Investigation of physical and combustion properties of briquettes from cashew nut shell and cassava binder

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Abstract: The paper shows the results of a study on the investigation of physical and combustion properties of briquettes from cashew nut shell and cassava binder. Carbonization of cashew nut shell was carried out at temperatures of 250°C in a furnace. The charcoal produced after carbonization was pulverized and the powder was used to make briquettes using cassava paste as the binding material. Briquettes were made with different particle sizes of 0.5mm, 1.0mm and 2.0mm. Different compaction pressures (100Kg/cm^2, 200 Kg/cm^2 and 300 Kg/cm^2) in absence and presence of different ratios of binder (10%, 20% and 30%). The combustion and physical properties of the briquettes improved when a binder was introduced. The maximum calorific value obtained was 30.5MJ/Kg which is very close to that of that ordinary wood charcoal 31.38MJ/kg. The results will contribute to further implementation of the Kenyan energy policy by providing an alternative to firewood.

Keywords: Physical, combustion, binder, Briquettes, cashew nut shell, cassava

1. Introduction

Worldwide deposits of fossil fuels are decreasing at a high pace, requiring alternative renewable energy sources to satisfy the growing energy demand for development (Hook & Tang, 2013; Singer et al., 2011). For most developing countries such as Kenya, biomass, especially agricultural waste such as cashew nut waste, appears to have become one of their most promising and alternative sources of energy. The concept of using agricultural residues as main or secondary sources of energy is somewhat appealing as they are accessible as free, indigenous and eco-friendly. Moreover, the declining availability of firewood has required attempts to make efficient and serious use of agricultural waste (Kimutai et al, 2014).

Cashew nut (*Anacardiumoccidentale*) is an important agricultural crop in Kenya as well as in many parts of the world. In Kenya, the crop is grown along the coastal region in Kwale, Mombasa, Kilifi, Lamu, Tana River, and TaitaTaveta counties. The total area under cashew nut cultivation is estimated at 30,921 hectares (M' Rabu 2001). The yield can be up to 4,100 kg/ha (Waithaka, 2002) and a good average crop yield for a mature plantation tree is around 13.3 kg/year. Kenya produced an average of 24000 tons/year (5.9% of world production) (Waithaka, 2002) and it is ranked number 14 in the world ranking of cashew nut producing countries. After processing, the cashew gives out the nut; 30% of the total weight and the shell which are 70% of the total weight are normally left as waste.

Briquettes are eco friendly and sustainable fuel pellets produced by waste compression. The quality of a briquette can be evaluated by its thermo-physical characteristics, including heating value, ash content, volatile material content, moisture content, fixed carbon content and density. (Sastry et al., 2013). Binder is a substance with adhesive characteristics that agglomerates the briquetting material to generate high density, durability and compressive strength briquettes. (Bhattacharya and Salam, 2006). These binder-based briquettes also enhance their transportability and durability. Accordingly, research has been conducted in this study to generate cassava binder briquettes.

The thermo-physical characteristics rely on structure, geometry, particle size, density of material and compaction pressure (Mandal et al., 2014, and Lubwama & Yiga, 2017). The type and quantity of binder influence briquettes ' thermo-physical characteristics (Sotannde et al, 2010; Chirchir et al. 2013). Optimizing the compaction pressure (Araujo et al, 2016), particle size and cassava binder ratio will help to produce affordable, high-quality briquettes and thus promote the briquette market. The aim of this study is to produce clean burning charcoal briquettes from cashew nuts shells in order to provide an alternative energy source for Kenya and also provide an efficient way to use these waste.

2. Materials and Methods

2.1Preparation of Cashew nut shells charcoal

Cashew nut shells from coast region in Kenya were sun dried under the sunlight for 2–3 days and then and sorted for any foreign material such as stones. The metal box was filled with the shells and placed in the oven for carbonization at a temperature of 250°C for time duration of 3 hours as it gives the best results (Sen et al, 2016). The charred shells were then ground using milling machines. The pulverized charcoal was then taken through a sieving process to obtain samples of three different particle sizes: 0.5 mm, 1.0 mm and 2.0 mm. The remaining particles which were bigger than 2.0 mm were then taken to a motor driven mill whereby they were further pulverized into smaller particle sizes and again passed through the sieving process.

