Physico-mechanical characteristics of rice husk briquettes using different binders

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Abstract: This study evaluated the physico-mechanical characteristics of rice husk briquettes using plantain peels and gum Arabic as binders. The rice husk residues were milled into particle size of 1.18 to 0.6 mm, plantain peels and gum Arabic as binders at binder ratios of 10%, 20%, and 30% by weight of the rice husk residue. The two sets of briquettes produced were cylindrical in shape with a central hole using cylindrical die (70 mm height × 50 mm diameter) in a hydraulic press briquetting machine at a dwell time of 5 min, under a die pressure of 2.5 MPa. The physical and mechanical properties analyzed were moisture content, relaxed density, stability, durability index, water resistance index and compressive strength. The data obtained were statistically analyzed by Analysis of Variance (ANOVA) at significant difference of 0.05.

The test results showed that: the moisture content of the briquettes produced varied from 8.03% to 10.13%, relaxed density varied from 491.46 to 623.18 kg/m^3. The durability index of the briquettes produced varied from 29.33% (30% plantain peel binder) to 93% (30% gum Arabic binder), compressive strength varied from 1.29 to 4.77 kN/m^2. Both axial and longitudinal expansion of the briquettes took place within the first 30 minutes, though briquettes with gum Arabic as binder had better stability than those with plantain peels. Rice husk briquettes produced with gum Arabic as binder was more reliable, durable and can withstand mechanical handling than those with plantain peels as binder. However, both briquettes thus produced are viable fuels for domestic purposes in rural areas.

Keywords: briquettes, rice husk, plantain peel, gum Arabic, binder

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1 Introduction

The importance of energy in nation development cannot be over emphasized as this can contribute immensely to economic growth and social life of such a nation. Presently, there is a problem of shortage of energy worldwide, including Nigeria (Oladeji and Lucas, 2011).

One of the principal sources of energy is fossil fuels. According to Kaliyan and Morey (2009) about 89% of the world's energy demand is met by fossil fuels. The use of fossil fuels is very convenient. However, many problems are associated with its application. One of such is the issue of global warming. In this regard, there is a great need for a gradual shift from fossil fuels to agricultural residues which can play a significant role in alternative energy generation on a renewable basis.

Globally, 140 billion metric tons of biomass is generated every year from agriculture. This volume of biomass can be converted to an enormous amount of energy and raw materials (UNEP, 2009). Out of the three categories of biomass: biomass plantation, forest residues and agricultural residues that are available, agricultural residues account for the largest amount available worldwide (Wilaipon, 2007). He added that, agricultural residues thus generated could serve as alternative sources of energy with potentials of replacing the fossil fuel. Most developing countries produce huge quantities of agricultural residues but they are used inefficiently causing environmental pollution.

The major limitations in the utilization of agricultural residues like rice husk (biomass material) as energy source include, low energy density/value,

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transportation, handling and storage cost high (Oladeji, 2012; Kaliyan and Morey, 2009). One of the technologies through which the fuel values from rice husk can be harnessed is briquetting (Oladeji, 2012; Davies and Abolude, 2013; David et al., 2013).

Biomass briquetting is the densification of loose biomass material to produce compact solid composite fuel of different sizes with the application of pressure (Olorunnisola, 2007). Briquetting of residues takes place with the application of pressure, heat and binding agent on the loose materials to produce the briquettes. Briquetting of biomass improves its handling characteristics, increases the volumetric calorific values, reduces transportation, collection and storage cost and makes it available for a variety of purposes/applications (Grover and Mishran, 1996). Thus, it serves as a mitigation measure for environmental pollution pose by indiscriminate dumping of the rice husk. Due to the advantage of densification, several biomass materials have been experimentally studied to densify agricultural waste to solid fuel. Examples of agricultural waste briquetted are corncob, saw dust, rice husk, peanut shell, groundnut shell, coconut fibre, water hyacinth, banana peels, plantain peels, and waste paper. Briquettes can be used for domestic purposes (cooking, heating, barbequing) and industrial purposes (agro-industries, food processing) in both rural and urban areas.

Sotannde et al. (2010) reported the effect of binder type and their proportion on the durability of briquettes produced from neem residue. The study revealed that briquettes produced from gum Arabic and cassava starch and of the same blending ratio had different durability rating and the values were significantly different. Davies and Abolude (2013) studied the mechanical characteristics of briquettes produced from water hyacinth and plantain peel as binder. It showed that the binder proportion had significant influence on the durability of the briquettes. David et al. (2013) investigated the effect of binder types (molasses, cowdung and clay) and amount on physical and combustion characteristics of composite briquettes made from rice husk and bagasse. It revealed that binder has positive effect on the mechanical characteristics of briquettes.

Selection of binder is based on the availability, cost, environmental friendliness, and on the material of the briquettes. Binder is necessary in briquetting of material to produce briquettes with adequate mechanical properties under low pressure systems.

The objectives of this study were to investigate the influence of binder types and ratios on some of the physical and mechanical properties of briquettes produced from rice husk.

