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FABRICATION, CHARACTERIZATION, MECHANICAL AND COMBUSTION PROPERTIES OF BIO-BRIQUETTES DERIVED FROM AGRO-WASTES OF BUSH MANGONUT SHELL AND SUGARCANE BAGASSE

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ABSTRACT

Sequel to the environmental problems associated with wastes in our environment and coupled with the need for effective waste management, this work produced briquettes from agro-wastes of bush mangonut shell (BMS) and sugarcane bagasse (SB). The agro-wastes were crushed to small particle sizes, and compressed in a screw press with compaction pressure of 13.4kPa to produce the briquettes. The metal content and morphology were determined using an Atomic Absorption Spectrometer (AAS) and Scanning Electron Microscope (SEM) respectively. Proximate analyses of the biomasses and briquettes were done using standard methods. Compressive strength and calorific values of the briquettes was determined using compressive strength testing machine and Oxygen Bomb calorimeter respectively. The AAS analyses indicated the presence of Ca (32.19mg/kg), Si (1.43mg/kg), K (0.66mg/kg), P (0.04mg/kg) in SB and Ca (22.20mg/kg), Si (2.05 mg/kg), K (1.21mg/kg), P (0.02mg/kg) for BMS. SEM analyses showed different lignocellulosic structures. The ash contents of the BMS and SB were 4.92 ± 0.05% and 4.16 ± 0.02% respectively. The calorific value of the BMS briquette was 20.9 ± 0.36 MJ/kg and 20.8 ± 0.00 MJ/kg for SB briquette. The low ash content and low concentration of metals in the biomasses presented them as suitable feedstock for bio-fuel production. The briquettes have high calorific values and good mechanical properties, and are recommended for domestic and industrial purposes. Briquetting of agro wastes is economical as it is a way of converting wastes to wealth, and at the same time providing an alternative and renewable source of energy to man.

Contribution/Originality: This study contributes in the existing literature on bio briquette production. The study used new estimation methodology for fabrication of biobriquette. The paper contributes the first logical analysis of (BMS) and (SB). The paper's primary contribution is finding that (BMS) and (SB) can be a good source of energy. This study documents the fabrication of biobriquettes from waste (BMS) and (SB).

1. INTRODUCTION

With increase in population, urbanization and industrialization, the challenge of solid waste management has increased and even now more complex. Waste is unavoidable and unwanted materials resulting from industrial operations, domestic and agricultural activities of which there is no economic demand and which must be disposed off. It is an incident by-product of the processing of a substance and for which no use can be found. Waste is also something which the owner no longer wants at a given place and time and which has no current or perceived market value (Ikelle, Nworie, Ogah, & Ilochi, 2018).

Waste in the environment has health and environmental implications such as breeding of disease vectors, air pollution (caused by uncontrolled and inefficient burning of wastes), water pollution (caused by leachates from refuse dumpsites to surface and underground water), as well as destruction of the beauty of countryside by uncountrolled dumping of wastes. The problem of solid waste generation control has continued to be a threatening global and environmental health issue but more pronounced in developing countries like Nigeria. Infact, Nigeria's major urban centers are today grappling with the problems caused by indiscriminate heaps of solid wastes from the environment (Okwesili & Iroko, 2016).

Although the Ebonyi State Environmental Protection Agency (EBSEPA) was constituted to take care of waste in the environment and their potential hazards, Okwesili and Iroko (2016) reported that waste disposal in Abakaliki does not follow the latest 21st century method of converting waste to wealth. The commonly repeated experience is a simple transfer of refuse from one point to another in open trucks to sites where they are either burnt or buried. The wastes still constitute environmental pollution and degradation, as the burnt wastes lead to particulate matter emission and buried waste leach into underground and surface water bodies. Nwofe (2015) studied the management and disposal of municipal solid wastes in Abakaliki metropolis, Ebonyi state. The study revealed that wastes are burnt in refuse dumps and recommended that government should strongly consider introducing waste to energy technology as a way of curbing the menace of waste management and simultaneously solving the energy needs of the state. Analysis of water and air nearer to different dumpsites in Abakaliki carried out by Njoku (2017), showed that waste dumpsites reduces quality of air and water in the study area. The study recommended that a better method of waste management such as reuse, recycling and incineration should be adopted in Abakaliki in place of waste dumpsite which is currently used in waste management. Elom et al. (2015) also stated that wastes in Abakaliki capital city were simply evacuated from different points (streets) to a central dumpsite where they are buried underground or burnt. The study recommended that higher institutions and research centers should be restructured to focus on research aimed at converting waste to wealth. Hence, waste disposal, not management is generally practiced in Ebonyi State.

