PHYSICAL AND MECHANICAL CHARACTERISTICS OF CHARCOAL, SAWDUST AND SUGARCANE BAGASSE AS SOLID FUEL MATERIALS

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ABSTRACT

This paper reports on the physical and mechanical characteristics of briquettes produced from charcoal, sawdust and sugarcane bagasse using molasses with sodium silicate as binders. Charcoal, sawdust and sugarcane bagasse were mixed in a respective ratio of 20:20:60, 20:30:50, 20:40:40, 20:50:30 and 20:60:20. The briquettes were produced using Budenberg dial gauge compression machine, with a pressure of 64 MPa at 120 seconds dwell time. Physical properties (relaxation ratio, compaction ratio and shattering index) and mechanical property (compressive strength) of the produced briquettes were investigated. Results show that briquette with sample composition of 20:30:50 has better physical properties with a relaxation ratio of 1.562, a compaction ratio of 7.573 and shatter index of 99.6%, while sample with ratio 20:40:40 has the highest compressive strength of 55.43 kN/m²^{2}.

KEYWORDS: *briquette; biodegradable; biomass; physical and mechanical properties; shatter index; solid fuel*

1.0 INTRODUCTION

Agricultural residues (biomass) are the most promising energy resources for developing countries (Onuegbu et al. 2010; Oladeji 2012). In recent years, there has been a strong worldwide interest in the development of technologies that exploit renewable energy sources otherwise known as green energy, both for environmental and economic reasons (Oyedepo, 2012). More so accumulation and disposal of some of these major sources of renewable energy which are mostly wastes at the various cities and town have always created an environmental problem (Aina et al, 2009).

The requirement for renewable and sustainable alternative sources of energy are on the rise as a result of depletion of the non-renewable fossil energy resources and the demerit associated with fossil fuels which include; global warming, the need for alternative sources of energy and intermittent supply. In light of this, biomass is of great interest because of its advantages such as availability, low price, carbon dioxide neutral feature,

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and high potential (Aina et al., 2009; Adegoke and Lawa, 1997; Adegbulugbe, 1994; Sambo, 2009; Emerhi 2011).

Many researchers have carried out different studies on varieties of biomass materials and their combinations with the aim of utilizing waste materials (i.e. agro-waste and other type of waste) as alternative sources' of energy. Among these researchers are; Abdu and Sadiq (2014) carbonized agricultural biomass (corn cobs) in a metal kiln of 900mm height and 600mm diameter. They produced four different briquettes charcoal grade using a locally sourced tapioca starch as a binder at concentrations of 6.0, 10.0, 14.0 and 19.0% w/w. The briquettes they produced were characterized and compared with bagasse and wood charcoal, they concluded that carbonizing corn cobs biomass resources into briquette charcoal is an effective means of managing solid wastes and a viable means of alternative energy source. Also Emerhi (2011) carried out study on briquettes produced from mixed sawdust of three tropical hardwood species which are; *Afzelia africana*, *Terminalia superba* and *Melicia elcelsa*, with starch, cow dung and wood ash independently used as binders. This researcher, mixed the sawdust in the ratio of 50:50 with the binder using different ratio. He studied the combustion related properties such as percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of the briquettes. He concluded that briquette produces from sample of *Afzelia africana* and *Terminalia superba* combination bonded with starch is more suitable for alternative source of energy, having a highest calorific value of 33116 kcal/kg.

Adetogun et al, (2013) examined combustion properties of briquettes produced from maize cob sieved into different mesh sizes of 2.30 mm, 4.75 mm and 6.30 mm with starch used as a binder. Combustion related properties of the briquettes were determined. They observed from their result that the calorific value is directly proportional to the maize cobs particle size. Therefore, they concluded that the sample with particle size of 6.30 mm has the highest calorific value of 24970 kcal/kg. In a related work of Rotimi et al, (2013), they investigate the combustion characteristics of briquettes produced from some biomass materials which are water hyacinth with plantain peel used as binders, red mangrove wood, charcoal and *Anthronotha macrophylla* (firewood). The characteristics investigated includes calorific value, ignition time, burning rate, specific fuel consumption, fuel efficiency and water boiling time. The aim of their study is to investigate how briquettes produced from water hyacinth will compete with charcoal, firewood and red mangrove wood. Their results showed that water hyacinth compete favourably with charcoal, firewood and red mangrove wood for having a fuel efficiency of 28.17±0.88%, which was surpassed only by charcoal with fuel efficiency value of 31.29±0.19%. They concluded that water hyacinth briquette is a good alternative source of energy with high material strength as well as high value combustible fuel (Rotimi, 2015).

