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Binding properties of starch and bentonite in the briquetting of fine particulate charcoal

Adesigbin, A.J.[1]*, Adedeji, M.A.[1], Oyeleke, M.O.[2] and Ologunye, O.B.[3]

[1]Department of Agricultural and Bio-Environmental Engineering Technology, Federal Polytechnic Ede, Nigeria
[2]Nigerian Institute of Oceanography and Marine Research, Lagos, Nigeria
[3]Department of Mechanical Engineering Technology, Federal Polytechnic Ede, Nigeria

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ABSTRACT

The main objective of this study is to determine the possibility and to what extent the manufacture of briquettes from slack or charcoal fines may succeed commercially under the conditions existing in Nigeria. The need for Charcoal briquette is of utmost importance in this contemporary world. Data available on the binding properties of starch and bentonite in the briquetting of fine particulate charcoal is very limited. In this study different percentage compositions of the materials such as charcoal fine, sawdust, limestone, cassava starch, borax and bentonite were used for modelling charcoal briquettes and were subjected to different engineering properties analysis such as porosity, bulk density, compressive strength, hardness, shearing strength, permanent linear change and modulus of rupture. The quantities of these materials at different formulations with the percentage composition of starch ranges from 9.6%, 7.7%, 5.8%, 3.8% and 1.9%, and the bentonite for the same percentages but in a descending order, respectively. Five different formulation samples A, B, C, D and E were used. The samples of formulation A had the lowest average porosity of 6.80 % when compared to the highest average porosity of 8.60 % obtained from samples of formulation E. From the result obtained bulk density was highest (0.57 g cm^{-3}) in samples from formulation A which shows that samples from formulation A is more compacted in structure and cannot be easily broken compared to the samples obtained from B to E formulations. Results obtained show various rupture point of the charcoal briquette for all the formulations i.e. formulation. The highest mean value (1455.23) of samples from formulation E was recorded compared to the samples from formulations A, B and C, while lowest mean value of 214.51 was recorded in formulation A. The results for permanent linear change show a little difference in percentage among the samples at different formulation. The pattern of the percentage differences at different formulation is in increasing order and this was obtained as a result of the increasing order of porosity of all the samples at different formulations. As the permanent linear change increases the porosity also increased. The result for hardness showed different ability of all the samples from different formulation to resist indentation. Formulation A had the highest value when compared with formulations B, C, D, and E. Formulation A also had the highest mean value of 14.3 HBN (Hardness Brinel Number) while formulation B had the mean value of 10.72 HBN which was higher compared to the mean values of formulations C, D and E. Formulation A had the highest compressive strength of 259.11 kgf compared to the remaining formulation B, C, D and E. Maximum shear strength of 1081.23 kgf was obtained at formulation A but gradually decreased to 307.03 kgf in formulation E.

Key words: Bulk density, Porosity, Permanent linear change, Compression strength, Shear strength, Hardness and modulus of rupture

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INTRODUCTION

The use of firewood and misuse of the existing energy resources (agricultural residues) is creating human and environmental crisis in the developing countries which is resulting in deforestation and subsequent global warming. According to Rodas [1], Nine-tenths of all the wood harvested annually is used for energy; “it accounts for over two-thirds of total energy consumption in 24 tropical countries of which 16 are least-developed countries. The decreasing availability of fuel wood, coupled with the ever increasing prices of kerosene and cooking gas in Nigeria draws attention to the need to consider alternative sources of energy for domestic and cottage level industrial use in the country [2]. Such energy sources should be renewable, environmentally friendly and should be accessible and avoidable to the poor in the society. A pronounced shift from fuel wood to charcoal, especially in Africa, has raised concerns among environmentalists and those responsible for forest development and management [3]. In general, energy consumption in rural areas of Africa is still low and is limited almost exclusively to fuel wood. However, energy consumption and the type of fuel used by households evolve as countries develop. As rightly noted by Stout and Best [4], a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria. Over the years, different kinds of adhesive have been used for the production of briquette and the most traditional one used was starch. Briquetting involves the compression of a material into a solid product of higher bulk density, lower moisture content and uniform size, shape and materials; properties that would allow them to be used as fuel just like wood or charcoal [5]. A briquette is a block of compressed coal dust, charcoal dust, sawdust, wood chips or biomass, and is used as a fuel in stoves and boilers. Charcoal is not like clay. Charcoal is a material without plasticity and cannot be mould into shape without adding a binding material. Charcoal briquettes appeared on the markets of developed countries as a serious alternative to lump charcoal in the early fifties with the development of methods for producing fine charcoal from sawdust and bark on a large scale [6]. There has been challenges of cracking of briquette products after drying in an Asia industries using the following production formulation (6% cassava starch, 2% borax, 1% limestone, 1% kaolin and the rest is 90% charcoal powder), which reduced the quality of the product to be effective and also with the current fuel shortage and over rising price, consumers are looking for affordable alternative fuels and briquettes fill this gap for cooking and water heating in households, Heating production processes. This research work was carried out in order to give reasonable solutions to the challenges of cracking of the products. The main objective of this study is to determine as far as possible to what extent the manufacture of briquettes from slack or charcoal fines may succeed commercially under the conditions existing in Nigeria.

