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Effect of carbonaceous materials on the physical properties of pellets produced by different methods of addition of materials

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Abstract

The demand for hardened, metallized iron pellets has increased significantly in the last decade alongside with an increase in the use of electric furnaces for producing steel. Metallized iron pellets having a consistent chemical composition and a reasonably stable price are desired as replacement for scrap steel commonly used as part of the charge in electric steelmaking furnaces. These 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 binding agents, presence of carbonaceous material and firing temperature, affected the quality of pellets produced. Analysis and test results depict that the addition of carbonaceous materials reduced the compressive strength of the fired pellets. The reduction in the compressive strength observed is a consequence of the formation of micro-pores which is a due to the addition of carbonaceous materials. The investigations also revealed that the % apparent porosity of the fired pellets increased with increasing % carbonaceous materials addition. It was also observed that the addition of carbonaceous materials (in increasing order) made the green pellets to be brittle. The result obtained also showed that the presence of carbonaceous materials to the pellets reduced the bulk density. Test result and analysis also revealed that pellets with high porosity have small (low) bulk density.

Keywords: carbonaceous materials, coke breeze, sawdust, iron ore pellet, physical properties of pellets

1. 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].

The desired properties of iron oxide pellets for direct reduction are as follows: (1) narrow size range and minimum of fines, (2) good cold strength and resistance to degradation during handling, (3) high reducibility, (4) resistance to degradation during heating and reduction, (5) minimum amount of swelling during reduction, (6) little or no tendency to stick and form clusters at reduction temperatures, (7) high strength of reduced product, (8) resistance to reoxidation of the reduced product [12-17]. 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 [18]. 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 [19]

Suitable solid carbonaceous material include both agglomerating and non-agglomerating coals, such as coking and non-coking bituminous coals, anthracite coals and lignite, and various forms of pyrolyzed carbon, such as coke breeze, bituminous and anthracite coal char, lignite char, wood char, graphite and the like. Less volatile coals and chars are preferred because they generally provide higher compressive strengths. The primary function of the carbonaceous material is to supply internal carbon for reducing the iron oxide to metallic iron during the reduction [1]. 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 [20, 21].

It is also generally accepted that pores play an important role in influencing the properties of iron ore sinter and pellets [22, 23], and that the properties of iron ore sinter and pellets are related to the mineral constituents [24, 25, 26, 27]. During the induration of pellets, crystal changes occur as a function of induration time and optimum induration temperature [28].

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.

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

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

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

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

Where Ws = soaked weight, Wd = Dry weight, Wa = Suspended weight, The liquid of immersion is water (density = 1g/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 - 6. While the result of the drop number is depicted in Table 4, the results of the tested properties of the fired pellets are tabulated in Table 5.

