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Briquettes from bamboo wastes blended with lignocellulosic biomass

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Abstract
This paper presents the potential of bamboo wastes *viz.*, bamboo stalks, sheaths and leaves as a feedstock for high-energy content briquette production. The calorific value of bamboo stalks, sheaths and leaves was found as 4660, 4100 and 3680 kCal/kg respectively. The volatile content of bamboo wastes was found in the range of 72.5 to 79%. Bamboo wastes were briquetted with sawdust and their properties were studied to determine the best blend of bamboo wastes and sawdust. Bamboo wastes blended with sawdust in a 50:50 ratio yielded good quality briquettes with a bulk density of 705 kg/m^3 and a calorific value of 4372 kCal/kg. The volatile, fixed carbon and ash content of the optimized briquettes were 77.05, 20.23 and 2.72% respectively. The impact resistance and compressive strength of optimized briquettes were found to be 95.43% and 7.2 kN respectively. These briquettes can be used as a replacement for wood or coal in boilers, furnaces and gasifiers in industries.

Keywords: Activation, briquette, calorific value, combustion, durability

1. Introduction
Bamboo is a perennial evergreen plant species of the Gramineae grass family, distributed mainly in tropical and subtropical areas and their growth harmonizes with the principles of sustainability due to their fast growth and annual stalk production. Many Asian species of bamboo have strong, light and flexible woody stems, which lend themselves to applications as a construction material, paper production, fishing tools, handicrafts, musical instruments, furniture, scaffolding poles etc. (Vatsala 2003) [14]. Presently, the demand for bamboo in India is around 26 million metric tonnes. In order to meet this demand, the Indian government launched the "National Bamboo Mission" under the Ministry of Agriculture for expanding the bamboo industry (Improvement 2018) [7]. In their natural form, fallen sheath and leaves from bamboo are often inefficient fuel because it is bulky and dispersed. Density can be increased by compacting the loose residues by adopting proper densification technologies.

2. Materials and Methods
Beema bamboo is the highest biomass yielding bamboo species in India. Bamboo stalk, bamboo sheath, bamboo leaves and saw dust were selected to study the characteristics of bamboo, bamboo residues and selected lignocellulosic biomass to assess the suitability for densification process.

2.1 Characterization
Moisture content (ASTM D 3173-87) of the bamboo residues was determined by heating the sample in a hot air oven at 103 ± 2 °C up to the arrival of constant weight. The volatile content (ASTM D 3175-89) was found out by heating the sample at 650 °C for 10 min in an oxygen depleted environment. Ash content (ASTM D 3174-89) was determined by heating the sample at 750 °C for 3 h. Fixed carbon was the content that remains after complete volatilization. High Heating value of the sample was tested in a bomb calorimeter (Adithya make, India). The major constituents (cellulose, hemicellulose, lignin) of sample were determined as per AOAC standards. Thermo gravimetric analysis (TGA Q50) was carried out for the bamboo residues at a heating rate of 40 °C min^{-1}. A representative sample from each group was chosen for this analysis. N_2 was used as the purge gas with a flow rate of 60 ml min^{-1}.

2.2 Production of briquettes
The densification process involves four steps *viz.*, collection of raw materials, preparation of raw materials, compaction and cooling and storage.

The preparation of raw materials comprises drying, shredding, mixing of various residues in right amount to yield high calorific value, addition of binder etc. Permissible moisture content of agricultural residues for densification is less than 15%. The drying process is evicted, due to bamboo waste consists of moisture content less than 15%, The bamboo residues were size reduced by shredding yield

5 to 10 mm particle size. It is desirable to make briquettes with more than one raw material to get product of good compaction, higher calorific value and less ash content.

The briquettes were produced using a commercially viable binder less piston press briquetting method. In piston press technique, pressure is applied intermittently on the residues packed inside the cylinder using a piston energized by a flywheel. The piston of the press reciprocates and compresses the residues supplied from the feed hopper. The residues are taken into the conical die, compressed by the piston, and the briquetted part is extruded through the die opening. During compression process the residue material is heated to around 150 °C to 300 °C due to friction (Vijayakumary *et al.* 2023) [15]. Bamboo residues (sheath and leaves) and saw dust were used in different combinations with each other (50:50; 75:25 and 100:0) for making briquettes.