2 Materials and methods

2.1 Raw material preparation

This research was conducted in the Department of Agricultural and Environmental Engineering, University of Ibadan, Ibadan, Oyo State, Nigeria in 2015.

The rice husk of a local rice breed (Ofada rice) was collected from a rice mill in Ojagboro, Ilorin Kwara state. It was sun-dried to a moisture content of 11.84% (wb). Size reduction of the rice husk was done using a mill. This milled rice husk was sieved to particle sizes of 0.6 mm to 1.18 mm. This particle size was based on the study of (Hussain et al., 2002) for producing and strong, cohesive briquettes.

The plantain peels were collected from restaurants in Student Union Building, University of Ibadan. The plantain peels were collected in its fresh state, at moisture content of about 81.03% (wb). The plantain peels were shredded, sun-dried to a moisture content of 9.85% (wb) which was within the 15% moisture content recommended by Grover and Mishra (1996), Kaliyan and Morey (2009). The dried peels were ground using a mill. This was sieved to achieve particle size of about 0.85 mm.

The gum Arabic was gotten from Kawo market, Kaduna North, Kaduna State of Nigeria. Gum Arabic in its granular state was pounded and sieved. This was done to achieve speedy melting of the granular gum in hot water.

2.2 Briquetting process

The rice husk sample was mixed with an already prepared ground plantain peel and gum Arabic as binders in the proportion of 10%, 20%, and 30% by weight of residue respectively in line with the works of Musa (2007), Olorunnisola (2007) and Oladeji (2010).

Compression of the wet feedstock was carried out on the hydraulic press briquetting machine (Figure 1). A pre-determine weight of the mix was freely loaded into each of the steel cylinder moulds (dimension of each mould: 70 mm height × 50 mm diameter). The mix was compacted at a pressure of 2.5 MPa, at a dwell time of 5 minutes according to Musa (2007) and Olorunnisola (2007). Six briquettes were extruded at a time. The extruded briquettes were left in the open to dry for three weeks after which they were analyzed. Figure 2 illustrates the feeding of the moulds with feedstock.

The briquettes produced were cylindrical in shape with a central hole as is shown in Figures 3-4. Legacy Foundation (2003) stated that the central hole in doughnut briquette increases the combustion efficiency of the briquette. The central hole creates a draft which gives a clear path for good air-flow from underneath the briquette.

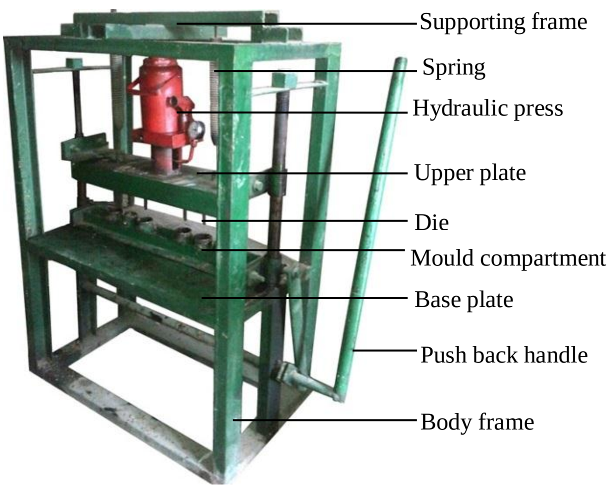

Figure 1 Hydraulic press briquetting machine

Figure 2 Feeding the moulds with feedstock

(a) Briquettes with plantain peels binder

(b) Briquettes with plantain peels binder ratio of 20%

ratio of 10%

c) Briquettes with plantain peels binder ratio of 30%

Figure 3 Briquettes with different plantain peels binder of a, b, and c

(a) Briquettes with gum Arabic binder

(b) Briquettes with gum Arabic binder ratio of 20% ratio of 10%

(c) Briquettes with gum Arabic binder ratio of 30%

Figure 4 Briquettes with different gum Arabic binder ratio of a, b, and c.

2.3 Determination of physical properties of the briquettes

In order to investigate the influence of binder type and ratio on the physical and mechanical properties of briquette produced, some standard tests and analyses were carried out.

2.3.1 Moisture content determination

The moisture content of the briquettes was determined on oven-dry basis; this was in accordance with European Standard EN 13183-1 (2002). The moisture content was then computed as follows:

$$\text{Moisture content (\%)db} = \frac{M_1 - M_0}{M_0} \times 100 \qquad (1)$$

Where;

M_1 – mass of briquette before oven drying (g)

M_0 – mass of briquette after oven drying (g)

2.3.2 Determination of loose bulk density of the rice husk

The loose bulk density (BD) of the rice husk was determined according to ASABE S269.4 (2003) and was calculated as:

$$BD = \frac{\text{Weight of rice husk (kg)}}{\text{Volume occupied (m}^3\text{)}} \qquad (2)$$

2.3.3 Relaxed density

Relaxed density can be defined as the density of the briquette obtained after the briquette has remained stable (at equilibrium moisture content). It is also known as spring back density. The relaxed density of the briquettes from rice husk was determined in the dry condition after 30 days (Mitchual et al., 2013). This was computed simply as the ratio of the briquette's weight to the new volume (the volume of the cylindrical material). The dimensions for computing the volume were noted with a digital vernier caliper. Three replicates of the sample were carried out and the average reported.