2.2 Preparation of binders

The cassava was used to make the binder (Figure 1). The cassava was peeled off using a knife and cut into pieces and boiled with plenty of water for about two hours and then crushed using mortar and pestle. Hot water was added to the ground cassava and thoroughly mixed to obtain a gelatinous (thick porridge-like) substance.

Figure 1**:** Sample of raw cassava (root starch)

The thick starch remaining was washed again by re-suspending in water and left to settle for overnight for thorough separation and was decanted to remove water. This binding material was as well taken for briquetting.

2.3 Briquettes Production Process

Mixture of Cashew nut shells charcoal with and without the binders were fed into hydraulic press for briquette production with compaction pressure of 100kg/cm^2,200k/cm^2 and 300k/cm^2,particle size of.5 mm, 1.00 mm and 2 mm and dwelling time of 0 secs, 60 sec and 120 secs. Briquettes were produced (Figure 2) stored under room temperature for a period of about 6 to 7 days to dry. The briquettes were then ready for analysis experiments.

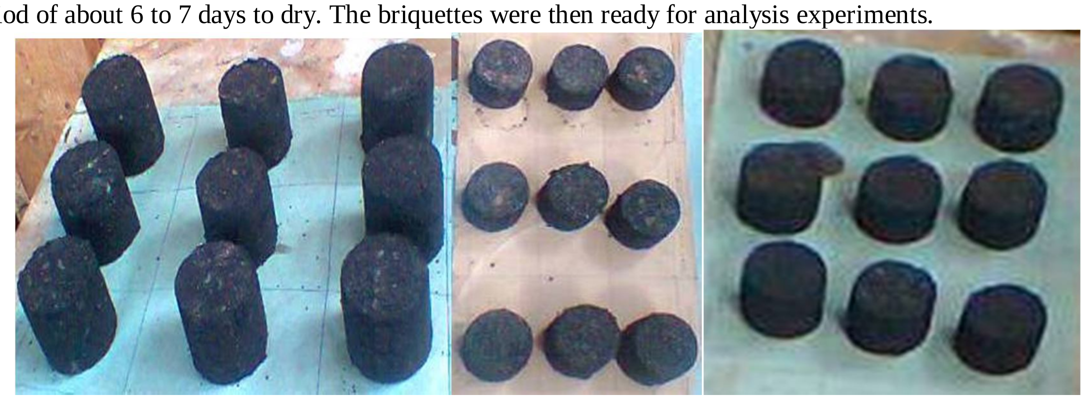

Figure 2: Sample briquettes from cashew nuts shells charcoal

2.4 Data analysis

Experiments were carried out to analyze the properties of the briquettes which included; physical and combustion properties according to standards. Physical properties included; density determination, compressive strength test, durability test, water resistance test, shatter index determination while combustion properties include; proximate analysis, ultimate analysis, calorific (heating) value determination, water boiling test, ignition time and combustion rate. Proximate analysis was done using thermo gravimetric analyzer to find moisture content, volatile matter content, fixed carbon content and ash content.

Excel software was used for data analysis. Because four of the independent variables (compaction pressure, dwelling time, particle size and binder percentage) and all dependent variables (calorific value, moisture content, volatile matter content, fixed carbon content, ash content, and density) are continuous, multiple linear regression models were selected to examine the effect of compaction pressure, binder percentage, dwelling time and particle size on each of the dependent variables. The models also enable interaction of the factors to be determined (Quinn &Keough, 2002). Data was presented in tables, graphs and pie charts.

3. Results and Discussion

3.1 Effects of parameters on density

Table 1 presents the results of multiple regression model on the effects of particle sizes, compaction pressure, dwelling time and binder content as explain below;

Table 1: Parameter estimates and P-values for density model

SUMMARY OUTPUT				
Regression Statistics				
Multiple R	0.812320099			
R Square	0.659863942			
Adjusted R Square	0.615975419			
Standard Error	0.044488039			
Observations	36			
ANOVA				
	df	*SS*	*MS*	*F*
Regression	4	0.119028219	0.0297571	15.03499979
Residual	31	0.061354753	0.0019792	
Total	35	0.180382972		
	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.61941	0.027920946	22.18442	1.388E-20 ***
Particle size	-0.064738	0.011889928	-5.44473	5.998E-06***
Dwelling time	0.000247667	0.000169441	1.4616651	0.154
Pressure	0.000509711	0.000101665	5.0136402	0.0000206***
Binder ratio	0.003834	0.000961051	3.9893805	0.000376***

(i) particle size

Relaxed density of the briquette is negatively associated particle size indicating that the briquette made with 0.5 mm particle size has the highest relaxed density compared to the particle sizes of 1.0 mm and 2.0 mm. This is because having the smallest grain means that the inter-particle and intra-particle spaces are very small and the particles pack together easily as opposed to the larger particle sizes where the spaces are larger leading to lower relaxed densities. The relaxed densities on the briquettes reduce as the grain size increase (Mitchual et al, 2013).

