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Briquetting of rattan furniture waste

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Abstract—This paper presents the findings of a study involving experimental production of briquettes from chopped rattan strands mixed with cassava starch paste. Samples of rattan strands of mixed species (*Laccosperma secundiforum* and *Eresmopatha macrocarpa*) were collected from a furniture workshop in Ibadan, Oyo State, Nigeria. The strands, having an average moisture content of 12% and an average dimension of 630 mm (length) by 4.0 mm (width) and 1.8 mm (thickness), were reduced to 25 mm (length) by 4.0 mm (width) and 1.8 mm (thickness) particles by manual shearing. They were subsequently mixed with cassava starch at six proportions by weight, i.e. 50%, 100%, 150%, 200%, 250%, and 300%. It was observed that the minimum proportion by weight of cassava starch required for briquette formation was 200%. Compression experiments were performed using a simple tabletop closed — end die piston press fitted with both a pressure and a dial gauge. Four levels of pressure application: 3.5 N/mm^2, 7.0 N/mm^2, 10 N/mm^2 and 14 N/mm^2, and two loading duration (dwell times), 3 min and 5 min, respectively were employed. Results obtained showed that the minimum pressure required for briquette formation was 14 MPa. The specific energy required to form the rattan strand briquettes at 200%, 250% and 300% cassava starch content levels was 8 J/t, 9.3 J/t and 11.1 J/t, respectively. A reciprocal relationship between binder content and relaxed density was observed. All the expansion (minimal in all cases) of the briquettes took place within 30 min. It was concluded that stable briquettes could be formed from rattan strands mixed with cassava starch paste.

Key words: Rattan strands; cassava starch; briquetting.

INTRODUCTION

Wooden furniture manufacturing is an important economic activity in Southern Nigeria [1, 2]. The industry, largely populated by small-scale operators, has continued to thrive given the abundance of wood raw material in Nigeria, ranging from solid-sawn lumber and wood-based panel products to rattan. The small-scale wooden furniture industry in the country can, therefore, be categorized into two, based on type of wood raw material employed, i.e. solid wood furniture workshops and rattan furniture workshops.

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Rattan is a favourite raw material for furniture in many parts of Nigeria, given the availability of rattan of different species, the simplicity of the furniture production technology and the wide acceptability of rattan furniture products in the country. However, a major problem currently associated with rattan furniture production, particularly in the city-based small-scale workshops, is waste disposal [3].

Waste generation in rattan furniture workshops arise largely from debarking and skinning operations in form of cane strands. These are usually disposed off by on-site incineration. A recent study [3] indicated that, with appropriate pre-processing operations, these furniture wastes can be converted into cement-bonded particleboard products, which can find application as roofing and siding materials in the local building industry.

Table 1.
Problems associated with the supply of the major domestic fuel products in Nigeria

Fuel product	Supply-related problems
Fuel wood	1. Relative non-availability in the semi-arid parts of the country (which have suffered largely from desertification) 2. Dearth of appropriate storage facilities 3. Relatively high cost of transportation 4. Susceptibility to seasonal variations in prices
Charcoal	1. Relative non-availability in the semi-arid parts of the country 2. Susceptibility to seasonal variations in prices 3. Dearth of appropriate storage facilities
Twigs, palm kernels and similar fire starters/sustainers	1. Relative non-availability in the semi-arid parts of the country 2. Susceptibility to seasonal variations in prices 3. Dearth of appropriate storage facilities
Kerosene	1. Erratic supply nationwide 2. Relative non-availability all-year-round in remote villages 3. Relatively more expensive than fuel wood and charcoal
Cooking gas	1. Erratic supply nationwide 2. Relative non-availability all-year-round in remote villages 3. Relatively more expensive than fuel wood, charcoal and kerosene
Electricity	1. Erratic supply nationwide 2. Relative non-availability all-year-round in remote villages 3. Relatively more expensive than fuel wood, charcoal, kerosene and cooking gas

A number of persistent problems have been associated with the supply of traditional domestic fuel products in Nigeria in the last 15 years (Table 1). In finding solutions to these problems, the introduction of biofuels produced from densified wood and agricultural wastes has been advocated by Olorunnisola [4, 5]. Rattan strands, like other wood and agricultural wastes (sawdust, bagasse, straw, etc.), are carbonaceous materials and as such should be amenable to densification (briquetting), with suitable pre-processing and binder application to produce biofuel products. The objective of this work was to test the validity of this hypothesis, i.e. to investigate the briquetting characteristics of rattan strands. In doing this, we sought to determine the extent to which chopped rattan strands mixed with cassava starch as binder could be compacted to form stable briquettes and to identify the factors responsible for the stability.

