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ANALYSIS OF PHYSICAL AND MECHANICAL PROPERTIES OF BIOMASS WASTE BRIQUETTES PRODUCTION USING CASHEW GUM AS BINDER

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Abstract - This research work analyzed physical and mechanical properties of biomass waste briquettes produced using cashew gum as binder. The briquettes were produced from two sawdust materials namely Gmelina and Oil bean wood at three particle sizes (315µm, 425µm and 630µm) using cashew gum as binder at material/binder ratio of 85:15 percentage volume. A locally designed and manually operated hydraulic H-frame briquetting machine was used to produce the briquettes. Physical properties considered in study of briquettes are height and bulk density and these were determined by direct measurements and calculations while mechanical properties (compressive strength) of the briquettes were determined using single column, table top Instron machine (3345 model). The results obtained from the analysis show that reducing particle size of the sawdust materials from 630µm to 300µm caused decrease in height of briquettes (2.94-2.38cm) for Oil bean sawdust. Same was applicable to Gmelina sawdust but at 425µm to 300µm there was constant height. It was also observed that reducing particle size of the materials increased bulk densities of briquettes for both materials though bulk densities of oil bean briquette were generally higher (0.63-0.75g/cm^3) than Gmelina briquettes (0.45-0.54g/cm^3). Highest compressive strength attained for Gmelina and Oil bean briquettes at lateral position were 1854.17N/mm^2 and 2512.37N/mm^2 at 300µm and 600µm, respectively. ANOVA show that sawdust specie has significant difference in the bulk density of the briquettes hence; oil bean sawdust has higher bulk density than Gmelina. However, particle size and sawdust specie has no significant difference on the height and compressive strength of the briquettes. The study demonstrated that use of cashew gum has great potential in briquette production and can compare favorably well with other binders.

KEYWORDS: Sawdust, Briquette, Cashew gum, Binders, Bulk density, Compressive strength

1. INTRODUCTION

Biomass compaction technology has been among the promising ways of overcoming the limitation of low bulk density in biomass wastes because it reduces the volume of biomass wastes and converts them to a solid form which is easier to handle and store when compared to the original material. Briquettes can be used as alternative to wood fuel as the demand for wood fuel especially in the developing countries continues to rise. As a result of increasing population, transformation of biomass wastes to briquettes can increase bulk density of the biomass wastes to about tenfold of its original bulk density (Tumuluru et al., 2015).

Binders are substances, organic or inorganic, natural or synthetic that hold two things together. When used in briquette production, they help to improve the binding characteristics of the biomass and produce a more durable product. There are so many binders which have been used in making briquettes. These binder include; cassava starch, cow dung, clay glycerol, bentonite, lignosulfonate etc. (Oladeji, 2011; Donghui et al., 2013; Katimbo et al., 2014, Oyelaran, et al., 2014).

Cashew gum is an exudate polysaccharide from *Anacardiumoccidentale tree (*Ofori-Kwakye et al., 2010).Its physio-chemical properties have been studied (Cunha et al., 2007; Akoto et al., 2007) and it was found to have similar rheological properties with gum Arabic and therefore has been used as substitute in the paper industry as liquid glue; agglutinant for capsules and pills, as well as polyelectrolyte complex with chitosan for drug delivery in the pharmaceutical industry; and as stabilizer in the food, and cosmetic industries (Akoto et al., 2007; De Paula et al., 1998). The use of cashew gum in briquette production has not been examined though it is widely applied in pharmaceutical industries. Considering the properties of cashew gum, it can also be applied as binder in briquette production. The extent to which binders affect the characteristics of biomass briquette is dependent on the binder and biomass composition and this makes biomass materials display different physical and mechanical characteristics when subjected to compaction. Kulig et al. (2012) study on binders found out that addition of a binding agent during briquetting increases compaction by 15.4% and briquette density by 37% on average and resulted in an approximately 7-fold increase in the mechanical strength of briquettes at all moisture content levels. Other studies on binding ratios of starch state that binding ratio of 15-25% mix with material gives high quality briquettes (Oladeji, 2011; Rotimi and Usman, 2013).

Particle size distribution is one of the material parameters that affect briquette quality during compaction process. A study by Ogbuagu (2017) on effect of varying pressure and grain size on physical properties of biomass briquettes found out that pressure has great influence on physical properties of briquette such that increase in pressure decreases height and increases bulk density. According to Mani (2006), briquettes quality is inversely proportional to the particle size. In similar studies, Arzola et al. (2012) and Lucas and Oladeji (2011) confirmed that average particle size had the most influence on briquette density. Ogbuagu et al. (2017) correlated particle sizes and compression ratios of biomass waste briquettes and found that particle sizes and compression ratio for different materials differed depending on the nature of the materials.