(ii) Compaction pressure

The results from multiple regressions found positive association between compaction pressures and relaxed densities. This is because with increase in compaction pressure, packing of the particles is enhanced and they are able to stick together to a greater extent increasing the relaxed density of the briquettes. The finding supports research by Thabuot et al (2015). On the other hand, when the pressure is low the bond is weaker hence inter-particle spaces are larger and therefore giving lower relaxed density.'

(iii) Dwelling time

Holding time is positively associated but not significant at P- value of 0.01 to the relaxed density. This is because adequate dwelling time allows time for the particles to come much closer together, fill the spaces between them and gives them a chance to firmly stick to each other hence generating very compact briquettes. On the other hand, zero or little dwelling time denies the particles the chance to fill the inter-particle space, only leaving them loosely packed. This is why briquettes made with zero holding time have the least relaxed density whereas those with holding time of 120 seconds the high relaxed density.

(iv) Percentage of binder content

The relaxed density is positive and significant with percentage of the binder content in all categories and supports the findings by Prasityousil & Muenjina (2013). The particles in samples with the highest binder ratios pack more closely leaving very small inter-particle and intra-particle spaces as compared to samples with lower binder percentages. This explains why 30% binder content gives the highest density and 10% binder content the least. In other words, binder increases adhesion of particles in the briquette body.

(v) Fitting model

By using multiple regression technique, the relationship between densities, particle size, compacting pressure and binder percentage over the studied range was developed. The empirical variables were particle size, compacting pressure and binder percentage and response was the densities. The regression is as shown

$$y = 0.6194 - 0.0647PS + 0.0005\ P + 0.00383\ BP \quad (1)$$

Where;
y = Relaxed density
PS = Particle sizes (mm)
D = Density (g cm^{-3}),
P = Compaction pressure (kg/cm^2)
BP = Binder percentage (%)

The fitting model showed that a particle size has the strongest effects on the density of the briquettes as compared to compacting pressure and binder percentage.

3.2 Combustion characteristics

3.2.1 Proximate analysis

Table 2 shows proximate analysis results for briquette without binder, with 10%, 20% and 30% binder. Results indicate that addition of binder reduces the water absorption. During carbonization process, all the oil and a considerable amount of moisture of the raw cashew nut shells were driven out as a result of the high carbonization temperatures.
The volatile matter was high for the sample without binder compared to the samples with binder. This indicates that introduction of a binder to the fuel leads to reduced volatile matter. The volatile matter recorded tends to increase as the binder ratio increases up to a certain point where it begins to fall. The sample without binder recorded the highest ratio of volatile matter compared to all the other samples with binder. According to Werther *et al* (2000), agricultural residues are characterized by high volatile values within the ranges of 65 to 80%. This makes them ignite easily and burn quite rapidly making it difficult to control the combustion process. This high volatile matter also makes them produce a lot of smoke during combustion.

Table 2: Proximate analysis for briquette without binder, with 10%, 20% and 30% binder

Cassava Binder content	***Weight %***			
	Moisture content	Volatile matter	Ash content	Fixed carbon
0%	6.87	25	10	58.13
10%	5.62	18.22	8.23	67.93
20%	5.42	20.5	6.81	67.27
30%	5.2	19.43	5.33	70.04

The amount of fixed carbon was 58.13%, 67.93%, 67.27% and 70.04% for the sample without binder, with 10% binder, 20% binder and 30% binder ratios respectively. The fixed carbon percentages obtained were higher than that of agricultural residues which are characterized by low content of fixed carbon (Omwando, 2006). This low composition of fixed carbon in biomass residues makes them uneconomical for production of briquettes hence favoring them for gasification. Introduction of a binder raises the fixed carbon content. This means that the samples with binder will have favorable combustion properties and will undergo complete combustion easier than the sample without a binder. The high percentage of fixed carbon and its smokeless flame in carbonized fuel enhances the heating value and combustion duration of the briquettes (Sotannde et al, 2010; Zapusek et al, 2003).

