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Influence of temperature on the compressive strength, bulk density and apparent porosity of pellets produced by different methods of addition of materials

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Abstract
Iron ore pellets which are predominantly being used in the blast furnace and direct reduction processes have undergone improvements in other to improve the aforementioned processes and increase efficiency using different methods. This present work which is of different approach whereby different methods of raw materials selection, composition, presence of carbonaceous material and firing temperature, affected the quality of pellets produced. Analysis and tests showed that the firing temperature and the constituent minerals had a significant influence such properties as compression strength, % apparent porosity, bulk density and % water absorption. Also, the pellets which were subjected to a higher firing temperature revealed improved compressive strength, % water absorption, % apparent porosity and bulk density than pellets fired at a lower temperature, this suggesting a more developed solid state reaction between the raw materials at high firing temperatures.

Keywords: iron ore pellet, compression strength, % apparent porosity, % water absorption, bulk density, temperature

Introduction

Over the years the growth of the iron and steel industry has been sustained and made to survive by extensive research works. The demand for iron and steel has increased drastically within the last decade sequel to breakthrough in technological increased developmental projects throughout the globe. The sintering method and the pelletizing method are the two principal methods for ore beneficiation as reflected by the high percentage of approximately 80%, which is ratio of ore beneficiated by the two methods relative to the total amount of raw materials charged into blast furnace in Japan [1].

Iron occurs in nature as Magnetite or black iron ore (Fe_3O_4). The mineral is composed of FeO and Fe_2O_3 and is magnetic – a fact that proves useful in locating deposits. It occurs in the ore as a dense, grained lustrous black – blue mass disseminated in siliceous or siliceous – argillaceous gangue. They are difficult to reduce but when oxidized to martite (Fe_2O_3), reduction becomes easy. They contain 50 – 60%. Fe. Hematite or red iron ore is an anhydrous iron oxide Fe_2O_3, softer than magnetite. A piece of the ore leaves a red track on porcelain when scratched upon. Hematite is formed as result of weathering the magnetite. Hematite contains 50 – 70%. They are easily reducible to metallic form. Their gangue is siliceous. Limonite (brown ore), Fe_2O_3. $3H_2O$, is formed by weathering and oxidizing other iron ores and contains 37 – 55%. Fe. It has low density and high porosity which increases as moisture evaporates, making the ore easily reducible. Siderite ($FeCO_3$). Has low carbon content 30 – 40%. Fe. Also known as spathic iron. Iron Pyrites (FeS_2) . its conversion is still not too convenient and economical [2]. Iron ore deposits in Nigeria were estimated at 800 millions tons in 1982, but the discovery of new deposits in the south of Nigeria has increased the availability. It is estimated that Agbaja has a total reserve of 2 billion tons of iron ore, Itakpe 200 – 300 million tons, Ajabanoko 30 million tons, Chokochoko 70 million tons [3].

To run a blast furnace properly and economically, the burden must be of high quality [4]. One of the most important requirements for the burden is that its iron content should be as high as practicably possible. Beneficiation processes have been developed to raise the level of iron content in low-grade iron ores, which had to be utilized as the deposits of natural high-grade iron ores becomes depleted with the development of the iron and steel [5, 6]. Also, the fractions of high-grade iron ores produced during mining need to use due to the lack of supply of high-grade lump ores. But concentrates and the fine fractions of high-grade iron ore produced during mining are too fine to be used directly in a blast furnace [7, 8], as they would cause difficulties in the operation of the blast furnace. Consequently, briquetting, sintering and pelletizing processes were developed to agglomerate such fine materials. The products of such processes, that is, briquettes, sinter and pellets also advantages over the natural lump iron ores, as some of the harmful elements in the ores could be eliminated in the process [4, 7]. Among the three agglomeration processes, briquetting, though the simplest and oldest process could not make headway due to relatively high processing cost and limited production capacity [7]. Both sintering process and pelletizing process, the latter being newer, however, have had rapid development. The tonnage of world production of both

sinter and pellets, and their proportions in the burden to blast furnaces have steadily increased over the years [7, 9]. And both sinter and pellets have made considerable improvements of blast furnace performance. The sintering process is made up of three stages [7], while the pelletizing process is made up of four steps [10].