MATERIALS AND METHODS

Materials used for Charcoal Briquettes

The following materials were used to form the samples used for this research work they are: charcoal fine, sawdust, lime stone, cassava starch, borax and bentonite. Different percentage compositions were formulated for better results and also to get the most preferred composition. A mould machine which is a hollow machine used to give shape to molten or hot liquid material when it cools and hardens was used to give shape to the charcoal briquetting at different formulation.

Experimental Procedures

In the processes of product preparation, the sawdust was soaked in water for five days to give smokeless flames when burning. Wood charcoals are crushed, to get charcoal fines which were used so as to emit less ash heat fuel material. Drying of starch and sieving of the charcoal were also done before the briquette materials were mixed together at appropriate predetermined quantities using different formulations. It is then treated to increase its ability to absorb various substances by reheating with oxidizing gas and other chemicals to break it into a very fine powder. The quantities of materials at different formulation with the percentage composition of starch ranges from 9.6%, 7.7%, 5.8%, 3.8%, 1.9%, and the bentonite from 1.9%, 3.8%, 5.8%, 7.7%, and 9.6%, respectively are stated in Tables 1, 2, 3, 4 and 5. Also the variation mass of starch and bentonite used is shown in Table 6. The different formulation was replicated three times to determine the most preferable result. After mixing the materials at different formulations, it was poured into the mould machine. The charcoal briquette was then extruded by using hydraulic press/ Screw press which came out easily with the aid of borax in the mixing proportion. The products were dried at approximately temperature of 70°Cin electrically controlled oven for 24 hours and were then later taken to the laboratory for the analysis. The analysis was carried out on the products to determine its strength, resistivity and efficiency. The engineering properties analyzed were porosity, bulk density, compressive strength, hardness, shearing test/ punching test, permanent linear change and modulus of rupture.

Table -1 Materials formulation for sample A

Raw materials	Mass (g)	Composition (%)
Fine Charcoal	120	76.9
Sawdust	12	7.7
Cassava starch	15	9.6
Borax	3	1.9
Lime stone	3	1.9
Bentonite clay	3	1.9

Table -2 Materials formulation for sample B

Raw materials	Mass (g)	Composition (%)
Fine Charcoal	120	76.9
Sawdust	12	7.7
Cassava starch	12	7.7
Borax	3	1.9
Lime stone	3	1.9
Bentonite clay	6	3.8

Table -3 Materials formulation for sample

Raw materials	Mass (g)	Composition (%)
Fine Charcoal	120	76.9
Sawdust	12	7.7
Cassava starch	9	5.8
Borax	3	1.9
Lime stone	3	1.9
Bentonite clay	9	5.8

Table -4 Materials formulation for sample D

Raw materials	Mass (g)	Composition (%)
Fine Charcoal	120	76.9
Sawdust	12	7.7
Cassava starch	6	3.8
Borax	3	1.9
Lime stone	3	1.9
Bentonite clay	12	7.7

Table -5 Materials formulation for sample E

Raw materials	Mass (g)	Composition (%)
Fine Charcoal	120	76.9
Sawdust	12	7.7
Cassava starch	3	1.9
Borax	3	1.9
Lime stone	3	1.9
Bentonite clay	15	9.6

Table -6 Starch and bentonite variation

S/N	Starch (g)	Bentonite (g)
1	15	3
2	12	6
3	9	9
4	6	12
5	3	15

Porosity

The apparent porosity is a measure of the volume of the open pores, into which a liquid can penetrate, as a percentage of the total volume. This is determined using Equation 1

$$A.P = \frac{W-D}{W-A} \times 100 \qquad (1)$$

where $A.P$ = % of apparent porosity

W = Weight of saturated specimen in air (dried at 110^0 C in an Oven)