The ash content analysis shows that increase in the ratio of binder reduces the amount of ash produced when the briquettes heated. An inclusion of a binder in the samples leads to complete combustion of the briquette hence little ash is produced.

3.2.2 Ultimate Analysis Results

Table 3 presents the ultimate results for different sample categories. Results found that there is high carbon content in the briquettes made without a binder whereas for the briquette with the greatest binder content showed the least carbon content. Further, results showed that addition of a binder leads to a decrease in oxygen and hydrogen content while nitrogen content increased. There was reduction of carbon with increase of binder ratio, but still the results are favorable for combustion. This is because too much carbon might favor production of carbon monoxide during combustion whereas a reduction of carbon content will favor complete combustion with the given oxygen content.

Table 3: The ultimate analysis results

Cassava Binder content	*Carbon (Wt %)*	*Hydrogen (Wt %)*	*Oxygen (Wt %)*	*Nitrogen (Wt %)*
0%	6.87	25	10	58.13
10%	5.62	18.22	8.23	67.93
20%	5.42	20.5	6.81	67.27
30%	5.2	19.43	5.33	70.04

Also the percentage oxygen content reduced with addition of binder. This is quite favorable in that the calorific value of the fuel might increase (increase in oxygen content causes a decrease in calorific value and vice versa) and a slight reduction of hydrogen content is still favorable because the end product water vapor (moisture) is reduced, though not in any way a toxic product. High oxygen content tends to lower the calorific value of the fuel while high carbon content tends to form high-grade biomass fuel (Ismaila *et al*, 2013). Nitrogen content is not desirable in biomass fuel because during combustion, it tends to increase the release of toxic gases that are either irritants (NO_x) or asphyxiants(HCN) which may cause adverse effect to living organisms.

3.2.3 Calorific Value (Heating Value) Results

Figure 3 presents the calorific Value results for samples with binder content. Mathematical computation of the heating value was performed using the formula defined in equation;

HV = 2.326(147.6FC + 144VM)/1000; $MJKg^{-1}$ (2)

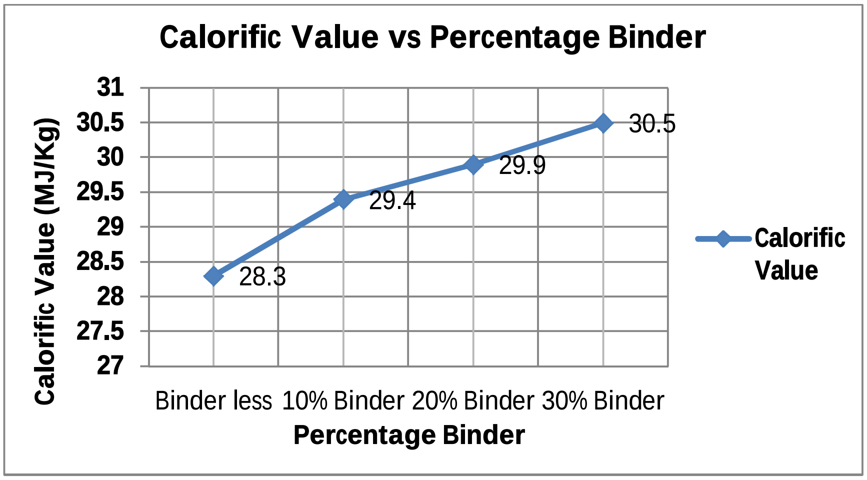

Figure 3: The calorific Value results for samples with different binder content

Results show that calorific value of the briquettes increases with increase in binder content. Heating value is the most important combustion property for determining the suitability of a material as fuel (Sotannde *et al*, 2010). It provides an indication of the quantity of fuel required to produce a certain amount of energy. The higher heating value of 30.5MJ/kg obtained in briquettes with 30% binder ratio compared to 28.3MJ/kg obtained in binder-less briquette could be attributed to its higher density, volatile matter, fixed carbon and low ash content.

3.2.4 Temperature Weight Loss Analysis

The results showed that the briquette with highest percentage binder ratio exhibits the greatest weight (Figure 4) indicating that addition of a binder to the cashew nut shells charcoal leads to maximum temperature weight loss; an indication of complete combustion.