A BRIEF REVIEW OF LITERATURE ON BRIQUETTING

Briquetting is another term for densification or compaction, i.e. the application of pressure on a material biomass to:

(i) Reduce the bulk, i.e. increase the density of the material, to make transportation easier and cheaper.

(ii) Increase the energy content per unit volume of the material by reducing the moisture content during the compaction process.

(iii) Obtain a homogeneous product, having the same physical characteristics (density, particle size and moisture content) from a highly heterogeneous group of materials.

(iv) Maintain uniform quantity of energy per unit feedstock.

(v) Obtain a highly cohesive fuel product from particulate materials that are otherwise difficult to process.

(vi) Increase resistance to breakdown of particles in shipping, handling and storage [6, 7].

In a typical densification process, a low to moderate pressure (0.20–5.0 MPa) is applied in addition to a binder to compact the loose biomass material. Pressure increases beyond 5.0 MPa cause a collapse of the cell walls (the cellulose constituents of the material) thus approaching the physical or dry mass of the material. The major cementing material that prevents spring back in this type of high-pressure compaction process is lignin, a thermoplastic polymer which is a major component of most plant tissues, or a natural or synthetic binder such as corn starch or cement. At temperatures between 80°C and 200°C, depending on the material being densified, lignin softens and its structure is altered. After cooling, it ensures the binding of the particles compacted [8].

The three groups of variables that govern the formation of briquettes are the die design, the method and duration of load application and material characteristics in terms particle size, moisture content, etc. [9]. While little work has been reported on the parameter of die design, a lot of work has been done on the effects of the other variables. It has been established that while there is a wide range of moisture content at which different materials can be compacted satisfactorily, moisture content in the range of 12–20% is satisfactory for many agricultural crops [8]. Chopping has also been recommended as a useful pre-processing operation for many materials to produce a homogenous sample suitable for compaction [10].

Special systems of densification have been developed over the years. These include:

(i) Densification after fermentation in which case the feedstock is composted so that it can ferment. The fermentation weakens the structure of the lignocellulosic material and makes densification easy.

(ii) Densification after partial pyrolysis which involves partial decomposition of the material by pyrolysis before densification. With this method, only about 18–30% of the pressure required for densification using conventional methods is required.

(iii) Densification after carbonisation, in which case the material is converted to charcoal before being densified. The process requires the use of a binder to hold the charcoal particles together after compaction [8].

There are two basic types of compression processes employed in briquette manufacturing. One is continuous or semi-continuous extrusion process which depends on friction forces acting on the sides of a die to produce pressure for compression. The other type of compression is a closed cylinder process which relies on the use of a suitable external binder for adequate compaction and in which only one briquette is formed at a time. Both the continuous and the closed cylinder types of briquetting machines have been developed and tested in Nigeria in the last 20 years [4, 11, 12].

Densified materials are usually distinguished by size and manufacturing method. Pellets usually have diameters and lengths ranging from 3 to 12 mm and 6 to 25 mm, respectively. Cylindrical briquettes are usually 25 to 100 mm in diameter and 50 to over 100 mm long. The final densities of both products usually range from 0.9 to 1.3 g/cm^3. Their heating values vary, the minimum being about 18.6 Btu [8] (editor's note: 1 Btu = 1055 J).

When talking about the density of briquettes, there is usually a clear distinction between the density of briquettes under compression and after removal from the die. This is because briquette density is usually reduced after removal from the production equipment, as evidenced by an increase in axial length and a minimal expansion along the orthogonal axes [9, 13]. This phenomenon is due primarily to two effects: an immediate elastic recovery of the compacted material, followed by a slow stress-relaxation process with a further reduction in density.

The following terms are usually employed in relation to briquette density: 'initial density', i.e. the density of the material before compression; 'maximum density', i.e. the density of the material in the die at maximum pressure; 'relaxed density', i.e. the final density of the briquette when it has attained its final and stable dimensions; 'compression ratio', i.e. the ratio of the material density in the die at any position in the compression cycle to the initial density, 'density ratio', i.e. the ratio of the relaxed density to the maximum compressed density and 'relaxation ratio', i.e. the reciprocal of the density ratio [13, 14]. As noted by O'Dogherty [13], this relaxed density is 'of practical interest because it is the final result of the compression process and is a determinant of the bulk density of the briquettes formed'.