D = Weight of dry specimen in air

A = Weight of saturated specimen submerged in water

Bulk Density

Bulk density is not an intrinsic property of a material; it can change depending on how the material is handled. The bulk density of a material depends greatly on the mineral make up of materials and degree of saturation [7]. The bulk density of material is inversely related to the porosity of the same material; the more pore space in a material the lower the value for bulk density .For charcoal briquetting, bulk densities of samples at different formulation were determined using Equation 2.

$$B= \frac{W}{V} \qquad (2)$$

where, B = Bulk density of the material

W = Weight of the test specimen, g

V = Volume of the test specimen .cm^3

Compressive Strength

According to the ASTM standard, the compressive strength is defined as the compressive stress at which an unconfined cylindrical specimen of material will fail in a simple compression test. In this test method, the compressive strength was taken as the maximum load attained per unit area during the performance of a test. The compressive strength of the materials on each of the formulation was determined using compression test machine (Plate1) at the Department of Material sciences, Obafemi Awolowo University, Ile-Ife. The compressive and shear strength of all the samples were determined and estimated.

Plate 1: Compression testing machine

Hardness

The ability of a material to resist indentation for all the samples at different formulation was determined by using Tensometer and the smallest load of 45 kg. Different diameters of indentation were used for samples of different formulation. Equation 3 was used to obtain various values of hardness at different formulations;

$$BHN = \frac{W}{\frac{\pi}{D}[D-\sqrt{(D^2-d^2)}} \qquad (3)$$

where D = diameter of indentation (10mm)

d = diameter of indentation, w = mass x acceleration due to gravity (10ms^{-2})

Permanent linear change (PLC)

The ratio of increase or decrease in length to the ratio of Original length in percentage was determined using the procedure in Equation 4;

$$PLC = \frac{increas\ einlengt\ h}{originallengt\ \ h} \times 100 \qquad (4)$$

Modulus of Rupture

Modulus of rupture (R) was determined using the same compression test machine used for compressive strength determination, with slight modifications following the procedure describe in Equation 5;

$$R = \frac{3wl}{2bd^2} \qquad (5)$$

where, w = total load at which the specimen failed, kg

l = distance between support, i.e. bearing edges, cm

b= width of specimen, cm

d = depth of specimen, i.e. thickness

RESULTS AND DISCUSSIONS

Mould Machine

A mould machine is a hollow machine used to give shape to molten or hot liquid material when it cools and hardens. The mould machine was used to give shape to the charcoal briquetting at different formulations (Plate 2);

Plate 2: Charcoal briquettes products

Porosity

The total volume of pore space of the charcoal briquette, that is, portion of the charcoal volume occupied by air and water shows different results at different formulations. The formulation for sample A (table 7) had the lowest average porosity of 6.80 % which was adequate for the charcoal briquette to provide optimum yield compared to the highest average porosity of 8.60 % obtained from formulation sample E (table 7) which can affect the yield of the charcoal briquette. The total porosity of the formulation samples A, B, C, D and E is shown in Table 7;

Table -7 Total porosity of the samples from all the formulation

Formulation (%) Samples	**A**	**B**	**C**	**D**	**E**
1	6.80	6.97	7.79	7.79	8.50
2	7.08	7.17	7.01	8.16	8.80
3	6.59	7.27	7.20	8.15	8.50
Mean	6.80	7.14	7.33	8.07	8.60

Bulk Density

The bulk density of all the samples for different formulation was obtained. Results obtained showed that the bulk density varied among formulations i.e. (Tables 1-5). The bulk density was highest (0.57 g cm^{-3}) in formulation for sample A, under mass ratio 15g to 3g and percentage composition 9.6 % of cassava starch and 1.9 % of bentonite respectively (Table 1) which shows that samples from formulation A is more compacted in structure and cannot be easily broken compared to the samples obtained from Formulation E (Table 5) that had the lowest bulk density of 0.51 g/cm^3. The bulk density from all the samples showed descending order in their result i.e. sample A > sample B> sample C > sample D > sample E. The results are shown in Table 8;

Table -8 Mean bulk densities for samples from all the formulations

Bulk density (g/cm^3)					
Sample	**A**	**B**	**C**	**D**	**E**
1	0.571	0.587	0.519	0.517	0.506
2	0.574	0.550	0.547	0.518	0.524
3	0.560	0.553	0.519	0.542	0.508
Mean	0.57	0.56	0.53	0.52	0.51