In summary, binders and particle sizes affect the use of biomass materials either in soil analysis, drug formulation, briquetting and other areas of its applications. The business of producing of briquettes is such that profit is maximized. Most binders used in briquette production are bought and sometime are not easily sourced. This work therefore studied the physical and mechanical properties of briquettes produced from cashew gum at varying particle sizes and also investigated the influence of particle sizes and sawdust specie on those properties.

2.0 MATERIALS AND METHODS

2.1 Materials

This study was carried out using the facilities at the material laboratory of Civil Engineering department, Enugu State University of Science and Technology and that of National Center for Energy Research and Development, University of Nigeria Nsukka Enugu State both in Nigeria. Materials used for the analysis are Gmelina (Gmelina arborea), and oil bean (Pentaclethra macrophylla Benth) sawdust. The sawdust materials were collected from sawmill at Kenyatta timber, in Enugu state, Nigeria (Plate 1). Moisture content of the materials were maintained within the acceptable moisture content of 8-15% (wb) for making briquettes (Erikkson and Prior, 1990; Jaan, et al. 2010). The binder used was cashew gum and it was obtained from cashew trees at Umuchigbo Nike Enugu East of Enugu state and also in Ezeagu both in Enugu state Nigeria.

Equipment used for the analysis include; digital weighing balance (Digital mettle

Toledo, 0.0001g sensitivity), hammer mill, measuring cylinder, flash dryer, mixer, manual press briquetting machine, Venier caliper, Instron machine (3345 model running on Bluehill software) and Tyler sieves.

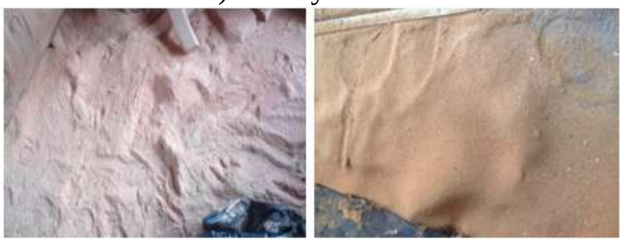

Plate 1: Gmelina and Oil bean (Ugba) Sawdust

2.2 Methods

2.2.1 *Sample preparation*

The two materials, Gmelina, and oil bean sawdust were designated with A and B respectively. Proximate and ultimate analysis on the materials were conducted at National Center for Energy Research and Development (NCERD), University of Nigeria Nsukka and the result of the analysis are shown in Table 1. The analysis specified the compositions of the materials used for the evaluation. The materials were then size-reduced using a disc attrition mill and sieved using Tyler sieves. Three particle sizes namely, 630μm, 425μm and 315μm, were obtained from each of the two materials. Equal volume of 100cm^3 of each sample was measure out and weighed in a digital weighing balance and the mass recorded. The experiment was replicated four times during briquette production. The treatment levels of the analysis were two saw dust materials, two binders, three particle sizes and four replications such that a total of 48 briquettes were produced.

Table 1: Composition of Biomass wastes used for the analysis

S/N	Parameter	Gmelina	Oil bean wood
1	Volatile matter (%)	86.22	81.76
2	Ash content (%)	0.55	1.26
3	Moisture content (%)	9.90	13.90
4	Fixed carbon (%)	3.33	3.08
5	Calorific value (kJ/kg)	30,009.93	28,419.69
6	Carbon content (%)	47.08	38.30
7	Nitrogen content (%)	0.55	0.38
8	Sulphur content (%)	0.10	0.04
9	Specific gravity (%)	0.15	0.14

2.2.2 Cashew gum preparation

Crude cashew tree gum was exudates from the stem of Anacardium Occidentale (Plate 2) and was prepared for briquette production using the method described by Toure et al., 2016. In this method, the collected cashew gum was dissolved in distilled water and allowed to stand for 24hrs and sieved to remove the unwanted particles. The filtrate was oven dried at 50^{o}C for 8hrs. It was further processed by grinding in a hammer mill and sieved into fine powder.

Plate 2: Cashew gum collection

2.2.3 *Compression operation*

Each particle size sample was fed into a bowl and mixed with binder (cashew gum) in percentage compositions of 89:11 percentage volume. Prior compaction, agitating process was done in a mixer to enhance proper blending. The briquettes were prepared in the laboratory of National Center for Energy Research and Developments, University of Nigeria, Nsukka using a manual hydraulic briquette machine with six cylindrical molds (Plate 3).The steel cylindrical crucibles of dimension 150mm height and 5cm in diameter was used for the compaction at maximum pressure of 5Mpa. The crucible was freely filled with known amount of weight of each sample mixture and positioned in the hydraulic briquetting press machine for compression. When the hydraulic jack valve is released, it lowers the press component of the machine and spaces were created for feeding the materials from the top of the mold. This was followed by placing the top plate (stop plate) mold on top and closing the release valve on the hydraulic jack. On actuating the jack manually, the top plate compresses the material to the maximum compression. Dwell (holding) time of 5mins was observed for each compression. At the elapse of the dwell times, the release valve was loosened to unlock the stop plate and consequently the compressed briquettes were extruded (Plate 4).