Table 4: Drop Number

A	B	C	D	E	F	G	H	I	J	K	L	M
3.67	5.00	4.67	1.00	1.00	1.67	2.33	3.00	1.00	5.33	2.33	2.67	2.00

Table 5: 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

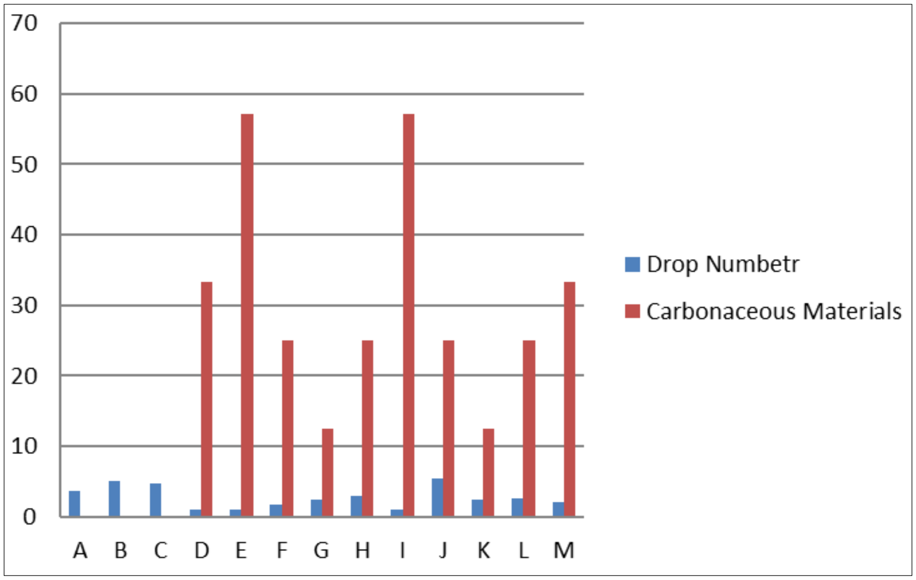

Fig 1: % Carbonaceous Materials Vs Drop Number of Green Balls

The Figure 1 shows the chart of the variation of the % carbonaceous materials added with the drop number of the different samples of the green pellets before firing.

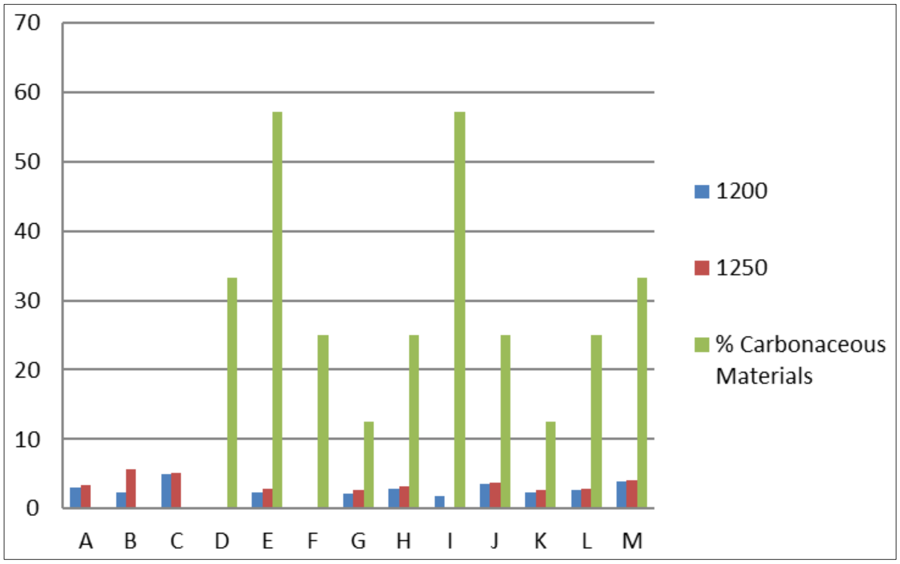

Fig 2: % Carbonaceous Material Vs Compreesive Strength of Samples at Different Temperaures

The Figure 2 shows the chart of the variation of the % carbonaceous materials added with the compressive strength of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively

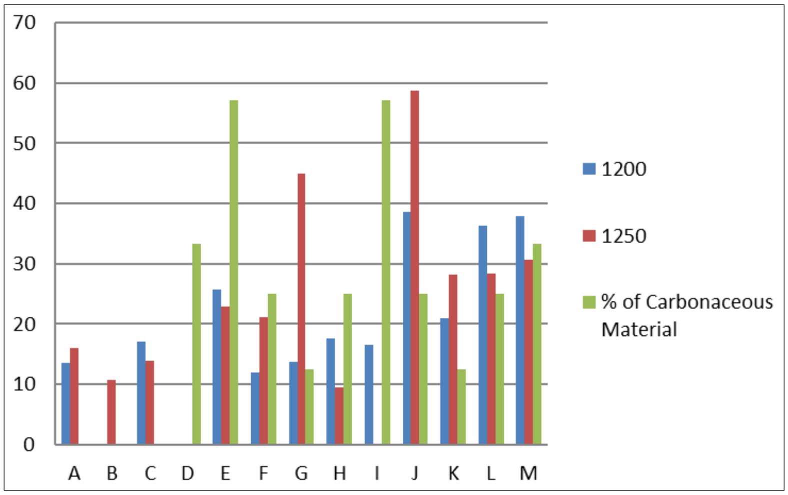

Fig 3: % Carbonaceous Material Vs % Apparent Porosity at Different Temperatures

The Figure 3 shows the chart of the variation of the % carbonaceous materials added with the % apparent porosity of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively

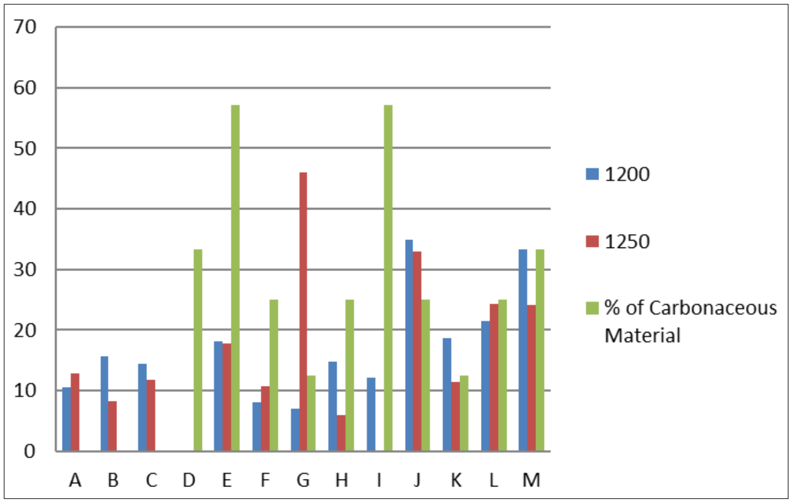

Fig 4: % Carbonaceous Material Vs % Water Absorption at Different Temperatures

The Figure 4 shows the chart of the variation of the % carbonaceous materials added with the % water absorption of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively

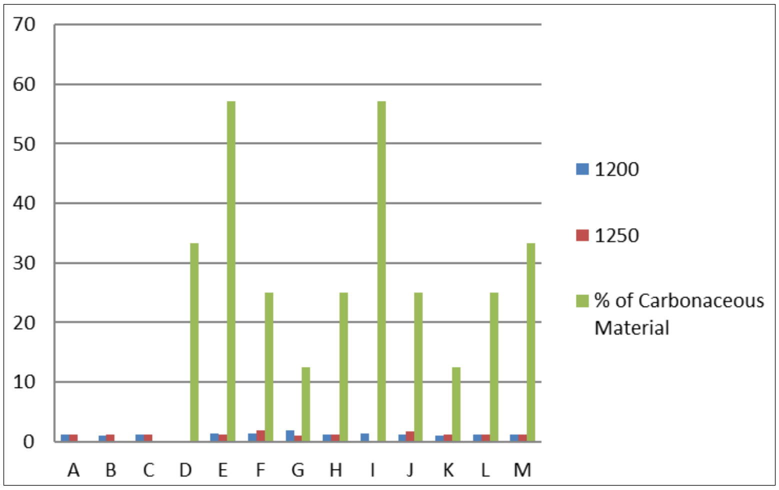

Fig 5: % Carbonaceous Material Vs Bulk Density of Samples at Different Temperatures

The Figure 5 shows the chart of the variation of the % carbonaceous materials added with the bulk density of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively

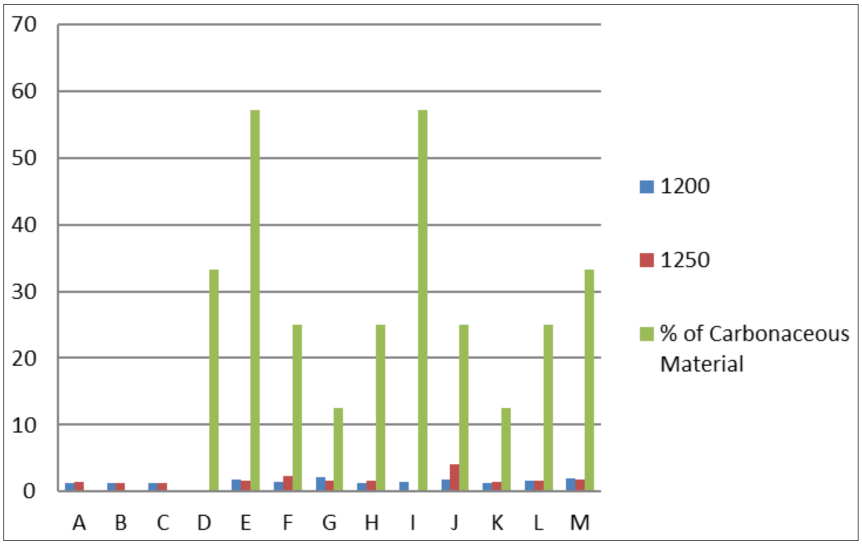

Fig 6: % Carbonaceous Material Vs Apparent Density of Samples at Different Temperatures

The Figure 6 shows the chart of the variation of the % carbonaceous materials added with the apparent density of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively.

