AUCTORES
Globalize your Research

International Journal of Materials Science and Engineering
Dare Victor Abere

Open Access

Research Article

Effects of Particles Sizes, Binders and Fluxes on the Physical Properties of Iron Ore Pellets

Olumide Moses Ogunronbi[1], Dare Victor Abere[1]*, Grace Modupe Oyatogun[2], Sammy Alaba Ojo[3], Temitope Emmanuel-Alonge[1], Florence Dennis Uzuh[1], Ojoma Helen Adejo[1], Christopher Gambo[1]
[1]National Metallurgical Development Centre, Jos, Nigeria
[2]Department of Materials Science and Engineering, Obafemi Awolowo University, Ile Ife, Nigeria
[3]Department of Mechanical Engineering, University of Akron, Akron, USA
***Corresponding Author:** Dare Victor Abere, National Metallurgical Development Centre, Jos, Nigeria. **E-mail:** aberevictor@gmail.com

Received date: November 22, 2019; **Accepted date:** December 17, 2019; **published date:** December 20, 2019

***Citation:** Olumide M Ogunronbi., Dare V Abere, Grace M Oyatogun·, Sammy A Ojo, Temitope E Alonge,. et al (2019) Effects of Particles Sizes, Binders and Fluxes on the Physical Properties of Iron Ore Pellets. J. Effects of Particles Sizes, Binders and Fluxes on the Physical Properties of Iron Ore Pellets, 1(1); **Doi**: 10.31579/ijmse.2019/005

Abstract

This work examined the suitability of Itakpe iron ore, Itakpe, Kogi State, Nigeria to meet the feed requirements of today's iron production methods using different particle sizes, binders and fluxes. Test such as crushing strength, green and dry compressive strength, metallization crushing strength, moisture content were carried out. Also, the tumbler, abrasion, and Shatter Indices of the ore were determined Addition to these, porosity, drop number, Drop Resistance tests were performed. From the result obtained, the Itakpe iron ore was found to have good mechanical properties exemplified with tumble and shatter index data >89.0 wt% and <2.5 wt%, respectively. Furthermore, its reducibility at 0.87%/min is within the acceptable range as a natural material feed for blast furnace and direct reduction furnaces. Also, the energy requirement for heating the ore to 1100°C was found to be higher in the samples containing a wider size range of irregular grains and the largest contaminations. In summary, it was concluded that the Itakpe iron ore has good physical and metallurgical properties to serve as a natural material for the blast furnace and direct reduction furnaces.

Keywords: iron; feed; binders; flux; crushing strength; moisture content; furnaces

Introduction

Nigeria is blessed with large quantity of iron ore deposit of about three billion (3×10^9) metric tonnes. Even with this large reserve of proven and unproven iron ore deposits, only one of the deposits in the proven reserves is currently being exploited and processed that is the Itakpe iron ore deposit. This deposit has an estimated reserve of about 200 million (200×10^6) metric tonnes and has been earmarked to supply Ajaokuta and Delta Steel Plants [1]. Pelletizing of iron ore was started in the 1950s to facilitate the utilization of finely ground iron ore concentrates in steel production. Two main types of processes have been developed, the straight Grate and the Grate kiln processes. In the straight Grate process, a stationary bed of pellets is transported on an endless traveling grate through the drying, oxidation, sintering and cooling zones. In the grate kiln process, drying and most of the oxidation is accomplished in a stationary pellet bed. Thereafter, pellets are loaded in a rotary kiln for sintering. This way, more homogenous induration in pellets is achieved [2]. Pelletizing requires ultra-fines of over 75% of -325 mesh and porosity of pellets is about 20 – 30%. The shape of pellets is near spherical and hence built permeability of the burden is much better than that of sinter [1]. Use of pellet burden reduces hanging, which is often observed if a high proportion of sinter is used; the used of pellets saves coke by 25kg/t and the productivity by 15% [1].

