DEVELOPMENT AND CHARACTERIZATION OF CHARCOAL BRIQUETTES FROM SHEA BUTTER SEED SHELL

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ABSTRACT

Conversion of shea butter shell charcoal to briquettes solid fuel is a means to reduce environmental pollution. This study investigated the potential of converting shea butter shell char to briquettes with cassava starch solution. The shell was pretreated and carbonized at temperature of 450°C for 45 min in a furnace. Five briquette samples were produced with constant weight mass of char and different masses of cassava starch binder was varied as 10 %, 30 %, 50 %, 70 % and 90 %. The briquettes produced were analyzed for moisture content, bulk density, shatter index, water resistance, calorific value and compressive strength. The effect of the different binder contents on quality of the briquette samples was also investigated. The result revealed moisture content varied from 9.12 % to 14.83 % and density varied from 0.61 g cm^{-3} to 0.85 g cm^{-3}. The water resistance of the briquettes increased from 40.7 % to 75.5 % and shatter index increased from 71.7 % to 92.1 %., while compressive strength values ranged from 18.63 MPa to 24.46 MPa. The calorific values of the briquettes in their increasing amount of binder were found to be between 16.94 and 22.33 MJ/kg. The briquette with the highest amount of binder had compressive strength of 24.46 MPa and calorific value of 22.33 MJ/kg. The results showed the conversion of sheabutter shell to briquette can serve as an effective technique to bringing value and use to biomass wastes.

Keywords: calorific value, shatter index, briquette, SEM, shea butter shell.

INRODUCTION

The technology of smokeless fuel is a good technique for energy renewal. It is a form of recycling agricultural waste into a useful source of energy [1]. Study shows that large quantity of forest and agricultural residues are generated but are not utilized optimally to add value especially in developing countries. Nigeria and some developing nations generate large number of agricultural by products such as wheat straws, cotton stalk, shea-butter seed shell, rice husk, corn cob or stalk, coal, jute sticks, groundnut shell, and lots more are produced every day. However, they are not maximized adequately to create further use but are dump as wastes. The conversion efficiency of this biomass into further relevance is less than 40 %, they are under exploited [2].

In Nigeria, over 30 million tons of solid waste is generated per year and only about 25 % of the generated wastes are recycled for human use. Biomass has been the earliest source of energy especially for rural settlers and they are also renewable source of energy [3]. Briquetting is an effective technique to bringing value and use to those biomass wastes. A briquette is a lump of flammable matter obtained from biomass or agricultural residues used as solid fuel for source of heat energy for household and industrial use [4]. Briquettes are also referred to as smokeless fuel. They can be obtained when raw biomass undergo carbonization in a furnace in order for thermochemical conversion to occur [5].

Biomass is abundant and dependable source of green energy which is used in small scale boilers in municipal heating. Biomasses are used to generate heat and electricity thereby minimizing carbon dioxide emission [6]. The term biomass refers to substances that have biological origin which is usually obtained from wastes, plants, residues and forestry products.

Materials that are biodegradable in nature could also be used as biomass [7]. Biomass is readily available in nature due to its abundance and renewability, it is used to produce biochar, a product of pyrolysis [8]. Biomass being a green source of energy can substitute sources of energy that are not renewable due to the danger of climate change that decrease emission of carbon (IV) oxide caused by deforestation. Also, over-dependence on non-renewable energy as a result of increase in population has caused the depletion of energy sources which are not renewable such as natural gas, crude oil and coal. These factors have made it necessary for agricultural wastes to be put into use in the form of briquettes [9]. The production of briquettes from biomass is highly imperative because of challenges associated with biomass resources. The challenges are high moisture content, hydrophilicity, low calorific value and bulk density. Researchers have attempted to solve these problems through densification. Densification is the process compressing residues so that they become products of higher bulk density than the initial material [10]. Densification of biomass makes the biomass easy to handle, transported, stored, and improves volumetric calorific value together with physical properties [11].

Environmental pollution is one of the major challenges in the society. The depletion of the ozone as a result of the release of smoke is alarmingly becoming a threat to humanity, there is therefore great need to consider the production of smokeless solid fuel in order to reduce to the barest minimum the depletion of the ozone and the environmental pollution. Biomass briquetting is a sure way to efficiently utilizing solid wastes [12].

In this study we investigated production of briquettes using shell obtained from shea butter seed and cassava starch as binder for the briquette.