It can be observed from the past works highlighted above that charcoal, sawdust and sugarcane bagasse are rarely combined to be used as solid fuel. Furthermore, the binders used contain very low carbon content. Therefore, there is need to study the physical and mechanical characteristics of these three bio-materials (charcoal, sawdust and sugarcane bagasse) combined for production of solid fuel briquettes with sodium silicate and molasses as a binder.

2.0 MATERIALS AND METHODS

The materials used in this study are charcoal, sawdust and sugarcane bagasse (Figure 1). These materials were collected locally at Tanke, and Zango in Ilorin, Kwara state. The samples were dried for 5 days to attain a bulk mass of 2000 g for charcoal, 2866 g for sawdust and 2345g for sugarcane bagasse. Bulk density is a desirable fuel parameter because it helps in estimating the heat or strength of any briquette (Jitthep and Akarawit 2013).
The charcoal was pulverized, using ingredient milling machine while sugarcane bagasse was ground with a grinder. The materials were sieved through a sieve size of 0.7mm for charcoal and sawdust while sugarcane bagasse was prepared between 1.5 and 2.41mm flakes-like structure (Figure 2). Sodium silicate and molasses were combined as a binding agent.

(a) (b) (c)

Figure 1 Materials used for the study before processing (a) Charcoal (b) Sawdust (c) Sugarcane bagasse

(a) (b) (c)

Figure 2 The materials used after processing (a) Charcoal (b) Sawdust (c) Sugarcane bagasse

2.1 Production of the Briquette

The briquettes were produced using Budenberg hydraulic compression machine with maximum compression capacity of 1,560kN used for densification together with a cylindrical mould (Figure 3) of 64 mm internal diameter. Briquettes of varied biomass proportions were produced by blending the materials (charcoal, sawdust and sugarcane bagasse) in various proportions (Table 1). Three samples of briquette each were produced for every mix of the materials with 13.8% (18 g) of Sodium silicate (Na_2SiO_3) and 9.2% (12 g) molasses based on total mass of 130g was used as a binder. A pressure of 64 MPa with 120 seconds dwell time was maintained throughout the briquettes production. The samples of the briquette produced are shown in Figure 4

Table 1 Proportion of charcoal, sawdust and sugarcane bagasse

S/N	Charcoal	Sawdust	Sugarcane bagasse
1	20	20	60
2	20	30	50
3	20	40	40
4	20	50	30
5	20	60	20

Figure 3 Metal mould used for the briquette

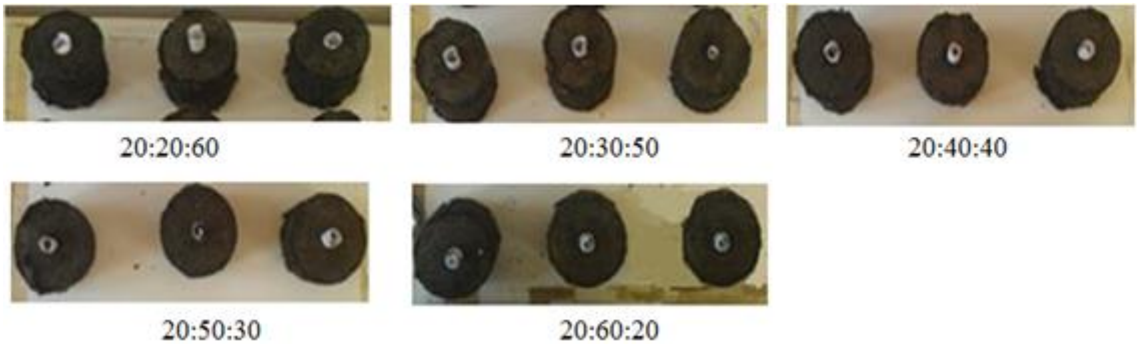

Figure 4 One set of briquettes produced
(All mix is in proportion of charcoal to sawdust to sugarcane bagasse respectively)

