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Suitability of Baobab Flour as a Binder and Comparative Study of Its Binding Potential with Some Locally Available Binders in Sawdust Briquetting

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Abstract

The suitability of baobab flour as a binder and comparative studies of its binding potential with some locally available binders in sawdust briquetting were carried out. The other binders studied were cassava starch and cow dung. Out of the three binders, the Baobab flour is the non-common binder which is being introduced to determine its suitability as a binder in sawdust briquetting and to compare it with the others. Nine different saw dust briquette samples were produced, samples A-I with different binder compositions. Samples A, B, and C contained only cassava starch, cow dung and Baobab flour as binder respectively while the other samples D-I contained blend of the binders at different formulations as presented in Table 1. All the binders used were found to have good binding potential for briquette production and can be used alone or as a blend in proportion with the other binders. However, Briquette sample C with pure baobab flour binder: (0% cassava starch; 0% cow dung and 30% Baobab flour) has the highest calorific value of 22.0 MJ/kg and the highest thermal efficiency of 35.48%. The briquette sample F with binder blend formulation of: (4.5%% cassava starch; 4.5% cow dung and 21% Baobab flour) on the average showed the optimal briquette qualities (Moisture content, ash content, shatter index, compressive strength, calorific value and thermal efficiency) being tested.

Keywords: *Saw dust, Briquettes, moisture content, ash content, shatter index, compressible strength, calorific value, thermal efficiency*

Introduction

The growing worldwide concern regarding the environmental impacts of the use of fossil fuels particularly causing climate changes coupled with the volatile fossil fuel market has necessitated the need for alternative energy supply to sustain economic development. In the recent years, researches on energy have been focused on renewable energy as alternative and sustainable energy sources to fossil fuels. Biomass is one of the most common and easily accessible renewable energy sources and represents a great opportunity as a feedstock for bioenergy (Merete, 2014). Biomass has historically been a cheap and accessible source of fuel in developing countries (Kamese *et al*., 2004). Biomass energy sources consist of any organic material that can be used as fuel and energy from biomass accounts for 15% of global energy consumption (Arvelakis and Koukios, 2002).

A wide range of biomass from crop residues (corn Stover, rice husk, groundnut shells etc.), wood wastes from forestry and industry, residues from food and paper industries, municipal solid wastes (MSW) and dedicated energy crops such as short rotation perennials can be utilized to generate electricity, heat, combined heat and power, and other forms of bioenergy (Atta *et al.*, 2016).

Huge quantities of agro-residues are produced by many of the developing countries but they are used inefficiently causing extensive pollution to the environment. The major residues are rice-husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Saw dust; a milling residue is also available in huge quantity (Oladeji, 2010). Problems associated with these residues are their transportation, storage and handling. The direct burning of loose agro-residues in conventional grates is associated with very low thermal efficiency and widespread air pollution. In addition, a large percentage of unburned carbonaceous ash has to be disposed (Lubwama and Yiga, 2017).

Briquetting is converting the low bulk density agro-residues into high density and energy concentrated fuel briquettes. Briquettes are in fact good substitute of coal/wood in industrial boiler and brick kiln for thermal applications. These briquettes are non-conventional source of energy, renewable in nature, eco-friendly, and non-polluting and economical. Briquettes have high calorific value compared to fire-wood or loose agro-residues. Briquettes give much higher boiler efficiencies (Makumbi, 2008).

Transforming biomass waste into a source of energy is a very important method of pollution control. It is a form of resource augmentation which has emerged a major issue in both developed and developing countries. Deforestation and rising oil prices have been a major challenge for the growing energy needs in developing countries. The development of renewable energy sources in the subtropical regions has the potential to decrease the dependence on increasingly scarce energy sources and contribute to the protection of vital ecosystems. Renewable energy offers possibilities to both reduce poverty and to allow sustainable development (Rahaman and Salam, 2017).