EXPERIMENTAL

Production of briquettes

Shea butter seed were collected from Baddegi, Niger State. Pretreatment techniques such as drying, screening, crushing, milling and sieving of the crushed sheabutter shells to a particle size of > 2.5 mm was performed. The carbonization was carried out at 450°C for 45 min. The product obtained from carbonization was a char after volatile matter was given off. Cassava starch binder was prepared by measuring 1 kg mass of cassava powder, poured in water heated to about 70°C - 100°C to become gelatinous. Five samples of briquettes were produced with different percentages of binder. Samples 1, 2, 3, 4, and 5 had 10 %, 30 %, 50 %, 70 % and 90 % starch binder, respectively. However, in each of the samples the same mass of 90 g char and varying percent of binder in other to analyze the effect in the briquette. The briquetting was done using manual screw and press briquetting machine whose cylindrical mould with dimension of 7 cm diameter and 5 cm long.

Characterization of Raw Materials (Proximate and Ultimate Analysis)

The amount of ash, fixed carbon, moisture content and volatile matter of shea butter shell was determined using proximate analysis method. The elemental composition of the raw sample which includes carbon, sulphur, nitrogen, hydrogen and oxygen was done using ultimate analysis method.

Moisture content

A sample of briquette of known mass of 10 g was placed in an oven and heated at a temperature of about 100°C - 105°C for about an hour and the sample was reweighed. Equation (1) was used to determine the moisture content in percentage (% MC).

$$\%MC = \frac{M_1}{M_2} \times 100 \quad (1)$$

where, M_1 - sample mass before heating, M_2 - sample mass of after heating.

Volatile matter

The mass of the briquette sample was measured and it was heated for 8 min at 400°C - 500°C, and it was re-weighed after heating. The percentage of Volatile Matter (VM) was calculated from equation (2);

$$VM = \frac{W_1}{W_2} \times 100 \quad (2)$$

where: W_1 - initial weight of sample, W_2 - mass of sample after heating.

Ash content

The initial sample weight was measured and placed in a furnace operated at 550°C for 4 h, until the sample would have turned to ash. The digital weighing balance was used to measure the both the initial and final weight of ash. Thus, equation (3) was used to calculate the ash content in percentage (% AC).

$$\%AC = \frac{W_1}{W_2} \times 100 \quad (3)$$

where: W_1 - initial sample weight, W_2 - final sample weight.

Fixed carbon

Thus equation (4) was applied to calculate fixed carbon in percentage using the values obtained from ash and volatile matter content.

$$FC = 100 - AC + VC \quad (4)$$

where: FC - fixed carbon, AC - Ash content, VC - Volatile content.

Characterization of Briquettes

Moisture content

The quality and performance efficiency of briquette depend on many parameters which moisture content is one of them. The initial weight (W_1) was taken and then heated at 105°C for 6 h. After which, it was removed and re-weighed (W_2) using a digital weigh balance. Thus, moisture content (MC) was calculated using equation (5):

$$\%MC = \frac{W_1 - W_2}{W_2} \times 100 \quad (5)$$

Bulk density

Density gives the mass-volume relationship of the briquette. Therefore, a digital weighing balance was used to determine the mass of briquette. The formula for volume of a cylinder, $\pi r^2 h$, after measuring the height h and the radius r of the briquette was used to calculate the volume. Hence, the bulk density was calculated using equation (6).

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad (6)$$

Calorific value

The calorific value of sample was analyzed with an adiabatic calorimetric bomb of model SHR-15. The procedure according to ASTM: D5885-10a method was employed to determine the calorific value of the briquette.

Water resistance

Water resistance was determined according to Kpalo et al. [3]. A digital weigh balance was used to measure the mass of each of the five briquette samples (M_1). The briquettes were then submerged into water and allowed for about 2 min. Afterwards, the briquette was removed from water and weighed (M_2). Equations (7) and (8), were used to calculate the amount of water absorbed in percentage (% W).

$$\%W = \frac{M_1}{M_2} \times 100 \quad (7)$$

Thus, $$\text{Water Resistance} = 100 - \%W \quad (8)$$

Compression test

The amount of load a briquette can with stand before failing, breaking or cracking is referred to as the compressive strength. The property was measured according to ASTM-D2166-85, by a setting a universal testing machine INSTRON OF Model 1000 at 1mm/min cross head speed with a cell capacity load of 50 000N [13].