Iron is a chemical element with symbol Fe. It is a metal in the first transition series. It is by mass the most common element on Earth, forming much of Earth's outer and inner core. It is the fourth most common element in the Earth's crust. Its large quantity in rocky planets like Earth is due to its copious production by fusion in high-mass stars, where it is the last element to be produced with release of energy before the violent collapse of a supernova, which scatters the iron into space. Iron, with its general products, is currently the most widely used metal in the various sectors of the world's economy. This is due to the good mechanical properties it possesses to the low cost associated with its production. Iron is mainly produced through two methods; the blast furnace, BF, route (pig iron), and the direct reduction, DR, route (sponge iron). According to the World Steel Association, 2011, crude steel production was standing at 1.4 billion tons by the end of 2010. Of these, 70% was produced via the basic oxygen furnace (BOF), which uses pig iron from the blast furnace, and 28% via the electric arc furnace (EAF), which uses sponge iron and scrap [3].

Iron ore can be used directly in its natural form as a raw material for processing iron and it can be upgraded through beneficiation before being used. The feedstock is evaluated for physical and metallurgical properties [4]. Physical properties give an indication of the material's behaviour during handling and descent in the furnace. Metallurgical properties on the other hand indicate the materials' behaviour during the reduction process. In selecting iron ore for iron and steel industries, some of the properties which need to be considered include tumbler, abrasion and shatter indices, porosity, chemical composition, loss on ignition, reduction behavior, and thermal degradation [5].

Binders are used in order to produce high-quality "green" pellets that can be handled at ambient temperatures, and that can also tolerate subsequent high-temperature processing at up to 1500^0C without allowing the pellets to disintegrate, with accompanying loss of product as environmentally objectionable dust, the binders include starch, bentonite which is a clay mineral predominantly consisting of the mineral Montmorillonite mixed with some related minerals like Nontronite and Beidellite [6]. Fluxes are the materials added to the contents of a smelting furnace for example, iron pellets for the purpose of purging the metal of impurities and of rendering the slag more liquid. The flux most commonly used in iron and steel furnaces is limestone which is charged in the proper proportions with the iron [6].

However, the process of pelletization enables converting iron ore fines into uniformed sized iron ore pellets that can be changed into the blast furnaces or for production of Direct Reduced Iron (DRI). Pellets are uniform in size, with purity level of 63% - 65% contributing to faster reduction and high metallization rates. Pellets with their high uniform mechanical strength and high abrasive strength increase production of sponge iron by 25% to 30% with same amount of fuel. Pellets are spherical balls formed by the agglomeration of natural or ground iron ore fines in the presence of moisture and binder. Again, on subsequent induration at around 1300 ^{0}C, they become suitable feed for downstream iron making processes like the Blast furnace and direct reduction furnace. Pelletizing process consists of three main stages namely; Raw material preparation, Green pellet formation and pellet hardening (induration) [2]. The functionality of a blast furnace depends mostly on the physical and chemical characteristics of the materials. The load materials, which are charged through the throat, are coke, lump ores, and agglomerated ores in the form of sinter or pellets. Lump ores are significantly cheaper than pellets and sinters. However, they are inferior, particularly with respect to softening-melting and they affect the smooth running of the blast furnace and increase the coke consumption [7]. Swelling and disintegration of iron ore have been two major draw backs in their acceptance as feed for blast furnaces and direct reduction furnaces [8]. Therefore, iron ore as mined from the earth has been almost completely replaced as a feed for iron blast furnaces by sinters and pellets.

In the study of Itakpe ores, it was found that the chemical composition and microstructure of the ore corresponds to the demands on high grade iron ore. Precisely, the Fe, silica, and alumina contents indicate that they can profitably be used for iron production [1]. This particular study examines the physical and metallurgical properties of Itakpe iron ore, Itakpe, Kogi State. It evaluates these with respect to the requirements for the different iron production processes, in order to establish the ore's suitability in meeting the necessary demands for iron production.

Materials and Method

12kg of Itakpe Iron ore concentrate was pulverized in Ball mill for 3 hours and further pulverized in Ring Pulverizing Machine for 5 minutes after which the Iron ore was sieved with different Mesh sizes to give particle sizes A (+0.125, -0.09), B(+0.09, -0.063) and C(-0.063). 500g of pulverized and sieved Itakpe Iron Ore was collected from each particle size as stated above into three different places, (A, B, C), (A1, B1, C1), (A2, B2, C2) and (A3, B3, C3), 15g of bentonite as binder, 10g of limestone ($CaCO_3$) as flux were added and mixed thoroughly with 60ml of water in palletizing disc of 40cm diameter and 10cm depth, Tilt angle = 38^0, rotating speed of 15rpm. The above steps were repeated varying the particle sizes, binders and fluxes.