Many studies have been reported related to the chemistry behind the bonding of biomass particles. The understanding of binding of saw dust particles requires knowledge of the uniqueness of the wood structure for bond formation. The main components of the wood are the cellulose, hemi-celluloses and lignin. Further, main types of natural binding agents of biomass particles are lignin, protein and starch (Kaliyan and Morey, 2010). The softening temperature of the lignin heavily depends on the moisture content of the raw material. It is around 90~100 oC at 30% moisture (wet basis) and around 130 oC at 10% (wet basis) moisture. So, Lignin is not softened at the ambient temperature. Likewise, protein acts as a binder in plasticized state which needs processing at high temperature too. Therefore, in ambient temperature processing, binding agents need to be supplied externally. These binding agents can be made of different materials. The waste materials or readily available materials are the best option for this type of applications for economic feasibility (Adetunji *et al.*, 2015). In Nigeria, cow dung, cassava starch and Baobab flour are found to be possible materials (Emerhi, 2011).

In this work, a briquette mould and a press machine were used to produce the briquettes of saw dust using the different binders. The utilization of waste sawdust that could accumulate and cause environmental pollution into briquette production so as to provide alternative, renewable and sustainable sources of energy (fuel) to fossil fuels and firewood particularly in the rural areas of the country is of a huge economic significance. The main aim is to examine the suitability of baobab flour as a binder and to compare its binding potential with some locally available binders in sawdust briquetting.

Materials and Methods:

Materials

The materials used in this research include; Sawdust, Gum Arabic, Cassava Starch and Baobab fruit powder. The sawdust was purchased from Panteka wood mill in Tundun Wada. The Cassava Starch, Baobab and the Gum Arabic were purchased from Katin Kwari, Bakin dogo and Kasuwan Barchi Market in Kaduna respectively

Methods

Material Preparation

The sawdust was pre-treated by removing unwanted particles and ground to obtain smaller particle sizes. Sieving was then carried out to obtain the required particle sizes. The binders were also prepared for the binding purpose in the briquetting process.

The cylindrical mould used for the briquetting was constructed by using steel metal with the internal and external diameter of 35cm and 30cm respectively and 15cm long as shown in figure 1.

Figure 1: The constructed Briquette mould (Length=15 cm ID=30 cm, OD= 35 cm)

Preparation of sawdust and binders for briquetting process

The sawdust used for the production of the different briquette samples was ground and sieved to obtain particle sizes range of 0.15-1.5 mm. The presence of different size of particles improves the packing dynamics and also contributes to high static strength. Also all the three types of binders used for this work were prepared by removing all unwanted particles and impurities. The cassava starch binder which was in a powdered form was gelatinized by using boiled water to mix the starch powder. The binders were measured to prepare nine briquette samples (Sample: A-I) according to the formulations presented in table 1. An equal volume of distilled water and fixed mass of sawdust were used for preparing all the samples. The sawdust, distilled water and the binder were mixed together thoroughly and ready for moulding to form the briquettes.

Briquette production

The thoroughly mixed sawdust samples with water and binders were then introduced into the mould and compacted. The muold was then taken for further compression using the Peterson press (Figure 2). It is relatively simple equipment having hydraulic jack and the frame. Cyclic pressure is applied on the mould with a lever of the hydraulic jack (Max. 1500kg) until required compaction is obtained. After the compaction, the mould is removed from the press and loosed to remove the briquette. The produced briquettes were then oven dried for 24 hours at temperature of 1050C. The procedure was repeated to produce all the nine (9) Samples.

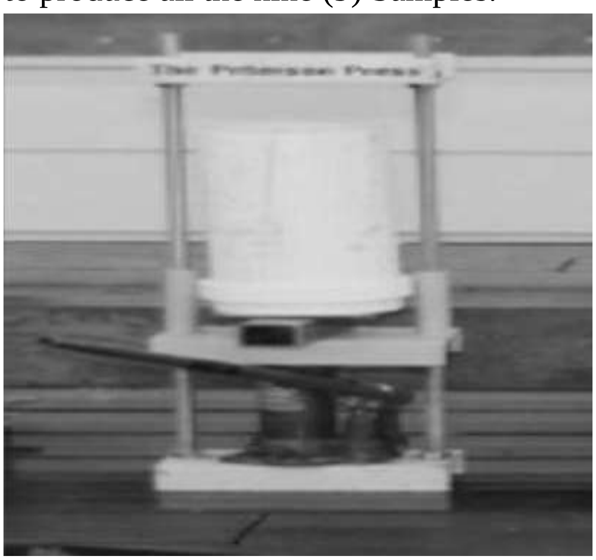

Figure 2: Peterson press

The moisture content of the ground material before and after compaction was determined using methods involving the use of oven drying. The initial weight of the sample was determined (W1), and placed in an oven set at 103 ºC for 24hours. The samples was removed and cooled in a dessicator, reweighed (W2). Moisture content of the sample was calculated by taking the percentage of the ratio of (W1-W2) and W1 (ASTM, 2012).