2.3.4 Water Penetration Resistance (WPR) or Water Resistance Index (WRI)

The water resistance of the briquettes was determined as reported by Wakchaure and Indra (2011) expressed as a percentage of water absorbed by briquettes when immersed in water at 27^0C for 30 seconds. Three replicates were made. Thus calculated as;

$$\text{percentage water absorbed} = \frac{\text{final mass of briquette} - \text{initial mass of briquette}}{\text{initial mass of briquette}} \times 100\% \qquad (3)$$

$$\text{Water Resistance Index} = 100\% - \text{percentage water absorbed by the briquette} \qquad (4)$$

2.3.5 Stability of the briquettes

Stability is the ability of a briquette to maintain its initial shape and size after compression in the axial and longitudinal directions. As the pressure is released after compression in mould (or closed cylinder) the briquettes tend to expand. The expansion takes place primarily in the longitudinal direction, i.e. in the direction at which force was applied.

To determine dimensional stability, the length and the diameter of three briquettes from each batch production were measured at 1 min, 30 min, 60 min, 1440 min and 10,080 min after production (Wamukonya and Jenkins, 1995). The dimensional changes were noted with a digital vernier caliper. Three replications were taken.

2.4 Determination of the mechanical properties of briquettes

Yaman et al. (2000), Ajayi and Lawal (1995) showed that the mechanical properties of briquettes can be characterized by two properties compressive strength and durability index. Before testing the strength of the briquettes, the briquettes were stored under ambient conditions for three weeks to stabilize inner tensions affecting the microstructure and the porosity of the briquettes (Yaman et al., 2000)

2.4.1 Compressive strength

The compressive strength of the briquettes was measured using the Universal Testing Machine in line with ASTM Standard D1037-93 (1995) and calculated as follows:

$$\text{Compressive strength } (\text{N/m}^2) = \frac{\text{Maximum force applied (N)}}{\text{Mean area of the face of the sample } (\text{m}^2)} \quad (5)$$

2.4.2 Durability index

This represents the measure of shear and impact forces a briquette could withstand during handling, storage and transportation processes. The durability index of the briquettes was measured using the ASAE standard method, S269.3 (Wamukonya and Jenkins, 1995) and calculated as follows;

$$\text{Durability } (\%) = \frac{\text{Weight loss (kg)}}{\text{Initial weight (kg)}} \times 100 \quad (6)$$

2.5 Statistical analysis

The experiment was set up as a Complete Randomized Block Design (CRBD) with three replications. Statistical Analysis was done to compare the properties of briquettes with plantain peel as binder with that of briquette with gum Arabic as binder, using means and Analysis of Variance (ANOVA) which was carried out at 5% significant level ($P < 0.05$)

3 Results and discussion

3.1 Moisture content of the briquettes

The moisture content of the briquettes was in the range of 8.07%–10.13%. There was no significant difference in the moisture content in the sets of briquettes produced at $p<0.05$. This range falls between the acceptable percentage moisture limits of 8%-12% recommended by Eriksson and Prior (1990). Wanmukonya and Jenkins (1995) reported the optimum moisture content for briquette raw material to be 12%-20% wet basis.

3.2 Relaxed density of the briquettes

The obtained initial bulk density of the loose rice husk residue was 135 kg/m^3. From Table 1, the densities of the rice husk briquettes ranged from 491.46 kg/m^3 (P_{10}) to 623.18 kg/m^3 (G_{30}). The relaxed density of the briquettes produced were significantly different ($p<0.05$). The average density for briquettes with plantain peels recorded 500.91 kg/m^3 while those with gum Arabic as binder, 590.67 kg/m^3. It was observed that the densities increased with the increase in percentage binder ratio. Idah and Mopah (2013) reported the bulk densities of briquettes produced from rice husk, maize cob, groundnut shell and sugar cane bagasse were 750 kg/m^3, 690 kg/m^3, 810 kg/m^3 and 650 kg/m^3, respectively. The values of the densities obtained in this research were less than the minimum value of 600 kg/m^3 recommended by and Gilbert et al. (2009) for efficient transportation and safe storage exception for the briquettes at G_{20} and G_{30} with density of 601.78 and 623.18 kg/m^3 respectively. Density is an important parameter in briquetting. The density of biomass briquettes depends on the density of the original biowaste, the pressure, temperature and dwelling time. The higher the density, the higher is the energy/volume ratio (Idah and Mopah, 2013).

Therefore, the densification of agricultural materials helps in reducing the cost and labor involved in handling the raw bulk residue which usually constitutes hazards in the dump ground. The reduction in the volume also saves space for storage of these residues.