Determination of Physical Properties

The physical properties of the ore were investigated by determining their crushing strength, compressive strength (green and dry), indurating compressive strength or metallization crushing strength, moisture content, tumble, abrasion, and shatter indices, micro porosity, drop number, drop resistance, as well as their bulk density.

Drop Number

Five samples from the ones formed earlier were dried in the oven at 200^0C – still in their green state. They were subjected to drop from a marked distance of 60cm height from the ruler to a hard but fixed base before chattering was noted and recorded. The procedure was repeated for the five pellets in which the calculated average gave the actual drop number of the pellets.

Drop Resistance

It is a test done to determine the crushing strength of green balls after three drops from different heights. These values are indications of the admissible height differences at various transfer points during green ball transportation. About 7N are required as minimum strength for three drops from a height of 46cm. In this study, five selected samples were also chosen in green state and then dropped at varying distance of 48cm, 60cm and 72cm height from the ruler to a hard but fixed base. Numbers of drop to shattered point were recorded and the average calculated.

Green Compressive Strength Test

This test was performed when the pellets were not yet totally dried but only heated to some degrees. Five pellets were heated to 200^0C and then subjected to chatter test using Hydraulic press crushing machine. Readings were taken and recorded.

Dry Compressive Strength Test

The test was carried out to determine the crushing compressive strength of different samples of the pellets made and to investigate how strong the pellet would be after they had been totally dried up. Five green pellets were heated in the furnace to about 900^0C, after which they were subjected to compressive strength test. Also, another five green pellets were heated in the Electric Carbonate furnace to about 900^0C and soak for 1 hour (h) after which they were subjected to the same compressive strength test. The results were taken and recorded.

Crushing Strength Test

Certain minimum crushing strength is quite necessary in order for the pellets to withstand the compression load in the pellet bed on a belt conveyor, drying grate, indurating grate, or in a shaft furnace [9] and therefore, the test was performed in three different ways, first, hand press which is operated by hand and the power being hydraulically transmitted, secondly hydraulic press with motorized drive, lastly electrically operated press with a weight place on a movable level area.

Indurating Compressive Strength Test or Metallization Crushing

Strength Test

The test was carried out to investigate the physical properties of iron pellet at the temperature it started changing to metal; this was necessary for their behaviour during transportation and primarily during metallurgical treatment either in the blast furnace or in direct reduction plants [10]. The pellets quality was evaluated by adopting appropriate testing methods, which were developed from experience gained mainly in industrial plants. Five green pellets were kept in Electric Carbolite Furnace heated to an indurating temperature of 1200^0C at which metal phase started to form.

Moisture Content

This was carried out to determine the percentage moisture content of the samples of iron ore pellets made. Weighed quantity of iron ore sample from each mesh sizes was charged into a known weight crucible and transferred into an oven at 150^0C. The crucible with its content was then heated for 2 hours after which it was brought out of furnace re-weighed and weight recorded until two same weights were recorded in two consecutive heating. Then the initial weight of sample "X" subtracted from the final heating of total sample "N" gave the volume of water expelled (V) from the iron sample, i.e. "X" – "N" = Total. Therefore, the moisture content per pellet produced can be determined from:

$$V = V_1 + \frac{V_2}{N} \qquad (1)$$

Where V = Volume of H_2O in pellet produce
V_1= Volume of H_2O moisture evolved
V_2= Volume of water used
N = No of pellet produced

Tumbler/Abrasive Resistance Test:

A tumble strength test measures two mechanisms of feedstock degradation, that is, the Tumble Index (TI) and the Abrasion Index (AI). It was carried out following the International Standard ISO 3271:1995(E) for determination of Tumble Strength for iron ore [11]. Precisely, 10 pellets weighing 250g, dried at 200^0C in an oven were introduced into a drum having diameter of 0.5m and length of 0.25m with two lifters each 0.5cm high located inside the drum which was rotated for 30 minutes in high speed, after which the pellets were screened and fraction +6.3mm and -0.5mm were collected differently. The percentage of separated fractions in proportion to the feed weight is the volume of Tumbled index (TI)(+6.3mm) and abrasion index (AI) (-0.5mm) can be obtained below

$$TI = \frac{W_t \ of \ +6.3mm}{W} \times 100\% \qquad (2)$$

$$AI = \frac{W_t \ of \ -0.5 \ mm}{W} \times 100\% \qquad (3)$$

Where:
T I = Tumbled Index
W_t = Weight
W= Total weight of pellet

Micro porosity:

The test was done in order to evaluate the reduction velocity in iron pellets. Weight of a fired pellet was measured; when the pellet was dipped into a beaker containing benzene, bubbles were then released until stoppage in bubbles. Then the sample brought out and weighed again to see the difference in weight. Therefore:

$$P = \frac{D - d}{D} \times 100\% \qquad (4)$$

Where P= Porosity
D = Weight of pellet in Benzene
d = Weight of sample
This was repeated for the samples from each group.

Results and Discussion

Physical properties of iron ores are determined by using crushing strength, compressive strength (green and dry), indurating compressive strength or metallization crushing strength, moisture content, tumble, abrasion, and shatter indices, micro porosity, drop number, drop resistance, as well as their bulk density. Tests such as tumbler and shatter tests give an indication of the material behaviour during ore mining, loading, transportation, handling, and screening. They also give an insight into the material's behaviour, during an initial period of the reduction process in its descent in the furnace. Results obtained during the course of this work are presented below:

Bentonite + $CaCO_3$			Starch + $CaCO_3$			Bentonite + $Ca(OH)_2$			Starch + $Ca(OH)_2$		
A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3
2	2	3	2	3	3	2	4	3	3	3	4
3	3	4	1	3	3	1	3	3	2	4	3
2	3	4	3	2	4	2	4	4	2	3	4
4	3	5	2	4	4	4	3	4	2	2	4
2	3	5	2	1	3	3	2	3	2	1	3
2.6	2.8	4.2	2	2.6	3.4	2.4	3.2	3.4	2.2	2.6	3.6

Table 1: Physical properties of Itakpe ore based on Drop Number Test

Bentonite + $CaCO_3$			Starch + $CaCO_3$			Bentonite + $Ca(OH)_2$			Starch + $Ca(OH)_2$		
Q A	Q B	Q C	Q A1	Q B1	Q C1	Q A2	Q B2	Q C2	Q A3	Q B3	Q C3
2	2	3	3	2	3	1	3	4	1	3	3
3	3	5	2	3	4	3	3	3	3	4	5
3	3	4	2	3	4	2	2	3	2	4	5
3	4	3	2	3	3	2	2	3	3	3	3
3	3	4	2	2	3	2	3	3	3	3	2
2.8	3.0	3.8	2.2	2.6	3.4	2.0	2.6	3.2	2.4	3.4	3.6

Table 2: Physical properties of Itakpe ore based on Drop Resistance Test

Key: $Q = \frac{X_1 + X_2 + X_3}{3}$

Where X1 = Average Drop Number in 48cm
X2 = Average Drop Number in 60cm
X3 = Average Drop Number in 7cm

Bentonite + $CaCO_3$			Starch + $CaCO_3$			Bentonite + $Ca(OH)_2$			Starch + $Ca(OH)_2$		
A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3
0.17	0.19	0.20	0.12	0.16	0.21	0.11	0.14	0.14	0.11	0.13	0.17
0.16	0.19	0.19	0.15	0.17	0.22	0.09	0.12	0.16	0.14	0.11	0.13
0.16	0.20	0.21	0.11	0.20	0.20	0.10	0.13	0.15	0.13	0.12	0.17
0.18	0.17	0.20	0.11	0.19	0.20	0.09	0.14	0.14	0.11	0.13	0.17
0.13	0.19	0.22	0.16	0.19	0.19	0.11	0.13	0.21	0.12	0.14	0.16
0.16	0.19	0.20	0.13	0.18	0.21	0.10	0.13	0.16	0.12	0.13	0.16

Table 3: Physical properties of Itakpe ore based on Green Compressive Strength Test