Shatter index

The procedure of the ASTM D440-86 method was used to measure the shatter index of briquettes. The initial weight of the sample was noted, and it was then subjected to a free fall from a fixed height of 2 m distance. The free fall was done thrice and after each fall the briquette is passed in a sieve shaker of 2.5 mm size. The weight of briquette particles left in the sieve was noted [3]. Equation (9) was used to calculate the shatter index.

$$K = \frac{S_1}{S_2} \times 100 \quad (9)$$

where: Shatter index - K, Briquette weight after fall - S_1, Briquette weight before fall - S_2.

SEM analysis

The surface morphology of shea butter shell charcoal and the briquette were analyzed by Scanning Electron Microscopy (SEM) machine model JEOL JFC-5510LV.

RESULTS AND DISCUSSION

Proximate and Ultimate Analysis of Raw materials

The proximate analysis of the shea butter shell will measure amount of ash, fixed carbon and volatile matter content (see Table 1). The volatile content recorded for shea butter shell was 59.1 % which agrees with literature as a biomass can have up to 80 % volatile content [4]. This shows good percentage of the briquette produced will undergo combustion due to high value of volatile content obtained. The ash content of the shea butter shell is 16.20 %. Low ash content means the biomass has good thermal efficiency. The ash cannot undergo any combustion thus, the more the carbon available for combustion, the better the heat the briquette can produce. The moisture content of the shea butter shell was 2 %, and is below the recommended standard value of 15 % [4]. The biomass fixed carbon is referred as the amount of available carbon for thermal combustion, and it was found to be 22.40 %. This suggests the briquette will experience a prolonged combustion as the fixed carbon is low [14]. Also shown in Table 1 is the ultimate analysis of shea butter shell. It shows the elemental chemical composition of shea butter shell are, 5.7 % of Hydrogen, 0.8 % of Nitrogen and 0.3 % of Sulphur. The briquette has nitrogen and sulphur content of 0.8 % and 0.3 % respectively. These values are below 1 %, in other words it means to minimize pollution effect due to low release of atmospheric nitrogen and sulphur oxide [15].

Characterization of Briquettes

The different formulations of shea butter shell char and starch binder briquettes are shown in Fig. 1. The images show the shape and surface characteristics of briquette samples. The densification of biomass depends largely on the mechanism of interlocking bonds in the force attraction in the char particles, which will eventually form a solid bridge [16]. The surface of sample 1 is rough as well as sample 2 and 3. Cracks were observed on their surfaces [13]. Considering the briquette samples from 1 to 5, increasing the amount of

Table 1. Proximate and ultimate analysis of shea butter shell.

Properties	Value
Moisture content (%)	2.00
Ash Content	16.50
Volatile Matter	59.10
Fixed Carbon	22.40
Carbon	39.10
Hydrogen	5.70
Oxygen	54.10
Nitrogen	0.80
Sulphur	0.30

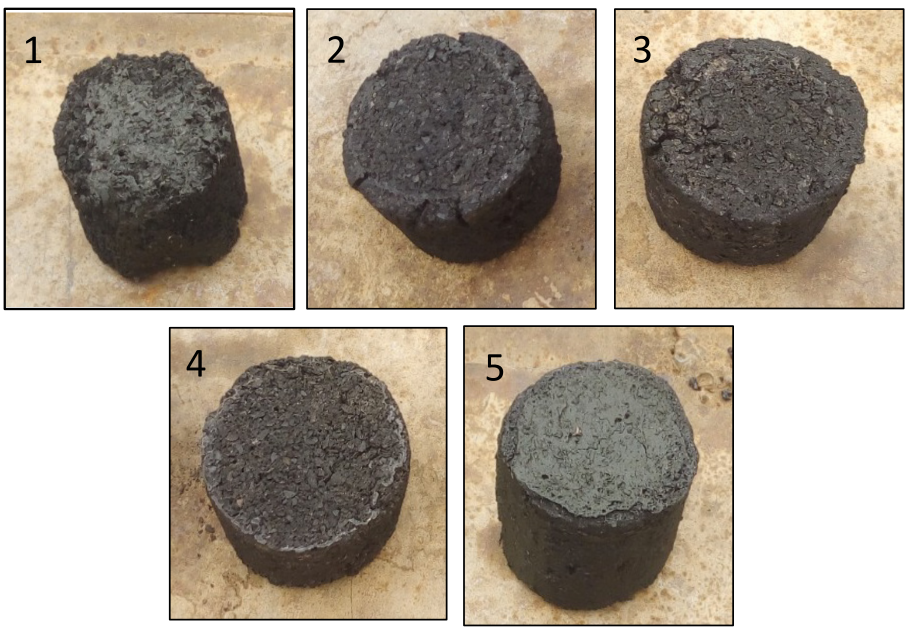

Fig. 1. Images of produced briquettes.