According to Ikelle et al. (2020) technological approach to solid waste management includes the use of waste to energy plants, e.g., refuse incinerators designed to recover heat energy from the waste and with extensive air pollution control devices to satisfy stringent standards of air quality, practice of recycling and waste reduction, composting, etc. Waste to energy systems are expensive to build and operate because of the need for special equipment and controls, highly skilled technical personnel and auxiliary fuel system. The technological option for sustainable waste management in a developing country like Nigeria should be simple, cost effective, and whenever possible should bring in some economic, health and social benefit to the community (Adewale, 2011; Sridhar, 2013). A functional waste management policy is to view waste as a resource (wealth). The most acceptable technologies are composting (of municipal wastes, agricultural residues, food wastes), biogas generation (from livestock wastes, faecal sludge, water hyacinth), recycling of specific wastes (plastics, metal scraps, glass) and energy from waste for small and medium scale industries (charcoal and briquettes from agrowastes).

Ebonyi State government established a waste recycling plant which was capable of recycling aluminum cans, scrap irons, electronic wastes, glass, plastic bottle and cardboard paper but is never functional. Ebonyi State is primarily an agricultural region leading in the production of many food crops (Nworie, 2021). Agricultural wastes are produced in large quantities. The waste can be sorted out from the entire waste and made into solid fuel known as briquettes which can be used for domestic and industrial purposes as suggested by Sridhar (2013) and Adewale (2011).

Recent years have seen an upsurge of interest in fuel briquetting. The interest, to an extent, has been spawned by the expectation that oil reserves will deplete very soon due to the over dependency on oil, and the concern about the serious environmental damage caused by cutting of trees for fuel. When formed correctly, briquettes can burn at same temperature and for an equal duration as wood and coal. The provision of the solid fuels will reduce the pressure on fossil fuels (oil and gas) on which Nigerians over depend on, as well as provide a cheap source of fuel. Briquetting of wastes is sustainable with various advantages such as provision of a source of energy, low operational cost and income generation. The use of briquettes as alternative source of energy for domestic and industrial purposes has gained much ground in many developed countries of the world, although it is yet to get strong foot hold in Nigeria.

In this work, agricultural residues of bush mangonut shell and sugar cane bagasse obtained from different dumpsites in Abakaliki were made into briquettes and characterized. These wastes were produced in large quantities during their seasons. Their use in the production of briquettes will help to put them into good use. The need to seek for effective agro-waste management necessitated this work.

1.1. Experimentals

Collection of bio-waste: Bush mangonut shells and sugarcane bagasse were collected from dumpsites at Abakaliki, in Ebonyi L.G.A.

Bush mangonut shell (a) **Sugarcane bagasse(b)**

Figure-1. Bush mangonut(a) and sugarcane bagasse(b) collected from waste dump site in Abakaliki metropolis, Nigeria.

1.2. Preparation of the Materials

The bush mangonut shells and sugarcane bagasse Figure 1 were sundried for two weeks in order to reduce their moisture content. They were pulverized using milling machine (Landers Y.C.I.A S. A) and sieved using a standard sieve, to obtain materials of particle size ≤3mm in diameter. The pulverized materials were stored in a polyethylene bag to prevent caking.