3.3 Water penetration resistance

Table 1 shows the effect of the binder types and binders ratio on the water penetration resistance offered by the briquettes produced. The water penetration resistance ranged from 0 to 32.4% for briquettes with plantain peel. The values were observed to be statistically significant ($p<0.05$). The water penetration resistance decreased with the increase in binder ratio. The highest water penetration resistance of 32.4% was observed at P_{10}, while the lowest 0 at P_{20} and P_{30}. Briquettes at P_{20} and P_{30} offered no resistance to water penetration since the percentage mass of absorbed water was 100%. Plantain peels are hygroscopic materials (ability to absorb water). Therefore, it could be inferred that increased percentage of the plantain peel means decreased water penetration resistance.

Table 1 Effect of binder type and ratio of the relaxed densities of the briquettes and resistance of water penetration

Briquette	Moisture content, %	Relaxed density, kg/m^3	Resistance to water penetration, %
P_{10}	10.13	491.46	32.4
P_{20}	10.10	495.63	0.00
P_{30}	8.53	515.63	0.00
G_{10}	8.07	547.08	53.27
G_{20}	8.03	601.76	65.53
G_{30}	8.83	623.18	78.96

Note: Mean values; P – Percentage of plantain peel binder and G – Percentage of gum Arabic binder.

Similarly, for briquette-gum Arabic binder, the water penetration resistance increased with increased gum Arabic binder proportion. Briquette at G_{30} had the highest water penetration resistance of 78.96%, while the lowest 53.27% at G_{10}. The increased value of water penetration resistance could be due to the low porosity of the briquettes (the higher the binder ratio the more compact the briquettes will be).

Davies and Davies (2013) reported water resistance property of briquettes produced from water hyacinth and phytoplankton scum as binder varied from 52% (B1) to 97.1% (B5) for the five binder levels (10% (B1), 20%(B2), 30%(B2), 40%(B2) and 50%(B2)). It showed an indication that hygroscopic property of briquettes at different binder proportions showed a decrease in water absorption capacity with increased binder proportion.

Wakchaure and Indra (2011) reported water penetration resistance range of 2.7% to 184.1% at binder (molasses, press mud and distillers dry grain) concentration of 5%, 10%, 15% and 20% for the briquettes produced from mustard stalk, mixed waste of tree leaves and grass and wood waste.

3.4 Stability of the briquettes

The dimensional (axial and longitudinal expansion) stability of the briquettes was measured in terms of its dimensional changes when exposed to atmosphere. The stability mean values are shown in Tables 2 and 3.

Table 2 Expansion of rice husk briquettes with gum Arabic binder at different binder ratios

	Axial Expansion, mm			Longitudinal expansion, mm		
Time, min / %Binder	**10**	**20**	**30**	**10**	**20**	**30**
1	54.36	54.29	53.37	62.71	64.38	64.49
30	54.39	54.54	53.90	63.25	65.26	65.51
60	53.71	54.07	54.21	63.21	64.83	65.53
1440	53.42	53.92	53.51	62.65	64.48	64.74
10080	53.03	52.79	52.44	62.47	63.84	63.62
30240	52.94	52.60	51.99	62.40	62.31	63.43

Note: Mean values

Table 3 Expansion of rice husk briquettes with Plantain peel binder at different binder ratios

	Axial Expansion, mm			Longitudinal Expansion, mm		
Time, min / %Binder	**10**	**20**	**30**	**10**	**20**	**30**
1	54.76	55.16	54.91	66.98	68.68	63.28
30	54.89	55.50	55.2	67.96	70.00	64.09
60	53.91	54.20	54.42	67.55	71.34	64.28
1440	53.69	53.80	54.31	67.45	69.34	63.19
10080	52.67	53.34	52.68	67.20	69.02	61.47
30240	52.40	53.32	52.55	66.59	68.23	60.22

Note: Mean values

Figures 5 and 6 show the longitudinal and axial expansion of the briquette produced with plantain peels as binder respectively. Briquettes with P_{20} appeared to be the most stable both longitudinally and axially, hence it can be inferred that it produced the most stabilizing effect when exposed to the atmosphere compared to briquettes at other plantain binder ratios. For all, briquettes expansion took place rapidly in the first 30 mins.