2.2 Analysis of the Physical Properties of the Briquette

2.2.1 Relaxation Ratio

The relaxation ratio *(R_{rel})* of the briquette is the ratio of the maximum density to the relaxed density, the R_{rel} was determined using Equation (1) in line with ASAE-269/04 (ASABE 2010).

$$R_{rel} = \rho_{max}/\rho_{rel} \qquad (1)$$

where- ρ_{max} = maximum density *(kg/m^3)*
ρ_{rel} = relaxed density *(kg/m^3)*

The maximum density ($\rho_{max} = {}^{m}/_{v}$) was obtained immediately after the compression while, the relaxed density $\rho_{rel} = m/v$ was obtained after 48 hours of production. Where *m* is in *kg*, and v in m^3

2.2.2 Compaction Ratio

In accordance to ASAE-EP413/02, the compaction ratio R_{com} which is the ratio of maximum density to the bulk density (Haque 2013). The compaction ratio was obtained by Equation (2)

$$R_{com} = \rho_{max}/\rho_{bulk} \qquad (2)$$

2.2.3 Shattering Index

Shattering index (Sh_{in}) is a means of indicating the ability of briquettes to withstand breakage during handling. The shattering index was determined by weighing the briquettes before and after dropping the briquette from a height of 1320 mm using a digital weighing balance. After the briquette was dropped from the height, the mass of the largest part of the briquette that holds together was then measured (Figure 5). The briquettes shattering index (durability index) was determined by Equation (3) according to ASTM D440-07 (ASTM 2012) in line with the work of (Oladeji & Oyetunji, 2013).

$$Sh_{in} = M_{ad}/M_{bd} \times 100 \qquad (3)$$

where Sh_{in} = Shattering index
M_{ad} = Weight of briquette after dropping
M_{bd} = Weight of briquettes before dropping

(a) (b)

Figure 5 Set-up during shatter index test (a) Weighing of sample before test
(b) Shattered sample after the test

2.3 Analysis of the Mechanical Properties of the Briquette

2.3.1 Compressive Strength

The compressive strength which determines how briquettes can be handled is a criterion of briquette durability (Jindaporn and Songchai 2007). A briquette sample with good compressive strength can easily be transported, packed, or handled (Jitthep and Akarawit 2013). The compressive strength was determined with the aid of a 50 kN load capacity Universal Testing Machine (UTM) model FS50AT in accordance to ASTM D-2166-85 (Kers et al, 2010). The flat surface of the briquette sample was placed on the horizontal metal plate of the machine (Figure 6). A constant load of 1 N was applied at a constant rate of 0.5 mm/min until the briquette failed. The briquettes absorbed compressive strength of 22kN with no sign of failure, this was noticed by a drop in the value of the applied load as indicated by the digital read-out on the compression machine. The average of three readings each was taken from each sample and their values recorded