Plate 3: Briquetting machine

Plate 4: Sample of Briquettes produced

2.2.4 Determination of physical properties

After compression on the hydraulic briquetting press, the briquettes produced were cylindrically shaped and of equal diameters of 5cm. Height of each briquettes were measured using Venier calipers while the mass was determined using digital weighing balance. The volume was calculated using $\pi r^2 h$ and then bulk densities of the briquettes were calculated using equation 1.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \quad \textbf{1}$$

2.2.5 Determination of compressive strength

Compressive strength of briquettes is an important parameter during storage and transportation of briquettes. It is defined based on the lateral (Horizontal) and longitudinal (Vertical) position of the briquettes. The compressive strength of the briquettes were determined using an Instron machine (3345 model) at Enugu State University of Science and Technology (ESUT), Enugu state Nigeria. The compressive strength of the briquettes at lateral (Plate 5) and longitudinal positions (Plate 6) were obtained from the computer attached to the Instron machine that gives the force-deformation curve of the operation.

Plate 5: Lateral compressive strength

Plate 6: Longitudinal compressive strength

3.0 RESULTS AND DISCUSSION

The results of the physical properties of the briquettes are analyzed as follows;

3.1 Physical properties of the briquettes

3.1.1 Height

Results of the height of the briquettes produced are presented in Fig. 1. It can be observed that reducing particle size of oil bean sawdust gave briquettes of lower height. This implies that interparticle spaces in 300µm were filled up than in 630µm particle size. Gmalina sawdust exhibited similar characteristic when particle size was reduced from 630µm to 425µm but further reduction to 300µm caused no change in height of the briquettes. This indicates that there is no noticeable change in height for cashew gum Gmelina briquette below 425µm. Considering the result of the ANOVA in Table 2, there was no significant difference in height of the briquettes at different particle sizes and for the two sawdust species used for the analysis.

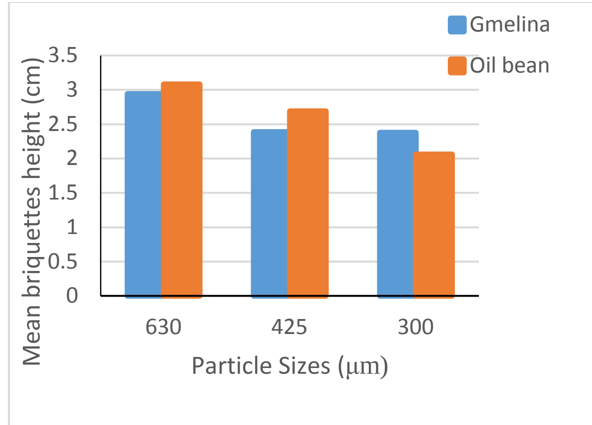

Fig. 1: Plot of briquette height vs particle sizes

Table 2: ANOVA for height of briquettes for briquettes produced from Gmelina and Oil bean sawdust

Source of Variation	SS	df	MS	F	P-value	F crit
Particle size	0.5092	2	0.2546	2.841518	0.260314	19
Sawdust specie	0.0006	1	0.0006	0.006696	0.942233	18.51282
Error	0.1792	2	0.0896			
Total	0.689	5				

3.1.2 Bulk density

The bulk density of the briquettes for the two materials exhibited the same characteristics (Fig. 2). It shows that reducing particle size of the material gave briquettes of higher bulk density. However, oil bean briquettes gave higher bulk density than Gmelina briquettes. This is because of the wood specie. Oil bean wood is classified as hard wood while Gmelina is classified as soft wood (Oboh, 2007, https://en.wikipedia.org/wiki/Gmelina_arborea). The ANOVA in Table 3 show that there is significance difference in the bulk density of the materials but not at different particles sizes.

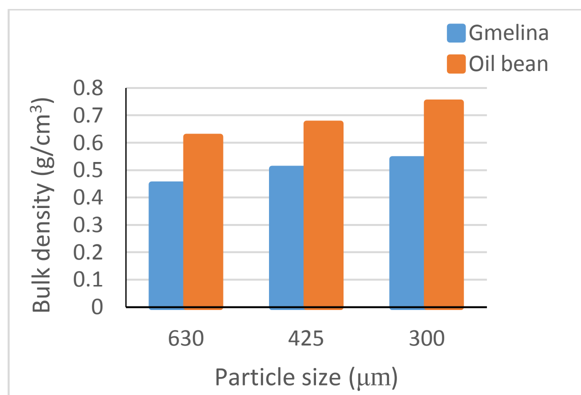

Fig. 2: Plot of briquette bulk density vs particle sizes

Table 3: ANOVA for bulk density of briquettes produced from Gmelina and Oil bean sawdust