1.3. Briquetting Procedure

The pulverized bush mangonut shells and sugarcane bagasse were made into briquettes using a manual screw press of compaction pressure 13.4kPa (Figure 2), fabricated by Eze – Ilochi and Oti (2017). Cassava starch, 20% by mass of the agro-waste was used as a binder. Cassava starch 100g was mixed with 100mL of water to make a paste of it. 400mL of water was put to boil in a container. The boiling water was added into the cassava paste and mixed properly to get the starch gel. While the starch gel was still hot, 500g of the pulverized materials was gradually added into the gel and mixed thoroughly using a stirring stick, until a homogenous mixture was obtained. The mixture was fed into the moulds of the screw press and pressure was applied to compact the materials into a whole mass. The mass was left in the mould of the screw press for 5 minutes (dwell time) to allow for the biomass consolidations in the mould so as to prevent the compressed biomass from spring back effect. After a dwell time of 5 minutes, the briquettes were removed from the moulds of the screw press and placed in an electrical oven (Model DHG 9023A, made in China) set at a temperature of 105^{o}C to remove the moisture and to achieve a constant weight.

Figure-2. Manually operated screw press briquetting machine (a) and the briquettes produces (b).

1.4. Characterization of the Materials and Briquettes

Determination of the metal content: Each of the ground samples (2.0 g) were weighed into different teflon crucibles. 25 cm^3 of aqua regia was added to each crucible. The whole mixture was thoroughly stirred using a spatula. The crucibles were properly covered and put into an oven set at 100^{0}C for 2 h, after which the samples got digested. The content of the crucibles were allowed to cool and transferred into a 200 cm^3 volumetric flask and made up to 200 cm^3 mark. The mixtures were then evaluated for metal content using Atomic Absorption Spectrometer (AAS) Instrument (Bulk Scientific, Model 210VGP) in air acetylene flame at flame temperature of 2000K. The metals evaluated were Ca, Mg, Na, Zn, K, P, and Si.

1.5. Scanning Electron Microscope (SEM) Analysis

Scanning electron microscope was used to observe the morphology of the materials. The SEM analysis was carried out using Phenom pro X Scanning Electron Microscope, at a voltage of 10 kV, and magnifications of 200 µm, 100 µm, 80 µm.

Proximate Analyses: The moisture content, volatile matter content, ash content and fixed matter content of the ground bush mangonut shell and sugarcane bagasse, and their briquettes produced were determined as follows:

Moisture content: The moisture content was determined as follows: A portion 2 g each of the samples was weighed out in a wash glass. The samples were placed in an oven for 1 hour at 105ºC. The moisture content was calculated using Equation 1 ASTM (2006a):

$$Mc\ (\%) = {W_1 - W_2}/{W_1} \quad X\ 100 \qquad (1)$$

W_1= Initial weight of sample, W_2= Weight after drying.

Ash content: A portion of 2 g each of the samples were placed in a pre-weighed porcelain crucible and transferred into a preheated muffle furnace set at a temperature of 600 ºC for 1 hour after which the crucible and its contents were put in a desiccator and allowed to cool. The crucible and its content were reweighed and the new weight noted. The ash content was calculated using Equation 2 as ASTM (2007):

$$Ac\ (\%) = {}^{W_2}/_{W_1}\ X\ 100 \qquad (2)$$

W_1 = initial weight of sample, W_2 = Weight of ash after cooling.

Volatile matter: A portion 2 g of the sample was heated to about 300 °C for 10 minutes in a partially closed crucible in a muffle furnace. The crucible and its content were retrieved and cooled in a desiccator. The difference in weight was recorded and the volatile matter was calculated using Equation 3 as ASTM (2006b)

$$Vm\ (\%) = W_1 - {}^{W_2}/_{W_1}\ X\ 100 \qquad (3)$$

W_1 = Original weight of the sample. W_2 = Weight of sample after cooling.

Fixed carbon: The fixed carbon was determined by difference using Equation 4 (ASTM, 1992):

$$Fc\ (\%) = 100 - (\%Vm + \%\ Ac + Mc\ ) \qquad (4)$$

Where Vm = Volatile matter, Ac = Ash content, Mc = Moisture content.