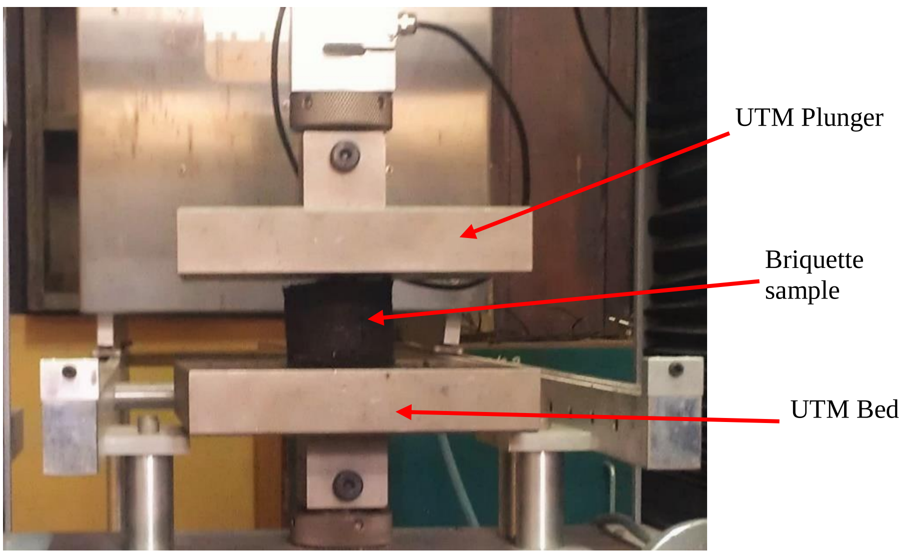

Figure 6. Sample within the compression plate of Universal Testing Machine

3.0 RESULTS AND DISCUSSIONS

3.1 Physical Properties

3.1.1 Relaxation and Compaction Ratio

The results of the density, compaction and relaxation ratios are presented in Table 2. It can be observed from Table 2 that the values of the maximum densities obtained in this work ranges between 876.7kg/m^3 and 894.2 kg/m^3. These values are better than the results obtained by Oladeji (2012) with the densities of 561 kg/m^3 obtained from melon shell and 741.13 kg/m^3 for cassava briquettes. Olorunnisola (2007) recorded density of 630 kg/m^3 for coconut husk briquette. Olorunnisola (2007) and Oliveira et al. (2014), reported density of 600 kg/m^3 for banana peel and density values of 534 kg/m^3 for rice husk was recorded by Deepak and Jnanesh (2015). Furthermore, the low values of relaxation ratios (Table 2) (which reduces with reduction of sugarcane bagasse quantity) obtained for briquettes in this study when compared with the ones of between –1.80 and 2.25 obtained by Olorunnisola (2007) for coconut husk briquettes, and between 1.65 and 1.80 obtained by O'Dogherty and Wheeler (2001) for hay wafer briquette and 1.17, 1.44 and 1.71 obtained by Oladeji (2012) for mixture of corncob and groundnut shell, groundnut shell and corncob respectively – are indications of more stable briquettes. This implies that the briquettes would experience minimal relaxation and this is a very good attribute as briquettes would not crumble with time, especially during transportation and handling. The values of density and compaction ratios in this work range between 0.6028 – 0.6402 and 4.8370 – 5.3200 respectively. The high values obtained for the density and compaction ratios is a pointer to the fact that the residues used in this study lent themselves easily to process of densification. This is because; the closer the density ratio is to the value 1, the better the densification process (Oladeji and Oyetunji 2013).

Table 2. The density, compaction and relaxation ratio of the briquette

Sample ratio	Density ratio	Compaction ratio	Bulk Density (kg/m^3)	Relaxation ratio	Maximum Density (kg/m^3)
C:Sa:Su					
20:20:60	0.6028	5.0430	175.9	1.6390	887.10
20:30:50	0.6402	4.9820	179.5	1.5620	894.20
20:40:40	0.6300	4.8370	181.4	1.5870	877.40
20:50:30	0.6325	5.0360	174.1	1.5810	876.70
20:60:20	0.6330	5.3200	167.3	1.5800	890.10

C=Charcoal; Sa=Sawdust; Su=Sugarcane bagasse

3.1.2 Shattering index

The results obtained for shattering index is presented in Figure 7. It can be observed that the specimen with a ratio of 20:30:50 charcoal, sawdust and sugarcane bagasse respectively has a smaller mass difference. The ranges of percentage weight-loss (0.387 – 39.774) obtained in this work, to a very large extent agrees with the ranges of values obtained by Tembe, et al (2014) with briquettes made from groundnut shell, rice husks and sawdust of *Daniella Oliveri*, which are between 9.7% and 34.6%. The shatter index values obtained by Rotimi (2015) for briquettes made from *White Afara* sawdust with no binder, with banana peel as a binder, with yam peels as binder and with the cassava peel as binder ranges between 0.61–0.96, 0.67–0.97, 0.72–0.99 and 0.77–1.00 respectively. The shatter index values obtained in this work fall between 0.602 and 0.996, which agrees with the value obtained by Rotimi (2015).