Pellets differed from lump ore and to certain extent also from sinter by several properties which are predetermined and definable. The primary purpose of pelletizing is to improve burden permeability and gas – solid contact in the blast furnace in order to increase the rate of reduction. A secondary purpose is to reduce the amount of fines blown out of the blast furnace into the gas recovery system [11]. Pelletizing is advantageous over sintering because sintering of finely comminuted concentrates is not economically feasible as the sintering machines would drop their output and the quality of sinter would be poor. The product of the pelletizing process (the pellets) goes to both blast furnaces and direct ironmaking by reducing pellets with gas. Also, pellets are stronger than sinter. The use of pellets raises blast furnace capacity because the materials lay in the furnace burden uniformly. Pellets offer high gas permeability. Pellets are better prepared for reduction, having ore and flux thoroughly mixed and in close contact with each other [2].

An excessive content of coarse particles lowers the pelletizability and pellet strength, hence, gigantic ore particles greater than 1mm in diameter considerably lowers the pelletizability and pellets strengths so that the coarse ore is preferred to have a particle size between 0.1mm and 1mm. the proportion of the gigantic particles over 1mm should be adjusted to a value smaller than 20% by weight [12]. At Kobe steel works Japan, a process for making ore pellets with lime/silica ratio from 0.5 1.3 has been developed. The fine materials, which are deleterious to sintering plant has been converted to suitable feed materials [13].

It has been discovered that carbonaceous materials exert a substantial influence on the macro – porosity of the pellet produced. The amount of carbonaceous materials added to the raw materials and the macro – pores produced provide a positive linear correlation [14, 15].

It is also generally accepted that pores play an important role in influencing the properties iron ore sinter and pellets [16, 17], and that the properties of iron ore sinter and pellets are related to the mineral constituents [18, 19, 20, 21]. During the induration of pellets, crystal changes occur as a function of induration time and optimum induration temperature [22].

2. Materials and Methods

2.1 Materials

The materials used for the formation of the pellets are iron ore concentrate, lime, bentonite, coke breeze, starch and sawdust. The chemical composition of the iron ore concentrate and lime are shown in the Table 1 and Table 2 respectively.

Table 1: Chemical Analysis of the Iron Ore Concentrate

Compound	Fe_2O_3	SiO_2	CaO	L.O.I
Composition	92.30	5.80	0.15	0.12

L.O.I = Loss on Ignition

Table 2: Chemical Analysis of Limestone

Compound	Fe_2O_3	MgO	K_2O	Na_2O	SiO_2	Al_2O_3	$MgCO_3$	$CaCO_3$	L.O.I
Composition	0.08	1.55	0.14	0.02	2.72	0.64	3.25	90.26	1.34

L.O.I = Loss on Ignition

2.2 Experimental Procedure

The lime, bentonite and starch were properly sieved to ensure uniform particle size, homogeneity and to avoid the presence of extraneous/other materials. Thereafter, the pellets (green balls) were formed using hand pelletizing method. In Batch A-D the materials were properly mixed before the formation of the green balls samples, for batch E-H, the green balls samples were formed starting with the iron ore concentrate as the core (innermost) constituent and coating it with other materials in the sequence and order in which they appear in the Table 3 below. While in batch I-M the constituent minerals were properly mixed together before the formation of the green pellets. The ratio of mixing and /or addition of the materials are shown in the Table 3 below:

Table 3: Constituent materials for the production of the Pellets

Sample	% of Iron Ore Concentrate added	% of Limestone added	% of Coke Breeze added	% of Bentonite added	% of Starch added	% of Sawdust added
A	80.00	20.00	0.0	0.0	0.0	0.0
B	72.70	9.10	0.0	9.10	9.10	0.0
C	80.00	0.0	0.0	10.00	10.00	0.0
D	66.66	0.0	33.33	0.0	0.0	0.0
E	28.57	14.28	57.15	0.0	0.0	0.0
F	25.00	0.00	25.00	25.00	25.00	0.0
G	50.00	12.50	12.50	12.50	12.50	0.0
H	50.00	0.0	12.50	12.50	12.50	12.50
I	28.57	14.28	57.15	0.0	0.0	0.0
J	25.00	0.00	25.00	25.00	25.00	0.0
K	50.00	12.50	12.50	12.5	12.50	0.0
L	50.00	0.0	12.50	12.5	12.50	12.50
M	44.45	0.0	11.11	11.11	11.11	22.22