1.6. Mechanical Properties

Density: The compressed and relaxed densities of the briquettes were determined following the procedures of Birtwatker, Khandetod, Mohod, and Dhande (2014). The compressed density is the density of the briquettes taken immediately they were removed from the press. Relaxed density is the density of the briquettes after it was removed from the press and dried. Both densities were determined by measuring the mass of each briquette (using an electronic weighing balance), and the height and diameter using a vernier caliper immediately (compressed) and after drying the briquettes in the oven (relaxed). The density was calculated using Equation 5:

$$Density\ (g/cm^3) = {}^{mass\ of\ the\ sample\ (g)}/_{volume\ of\ the\ sample\ (cm^3)} \qquad (5)$$

Compressive strength: Compressive strength in cleft of briquettes was determined in accordance with ASTM method (ASTM, 2008), using an Instron Universal Strength testing machine (Model 2914, made in USA) with load cell capacity of 100 kN. The cross-head speed was 0.305 mm/min. A sample of briquette to be tested was placed horizontally in the compression test fixture and a load was applied at a constant rate of 0.305 mm/min until the briquette failed by cracking. The compressive strength in cleft was then computed using Equation 6:

$$\text{Compressive strength in cleft (N/mm)} = 3 \times \text{The load } at \text{ fracture point(N) } [l_1(\text{mm}) + l_2\ (\text{mm}) + l_3\ (\text{mm})] \qquad (6)$$

where l_1, l_2 and l_3 were lengths of briquettes at points one, two and three, respectively in (mm).

Durability: Durability was determined in accordance with the chartered index (Birtwatker et al., 2014). Each briquette sample was weighed and put in a metallic box with a cover. The cover of the box was closed, and the box was shaken for 3 minutes. The cover of the box was opened and the remaining briquette weighed. Durability was calculated using the Equation 7:

$$Durability = \frac{\text{weight of the briquette after shaking the box } (W_2)}{\text{weight of the briquette before shaking the box } (W_1)} \qquad (7)$$

1.7. Combustion Analysis

The combustion analysis was conducted to determine the combustion characteristics of the briquette fuels. The ignition time, burning time, water boiling time and calorific value were determined as follows:

Ignition time: The different samples were ignited at their bases with a Bunsen burner. The time taken for each briquette to catch fire was recorded as the ignition time using a stopwatch (Onuegbu, Ilochi, Ogbu, Obumselu, & Okafor, 2012).

Burning time and rate: This was determined following the procedures described by Davies and Abolude (2013). Each (300 g) briquette sample was weighed out and ignited. The time from the ignition of each briquette to when they burn to ashes was measured using a stop watch. This is calculated using Equation 8.

$$\text{Burning time (minutes)} = \text{ashing time} - \text{ignition time} \tag{8}$$

Burning rate was calculated using Equation 9 Onuegbu et al. (2012); Sotannde, Oluyege, and Abah (2010):

$$Burning\ rate\ (g/min) = \frac{mass\ of\ fuel\ burnt}{time\ taken\ to\ burn\ the\ fuel} \tag{9}$$

Water boiling test: 100 g of each briquette sample was used to boil 250 ml of water using small stainless cups and domestic briquette stove (Onuegbu et al., 2012).

Calorific value: The calorific value of the briquette was determined using Oxygen Bomb Calorimeter (model OSK 100A, made in USA). The calorific value (MJ/kg) of the samples under test was calculated using Equation 10 from the temperature rise in the calorimeter vessel and the mean effective heat capacity of the system.

$$\text{Cv (MJ/kg)} = \frac{(Ew + W_1)\ TR - C)}{S \times 4.1868} \tag{10}$$

Where Ew is the water equivalent of the calorimeter (581 g), W_1 = quantity of water in the vessel, TR = Temperature rise ^{o}C, C = correction factor from ignition 154 Cal, S = weight of sample in grams (g).

2. RESULTS AND DISCUSSION

Metal content concentration of the materials: The results of the metal contents of the materials are shown in Table 1.

Table-1. Metal content concentration of the materials.