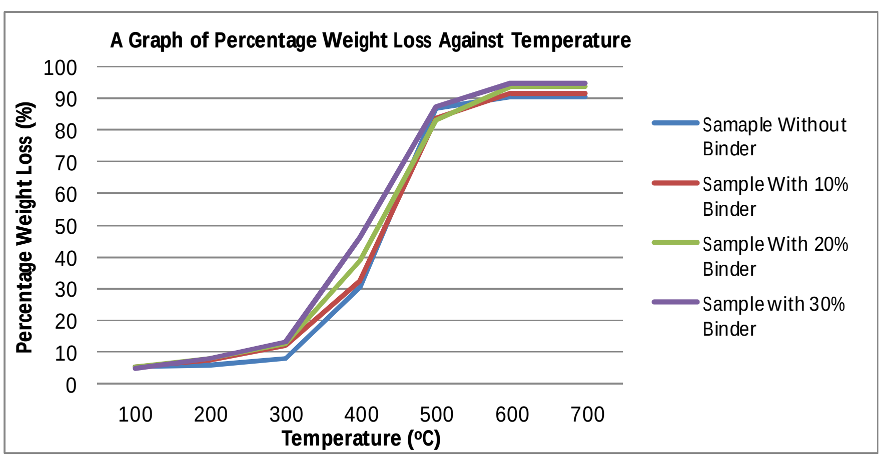

Figure 4: Temperature Weight Loss Analysis

The briquette with highest binder ratio lost the highest amount of weight an indication that it had a higher volatile matter content which burns enabling a more complete combustion process. It's followed by briquette 20% binder ratio, then 10% binder ratio and lastly the one without binder at all. A lot of weight was lost between the temperature range of

300^{0}C – 500^{0}C, and this is the time during which volatile matter and the fixed carbon undergoes combustion. At lower temperatures, the briquettes with binder ignited and combustion started while the briquette without binder burnt at a slower rate. It is noted that during combustion that the heat energy is released hence it can therefore be concluded that briquettes with adequate binder content burns fast in comparison to binder-less ones.

3.2.5 Water Boiling Test Analysis

Table 4 shows the effect of binder ratio on time taken to boil the given quantity of water as well as the burning rate of the briquettes. The table below gives the time for boiling 100cm^3 of water in minutes and burning rate, BR (g/min). The briquettes with least percentage binder ratio burn for longer periods i.e. burning is slower compared to briquettes with the highest binder ratios and therefore they burn for longer before end of combustion is reached. This indicates that introduction of a binder material in the briquettes improves the burning characteristics of the briquettes.

Table 4: Water Boiling Test Analysis

Sample	**Weight (g)**	**Time taken to boil 100cm^3 of water (min)**	**Burning, BR rate (g/min)**
Sample with 30% binder	168.7	4.00	9.416
Sample with 20% binder	168.2	4.883	8.822
Sample with 10% binder	168.3	6.033	7.436

3.2.6 Ignition Time

This was done using a cigarette lighter in a draught free area. The briquette was held on one top and the lighter's flame directed on the base. The time taken for each sample to ignite was recorded as shown in Figure 5.

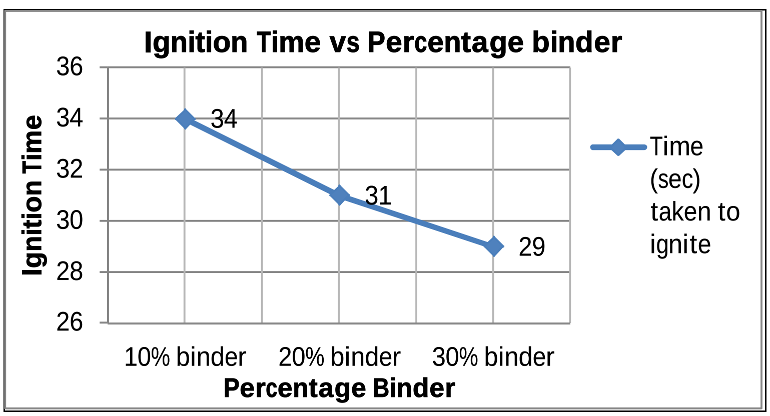

Figure 5: Time taken for samples with binder content to ignite

The results show that the ignition time is least for briquettes with higher binder ratio and highest for briquettes with the little binder ratio. This is because the increase in binder content increases the amount of volatile matter in the briquettes hence easier to ignite. The results further indicate that little the amount of volatile matter the longer is the ignition time.