2.3 Equations

Equations (1-4) were used to obtain the results of Figures 2-13.

$$\% \text{ Apparent Porosity} = \frac{Ws - Wd}{Ws - Wa} \times 100 + (\text{density of liquid of immersion}) \quad (1)$$

$$\% \text{ Water of Absorption} = \frac{Ws - Wd}{Wd} \times 100 \quad (2)$$

$$\text{Apparent Density} = \frac{Wd}{Wd - Wa} \quad (3)$$

$$\text{Bulk Density} = \frac{Wd}{Ws - Wa} \quad (4)$$

Where Ws = soaked weight, Wd = Dry weight, Wa = Suspended weight, The liquid of immersion is water (density = $1 g/cm^3$)

3. Results

The results of the compressive strength, % apparent porosity, % water absorption, apparent density and bulk density of the pellets at different firing temperature are given in Table 4 and Figures 1 - 5.

Table 4: Results of Tested Properties after Firing the Pellets

Sample/Firing temperature	% Apparent Porosity	% Water Absorption	Apparent Density	Bulk Density	Compressive Strength (KN)
A 1200 ^{0}C	13.50	10.49	1.36	1.19	3.0
1250 ^{0}C	16.00	12.76	1.38	1.18	3.4
B 1200 ^{0}C	18.00	15.74	1.30	1.08	2.4
1250 ^{0}C	10.64	8.23	1.30	1.11	5.7
C 1200 ^{0}C	17.02	11.41	1.32	1.11	4.9
1250 ^{0}C	13.92	11.69	1.26	1.10	5.1
D 1200 ^{0}C	-	-	-	-	-
1250 ^{0}C	-	-	-	-	-
E 1200 ^{0}C	25.73	18.07	1.82	1.37	2.3
1250^{0}C	22.29	17.73	1.59	1.24	2.8
F 1200 ^{0}C	12.00	7.99	1.51	1.34	0.6
1250 ^{0}C	21.19	10.70	2.36	1.89	0.7
G 1200 ^{0}C	13.70	7.00	2.08	1.81	2.2
1250 ^{0}C	45.00	46.02	1.71	0.96	2.6
H 1200 ^{0}C	17.57	14.74	1.35	1.12	2.9
1250 ^{0}C	9.56	6.02	1.56	1.42	3.2
I 1200 ^{0}C	16.45	12.04	1.52	1.28	1.8
1250 ^{0}C	-	-	-	-	-
J 1200 ^{0}C	38.68	34.94	1.81	1.11	3.5
1250 ^{0}C	58.77	32.19	4.16	1.75	3.8
K 1200 ^{0}C	20.91	18.65	1.33	1.07	2.3
1250 ^{0}C	28.11	11.35	1.39	1.20	2.7
L 1200 ^{0}C	36.26	21.43	1.56	1.13	2.7
1250 ^{0}C	28.43	24.24	1.56	1.11	2.8
M 1200 ^{0}C	37.95	33.33	1.96	1.11	3.9
1200 ^{0}C	30.72	24.06	1.76	1.24	4.1