2.3 Briquette characterization

The density of the briquettes was determined by the weighed sample occupied in a known volume (Bala, 1997) [2]. Heating value of the sample was tested in a bomb calorimeter. The ashes of briquettes were made to cone and kept in muffle furnace and fusion and deformation temperature was checked. Durability of the briquette was tested by finding the impact resistance (or drop resistance or shattering resistance) test by dropping briquettes from 1.85 m height onto a concrete surface 4 times. The weight retained as the percentage of the initial weight was taken as the briquette durability. The water resistance was assessed from the percentage of water absorbed by a briquette when immersed in water. Each briquette was immersed in water for 5, 10, 15 and 20 min and based on withholding capacity in water, it is termed as poor (5 min), fair (10 min), good (15 min) and excellent (20 min) quality. Universal Testing Machine (UTM) UNITEK-9410 is used to find out compressive strength of briquettes.

3. Results and Discussion

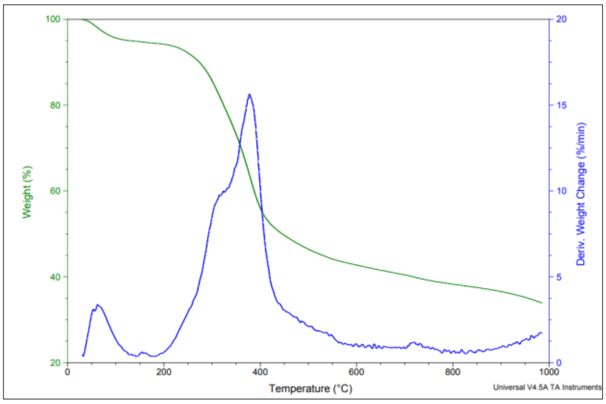
3.1 Characteristics of bamboo residues

Proximate analysis include moisture content, fixed carbon content, volatile matter content and the ash content. The moisture (MC), volatile matter (VM), ash and fixed carbon (FC) content of bamboo wastes were found in the range of 9.5 to 10.5%, 72.5 to 79%, 1.92 to 6.45% and 14.55 to 24.7%, respectively. Niedziółka *et al.* (2015) [12] point out that the biomass subjected to the compaction process must have a moisture content between 5% and 15%, since this range results in a dense, stable and durable product. The cellulose (C), hemicellulose (HC) and lignin content of bamboo wastes were found to be in the range of 36.2 to 42.3%, 24.1 to 34.02% and 25.2 to 27.15%. The saw dust consists of 12.5% moisture content, 77.4% volatile matter, 2.2% ash content and 20.4% fixed carbon content. The cellulose (C), hemicellulose (HC) and lignin content of sawdust were 36.8, 26.1 and 35.4% respectively. The high heating value (HHV) of bamboo stalks, bamboo sheaths, bamboo leaves and sawdust were found as 4660, 4100, 3680 and 4250 kCal/kg respectively. The high heating value confirms that it contains low inert and non-combustible fraction (Furtado *et al.* 2010) [4].

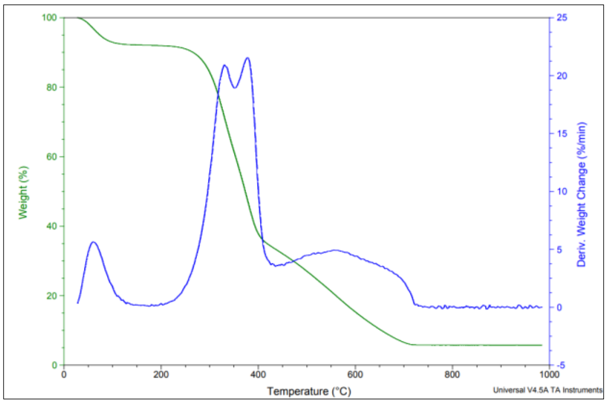
Table 1: Characterization of biomass samples

Biomass	MC (%)	VM (%)	Ash (%)	FC (%)	C (%)	HC (%)	Lignin (%)	HHV (kCal/kg)
Bamboo stalks	9.65	75.3	1.92	22.78	42.3	24.1	26.8	4660
Bamboo sheath	10.5	72.5	2.8	24.7	39.0	29.5	25.2	4100
Bamboo leaves	9.5	79.0	6.45	14.55	36.2	34.02	27.15	3680
Saw dust	12.5	77.4	2.2	20.4	36.8	26.1	35.4	4250