Many carbonaceous materials, such as charcoal breeze, sawdust and other wood wastes; bagasse, straw, and other agricultural wastes; leaves and other waste vegetable matter; and all coals, ranging from peat to anthracite, are all amenable to briquetting. To minimize air pollution, briquettes can be made smokeless by the choice of suitable binder or by carbonisation to devolitilize them. Briquettes have been and are still widely used as fuel for domestic, commercial and industrial purposes and for gas producers and, when carbonised, as a substitute for coke in metallurgical processes, and as a source of carbon in chemical manufacture in many parts of the world.

Several local agricultural and forestry residues have also been successfully tested as feedstock materials for briquetting in Nigeria. The major ones include sawdust, bean (cowpea) chaffs, corncobs and water hyacinth [5, 15–18]. Cassava starch and palm oil sludge have been reportedly used as binders in these studies. Some efforts have also been made to adapt existing domestic stove configurations and to evolve new stove design configurations for combusting briquettes in the country [5, 19].

MATERIALS AND METHODS

Sample collection and treatment

Samples of rattan strands of mixed species were collected from a furniture workshop in Ibadan, Oyo State, Nigeria. The common species of rattan employed in the workshop were *Laccosperma secundiforum* and *Eresmopatha macrocarpa*. The strands, having an average dimension of 630 mm (length) by 4.0 mm (width) by 1.8 mm (thickness) could not be used 'as is' for briquetting. Therefore, they were reduced to 25 mm (length) by 4.0 mm (width) by 1.8 mm (thickness) particles by shearing manually with the aid of a hand shear and sieving. The average moisture content of the particles was subsequently determined using the standard oven drying method and was found to be 12%. This was an indication that the particles were suitable for use as a feedstock in briquetting.

Binder selection and preparation

Previous studies [5, 18] have shown that cassava starch is an acceptable binder that closely meets the requirements of briquetting in terms of relatively high bonding strength, low cost, in-offensive odour emission, and minimal need for drying. Hence, cassava starch was selected for use in this study. The starch was purchased in a local market in the pre-processed granulated paste and converted to a paste by first dissolving the granules in cold water and then adding hot water at its boiling point of 100°C. The paste was allowed to cool at room temperature before use.

Furnish preparation and compression experiments

Furnish material was made up of a mixture of rattan particles and cassava starch. The three experimental variables were binder content, applied pressure and loading duration, i.e. the period of time for which the maximum pressure is maintained, commonly referred to as 'dwell time' or 'hold time'.

Samples of briquettes were produced by mixing known quantities of rattan particles with measured quantities of cassava starch in small plastic bowls. Six levels of cassava starch content (in terms of weight percentage) were used: 50%, 100%, 150%, 200%, 250% and 300%. A simple tabletop closed-end die piston press fitted with both a pressure and a dial gauge was used for the compression. The diameter of the die was 32 mm while the length was 80 mm. It had a capacity of 32 gram of furnish material.

For each briquette formation process, a die charge of 32 gram, i.e. wet weight of mixture of rattan particles and cassava starch fed into the die, was used. Pressure was applied with the aid of an hydraulic ram to the material in the die and the degree of compression was recorded with the mounted dial gauge at the following levels of pressure application: 3.5 N/mm^2, 7.0 N/mm^2, 10 N/mm^2 and 14 N/mm^2. The dwell time was also varied at 3 minutes and 5 minutes, respectively. The specific energy required to compress the mixture, i.e. energy per unit weight of material on a wet basis (usually expressed either in MegaJoules per tonne or Joules per tonne) was obtained by calculating the total energy from the force-displacement curve during compression and dividing by the die charge.

In order to assess the stability of the briquetted rattan particles, measurements of the length were taken immediately on removal from the die, 30 min after removal and after three weeks of exposure to the atmosphere.

RESULTS AND DISCUSSION

Minimum quantity of cassava starch required for briquette formation

It was impossible to produce any cohesive and stable briquette at a cassava starch content of 50%, 100% and 150% as they all simply fell apart after production. This was an indication that these levels of binder incorporation were insufficient. Hence, subsequent efforts were concentrated on producing briquettes at 200%, 250% and 300% cassava starch contents. Representative samples of the briquettes produced at these three levels of binder incorporation are shown in Fig. 1. Their average weight and basic dimensional properties are shown in Table 2.