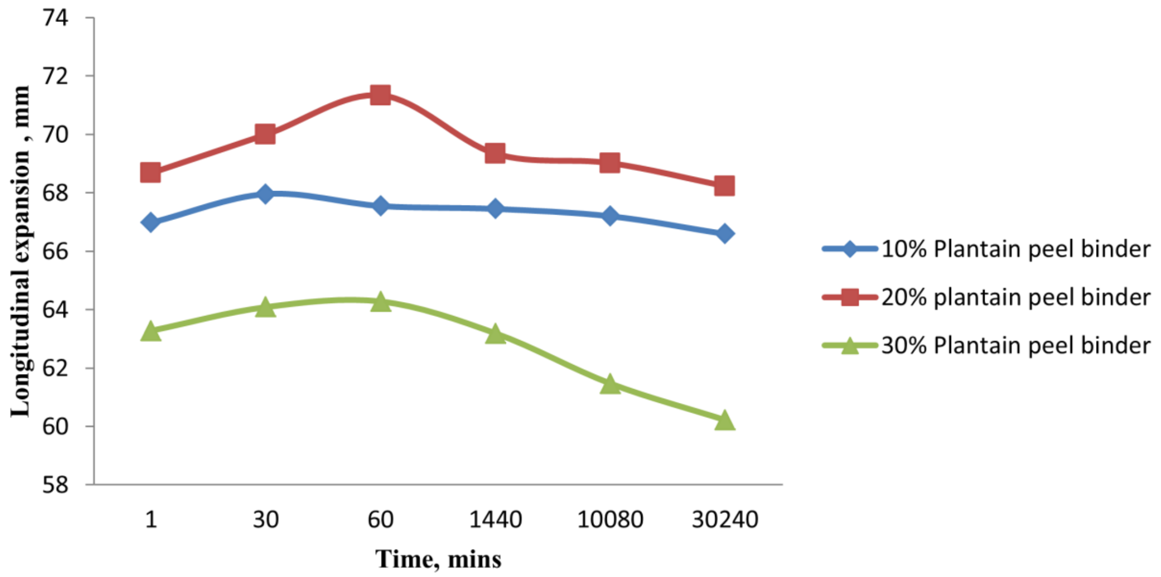

Figure 5 Longitudinal expansion of rice husk briquette-plantain peel binder with binder ratio

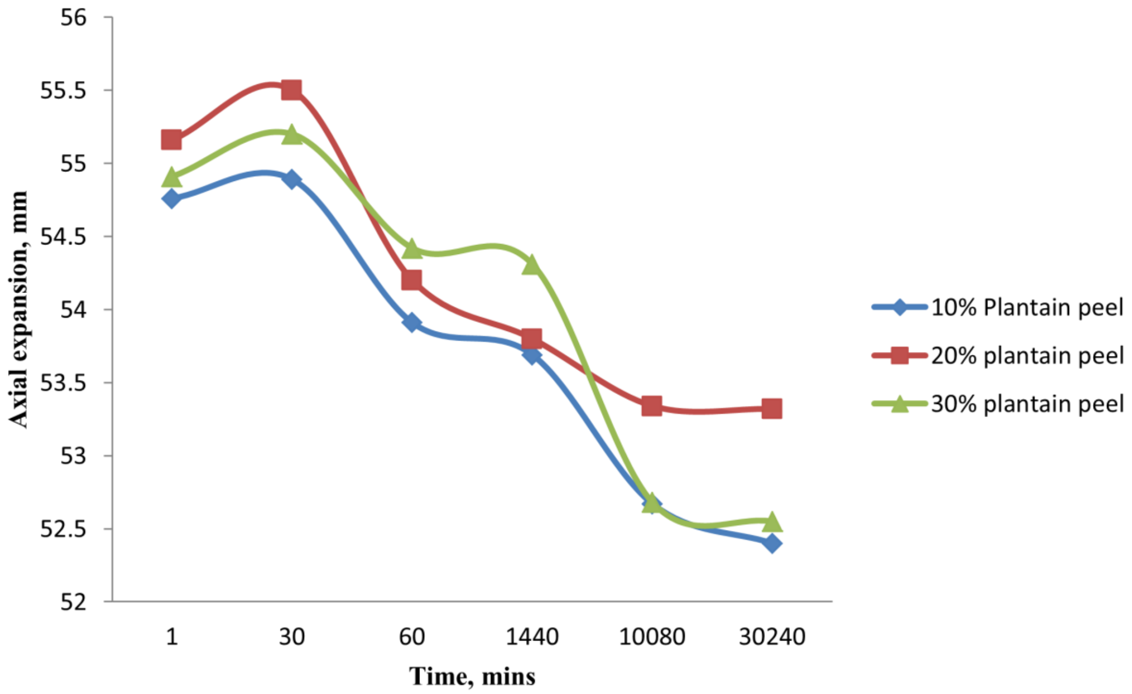

Figure 6 Axial expansion of rice husk briquette-plantain peel binder with binder ratio

Similarly, Figures 7 and 8 show the longitudinal and axial expansion of briquettes produced with gum Arabic as binder respectively. Briquettes at G_{30} appeared to be more stable both in the longitudinal and axial expansion than any of the binder ratios. For all briquettes expansion took place in the first 30 mins.