Materials	Ca	Mg	Na	Zn	K	P	Si
BMS	22.20	9.90	3.78	9.15	1.21	0.02	2.05
SB	32.19	9.17	4.44	4.45	0.66	0.04	1.43

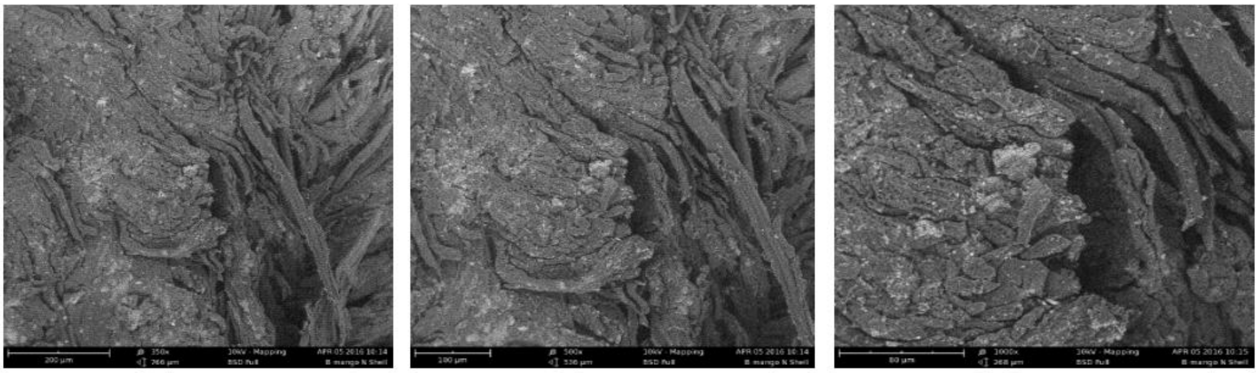
Note: BMS= Bush Mango nut Shell, SB= Sugarcane Bagasse.

The biomasses showed low concentration of metals in them as shown in Table 1. As reported by Savitri, Ubonwan, Suthum, and Jiltawadee (2006), high content of alkali causes technical problems when the biomass is used as feedstock for thermal power production. This is because they contribute to slagging, fouling, and sintering formation. Some authors., (Ajimotokan et al., 2019; Chirchir, Nyaanga, & Githeko, 2013; Karunanithy, Wang, Muthukumarappan, & Pugalendhi, 2012; Kumar, Rao, & Madhavi, 2016; Mlonka-Mędrala, Magdziarz, Gajek, Nowińska, & Nowak, 2020; Oladeji, 2012) stated that biomass ash consist of mostly Ca, Si, K, P and Na, and that alkaline metals lower the melting point of ashes during combustion causing fouling and slagging problems especially in super heater tubes.

The biomasses showed low concentration in Na, Mg, Si, P, and more especially, K, compared to that reported by Savitri et al. (2006). The low concentration of these metals in the biomasses showed that they are suitable feedstock for thermal power production.

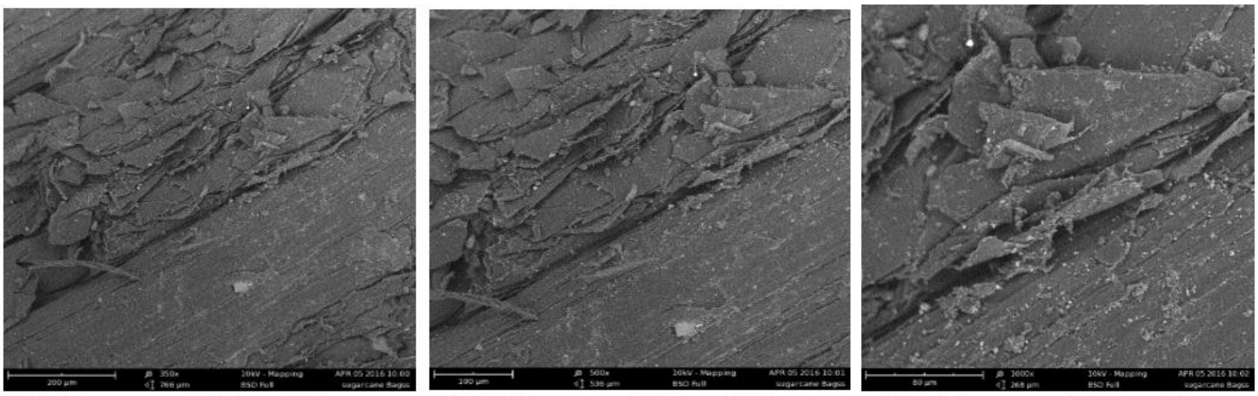
2.1. Scanning Electron Microscope Analysis of the Materials

The following SEM images were obtained for the coal and the biomass materials at 10kV and at 200 µm, 100 µm, and 80 µm magnifications.