Figure 1. Representative samples of the briquettes.

Table 2.
Basic physical features of the stable rattan briquettes.

	Starch incorporation		
	200%	250%	300%
No. of samples	11	11	11
Average dry weight (g)[a]	10	11	13
Average diameter (cm)	35	43	33
Average length (cm)	6.2	6.3	6.3

[a] These values were obtained after sun-drying the briquettes for a period of 3 weeks.

As should be expected, the briquettes produced at 300% level of cassava starch incorporation were generally relatively heavier and bigger than those produced at 200% and 250% cassava starch incorporation levels, respectively. However, the minimum binder proportion required for briquette formation was much higher than the 10% to 50% range reported for sawdust compaction in previous studies [5, 16–18]. This is due to the bigger particle size of the chopped rattan strands ($\cong$25 mm length) as compared to sawdust ($\leqslant$3 mm). Dobie [20] noted that small amounts of binding materials are usually ineffective with relatively long or chopped materials. Mixing the chopped rattan strands with sawdust may, therefore, reduce the binder requirement.

Minimum pressure and dwell time required for briquette formation

No stable briquettes could be produced at a pressure less than 14 N/mm^2 (14 MPa) for the three levels of cassava starch incorporation. Similarly, the minimum dwell time required for briquette formation was 5 min. The minimum pressure required for chopped rattan strands to produce stable briquettes is comparable to those that have been reported in works on straw, sawdust and hay. O’Dogherty [13] reported a pressure range of 11 to 34 MPa for straw briquettes with a relaxed density of between 250 and 300 kg/m^3, while Ajayi and Lawal [17] reported a pressure range of 2 to 21 MPa for sawdust/palm oil sludge briquettes having a relaxed density of between 580 and 860 kg/m^3.

Both the minimum pressure and dwell time required for briquette formation have significant implications for equipment design for rattan-cassava starch briquetting. They are indications of the levels of pressure that would have to be supplied by the equipment and the length of time during which the pressure should be sustained. As observed by O'Dogherty [13] it is of vital importance to know the pressure and dwell time required for producing a briquette of specified final (relaxed) density as these factors affect decision making about machine design parameters.

Specific energy required to form briquettes

The estimated values of the specific energy required to form the rattan strand briquettes were 8 J/t, 9.3 J/t and 11.1 J/t for briquettes produced at 200%, 250% and 300% cassava starch content levels, respectively. These values are much smaller than those reported in other works for high-pressure compaction (without binder application) of other materials especially straw for which values ranging from 5 MJ/t to 26 MJ/t were reported [9, 13, 14]. As noted by O'Dogherty [13], specific energy requirement for compressing materials in closed dies with parallel sides (as was used in this experiment) is usually much smaller than for extrusion through tapered dies.

The reciprocal relationship observed between binder content and specific energy requirement should be expected. This is because the more the binder, the more cohesive the material under compression and the less the frictional force within the particles that can resist lateral strain of the material.

Effect of binder quantity on briquette density

The average values for compressed and relaxation density for the stable briquettes produced at 200%, 250% and 300% cassava starch content levels are shown in Fig. 2. A minimal decrease in the average compression density was observed with

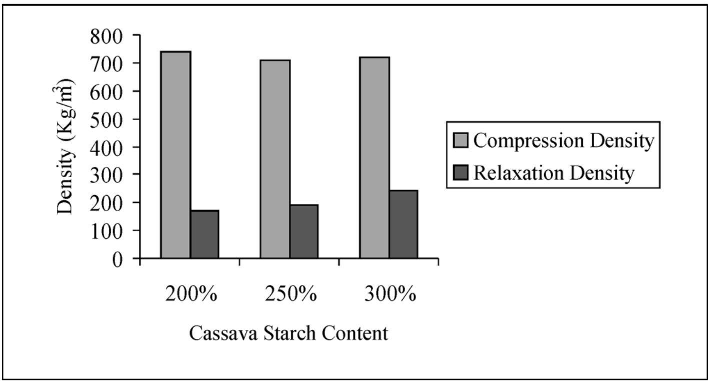

Figure 2. Compressed and relaxation densities of the rattan briquettes.

increase in binder content. For example, the compressed density at 300% cassava starch content (720 kg/m^3) was about 3% lower than the compression density at 200% cassava starch content (740 kg/m^3). However, a reciprocal trend was observed in relaxed density values, with higher cassava starch contents resulting in higher relaxed density values. This is expectedly so because a higher binder content is supposed to increase the material content of the briquette by enhancing the degree of compaction achievable. A similar trend was reported [17] for briquettes produced from sawdust blended with palm oil sludge.