The ash content was determined by the method of heating the test sample to a constant temperature within a specific time interval. 10g of the briquette sample was heated in the furnace at a temperature of 550 ºC for 4hrs and the ash residue was weighed after cooling. The resulting mass of ash residue was used to calculate the percentage ash content.

To determine the shatter index, the briquette samples were dropped three times from a height of 2.0 m onto a metal base, then the percentage Impact Strength Index was calculated using the weight of the disintegrated Briquette and the original weight. The minimum impact strength index should be at least 90%.

Compression strength test machine was used to determine the compressive strength of the briquette and it was carried out to measure the maximum amount of compressive load a sawdust briquette can bear before fracturing. The briquette was compressed between the plates of a compression-testing machine by a gradually applied load until its structure failed. The lower compressive strength value should be above 1.0 MPa (Sengar *et al.*, 2010).

Table 1: Different binder formulations used in the briquette production

Briquette Sample	Distilled Water (ml)	Sawdust (g)	Cassava Starch Powder (%)	Cow dung (%)	Baobab flour (%)
A	**200**	**500**	**30.00**	**0.00**	**0.00**
B	**200**	**500**	**0.00**	**30.00**	**0.00**
C	**200**	**500**	**0.00**	**0.00**	**30.00**
D	**200**	**500**	**21.00**	**4.50**	**4.50**
E	**200**	**500**	**4.50**	**21.00**	**4.50**
F	**200**	**500**	**4.50**	**4.50**	**21.00**
G	**200**	**500**	**0.00**	**21.00**	**9.00**
H	**200**	**500**	**21.00**	**9.00**	**0.00**
I	**200**	**500**	**9.00**	**0.00**	**21.00**

The calorific value of the test briquettes was determined by employing the calorimetric method. This involves ascertaining the heat of combustion of the test sample at a constant volume of bomb calorimeter, and is calibrated via the standard test combustion of benzoic acid. The calculation is based on the indicated heat of combustion decreased by heat of vaporization of the water separated out during the fuel combustion (ASTM, 2012).

Thermal Efficiency Test

One hundred liters of water was placed in a steel vessel. The vessel was properly sealed to minimize losses by evaporation and placed on a biomass stove. A thermometer was used to monitor the temperature of the vessel. An amount of 5.0 kg of the briquettes was measured and separated into 4 parts for testing. The ambient temperature of water in the pot was taken and then the briquettes were ignited. The final temperature of water after boiling was measured. The water was heated until evaporation and the briquette completely exhausted. The lid was removed and evaporation continued for 20 min. The vessel was removed from the stove and allowed to cool for 2 h. The final volume of water was measured. The time between T0 and Tb was measured using a stopwatch. This procedure was similar to that used by (Panwar and Rathore, 2008).The thermal fuel efficiency was evaluated as follows:

$$TE = \frac{M_w C_p (T_b - T_0)}{M_f E_f} \times 100\% \qquad (1)$$

Where Mw = mass of water (kg), Cp = specific heat of water (kJ/kg K); Tb = boiling temperature of water (K); T0 = initial temperature of water (K); Mc = mass of water evaporated (kg); L = latent heat of evaporation (kcal/kg); Mf = mass of fuel burnt (kg); Ef = calorific value of fuel (kJ/kg).

Results and Discussion

The results of the analyses of the produced sawdust briquette samples produced showing the physical and mechanical properties of the briquettes are presented in Tables 2.