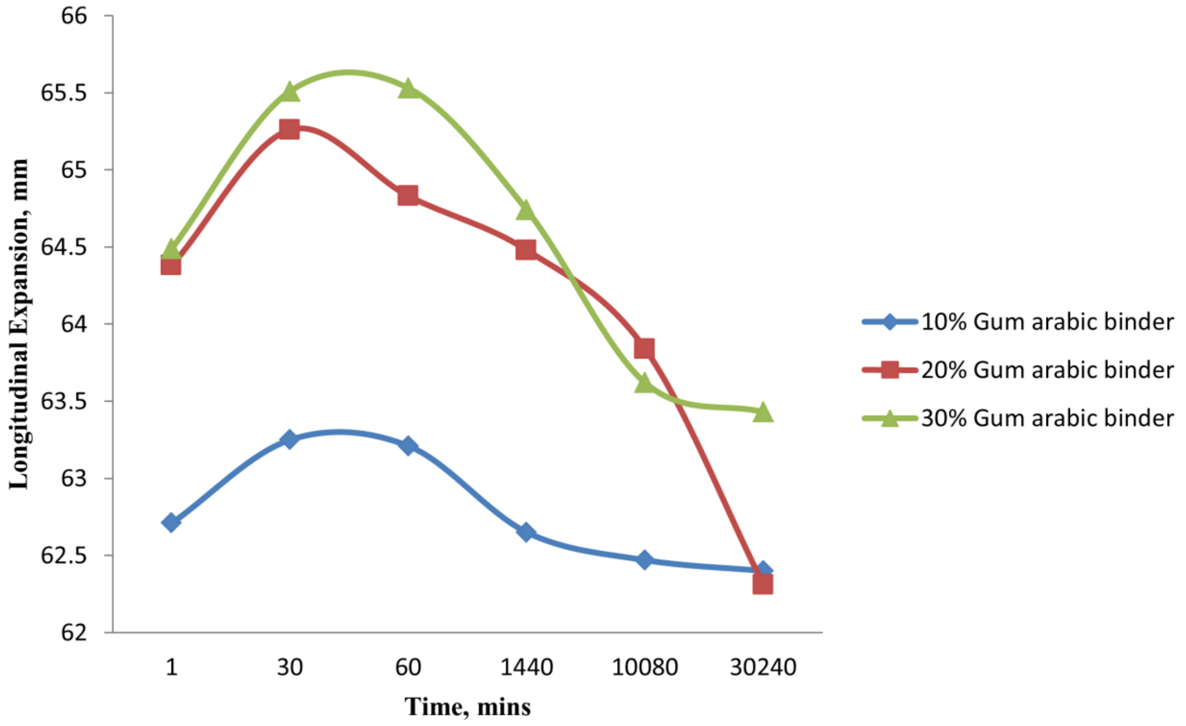

Figure 7 Longitudinal expansion of rice husk briquette-gum Arabic binder with binder ratio

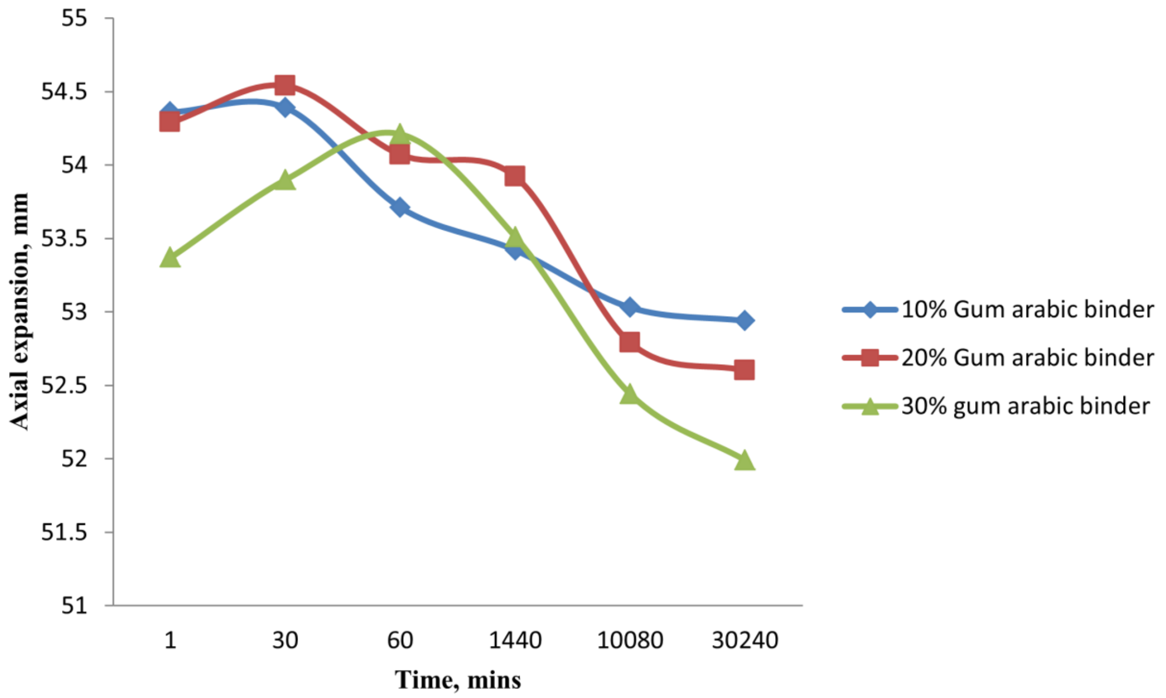

Figure 8 Axial expansion of rice husk briquette-gum Arabic binder with binder ratio

The first thirty minutes of the briquettes extruded was observed to be crucial to both the axial and longitudinal expansion characteristics. The highest and most rapid expansion took place within this period. From one hour after its extrusion and up to 24 hours, the expansions were minimal. This observation is in line with the work of Bolufowi, 2008. Obi et al. (2013) reported the most stability obtain in the briquetting of saw dust was at 35% binder between 30-1440 mins.