SEM image of BMS at 200µm. SEM image of BMS at 200µm. SEM image of BMS at 80µm

Figure-3. SEM images of bush mangonut shell at different magnifications.



SEM image of SB at 200µm SEM image of SB at 100µm SEM image of SB at 80µm

Figure-4. SEM images of sugarcane bagasse at different magnifications.

The morphological structure of the biomasses as shown in Figures 3 and 4 indicated that they have fibrous and spongy lignocellulosic structure which is a typical biomass structure (Nworie et al., 2018). The structures show inter-particle pores, this will aid combustion of the biomasses during burning.

2.2. Proximate Analyses of the Bush Mangonut Shell and Sugarcane Bagasse

The results of the proximate analyses of the bush mangonut shell and sugarcane bagasse were shown in Table 1 and Figure 1.

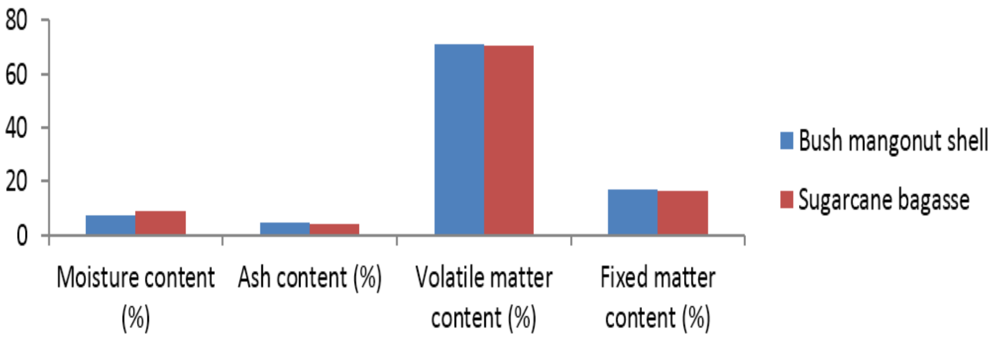


Figure-5. Proximate analyses of bush mangonut shell and sugarcane bagasse.

From the results as shown in Figure 5, the moisture content of bush mangonut shell (7.22 ± 0.36%) is lower than that of sugarcane bagasse (8.81 ± 0.23%). The moisture contents of the bush mangonut shell and sugarcane bagasse were less than 10%. This implies complete combustion and easy storage of the materials as low moisture content reduces rotting and decomposition of the briquettes during storage. The ash content results showed 4.92 ± 0.05% for bush mangonut shell and 4.16 ± 0.02% for sugarcane bagasse. The low ash content presented them as suitable feedstock for thermal utilization as they will not cause fouling and sinter formation in boilers. Volatile matter content of the bush mangonut shell is 70.81 ± 0.23% and that of sugarcane bagasse is 70.69± 0.03%. High volatile matter content is an indication of easy ignition and complete combustion of the briquettes. The fixed carbon content results showed 17.05 ± 0.24% for bush mangonut shell and 16.34± 0.66% for sugarcane bagasse.

2.3. Proximate Analyses of Bush Mangonut Shell (BMS) and Sugarcane Bagasse (SB) Briquettes.

The results of the proximate analyses of bush mangonut shell (BMS) and sugarcane bagasse (SB) briquettes are presented in Figure 2.