Sample melted

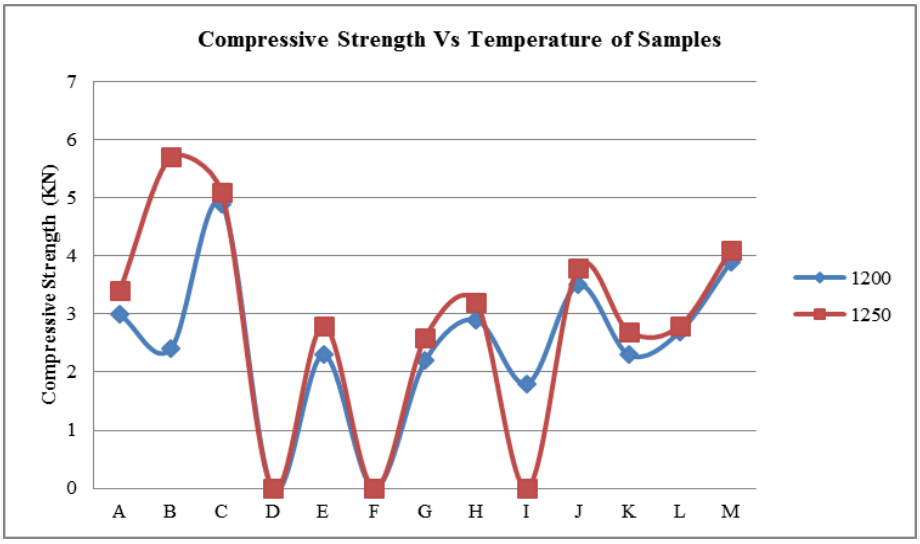

Fig 1: The Figure 1 shows the plot of the variation of the compressive strength with the different samples fired at 1200^0C and 1250^0C respectively

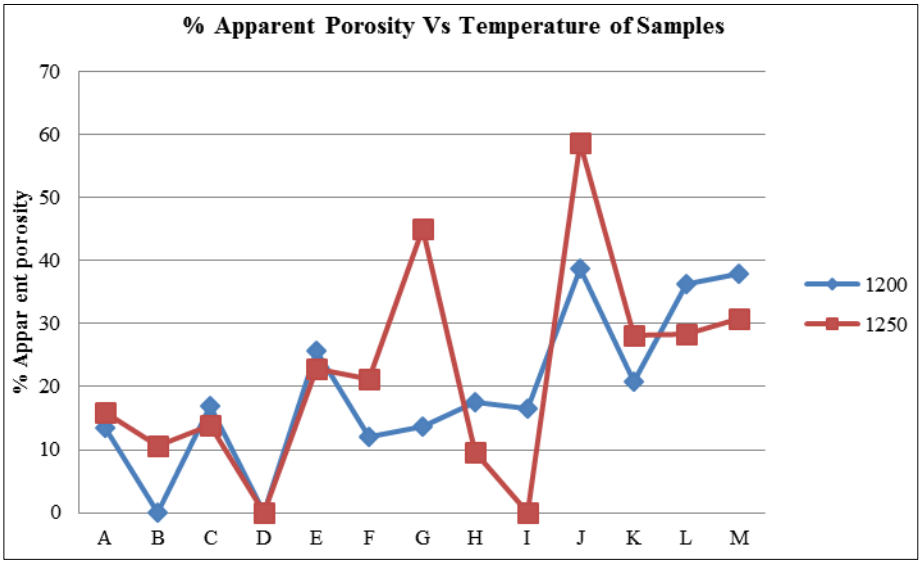

Fig 2: The Figure 2 shows the plot of the variation of the % Apparent Porosity with the different samples fired at 1200^0C and 1250^0C respectively