Source of Variation	SS	df	MS	F	P-value	F crit
Particle size	0.0091	2	0.00455	13	0.071429	19
Sawdust species	0.05415	1	0.05415	154.7143	0.006402	18.51282
Error	0.0007	2	0.00035			
Total	0.06395	5				

3.2 Compressive strength

Lateral compressive strength of the two biomass briquettes are given in Fig. 3. It was observed that strength of Gmelina briquettes increased from 439.75N to 1854.17N as the particle sizes were reducing while for oil bean briquette, reverse was the case as 600µm had compressive strength of 2512.37N while 425µm and 300µm had 1387.80N and 970.25N respectively (Fig. 3). From the ANOVA (Table 4), there is no significant difference in the strength of the materials as a result of the particle size and the specie of sawdust.

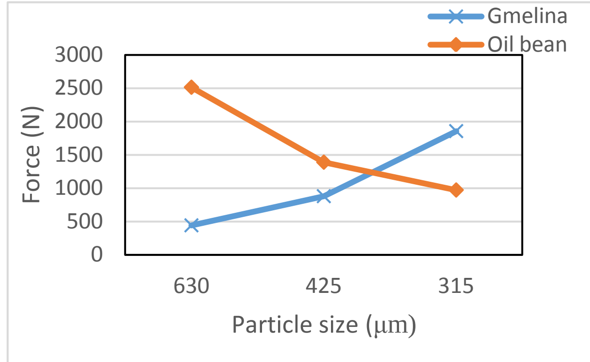

Fig. 3: Compressive strength at lateral position

Table 4: ANOVA for compressive strength of briquettes at lateral position

Source of Variation	SS	df	MS	F	P-value	F crit
Particle size	174854.7	2	87427.36	0.632573	0.61253	19
Sawdust specie	523425.2	1	523425.2	3.787198	0.191044	18.51282
Error	276418.2	2	138209.1			
Total	974698.1	5				

Longitudinal compressive strengths of all the briquettes were smaller than lateral strength. For Gmelina briquettes, reducing particle sizes reduced strength of briquette while Oil bean briquette did not show a pattern in term of their behavior on when force is applied at longitudinal position of the briquettes. However, the binding characteristics of the binder may have contributed to this as finer materials tend to bind adhesively to the binder. ANOVA in Table 5 also show that neither particle size nor specie of sawdust has effect on the strength of the briquettes at longitudinal position.

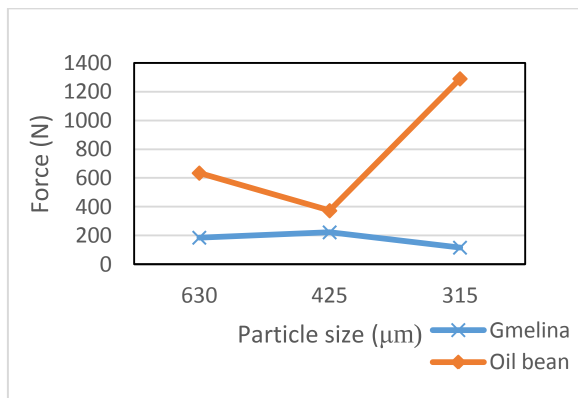

Fig 4: Compressive strength at longitudinal position

Table 5: ANOVA for compressive strength of briquettes at longitudinal position

Source of Variation	SS	df	MS	F	P-value	F crit
Particle size	133428.2	2	66714.12	0.060992	0.942514	19
Sawdust material	481083.2	1	481083.2	0.43982	0.575421	18.51282
Error	2187639	2	1093819			
Total	2802150	5				

4.0 CONCLUSION

This research has shown that cashew gum can be used as binder in briquette production in alternative to starch and other chemical binding additives. Results of briquettes produced has obviously satisfy that cashew gum has sufficient binding properties for briquette production. Its use as binder in briquetting will reduce cost of briquette production and also divert the consumption of starch to its other uses such as industrial feedstock and food chain. ANOVA conducted showed that specie of sawdust effects bulk density while height of briquette and compressive strength are independent on either particle size or specie of the material. Therefore, this study has shown that composition of a given material determines its cashew gum binding characteristics. On the other hand, previous work on use of starch as binders has shown high significant difference in particle sizes which is contradictory to this present study. However, this may be attributed to the lower binding power of cashew gum in comparison with starch which has to be verified critically in subsequent research works on cashew gum as briquette binder.

RECOMMENDATION FOR FURTHER STUDIES

It is therefore recommended that further studies should be carried out comparing cashew gum briquette with other binders. It is also important to examine other functional properties of cashew gum briquettes such as calorific value, ash content etc and also optimize cashew gum addition during briquetting.

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