Modulus of Rupture

Results obtained showed various rupture point of the charcoal briquette for all the formulations. The mean value (1455.23) of samples from formulation E was highest compared to the rest samples with sample having the least value. The values are 214.51< 226.55 < 730.29 < 869.59 < 1446.39, A B, C, D& E, respectively. According to the result obtained, it was only the formulation E that had the highest probability of rupture which reduces its yield compared to formulation A that had the lowest modulus of rupture and also lowest probability of bursting. Table 9 shows detailed result of modulus of rupture obtained at different formulation for all the samples;

Table -9 Detailed result of modulus of rupture for samples from all the formulation

Modulus of rupture (kg/cm^3)					
Samples	**A**	**B**	**C**	**D**	**E**
1	208.92	229.73	694.84	922.19	1455.23
2	220.15	217.15	742.16	885.14	1401.44
3	214.45	232.77	753.87	801.45	1482.51
Mean	214.51	226.55	730.29	869.59	1446.39

Permanent Linear Change

The results for permanent linear change show a little difference in percentage among the samples at different formulations. The pattern of the percentage differences at different formulation is in increasing order i.e. Formulation A < B < C < D < E and this was obtained as a result of the increasing order of porosity of all the samples at different formulation. The more permanent linear change the more the porosity and vice – versa. Table 10 shows permanent linear change recorded at different formulation. Also Figure shows the relationship between the porosity and permanent linear change.

Table -10 Permanent linear change for samples from all the formulation

Permanent linear change (%)					
Sample	**A**	**B**	**C**	**D**	**E**
1	3.0	1.45	4.3	2.94	3.03
2	1.5	2.94	2.9	3.03	4.41
3	1.49	3.0	1.5	2.90	2.94
Mean	1.99	2.46	2.90	2.96	3.46

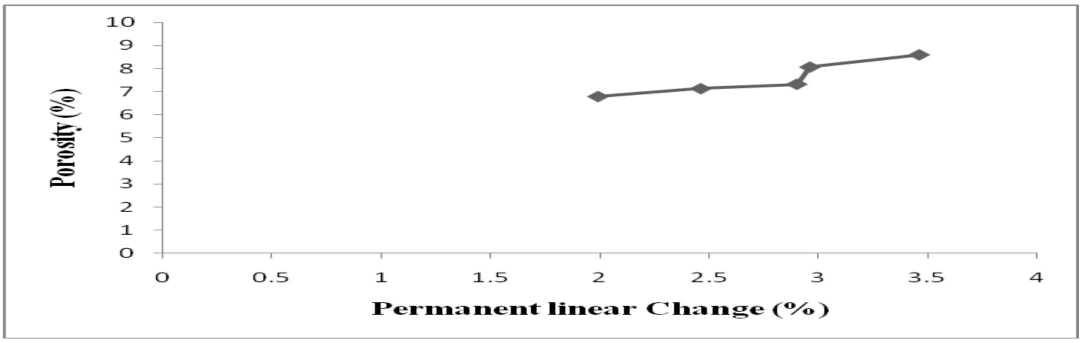

Fig. 1 Relationship between porosity and permanent linear change

Hardness

The result for hardness show different ability of all the samples from different formulation to resist indentation. The result of samples from formulation A was higher than the remaining formulation B, C, D, and E. Formulation A had the highest mean value of 14.3 HBN (Hardness Brinel Number) which implies that samples from formulation A had more ability to resist indentation to increase charcoal briquette production. Formulation B had the mean value of 10.72 HBN which was higher compared to the mean values of Formulation C and D. Formulation E under mass ratio 3g to 15g and percentage composition 1.9 % of cassava starch and 9.6 % of bentonite respectively. Table 11 gives clear information on the ability of the samples from all the formulation to resist indentation. There is a relationship between the hardness and the bulk density of all the samples at different formulation, the more the bulk density of the materials the more the hardness and vice – versa. Figure 2 shows detail relationship between the hardness and the bulk density using mean value.