The compressed agricultural residue responds to the basic law of stress and strain in diverse forms. The material rebounds according to its viscoelastic properties, which may continue for several days with slight increments with a considerable portion of this rebound taking place within a short time after unloading (Bolufawi, 2008).

3.5 Compressive strength of the rice husk briquette

Figure 9 shows the compressive strength of the briquettes produced. The compressive strength ranged from 1.29-4.77 kN/m^2. The least compressive strength of 1.29 kN/m^2 recorded at P_{30}, the highest 4.77 kN/m^2 at G_{30}. These values of compressive strength were significantly different ($p<0.05$). There observed a decrease in compressive strength with an increase in binder ratio in the case of briquettes with plantain peels. But briquettes with gum Arabic binder, the compressive strength was observed to increase with an increase in binder ratio. It could be said that briquettes produced with plantain peels binder were less durable than briquettes produced with gum Arabic binder. It could then be inferred that the amount of binder used had significant influence on the compressive strength of the briquettes. The implication of this is that rice husk briquette-plantain peel binder will suffer more damage during handling, transportation and storage than the rice husk briquettes-gum Arabic binder. Onuegbu et al. (2012) reported the compressive strength of spear grass briquette of 2.00 N/mm^2 at pressure of 5 MPa using 25% starch binder. Wakchaure and Indra (2011) reported a decrease in compressive strength with increase in concentration of molasses as binder. Oladeji (2010) reported on the compressive strength of briquettes made from corncob and rice husk as 2.34 and 1.07 kN/m^2 respectively using starch as binder. Oladeji (2012) also reported the compressive strength of briquettes from corncob, groundnut shell, melon shell, cassava and yam peels as 2.34, 1.67, 2.3, 1.53 and 1.76 kN/m^2 respectively. The mean values are shown in Table 4.

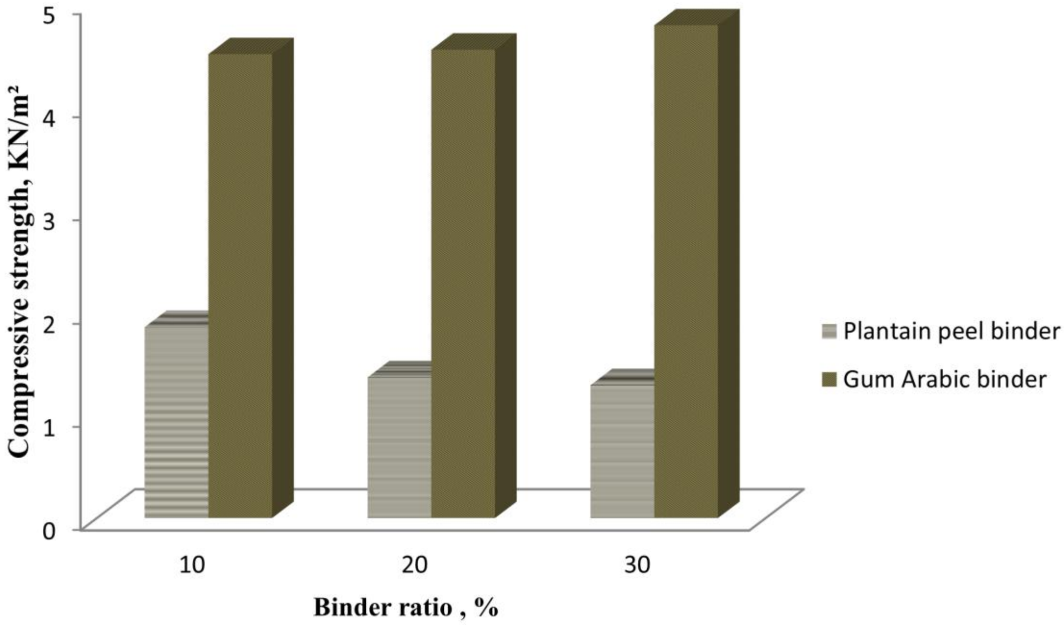

Figure 9 Effect of binder type and ratio on the compressive strength of the briquettes

Table 4 Compressive strength and Durability of the rice husk briquettes

Briquette	% Binder	Compressive Strength, KN/m^2	Durability, %
Plantain peels	10	1.85	39.00
	20	1.36	36.67
	30	1.29	29.33
Gum arabic	10	4.49	76.67
	20	4.54	87.70
	30	4.77	93.00

Note:Mean values

3.6 Durability of the rice husk briquettes

Figure 10 shows the variation in the durability index of the briquettes. The durability index varied from 29.33% (P_{30}) to 93% (G_{30}). These values were seen to be significantly different ($p<0.05$). It was observed that the durability resistance for rice husk briquette-plantain peel binder decreased with the increase in binder ratio. The highest durability resistance of 39% was recorded at P_{10} the least 29.33% at P_{30}. Briquettes with gum Arabic as binder recorded the highest resistance of 93% at G_{30} and the least 76.67% at G_{10}. It was observed that the durability resistance increased with increase in binder ratio. This is not represented in the briquettes with plantain peel binder. The mean values are shown in Table 4.