4. Discussion

The Figure 1 shows the chart of the variation of the % carbonaceous materials added to the pellets with the drop number of the different samples of the green pellets before induration. It was evident that the use of carbonaceous materials of a particular form is essential to the formation of pore in the pellets in the defined porosity and size. A reduction in the drop number was observed as the amount of carbonaceous materials increased as seen in Samples D - M. It can be concluded that the presence of carbonaceous materials (in increasing order) makes the green pellets to be brittle.

The Figure 2 shows the chart of the variation of the % carbonaceous materials added with the compressive strength of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively. Analysis of Table 5 and Figure 2 suggest that the addition of carbonaceous materials reduced the compressive strength of the fired pellets. It was observed that due to micro-pores formation, which is a consequence of the presence of carbonaceous materials, the compressive strength was reduced. Thus, it can also be seen that in Sample J (1250 ^{0}C) with an apparent porosity of 58.77%, the compressive strength reduced having a value of 3.8KN as against Sample B (1250 ^{0}C), with an apparent porosity of 10.64% with the highest value of 5.7KN leading to the confirmation that micro-pores lower the compressive strength of pellets. Generally speaking, most of the samples experienced improved compressive strength at higher temperature except sample D which melted completely at both temperatures and sample I which melted at 1250^{0}C. This observation is attributed to the various mixing sequence/mixing ratio employed and the constituent materials addition used.

More so, the charts of Figure 3, Figure 4, Figure 5 and Figure 6 show the variation of the % carbonaceous materials with the % apparent porosity, % water absorption, bulk density and apparent density of the various samples at different firing temperatures respectively. It was noticed that the properties being investigated varied significantly with increasing percentage addition of the carbonaceous materials added alongside the various mixing sequence/mixing ratio adopted, constituent materials and firing temperature employed. From Figure 3 is observed that the % apparent porosity increased with increasing % carbonaceous materials addition as shown in sample E to M respectively. It is however noticed that the % apparent porosity decreased with increasing temperature. The high % apparent porosity noticed can be attributed to the formation of pores was due to the burnt off carbonaceous materials having a low inflammable temperature thereby facilitating the formation of pores and encouraging diffusing of water in the apparent porosity experiment. Figure 4 reveals that addition of carbonaceous materials resulted in an increase in the % water absorption depending on the mixing sequence. Figure 5 reveals that the addition of carbonaceous materials has significant impact on the bulk density of the fired pellets. Analysis of the result indicates that the introduction of carbonaceous materials to the pellets reduced the bulk density. This is understandable from the basis of the fact that addition of carbonaceous materials caused the formation of micro-pores leading to high apparent porosity. Thus, it is evident and therefore can be concluded that pellets with high porosity usually have small (low) bulk density. However, the composition of the pellets and the manner/sequence of addition of constituent materials are also determining factors. The Figure 6 shows the chart of the variation of the % carbonaceous materials added with the apparent density of the different pellets samples fired at 1200^{0}C and 1250^{0}C respectively. From the Figure 6 it is clear that the addition of carbonaceous materials significantly affects the apparent density by reducing the apparent density. Again, the compositional make-up of the pellets and the manner/sequence of addition of constituent materials are also determining factors.

5. Conclusions

The following conclusions can be drawn on the studies undertaken on the effect of carbonaceous materials on the physical properties of pellets produced by different methods of addition of materials

1. The presence of carbonaceous materials (in increasing order) makes the green pellets to be brittle.
2. The addition of carbonaceous materials reduced the compressive strength of the fired pellets
3. Micro-pores formation, which is a consequence of the presence of carbonaceous materials, reduced the compressive strength of the fired pellets
4. The % apparent porosity increased with increasing % carbonaceous materials
5. Addition of carbonaceous materials to the pellets reduced the bulk density
6. Pellets with high porosity have small (low) bulk density.

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