Bentonite + CaCO3			Starch + CaCO3			Bentonite + Ca(OH)2			Starch + Ca(OH)2		
A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3
2.60	2.60	2.70	1.20	1.34	1.40	3.30	3.40	3.63	2.15	2.77	3.5
2.50	3.10	2.80	1.11	1.21	1.45	3.35	3.50	3.60	3.00	3.26	3.36
2.70	2.10	2.90	1.20	1.20	1.14	3.40	3.55	3.50	3.05	3.16	3.33
2.60	2.60	3.00	1.30	0.95	1.37	3.30	3.40	3.55	2.90	3.30	3.40
2.70	2.70	3.10	1.11	1.25	1.42	3.00	3.45	3.60	2.91	3.20	3.40
2.62	2.70	2.74	1.18	1.19	1.41	3.27	3.46	3.57	2.80	3.13	3.39

Table 4: Physical properties of Itakpe ore based on Dry Compressive Strength Test

Bentonite + $CaCO_3$			Starch + $CaCO_3$			Bentonite + $Ca(OH)_2$			Starch + $Ca(OH)_2$		
A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3
2.70	2.80	2.75	1.00	1.11	1.14	3.40	3.50	3.60	3.05	3.50	3.70
2.50	2.80	2.90	0.90	1.20	1.14	3.50	3.45	3.70	3.06	3.40	3.65
2.50	2.70	2.90	0.85	1.31	1.20	3.40	3.45	3.60	3.14	3.50	3.60
2.60	2.60	2.80	1.10	1.20	1.21	3.30	3.40	3.60	3.00	3.50	3.50
2.50	2.60	2.85	1.20	1.13	2.20	3.40	3.40	3.50	3.10	3.40	3.60
2.56	2.70	2.84	1.01	1.19	1.37	3.40	3.44	3.60	3.07	3.46	3.61

Table 5: Physical properties of Itakpe ore based on Dry Compressive Strength Test soaking the Pellets in the furnace at 900^0C for 1 h.

Bentonite + CaCO3			Starch + CaCO3			Bentonite + Ca(OH)2			Starch + Ca(OH)2		
A	B	C	A1	B1	C1	A2	B2	C2	A3	B3	C3
3.40	3.38	3.65	3.40	3.30	3.50	3.00	3.31	3.32	1.40	1.30	1.40
3.42	3.60	3.50	2.70	3.38	3.40	3.20	3.01	3.28	1.40	1.40	1.40
3.36	3.60	3.60	2.00	3.34	3.45	3.11	3.31	3.40	1.30	1.49	1.58
3.47	3.50	3.70	2.80	3.30	3.50	3.11	3.22	3.48	1.10	1.10	1.42
3.55	3.50	3.70	2.70	3.40	3.46	3.11	3.20	3.00	1.200	1.30	1.43
3.60	3.51	3.63	2.84	3.34	3.46	3.12	3.27	3.41	1.24	1.35	1.40

Table 6: Physical properties of Itakpe ore based on Dry Compressive Strength Test on Pellets fired to Indurating temperature of 1200^0C

	Itakpe Iron Ore	Iron Ore Pellets		
		Mesh Sizes		
		-0.125 +0.09	+0.09 -0.063	-0.063
Weight of Crucible	20.8	20.8	20.8	20.8
Weight of Crucible + Sample	50.08	50.0	50.0	50.0
1st Weight (2hrs)	49.96	49.00	49.01	49.01
2nd Weight (2hrs)	49.84	49.04	49.04	49.04
3rd Weight (2hrs)	49.84	49.04	49.01	49.01

Table 7: Moisture Content of Iron Ore used and that of the Pellets

Moisture Content for Itakpe Iron Ore:

= 50.08 – 49.84

= 0.96ml

$$Moisture = \frac{60}{15} + 0.96\ ml$$

Therefore, moisture content = 4.76 ml/pellet

	Bentonite + $CaCO_3$	Starch + $CaCO_3$	Bentonite + $Ca(OH)_2$	Starch + $Ca(OH)_2$
Weight of 10 Samples	250	250	250	250
Abrasion Wt (g)	140.6	150.0	90.0	114.4
Tumble weight (g)	109.4	100.0	160.0	135.6
Abrasion Index Test	140.6 x 100 250 = 56.2%	150 x 100 250 = 60.0%	90 x 100 250 = 36.0%	114.4 x 100 250 = 45.76%
Tumble Index Test	109.4 x 100 250 = 43.76%	100 x 100 250 = 40.0%	160 x 100 250 = 64.0%	135.6 x 100 250 = 54.24%