binder from 10 % to 90 %. It can be observed in Fig. 1, the solid bridges are progressing by molecular diffusion due to the interaction among the particles [17, 18]. Briquette sample 5 containing 90 % by weight starch has no visible cracks, it has smooth edges and the surface was evenly coated because it has enough binder. The binder was enough to penetrate and filled the pore voids in the char. Therefore, the increase in binder content resulted to more bonds between the charcoal particles and binder which will result to durable briquette [19].

Moisture content

Percentage moisture content of the briquettes are presented in Table 2. Their values varied from 9 % - 15 % (see Fig. 2). This implies that the briquettes are not too dry and thus do not have very high burning rate. The recommended standard value of moisture content for briquette is the range of 8 % to 12 %, although it can depend on the type and nature of the resources. The values obtained are in agreement with the briquette of rice husk and cassava starch binder [3, 20]. These moisture contents are not far values from Japan standard that suggests the value should be less than 15 % as higher moisture content reduces the combustibility, heating temperature, heat output and burning rate of the briquette, and increases the resident time [12].

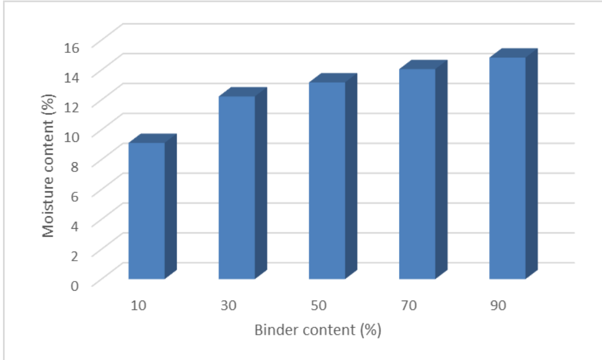

Fig. 2. Effect of binder on the moisture content of briquette.

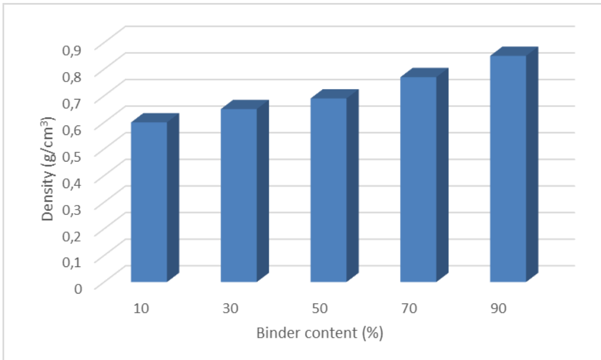

Fig. 3. Effect of binder on density of briquettes.

Bulk density

The density of a briquette is largely determined by the briquetting pressure or compressive strength, and densities of the biomass and binder used. The densities of the different samples are not the same even though equal mass was maintained for all the samples. The values were generally between 0.60 - 0.85 g cm^{-3}, as shown in Table 2 and Fig. 3. These values fall within the acceptable range of less than 1.2 g cm^{-3} in accordance with the Japan standard for briquette's density [12]. The variation of the densities may be due to different amount of binder used and different compressive pressure applied during briquetting. Briquettes with high density take long burning time and burns with more energy [3]. The effect of density on the combustion of briquette, briquettes with high density invariably have low porosity and as such less combustibility as there will be less penetration of oxygen or oxidant during burning.

Table 2. Properties of briquettes.