3.3 Physical properties

3.3.1 Compressive Strength Analysis

Figure 6, 7 and 8 shows the effects of the particle size, binder ratios and compaction pressure on the compressive strength of the briquettes.

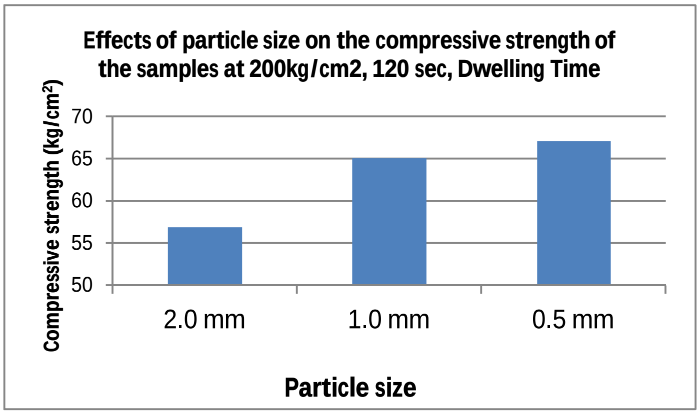

Figure 6: Effects of particle size on the compressive strength

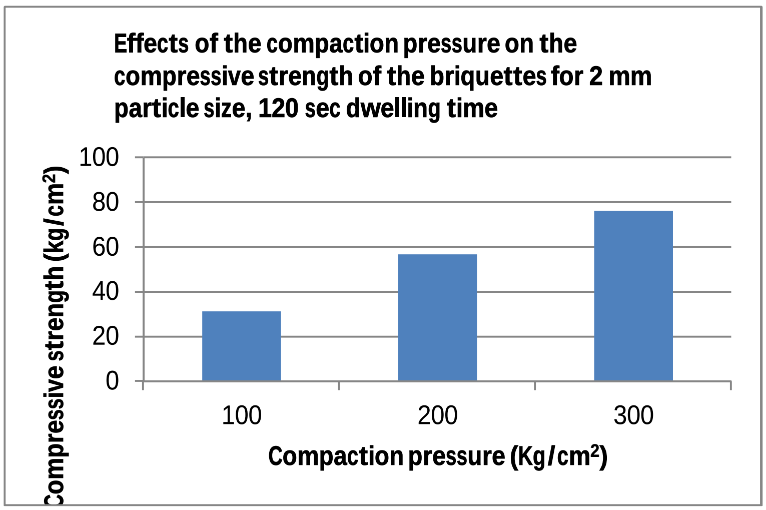

Figure 7: Effects of the compaction pressure on the compressive strength

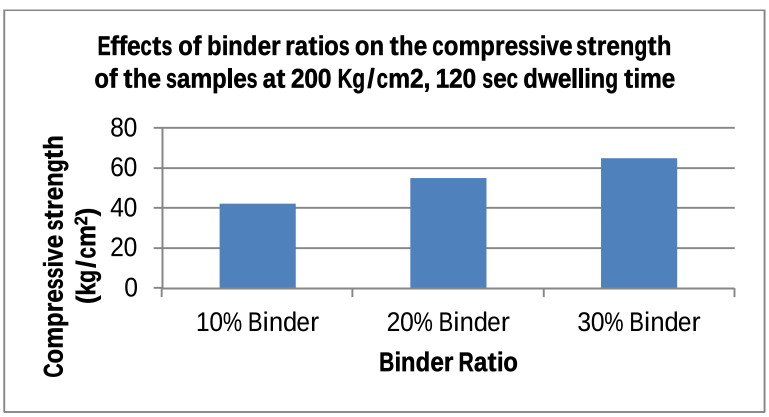

Figure 8: Effects of binder ratios on the compressive strength

The compressive strength, from the results obtained, increases with:

i. Decrease in particle size
ii. Increase of percentage binder ratio
iii. Increase in compaction pressure

The compressive strength is highest in briquettes of 0.5mm particle size and least in briquettes of 2.0mm particles. Grain size of 0.5mm is very small hence has more uniformity and cohesiveness thus bonding firmly resulting into high strength; it leaves very tiny inter-particle spaces and little cleavages. On the other hand 2.0mm particles have more irregular shape and they arrange themselves irregularly leaving many lines of weaknesses hence cracking easily takes place along these lines.