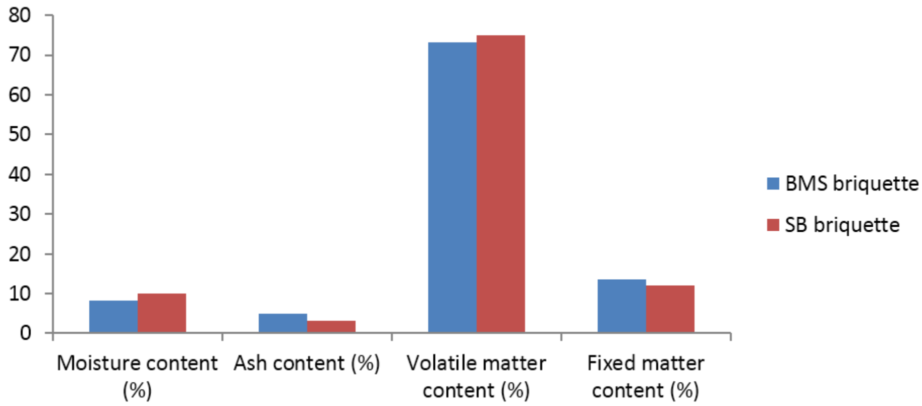


Figure-6. Proximate analyses of bush mangonut shell (BMS) and sugarcane Bagasse (SB) briquettes.

The moisture contents of the briquettes were 8.35 ± 0.15% for BMS briquette and 9.94 ± 0.42% for SB briquette Figure 6 . These values are less than 10% which shows that the briquettes will have excellent combustion and storability properties (Sotannde et al., 2010). The ash content was low, 3.01 ± 0.17% for BMS briquette and 4.23 ± 0.25% for SB briquette, therefore, they will not cause an increase in the combustion remnant in the form of ash (Sotannde et al., 2010). The volatile matter content was 73.15 ± 1.05% for BMS briquette and 74.90 ± 1.21% for SB briquette. Davies and Abolude (2013) reported that high volatile matter is an indication of easy ignition of the briquette and proportionate increase in flame length. This implied that SB briquettes will have shorter ignition time than the BMS briquettes. The fixed carbon content was 13.49 ± 0.94% for BMS briquette and 11.93 ± 1.33% for SB briquette.

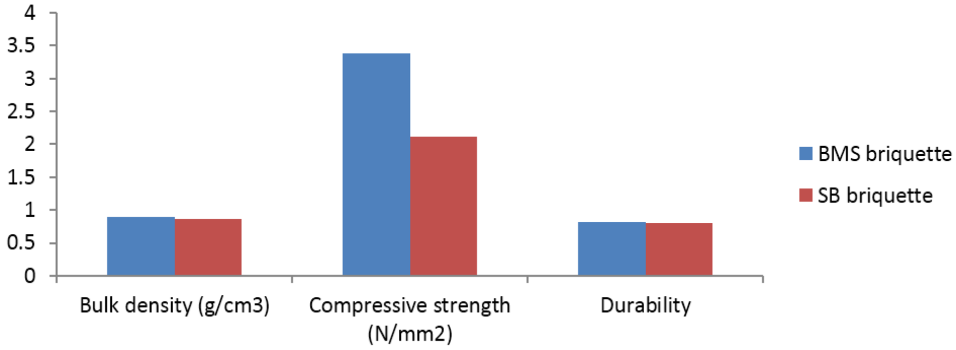


Figure-7. Results of the mechanical properties of the briquettes.

2.4. Mechanical Properties of the Briquettes

Figure 7 showed that the bulk density, compressive strength and durability of the BMS briquette were 0.892 ± 0.07g/cm^3, 3.39 ± 0.31 N/mm^2 and 0.81 ± 0.04, while those of SB briquettes were 0.859 ± 0.04g/cm^3, 2.11 ± 0.06 N/mm^2 and 0.80 ± 0.04 respectively. These values were higher for BMS briquette than for SB briquette. Mechanical properties determine briquette's strength and their resistance to external forces such as compression and weathering. It also determines the storability of the briquettes. Hence, BMS briquette can withstand external forces as well as stress during transportation and storage than the SB briquette.