Table -11 Hardness values for samples from all the formulation

Hardness (HBN)					
Sample	**A**	**B**	**C**	**D**	**E**
1	14.04	10.72	9.00	6.93	6.86
2	14.32	10.80	9.60	7.12	6.93
3	14.54	10.93	8.18	6.70	6.78
Mean	14.3	10.8	8.92	6.91	6.85

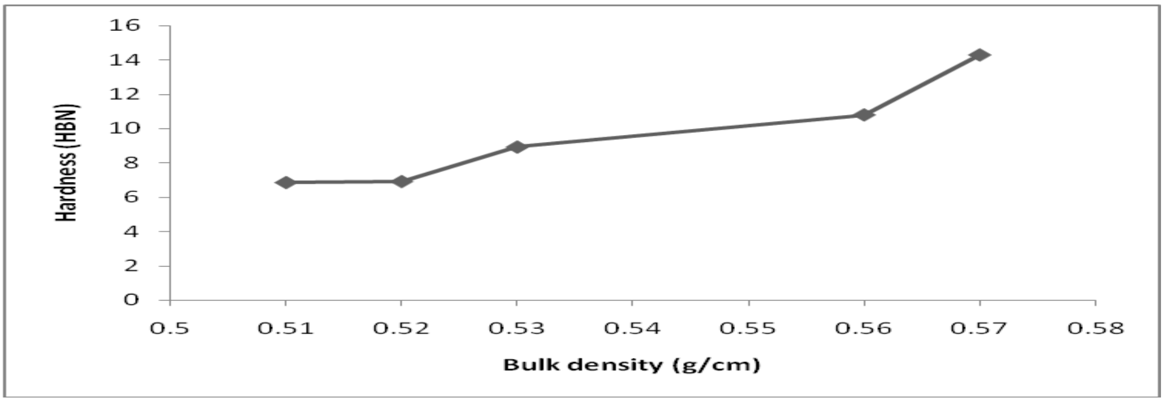

Fig. 2 Relationship between hardness and bulk density

Compressive and Shearing Strength

The influence of different formulation on compressive strength of the samples was noticed as shown in Table 12 using 304.78 kgf loads. Formulation A had the highest compressive strength of 259.11 kgf (Table 12) which shows that samples from formulation A possessed higher energy content for effective use and enhanced binding yield compared to the remaining formulation B, C, D and E (Table 12). Formulation B has mean compressive strength of 248.92 kgf, formulation C has 246.86 kgf, formulation D has 244.80 kgf and formulation E has the lowest compressive strength of 238.73 kgf resulted in lower energy content of the materials. Maximum shear strength of 1081.23 kgf was obtained at formulation A (Table 13) but decreased to 307.03 kgf in formulation E, which shows that shearing strength decreased in the order of material formulation from A to E, respectively. The Mean compressive data of samples from all the formulations (A, B, C, D and E are statistically in Tables 14, 15, 16, 17 & 18.Also, Figures 3, 4, 5, 6 & 7 were used to analyze the force (kgf) against compression at different formulations showed failure point of samples.

Table -12 Compressive strength for samples from all the formulation

	Compressive strength (kgf)				
Sample	**A**	**B**	**C**	**D**	**E**
1	262.15	255.98	252.94	252.94	243.82
2	259.11	246.86	246.86	243.82	234.71
3	256.07	243.82	240.69	237.65	237.75
Mean	259.11	248.92	2.46.86	244.80	238.73

Table -13 Shearing strength for samples from all the formulation

	Shearing strength (kgf)				
Sample	**A**	**B**	**C**	**D**	**E**
1	1029.00	1009.40	627.20	333.20	294.00
2	1127.00	980.00	637.00	382.20	323.40
3	1087.80	1068.20	656.60	401.80	303.80
Mean	1081.23	1019.20	640.23	372.40	307.03

Table -14 Mean compressive data of samples from formulation A

Force (kgf)	**Compression (%)**
30.48	1.0
91.43	2.0
156.51	3.0
225.50	4.0
259.11	4.6

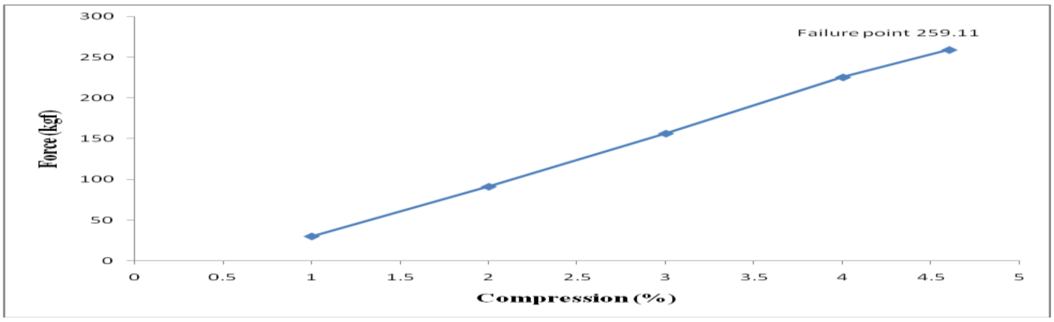

Fig. 3 Force (kgf) against compression at formulation A showing failure point of samples