Sample C: B	Moisture Content (%)	Density (g cm^{-3})	Water Resistance (%)	Shatter Index (%)	Compressive Strength (MPa)	Calorific value (MJ kg^{-1})
1 (90:10)	9.12	0.60	40.70	56.10	18.63	16.94
2 (90:30)	12.23	0.65	65.50	76.40	19.82	17.98
3 (90:50)	13.17	0.69	80.10	90.60	21.14	18.60
4 (90:70)	14.06	0.77	90.40	94.40	22.14	19.27
5 (90:90)	14.83	0.85	97.50	98.70	24.46	22.33

C: B = Charcoal to Binder ratio

Water resistance

Table 2 shows that briquettes have value of water resistance that varied from 40.70 to 97.5 %. The results showed sample 5 has the highest water resistance value of 97.50 %, as shown in Fig. 4. This is the briquette with the highest percentage of binder. The value agrees with the greater than 70 % resistance obtained for neem powder and sawdust briquette [21]. Thus, water resistivity of a briquette is directly proportional to the percentage of binder present in a briquette. The more the binder, the higher the water resistance as shown in Fig. 4. This is because the binder glues the char particles together and make them firmly packed together thereby decreases water penetration. The firmer the briquette particles, the more resistive the briquette to water. It is important to note that when the molecular structure is loosely packed, water penetration is higher. The loosely packed molecules of a briquette contain more internal spaces that can accommodate fluid than a tightly packed one. Hence, the porosity of a briquette affects the water resistivity of a briquette.

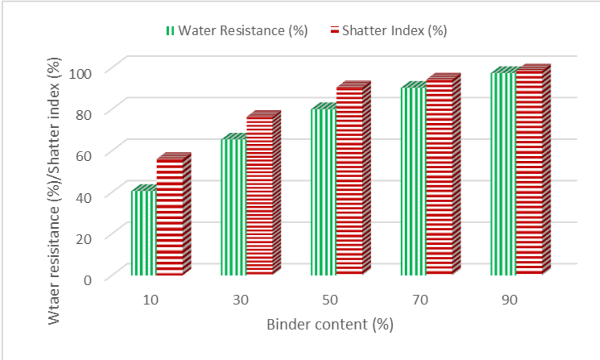

Fig. 4. Effect of binder on the shatter index and water resistance of briquette.

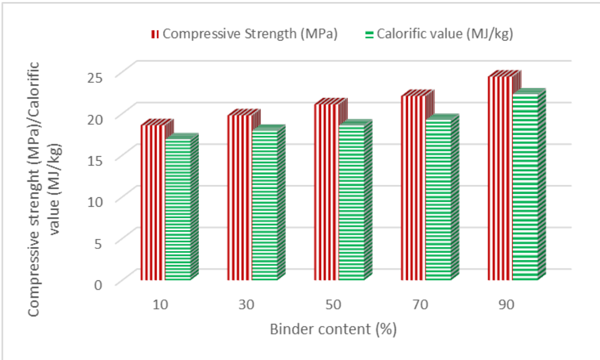

Fig. 5. Effect of binder on the calorific value and compressive strength of briquette.

Shatter index

The shatter index tests for the hardness or crushing resistance test of a briquette. In other words, its ability of briquette to have fewer fines when is being handled [3]. The shatter indices are shown in Table 2. The shatter index increased from sample 1 (56.10 %) to 5 (98.70 %) as shown in Fig. 4. Sample 5 has the highest shatter index (98.70 %). The more the binder, the stronger the briquette and the more durable. The quality and durability of briquette to deterioration is determine by shatter index value [22 - 24]. According to the recommended standard of shatter index, the value must not be less than 90 % [25]. Considering the stress on the briquettes upon carriage, transportation and storage, the durability of the solid fuel becomes an important factor to consider [26]. Based on the result obtained in this work the briquettes can be stored and transport safely to their destination [3].

Calorific value

The amount of energy released by the fuel as measured during combustion is referred as calorific value of the briquette. Table 2 and Fig. 5 shows that the values varied from 16.94 to 22.33 MJ kg^{-1}. The findings shows that sample 5 had the calorific value of 22.33 MJ kg^{-1}. Sample 5 has the highest percentage of binder. It can be observed that calorific value increases as the amount of binder increased. The more the binder, the better the thermal output, durability, and burning time it takes for the briquette to turn to ash [27]. Therefore, a briquette with more quantity of binder will give a better performance in terms of the heat value [28]. The calorific value of 22.33 MJ kg^{-1}, is higher than 16.68 MJ kg^{-1} for sawdust and paper briquette [29, 30, 31], 13.70 MJ kg^{-1} for waste vegetables briquette [32] and 15.61 MJ kg^{-1} for rice straw briquette [33, 34]. The results are in agreement with the Canadian Wood Pellet Association minimum standard calorific value of 16.0 MJ kg^{-1} [35].