The briquettes with the highest binder ratio showed the highest compressive strength (Lu et al, 2014). This is because the binder enhances bonding and adhesion of grains hence making it difficult to break. The briquette with the least binder ratio has loosely packed grains which can easily disintegrate when subjected to compressive force. Greater pressing pressure aides in effective compaction of the grains within the briquette body as opposed to lower pressures. As a result briquettes produce with a pressure of 300kg/cm^2 had the greatest compressive strength while those made with 100kg/cm^2 exhibited the least compressive strength. However, too high compaction pressure might deform the grains such that only a little more force will be needed to fracture the briquette.

3.3.2 Durability Test Analysis

The tumbling can test is the method predominantly used for measuring durability of the briquettes as this test gives an indication of the ability of the briquettes to retain their structural integrity. Figure 9 gives the percentage weight loss and durability indices:

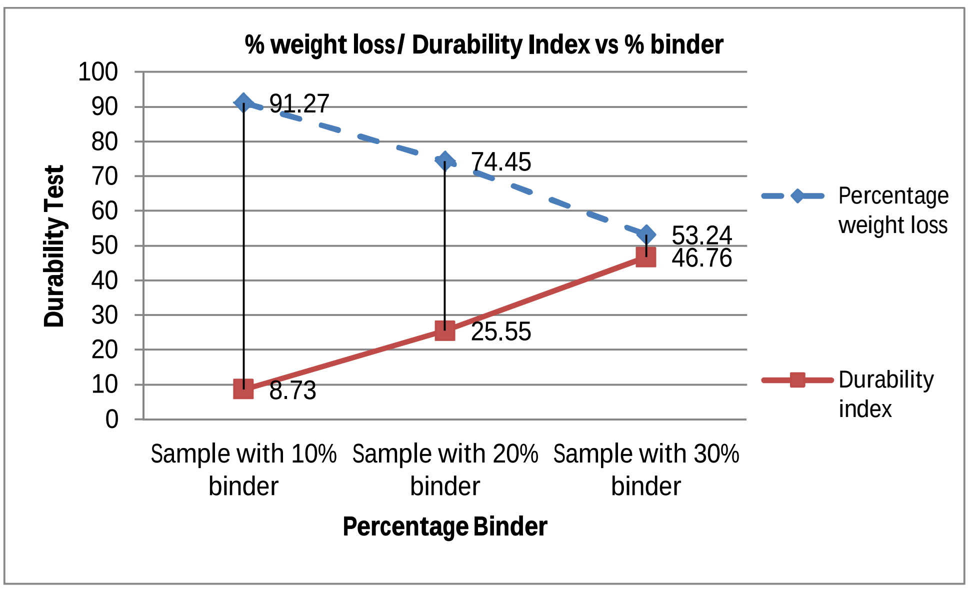

Figure 9: Weight loss and durability indices for briquettes

Results showed that the duarability of the briquettes is proportional to the percentage binder ratio. The briquettes with higher binder ratio have higher durability index while those with lower binder ratio have lower durability index. During transpotation and handling, briquettes are knocking against each other or against the vessel in which they are held. This causes wear of the briquttes by disintegration or erosion of particles from the briquette body. The durability of briquettes is therefore, vital to pre-determine in order to obtain an estimate of their life span.

3.3.3 Shatter Index

A sample briquette was drop from a distance of 1.8m to a reinforced cement concrete floor. The weight of the sample before and after the test were recorded and used to calculate the shatter resistance as shown in Figure 10. The results of this drop test show that the shatter resistance increase with increase in percentage binder ratio. It is highest for briquettes with 30% binder ratio and least for briquettes with 10% binder ration. The shatter resistance is very important because it helps to estimate the ability of the densified products to retain their original structure when they collapse from a considerable height (Tembe et al, 2014).This explains the necessity of estimating the amount of damage that the densified products mightundergoe at the point of utilization in terms of shatter resistance.