Table -15 Mean compressive data of samples from formulation B

Force (kgf)	**Compression (%)**
36.55	1.0
100.55	2.0
170.72	3.0
243.82	4.0
248.92	4.2

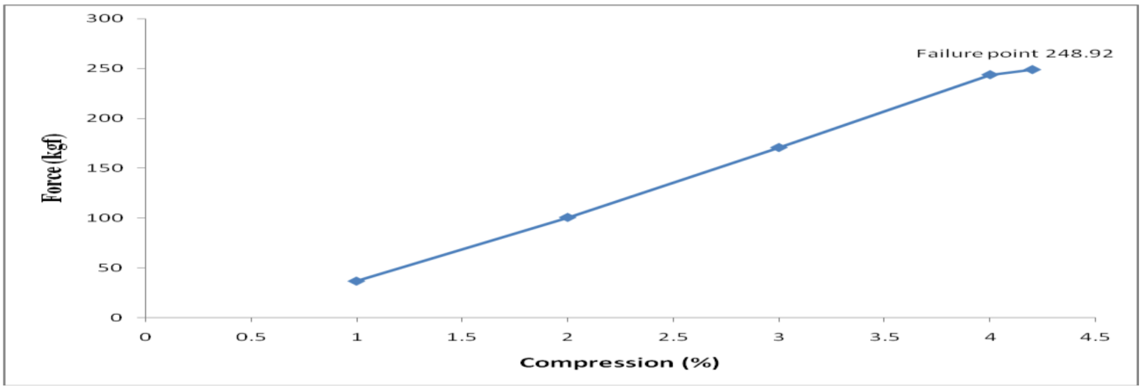

Fig. 4 Force (kgf) against compression at formulation B showing failure point of samples

Table -16 Mean compressive data of samples from formulation C

Force (kgf)	**Compression (%)**
33.52	1.0
97.51	2.0
164.64	3.0
243.82	4.0
246.86	4.1

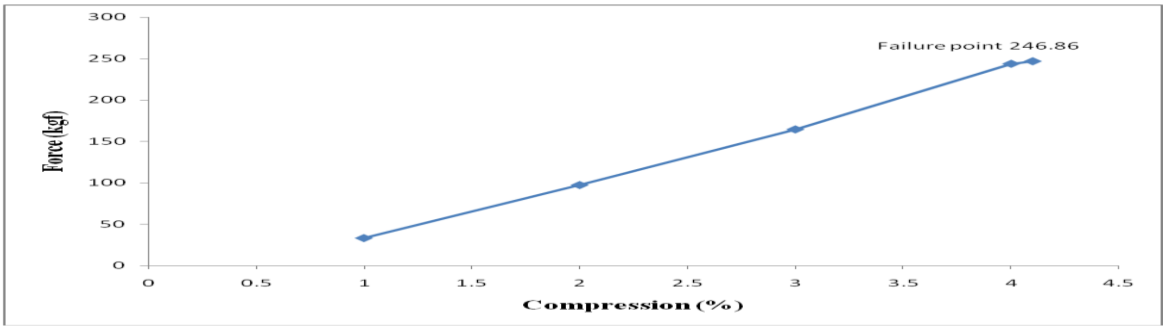

Fig. 5 Force (kgf) against compresssion at formulation C showing failure point of samples

Table -17 Mean compressive data of samples from formulation D

Force (kgf)	**Compression (%)**
12.15	1.0
73.11	2.0
140.24	3.0
207.37	4.0
244.80	4.5