Table 2: Properties of the produced Sawdust Briquette samples

Briquette Sample	Moisture Content (%)	Percentage Ash content (%)	Shatter Index (%)	Compressive strength (MPa)	Calorific Value (MJ/kg)	Thermal Efficiency (%)
A (30:0:0)	**30.51**	**4.35**	**32.20**	**25.51**	**20.15**	**29.70**
B (0:30:0)	**30.74**	**4.80**	**20.50**	**20.41**	**21.70**	**26.84**
C (0:0:30)	**31.55**	**5.15**	**28.80**	**23.47**	**22.00**	**35.48**

D (21:4.5:4.5)	30.20	4.10	29.50	23.51	19.80	30.12
E(4.5:21:4.5)	30.85	4.65	22.05	21.00	20.45	32.65
F(4.5:4.5:21)	31.65	5.20	33.00	24.07	21.40	34.69
G (0:21:9)	30.95	4.90	22.30	21.56	19.80	31.61
H (21:9:0)	30.45	4.30	28.62	23.68	18.90	27.39
I (9:0:21)	31.35	5.05	35.81	26.53	20.45	33.85

From the results shown in table 2, the percentage ash content (PAC) of all the briquette samples A-I falls within the normal acceptable range of 4% to 10%, where briquette sample F with binder content of (4.5% cassava starch; 4.5% cow dung and 21% Baobab flour) has the highest PAC of 5.20% while the briquette sample D with binder content of (21% cassava starch; 4.5% cow dung and 4.5% Baobab flour) has the lowest PAC of 4.10%. PAC of the briquette depends on the fixed carbon content and the percentage moisture content (PMC) (Andrijko and Grochowicz, 2007). From the results, it can be observed that as the PMC of the briquette increases, the PAC also increases clearly represented in figure 1. Daham *et al.*, (2015) also reported that higher PMC also decreases the heating value of briquette because a portion of the combustion heat is used to evaporate the moisture in the biomass which is not condensed to return the heat back to the system.

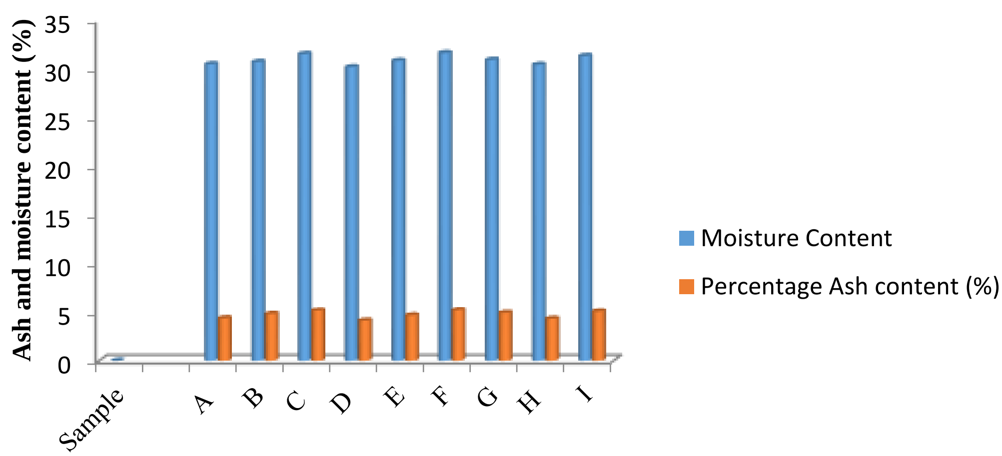

Fig. 1: Ash and moisture contents (%)

The Shatter index and the compressive strength test are a measure of the briquette strength. A high shatter index and compressive strength are necessary to avoid damages from handling. The contribution of different binding agents and percentage blends of the binders for the strength and durability of the briquettes as the function of shatter index and compressibility strength are also shown in the results presented.

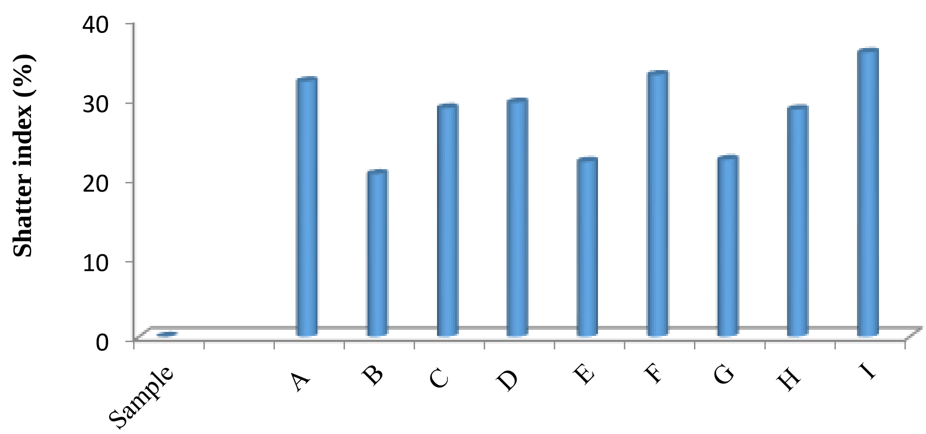

Fig. 2: Shatter index of the produced Briquettes (%)