Effect of binder quantity on briquette stability

Figure 3 shows the trends observed in the elongation of the three categories of briquettes produced at various time intervals, while Fig. 4 shows a comparison between the compressed and relaxed length of the briquettes. There was a direct relationship between binder quantity and briquette stability in terms of elongation after removal from the press. Briquettes produced at 250% binder content exhibited the highest elongation in length (1.0 cm), representing about 20% elongation, while those produced at 300% binder content exhibited the least elongation (0.4 cm, representing about 6.8% elongation). This is expectedly so because the higher binder content was able to restrain the expansion of the compressed material.

It was also noted that while the briquettes produced at 300% binder content achieved stability within 15 min of removal from the press, those produced at 200% and 250% binder contents respectively achieved same after about 30 min. These observations are in agreement with the observations of Osobov [21] and O'Dogherty [13] that nearly all the expansion of briquettes takes place within 30 min.

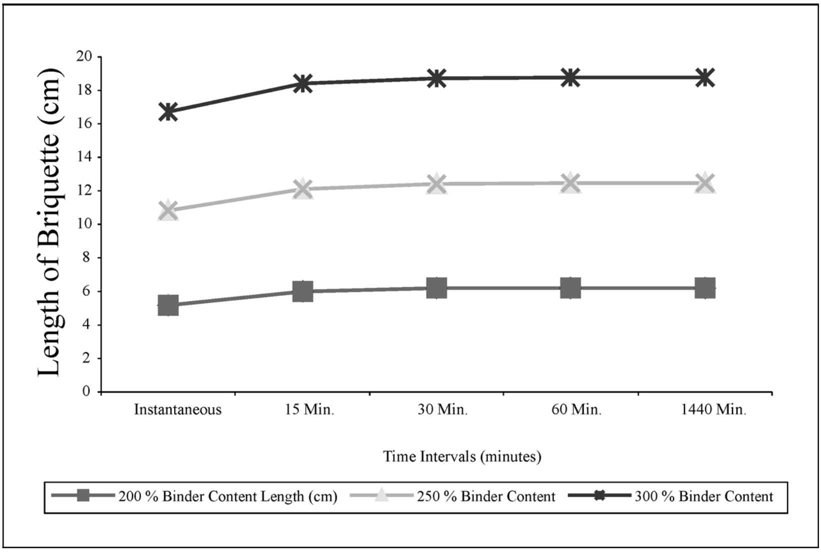

Figure 3. Trends in briquette elongation with time.

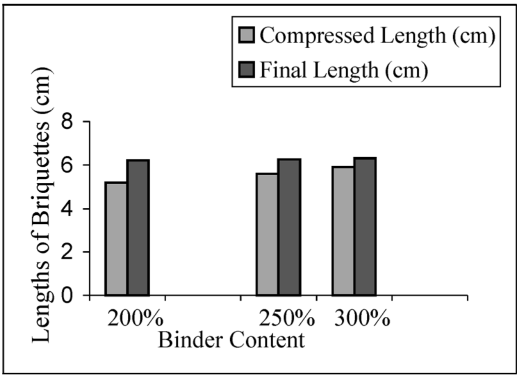

Figure 4. Compressed and final lengths of briquettes.

CONCLUSIONS

The briquetting characteristics of rattan strands mixed with cassava starch paste were examined. It was observed that the minimum proportion by weight of cassava starch required for briquette formation was 250%. The minimum pressure required for briquette formation was 14 MPa. The estimated values of the specific energy required to form the rattan strand briquettes at 200%, 250% and 300% cassava starch content levels respectively were 8 J/t, 9.3 J/t and 11.1 J/t. A reciprocal trend was observed in relaxed density values. All the expansion of the briquettes took place within 30 min. It was concluded that stable briquettes could be formed from rattan strands mixed with cassava starch paste.

Areas of further research studies being suggested include an evaluation of the durability of rattan briquettes; investigating the efficacy of other types of binders in forming rattan briquettes; and exploring the possibility of mixing rattan with other agricultural/wood residues (e.g. ground corncobs, sawdust, etc.) prior to briquette formation.

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