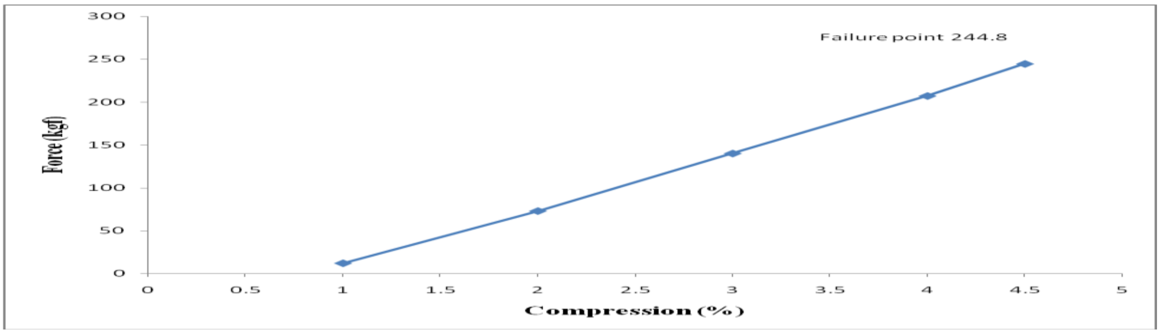

Fig. 6 Force (kgf) against compression at formulation D showing failure point of samples

Table -18 Mean compressive data of samples from formulation E

Force (kgf)	Compression (%)
48.80	1.0
112.80	2.0
173.75	3.0
238.73	4.0

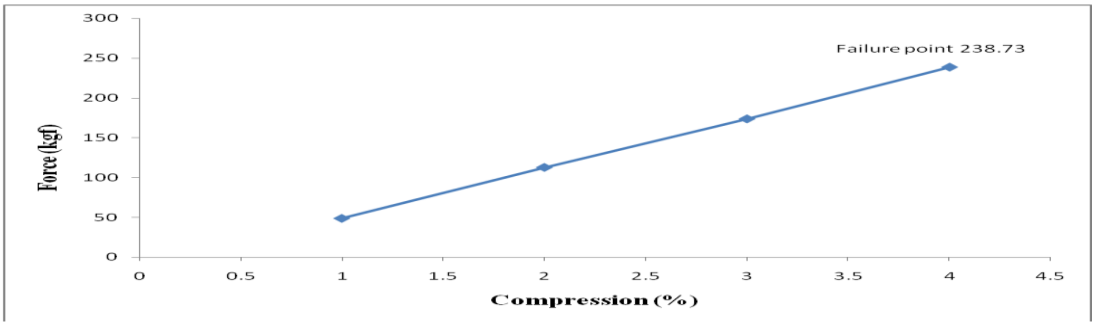

Fig. 7 Force (kgf) against compression at formulation E showing failure point of samples

CONCLUSION

The results of this study indicate the potential of the produced briquettes as fuel for heat application. The Samples of formulation A (under mass ratio 15.0 g to 3.0 g and percentage composition 9.6 % of cassava starch and 1.9 % of bentonite respectively) has the highest bulk density of (0.57 g cm^{-3}) but decreased from 0.56 g cm^{-3} in formulation B to 0.53 g cm^{-3} in formulation C and also 0.52 g/cm^2 in formulation D to 0.51 g/cm^3 in formulation E which implies that samples from formulation A cannot be easily broken which resulted to the highest hardness to enhance resources recovery from charcoal waste. It has the lowest total porosity (The amount of “void” space within sediment) and also lowest permanent linear change, which resulted to the lowest modulus of rupture when compared to the remaining formulations (B, C, D and E respectively). Formulation A had the highest compressive strength (maximum load attained per unit area) which resulted to the highest shearing strength when compared to the remaining Formulation (B, C, D and E respectively).The highest density observed in the briquettes samples from formulation A may be due to its homogenous nature, which may have enabled the material to form a stronger bond, resulting in denser and more stable briquettes [8] leading to improved quality of briquettes which is in line with the findings of Chin & Siddiqui [9] compared to those from the four other formulation mixtures. Samples of formulation B, C and D has lower compressive strength resulted to lower shearing strength and samples of formulation E has the lowest compressive strength resulted to lowest shearing strength. Charcoal briquettes under mass ratio 15.0 g to 3.0 g and percentage composition 9.6 % of cassava starch and 1.9 % of bentonite provides optimum yield which according to Bhattacharya, et al., [10] strongly imply that briquettes with high density are also favored due to enhanced features for transport, storage and handling when compared to the remaining percentage composition of cassava starch and bentonite. Yield reduction was recorded in formulation E. Results of the conducted test showed that the briquettes produced can be well suited as an alternative fuel. The results discussed in the study emphasize that briquette production is feasible due to the availability of raw materials and formulation that are considered appropriate for briquetting.

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