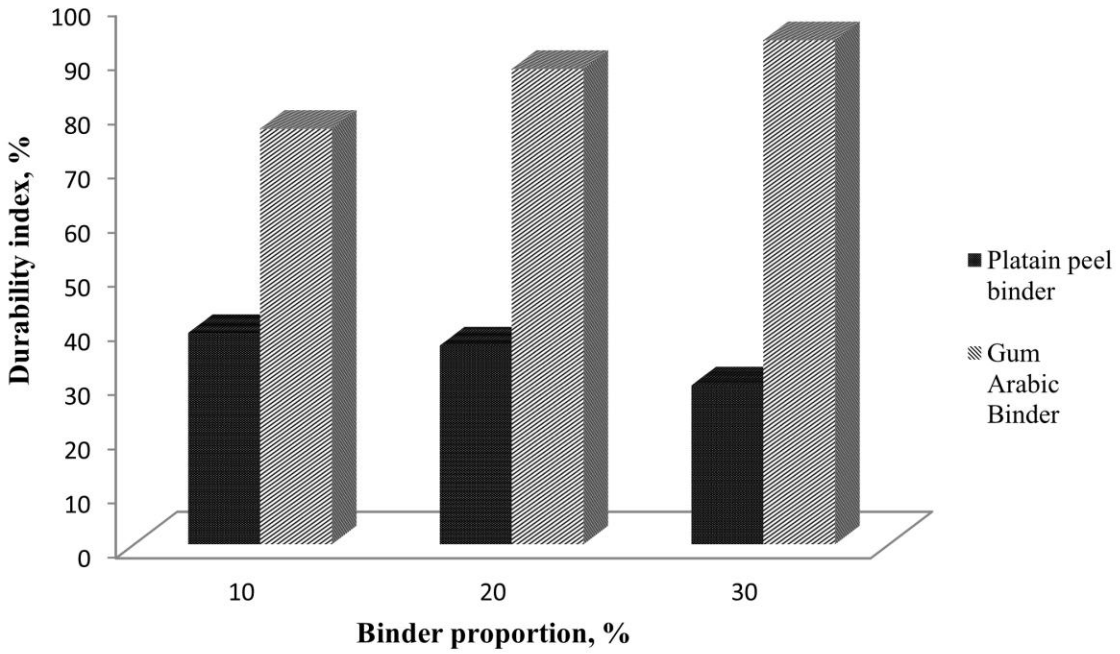

Figure 10 Effect of binder type and ratio on the durability index of briquettes

Singh and Singh (1982) studied the effect of some binders on the durability of briquettes. The study revealed that adding 10%-25% (by weight) of molasses or sodium silicate, or a mixture of 50% molasses and 50% sodium silicate with rice straw produced briquettes with 40%-80% durability at a particle size 0.5 mm and forming a pressure of 29.4 MPa. Conclusions were made from the study that the higher the amount of binder, the higher the briquette durability rating was. In view of this, this present study deferred the rule of thumb in the case of briquettes produced with plantain peel binder. However, increasing the binder ratio had positive effect on the durability index of the briquettes with gum Arabic binder. Davies and Abolude (2013) reported an increase in durability with an increase in the quantity of binder for briquettes produced from water hyacinth with plantain peel as binder at 9 MPa, particle size of 0.5 mm. Onuegbu et al. (2012) reported the durability of spear grass briquette of 90.54% at a pressure of 5 MPa using 25% starch binder.

Therefore, briquettes with gum Arabic binder are very durable. Briquettes at G_{30} had the highest durability index. Also, it shows that the durability of briquettes is dependent of the compressed density.

4 Conclusions

The present work examined the physico-mechanical properties of briquettes produced from rice husk residues using two different binders at different proportions. The following conclusions have been made:

i. Briquettes produces were affected by types and proportions of binders. Good quality and more durable briquettes were produced from rice husk residue when gum Arabic was used as binder than plantain peels.

ii. The relaxed density of briquettes (491.6 kg/m^3 at P_{10}) is higher than that of the residue materials which is 135 kg/m^3. This translated into a huge volume reduction and useful in material storage, packaging and transportation.

iii. Increase in compressive strength was observed with an increase in proportion of binder when gum Arabic was used. However, the reverse was observed when plantain peels was used as binder.

In general, the use of the briquettes produces form the binders would make a good biomass fuels and reduce the use of fuel wood, deforestation and its attendant complications.

Recommendations

The following are recommended:

- More research work on the physical properties, e.g. maximum density, energy ratio, shattering index for rice husk briquette using plantain peel and gum Arabic as binders.
- Briquettes produced using plantain peels as binder demonstrated relatively low mechanical properties. More research could be done to look into improving its mechanical properties.

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