration temperature of producing fired pellets will be another potential research area (P_2O_5 + 5C---->2P + 5CO).

Fired pellets show magnetic properties because Fe and FeO. So, after crushing using this method impurities can be removed using magnetic separation. It might increase the efficiency of Iron extraction process.

Green Iron pellet composition and firing temperature can be found to several deposits in Sri Lanka. From those information Iron extraction for local context can be studied.

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