According to the durability rating proposed by Karunanithy et al. (2012); Chirchir et al. (2013); Oladeji (2012); Ajimotokan et al. (2019); Kumar et al. (2016), briquettes with durability < 0.7 are rated as low durable briquettes, between 0.7-0.8 are rated as medium durability briquettes and > 0.8-1 are rated as high durable briquettes. The briquettes produced can be said to be high durable briquettes.

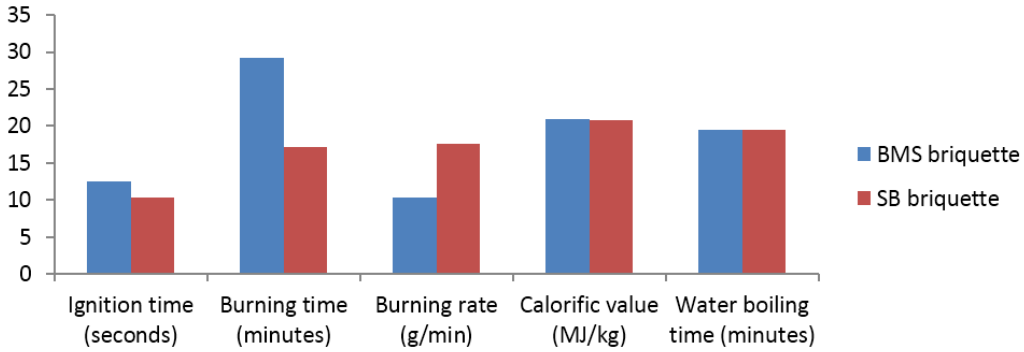


Figure-8. Combustion properties of the briquettes.

2.5. Combustion Properties of the Briquettes

The combustion properties of the bio-briquettes are shown in Figure 8. The ignition time of BMS briquette (12.53 ± 0.05 seconds) was longer than that of the SB briquette (10.27 ±0.04). BMS briquette also have longer burning time (29.27 ± 0.11) compared to SB briquettes (17.11 ± 0.11minutes). The burning rate of BMS briquette (10.25 g/min) was shorter than SB briquette (17.53 g/min). The reason for the longer ignition and burning time and shorter burning rate of the BMS briquette compared to the SB briquette may be attributed to its higher bulk density. The higher the bulk density of briquette, the longer the ignition and burning time, and the shorter the burning rate of the briquettes (Chirchir et al., 2013; Davies & Abolude, 2013; Kumar et al., 2016; Nworie et al., 2018).

The calorific value of BMS briquette was 20.9 ± 0.36 MJ/kg and SB briquette was 20.8 ± 0.00 MJ/kg. Calorific value is a very important property of a fuel as it gives the estimate of the amount of heat the briquette will give off during combustion. The calorific values of the briquettes were roughly the same value with that of BMS slightly more than that of SB briquettes. The values obtained were comparable to 20.8 MJ/kg, 18.6 MJ/kg and 21.8 MJ/kg obtained by Oladeji (2012) for corn cob, groundnut shell and melon seed respectively, 19.4 MJ/kg for pine sawdust briquette (Ajimotokan et al., 2019), 18.9MJ/kg for palm branch briquette (Kumar et al., 2016). The calorific values obtained are therefore sufficient enough to produce heat required for household cooking and small scale industrial cottage applications.

3. CONCLUSION

This study produced a solid fuel from bush mangonut and sugarcane bagasse as a means of removing them from waste stream, thereby reducing the quantity of waste generated and converting the wastes to resourceful materials called briquettes. The results of the analyses showed that BMS briquette have better mechanical and combustion properties than SB briquette.

The briquettes produced proved satisfactory in cook stoves and can be utilized for domestic purposes. The briquetting process is economical, cheap and affordable to the rural and low income urban dwellers. Briquettes can be used for domestic and residential heating, and small scale industrial heating e.g. in brick kilns, paper mills, chemical plants, oil mills, food processing units, etc. Moreover, using bush mango nut shell and sugarcane bagasse for briquette production will increase the farmer's income, thereby encouraging more production. Briquetting of agro-wastes is economical; it removes agro-wastes from waste stream, provide an alternative source of energy to oil and gas, as well as create employment opportunities. It should therefore be recommended and implemented in Nigeria as a means of effective waste management.

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