Table 8: Showing the Tumble Index Test Result performed on the Pellets

	Bentonite + $CaCO_3$	Starch + $CaCO_3$	Bentonite + $Ca(OH)_2$	Starch + $Ca(OH)_2$
Initial wt of pellet (d)	32.0	32.0	32.0	32.0
Final wt of pellet (D)	34.6	34.2	36.4	33.0
Tumble weight (g)	109.4	100.0	160.0	135.6
Micro porosity	$\frac{D-d}{D} \times 100$	$\frac{D-d}{D} \times 100$	$\frac{D-d}{D} \times 100$	$\frac{D-d}{D} \times 100$
Tumble Index Test	34.6 - 32 x 100 34.6 = 7.51%	34.2 - 32 x100 34.2 = 6.0%	35.4 - 32 x 100 34.6 = 9.0%	34.1 - 32 x 100 34.1 = 6.06%

Table 9: Showing the Result of Micro porosity test

The test was carried out on the Green Pellets fired at 200^0C for 1 h and it was observed in the table 1 that even though the binders and the fluxes used might have played one role or the other on the test, it could be observed that particle sizes play some reasonable effects on the test. In the computation of the averages, there was an increase towards the particle sizes. Drop Resistance Test (48, 60, 72cm) was carried out on the Green pellets fired at 200^0C for 1 h. The result in table 2 shows that the effect of particle sizes on the drop resistance test cannot be overlooked. The drop number indicates how often green balls can be dropped from a height of 60cm before they show perceptible cracks or crumble. According to experience, the minimum value is four, which means a pellet should be able to withstand without any damage, four drops from a height of 60cm [12]. It was shown clearly that because of the smaller in sizes, they were able to be adhered together strongly by the binders used. Their resistances were increased as we were getting to finer particle sizes. From the table 3, it can be observed that the compressive strength of the ore increases with decrease in particle sizes and this could be attributed to the fact that there was little chemical reaction taken place in the pellets since they were just fired at 200^0C for 1 h and hence yielded low result were improved as the particle sizes were becoming finer. High records in the Dry Compressive Strength test was discovered after firing the pellets to 900^0C as in table 4. Most significantly, record of high dry compressive strength was noted in the pellets that had Bentonite as binder and Calcium hydroxide as flux. This was because Calcium hydroxide can also serve as binder. To this effect, as Calcium hydroxide was acting as a flux, in some other way, it acted as a binder too therefore increasing the compressive strength of the pellet [13]. It was discovered from table 5 that the dry compressive strength test at 900^{0}C and soaking for 1 hr was negatively affected by $CaCO_3$ being that it only served single purpose and positively affected by $Ca(OH)_2$ because it served duo purpose; binder and flux consecutively. More still the finer the particle sizes, the brighter the result. Also, chemical reaction had already taken place at this point and thus increasing the bond strength of the pellets [14]. At this indurating temperature, also known as metallization point at which the pellets were already forming metal, there was increase in the compressive strength of the pellets but in the case of Bentonite and $Ca(OH)_2$, greater compressive strength was observed in table 6, this is due to the fact that as Calcium Hydroxide was acting as flux in the composition, it also acted more or less as a binder [15]. As indicated in table 8, it can be deduced that the effect of Bentonite as binder and $Ca(OH)_2$ as flux recorded high abrasive index. It shows a good binder has much effect on the strength of the iron pellet [16]. Table 9 shows that the major parameter that played significant role on the micro porosity is particle sizes because finer sizes have more compatibility more than those of coarser ones [17].