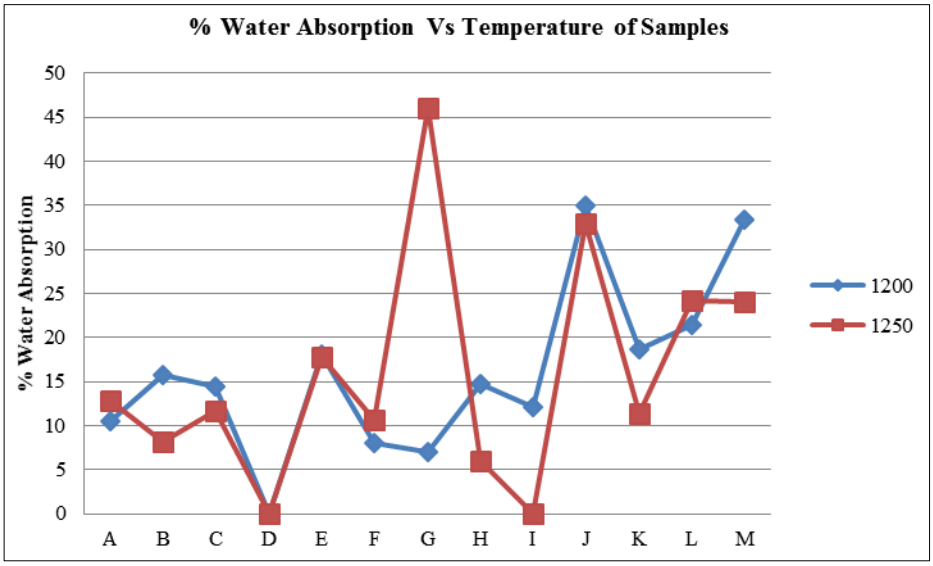

Fig 3: The Figure 3 shows the plot of the variation of the % Water Absorption with the different samples fired at 1200^0C and 1250^0C respectively

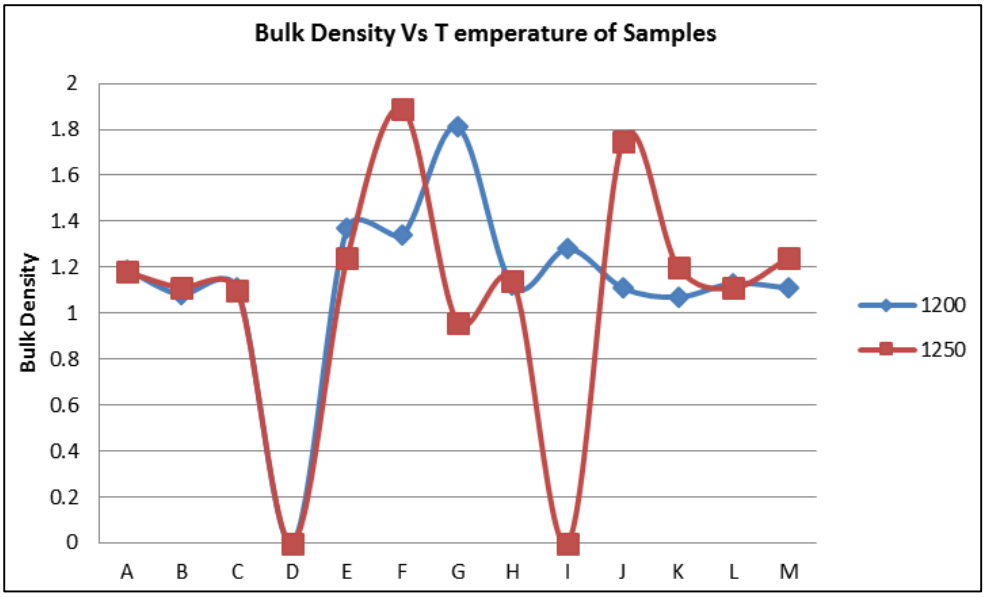

Fig 4: The Figure 4 shows the plot of the variation of the Bulk Density with the different samples fired at 1200^{0}C and 1250^{0}C respectively.