The maximum shatter resistance valuesof 99.61% was obtained for briquette of ratio 20:30:50, while the minimum values of 60.22% was obtained for 20:50:30. This value (99.613%) is higher than 99.1% shatter resistance obtained by Tembe et al. (2014) in his work. The higher shattered index value of 99.61% obtained in this work can be responsible for the fact that there exist better cohesion force between the molecules of sugarcane bagasse as against the low cohesion force between the molecule of rice husks used in the work of Tembe et al. The cohesive force between the molecules ensures high energy bond when the materials were bonded together.

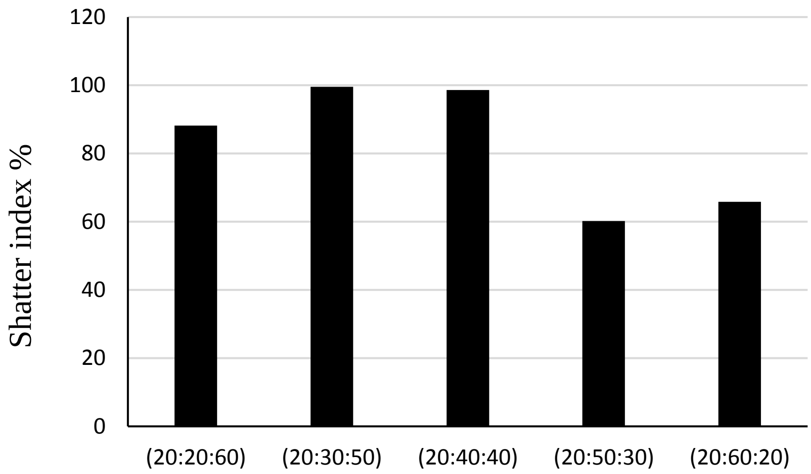

Figure 7. Results of shattered index

3.2 Mechanical Property

The result of the analysis of compressive strength of the briquette is presented in Table 3. The compressive strength is one of the indices used to assess briquettes ability to be packed and transported with little or no breakage Stephen et al, (2013). The results of compressive strength (i.e. the force required to crush the briquettes) as shown in Table 3, revealed that the compressive strength scattered about the mean values of 48.242kN/m^2 which is below the value of compressive strength obtained for fuels with ratio 20:20:60, 20:30:50 and 20:40:40. It was observed that the maximum compressive strength of 55.43kN/m^2 was obtained for the briquette sample with ratio 20:40:40 and minimum value of 40.21kN/m^2 for fuel ratio 20:50:30. Oladeji and Oyetunji (2013) obtained compressive strength of 1.76kN/m^2 and 1.53kN/m^2 for yam peels and cassava respectively. The high compressive strength can be said to be as a result of large particle size Stephen et al. (2013), which compared favourably with that of Oladeji and Oyetunji (2013).

Table 3. Analysis of the compressive strength

Sample Ratio C:Sa:Su	**Force at Break (N)**	**Compressive Strength (kN/m^2)**
20:20:60	162.4	51.74
20:30:50	156.9	49.99
20:40:40	174.0	55.43
20:50:30	126.2	40.21
20:60:20	137.6	43.84

C=Charcoal; Sa=Sawdust; Su=Sugarcane bagasse

4.0 CONCLUSIONS

Investigation of the physical and mechanical properties of charcoal, sawdust and sugarcane bagasse biomass materials as solid fuel has been carried out. The following conclusions resulting from the outcome can be made:

(a) Sample with charcoal, sawdust and sugarcane bagasse in proportion of 20:30:50 has the best physical and mechanical characteristics having highest maximum density of 894.20 kg/m^3 and a relaxation ratio of 1.562
(b) The highest shattering index of 99.61% and compressive strength of approximately 50kN/m^2 is recorded for sample with 20:30:50 charcoal, sawdust and sugarcane bagasse respectively; this implies that the sample has less likelihood to crumble during handling/transportation.
(c) The briquettes produced can be said to be durable and good for transportation, handling and packaging.

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