Conclusion

Based on the analysis of the effects of Particle sizes, Binders and Fluxes on the Physical and properties of Iron Ore pellets with Itakpe Ore as case study, it could be concluded and suggested that the effect of sizes as shown in the test showed that the finest particle size of (-0.063) has the best quality in time of drop number test, drop resistance and compressive strength test. Also, the effect of binders as shown showed that the samples containing bentonite as binder produced the best physical properties of the pellets. The effect of fluxes as shown in the test, samples containing Calcium hydroxide showed a great improvement in its physical properties; tumbler index, abrasive index, compressive strength at 200^{0}C, 900^{0}C holding, 1200^{0}C. Using the composition of binder and flux as 3% and 2% respectively with the Ore weight, not neglecting the par ticle sizes which also played a greater role as that of 0.063mm. Using the composition of 3% binder 2% respectively for bentonite as binder and $Ca(OH)_2$ as the flux being shown in the results, bentonite has a selling and gelling properties and it is sodium ion that helps during bonding – for combination when necessary. It recommended that bentonite should be used with Calcium hydroxide as flux at a composition of 3% and 2% of ore weight when using Itakpe ore for Iron production.

Reference

1. Yakubu, S.I. (2006). Sintering characteristics of Itakpe and Agbaja Iron ore concentrate blends. M.sc Thesis: Department of Metallurgical Engineering, Ahmadu Bello University, Zaria.
2. Forsmo, S. (2007). Influence of green pellet properties on pelletizing of magnetite iron ore. PhD Thesis: Department of chemical Engineering and Geosciences, Lulca University of Technology, Division of Process Metallurgy.
3. World Steel in Figures, (2011) World Steel Association, Brussels, Belgium.
4. “Evaluation of iron ore pellets and sinters for BF and DR use” The Southern African Institute of Mining and Metallurgy, 2009.
5. Kumar M., Jena S., and Patel S. K., (2008.) “Characterization of Properties and Reduction behavior of Iron ores for Application in sponge Iron making,” Mineral Processing and Extractive Metallurgy Review, vol. 29, no. 2, pp. 118–129.
6. Eisele, T. and Kawatra, S.K. (2003). A review of binders in iron ore pelletization. Mineral Processing and Extractive Metallurgy Review. 24(1): 1-90
7. Sharma T., Gupta R. C., and Prakash B., (2015) “Effect of Gangue content on the swelling behaviour of Iron ore pellets,” Minerals Engineering, vol. 3, no. 5, pp. 509–516,
8. Muwanguzi A. J. B. Karasev A. V., Byaruhanga J. K, and Jönsson, P. G (2010) Characterisation of the Chemical Composition and Microstructure of Natural Iron Ore from Muko Deposits in Uganda, KTH Royal Institute of Technology,
9. A. Cores, A. Babich, M. Muñiz, A. Isidro, S. Ferreira, et al (2017) “Iron ores, fluxes and tuyere injected coals used in the blast furnace,” Ironmaking and Steelmaking, vol. 34, no. 3, pp. 231–240.
10. Zervas T., Mcmullan J. T., and Williams B. C (2014)“Developments in iron and steel making,” International Journal of Energy Research, vol. 20, no. 1, pp. 69–91.
11. A. Chatterjee (1994.) Beyond the Blast Furnace, CRC Press, Boca Raton, Fla, USA,
12. Kempken J. , Kleinschmidt G., Schmale K., Thiedemann U., Gaines H. P., et al (, 2008) “Short route—long-term success: integrated mini-mill solutions by midrex and SMS demag,” Archives of Metallurgy and Materials, vol. 53, no. 2, pp. 331–336.
13. Wynnyckyj J. R and Fahidy T. Z.,((1974)) Solid State Sintering in the induration of Iron Ore Pellets, Metallurgical Trans., May 1974, 5, 991 – 1000.
14. Cornell R. M. and Scwertmann U (2016.) The Iron Oxides, Structure, Properties, Reactions, Occurrences and Use, Wiley-VCH, Weinheim, Germany,
15. PI: S. K Kawatra, T. C. Eisele, and S. J. Ripke (2004) High Carbon Fly-ash as a Binder for Iron Pellets, Department of Metallurgical and Materials Engineering, Michigan pp. 73 – 79.
16. Callendar W., (2012) Heat fastening of artificial magnetic pellet, International Symposium on Agglomeration, Philadelphia, Pennsylvania, 1961, 641 – 660,
17. Cojić M. and Kožuh S., (2006) “Development of direct reduction processes and smelting reduction processes for the steel production,” Kemija u Industriji, vol. 55, no. 1, pp. 1–10,