Compressive test

Table 2 and Fig. 5 shows that compressive strength value of briquettes varied within 18.63 to 24.46 MPa. The results show that the sample 5 has the highest compressive strength. The high value of compressive strength, suggests a very strong Vander Waal forces exists between the bonds formed by the binder and char particle in the briquette [36]. This may be due to

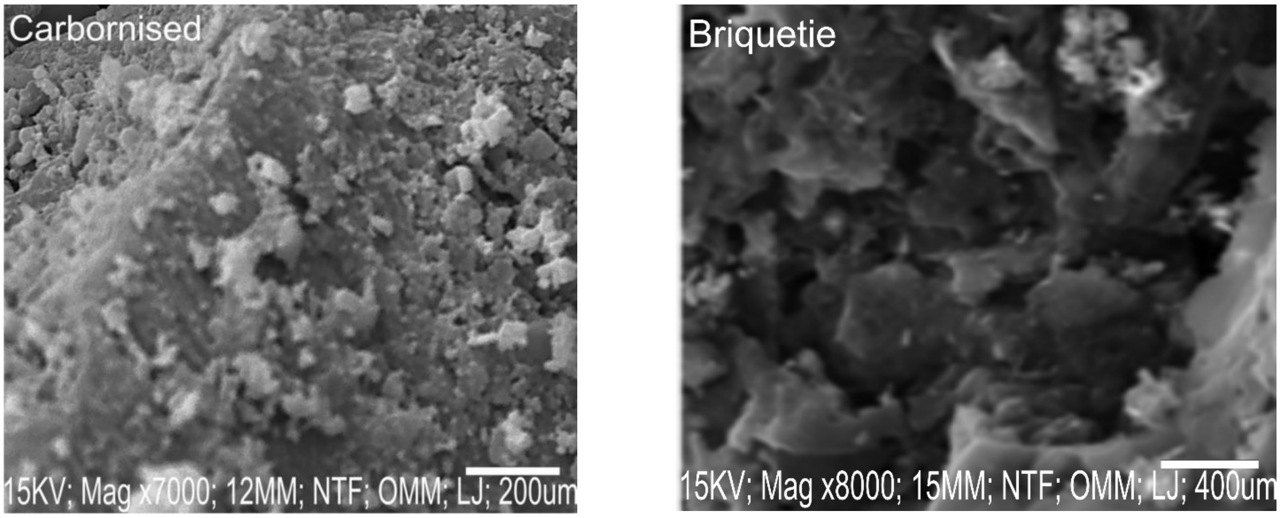

Fig. 6. SEM Images of Shea butter shell charcoal and Briquette.

its elastic nature influenced by the presence of binder. While sample 1 has lowest compressive strength of 18.63 MPa. This is in agreement with [37]. Some studies have suggested the acceptable minimum value of compressive strength for briquette as 0.38 MPa [38] and 1.0 MPa [39]. The compressive strength values obtained in this study are in agreement with previous reports. And the durability and stability of briquette depend largely on compressive strength [11].

SEM analysis

The surface morphology of the carbonized residue and briquette are shown in Fig. 6. The carbonized shell has porous rough surface with fine and coarse particles sizes and this provides a large surface area for bonding. These fine particle size, will make compaction easier during densification [19]. The morphology structure of charcoal helps in the prediction of agglomeration properties in order to be briquetted [15]. The image for briquette shows the level of coating by starch binder. The formation of shea butter shell briquettes with the cassava starch binder occurs as a result of adhesion of char particles with the starch binder (Fig. 2) [13, 40].

CONLUSIONS

The primary function of a briquette is to generate heat energy for domestic and industrial uses. The briquettes produced were analyzed for moisture content, bulk density, shatter index, water resistance, calorific value and compressive strength. The effect of the different binder contents on quality of the briquette samples was also investigated. The result revealed density varied from 0.60 g cm^{-3} to 0.85 g cm^{-3} and moisture content varied from 9.12 % to 14.83 %. Water resistance of the briquettes increased from 40.7 % to 97.5 % and shatter index from 56.10 % to 98.7 %, while compressive strength values ranged from 18.63 - 24.46 MPa. The calorific values of the briquettes in their increasing amount of binder were found to be between 16.94 and 22.33 MJ/kg. The briquette with 90 % binder had the compressive strength of 24.46 MPa, calorific value of 22.33 MJ/kg and shatter index of 98.7 %.

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