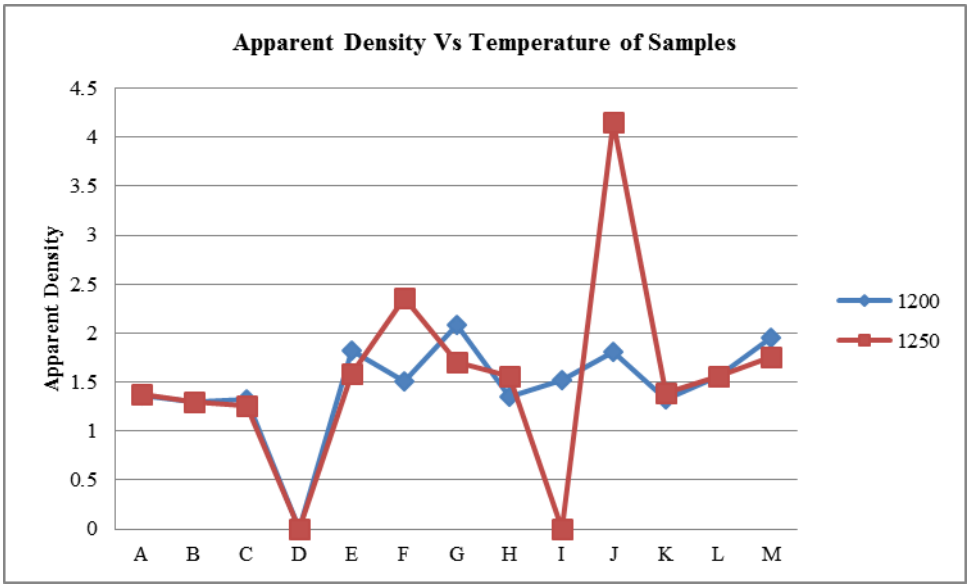

Fig 5: The Figure 5 shows the plot of the variation of the Apparent Density with the different samples fired at 1200^{0}C and 1250^{0}C respectively.

4. Discussion

The plot of Figure 1 shows the compressive strength of the various samples at different firing temperatures. The different firing temperature at which the pellets were fired affected the compressive strength as evident in Table 4. The highest value of Sample B at 1250 ^{0}C was 5.7KN which could be due to the amount of binding agents added and the absence of carbonaceous materials. This firing strengthen the iron oxide bond to the iron ore particles and strengthened the bond of the Calcium oxide (CaO) thereby adjusting the compressive strength in appropriate ranges. The lower compressive strength of the same B at 1200 ^{0}C resulted probably due to insufficient firing temperature. Also, the lowest compressive strength observed in sample F within the temperature range investigated could be due to the increased amount of the added coke breeze and a complete absence of a fluxing agent. Similarly, the sample D melted at both 1200^{0}C and 1250^{0}C which was probably consequent upon the complete absence of both a binding agent and fluxing agent respectively. Also, the high percentage of carbonaceous material (coke breeze) must have aided the melting of the sample. Generally, the increased compressive strength noticed at 1250^{0}C for all the samples can be attributed to better burn out at higher firing temperature and also due to decreased porosity of the pellets samples. It is also worthwhile to affirm that samples with approximate amount of binders have higher compressive strength due to effective removal of binders.

Also, the charts of Figure 2, Figure 3, Figure 3 and figure 4 show the % apparent porosity, % water absorption, bulk density and apparent density of the various samples at different firing temperatures respectively. It is clear that the different firing temperature at which the pellets were fired affected the aforementioned physical properties under investigation. It is observed that the % apparent porosity, % water absorption, bulk density and apparent density were significantly improved for all the samples at higher firing temperature. Although, samples L and M show a reduction in the value of the % apparent porosity at higher firing

temperature. This is could be attributed to the increased presence of the coke breeze and sawdust added to these samples. In the same vein, Sample M shows a reduction in the values of the % water absorption and apparent density at higher firing temperature which probably could be due to the significant increase of the percentage of the carbonaceous materials added. In addition, the sample D melted at both 1200^0C and 1250^0C which was probably consequent upon the complete absence of both a binding agent and fluxing agent respectively and a significant percentage addition in the amount of coke breeze (with an inflammation point at about 312^0C). Thus, the high percentage coke breeze must have facilitated the melting of the sample. It can be therefore be said that the various mixing ratio and the methods adopted for raw materials is very essential during green ball formation and determine and affects the properties of the fired pellets.

5. Conclusions

From the foregoing, it is pertinent to conclude that the increased compressive strength noticed at 1250^0C for all the samples can be attributed to better burn out at higher firing temperature. It is also worthwhile to affirm that samples with approximate amount of binders have higher compressive strength due to effective removal of binders. It can also be concluded that the various mixing ratio and the methods adopted for raw materials is very essential during green ball formation and determine and affects the properties of the fired pellets.

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