The shatter index and compressive strength the produced briquette samples are shown in Fig. 2 and Fig. 3 respectively. Higher values of the Shatter index and the compressive strength of a briquette make it stronger and tougher. According to the report of Emerhi (2011), the strength and the toughness of a briquette are a function of the type and the percentage of binder used in its production. The aim of this work is to determine the suitability of the different binders used in at different percentage composition in the production of high quality briquette from sawdust. From the results, the briquette sample I with binder content of (9% cassava starch; 0% cow dung and 21% Baobab flour) has the highest shatter index of 35.81% and compressive strength of 26.53 MPa while the briquette sample B with binder content of (0% cassava starch; 30% cow dung and 0% Baobab flour) recorded the lowest shatter index of 20.50% and compressive strength of 20.41 MPa. The results show that the cassava starch binder has the highest binding effect on the sawdust briquette followed by the Baobab flour with cow dung having the least. Since the binding effect of a binder determines the durability of a briquette, Rajaseenivasan *et al.* (2016) reported that high durability index is required to prevent briquettes from damage as a result to exposure to vibrations, rain or high humidity conditions during transportation.

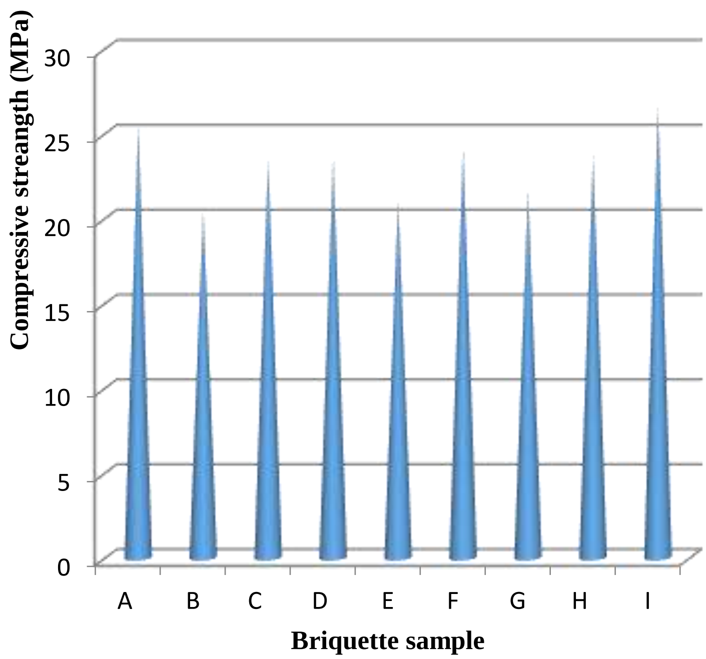

Fig. 3: Compressive strength of produced Briquettes (MPa)

The calorific value determines the amount of heat energy present in a material. From Table 2, briquette sample C with binder content of (0% cassava starch; 0% cow dung and 30% Baobab flour) has the highest calorific value of 22.0 MJ/kg, which is probably due to the high carbon content and the presence of high baobab flour binder in its formulation. Briquette sample H with binder content of (21% cassava starch; 9% cow dung and 0% Baobab flour) recorded the lowest calorific value of 18.9 MJ/kg, and this perhaps could be due to the low carbon content in the percentage cassava starch and cow dung binders present in its formulation. The calorific properties of the briquettes produced varied with the binder type and the blend of the binders with different formulations and it can be seen from Fig. 4 that the its value in each of the briquette sample depends on the percentage carbon content of the binder formation used to produce the briquette.