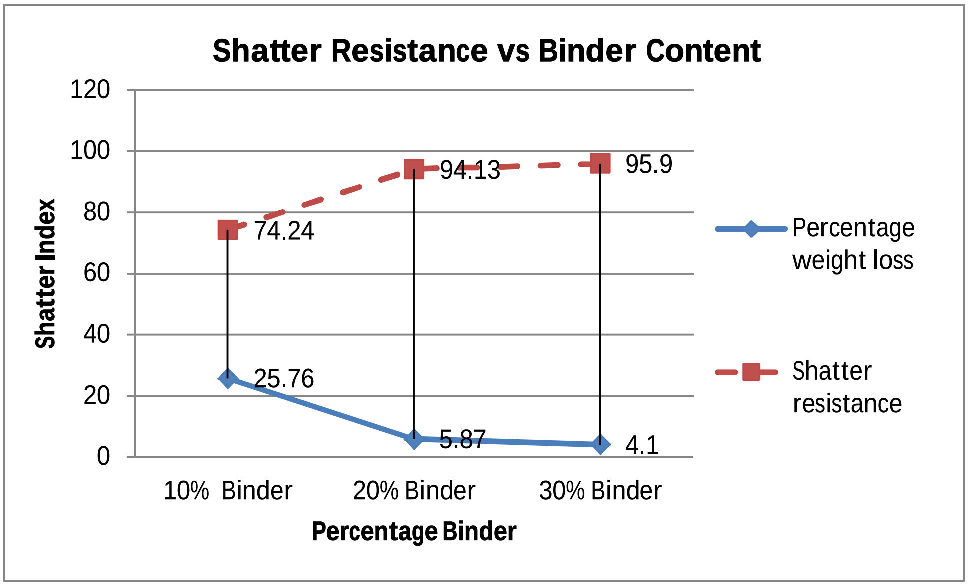

Figure 10: shatter resistance against percentage binder ratio

3.3.4 Water Resistance Test Analysis

This was performed by immersing a dry sample in a basin of water for 30 seconds. The weight before and after the test were recorded. Water resistance was computed according to the formula below;

$$WaterResistance = 100\% - \frac{W_f - W_i}{W_i} x\ 100 \quad (3)$$

Where;
W_i = weight before immersion into water
W_f = weight after immersion into water

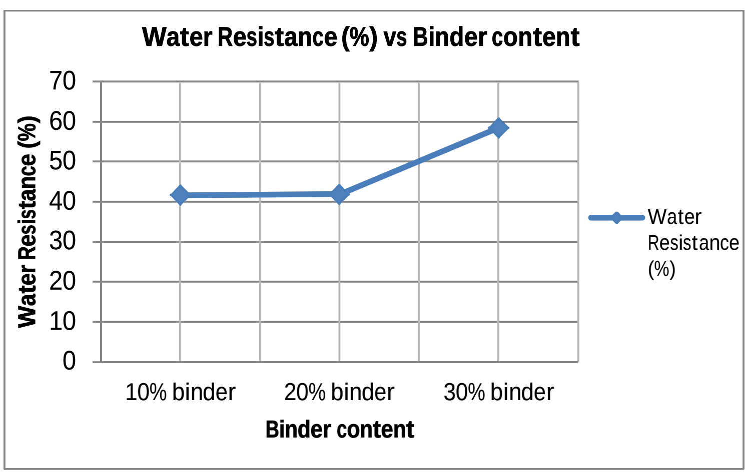

Figure 11: Water resistance against binder content

The results on Figure 11 showed that briquettes with higher percentage binder ratio have greater resistance to water penetration than those with little binder percentage and concurs with Demirbaş (1999). The purpose of this test was to help determine the extent to which water and humidity can affect the quality of the briquettes. During transportation and storage, some exposure to rain or high humidity conditions might adversely affect the quality of the briquettes i.e. strength and durability, hence necessary to investigate their resistance to water absorption.

4. Conclusion

Compaction pressure, binder content and particle size have a significant effect on physical and combustion properties of cashew nut shell and cassava binder briquettes. Cassava binders improve the combustion and physical properties of cashew nut shell briquettes. The briquetting of cashew nut shell into solid fuel does not only provide fuel but also keep the environment clean. In addition, it helps to prevent deforestation of the diminishing forest cover. The briquettes will further serve as substitute for fuelwood since its maximum calorific value obtained is 30.5MJ/Kg which is very close to that of that ordinary wood charcoal (31.38MJ/kg).

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