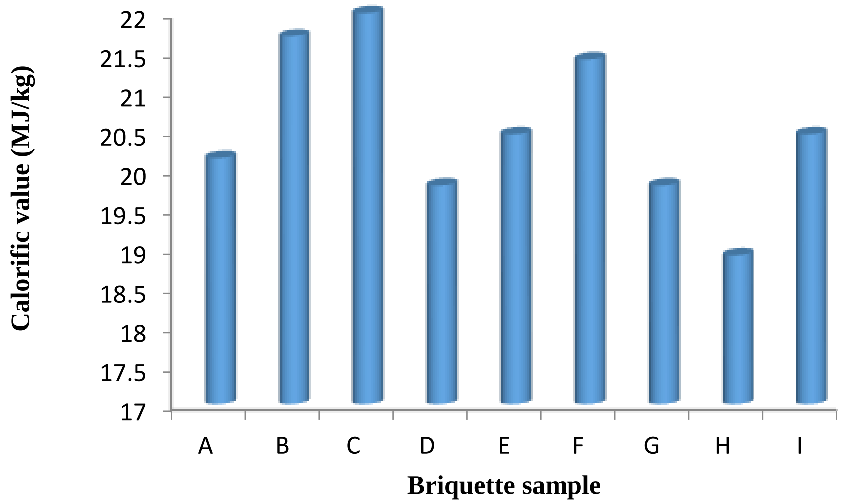

Fig. 4: Briquette Calorific Value of the produced Brriquettes (MJ/kg)

The thermal efficiency (TE) indicates the amount of the energy present in the briquette that is being converted into thermal (heat) energy. The briquette sample C with pure Baobab flour binder has the maximum thermal efficiency obtained as 35.48% while the minimum TE recorded was 26.84% for briquette sample B with pure Cow dung binder as shown in Table 2. The thermal efficiency was observed to be a function of the calorific value of the briquette sample which in turn determines the water boiling rate using the briquette as combustion fuel. Imeh *et al.* (2017) also reported that higher thermal efficiency of a briquette the lowers the burning rate. This research findings shows from the results obtained that all the three binders used for the sawdust briquetting in this work (cassava starch, cow dung and baobab flour) are found to be suitable and can be used as a single binder or as a blend binder formulation to produce good and durable sawdust briquette. The baobab flour is a newly introduced binder in this research which was found to possess good binding property for sawdust briquette processing. From the results, looking at all the parameters investigated, on the average the formulation for briquette sample F with binder content of (4.5%% cassava starch; 4.5% cow dung and 21% Baobab flour) has the optimal briquette quality.

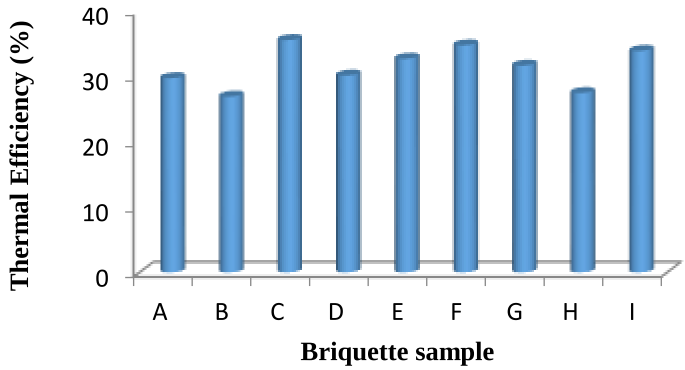

Fig. 5: Briquette Thermal Efficiency of the produced Briquettes (%)

CONCLUSIONS

The baobab flour was introduced as a binder in sawdust briquetting and its binding potential was compared to that of cassava starch and cow dung. From the findings of the research, the following conclusions are drawn:

1. The baobab flour was also found to be a suitable binder in sawdust briquetting and compete favorably with cassava starch and cow dung.
2. Briquette sample C with pure baobab flour binder: (0% cassava starch; 0% cow dung and 30% Baobab flour) has the highest calorific value of 22.0 MJ/kg and the highest thermal efficiency of 35.48%.
3. The blends of the binders at different formulation also proffer some improved briquette qualities.
4. The briquette sample F with binder blend formulation of: (4.5%% cassava starch; 4.5% cow dung and 21% Baobab flour) on the average has the optimal briquette qualities (Moisture content, ash content, shatter index, compressive strength, calorific value and thermal efficiency) being tested.

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