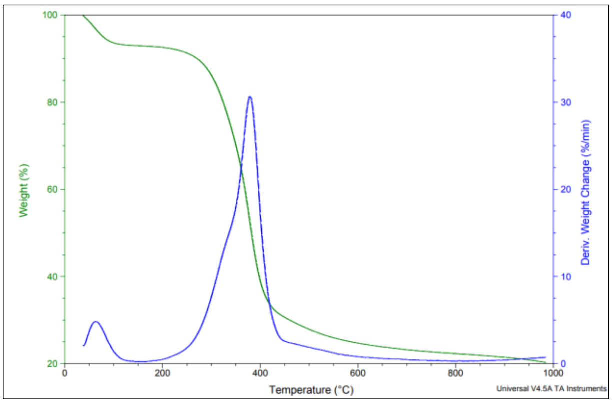
Fig. 1 represents the TGA graph of selected biomass. Highly volatile matter is the material that burns off in nitrogen between ambient and 150 °C. Medium volatile matter is the material that burns off in nitrogen between 150 °C and 700 °C. Combustible matter is the material that burns off in air but not in nitrogen at 700°C. Ash content is the material left at 900 °C in air. The sample size is small so the measurements can vary a lot for samples that are not uniform on a microscopic basis (Josea *et al.* 2010). The graph indicates that these samples are suitable for thermochemical conversion to harness energy.



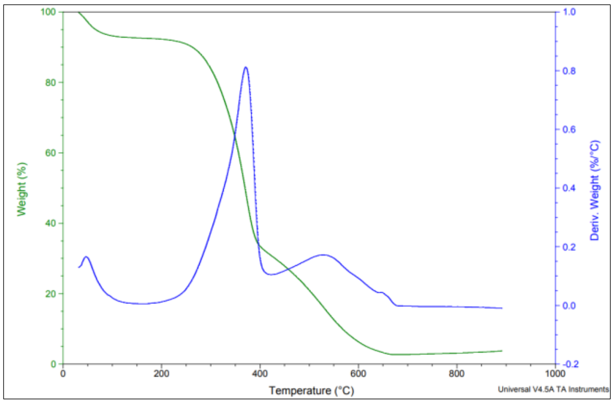
Bamboo leaves



Bamboo sheath



Bamboo stalks



Saw dust

Fig 1: TGA of selected biomass

3.2. Production of briquettes

The bamboo residues were collected from TNAU field and shredded. The shredded bamboo residues mixed with saw dust at different combinations were used to produce briquette from piston press briquetting machine. The briquette production process is illustrated in the Fig.2.


Collection


Shredding


Briquetting


50 BR: 50 SD


75 BR: 25 SD


100 BR

Bamboo briquettes

Fig 2: Production process of briquettes

3.3 Characterization of briquettes
Bamboo wastes were briquetted with sawdust and their properties were studied to determine the best blend of bamboo wastes and sawdust. Bamboo wastes blended with saw dust in 50:50 ratio yielded good quality briquettes with a bulk density of 705 kg/m^3 and calorific value of 4372 kCal/kg. The volatile, fixed carbon and ash content of the optimized briquettes were 77.05, 20.23 and 2.72% respectively. The durability of optimized briquettes was found to be 95.43% as the standard requirement of durability of briquette was 85% (Feng *et al.* 2020) [3]. The optimized briquette took more compression load to break with ultimate load value 7.2 kN.
It confirmed the ability of briquettes to withstand destructive forces during handling, storage, and transportation. The properties of produced briquettes confirms that briquette can be used as combustion and gasification feedstock (Gitanjali, Venkatachalam, and Subramanian 2014; Gitanjali *et al.* 2015; Ramjani *et al.* 2020) [5, 6, 13].

Table 2: Characterization of briquettes

Sample (Bamboo residues: Sawdust)	Bulk density (kg/m^3)	HHV (kCal/kg)	Durability	Water resistance	Compressive strength (kN)
50: 50	705	4372	95.43	Excellent	7.2
75:25	690	4278	92.57	Good	6.3
100:0	678	3949	84.61	Fair	4.8

4. Conclusion
Bamboo is significantly more productive than many other candidate bioenergy crops. Heating value of bamboo residues is lower than woody biomass. Bamboo wastes were briquetted with sawdust and their properties were studied to determine the best blend of bamboo wastes and sawdust. Bamboo wastes blended with saw dust in 50:50 ratio yielded good quality briquettes with a bulk density of 705 kg/m^3 and calorific value of 4372 kCal/kg. The volatile, fixed carbon and ash content of the optimized briquettes were 77.05, 20.23 and 2.72% respectively. The impact resistance of optimized briquettes were found to be 95.43%.
The optimized briquette took more compression load to break with ultimate load value 7.2 kN. Briquettes produced from bamboo residues blended with saw dust has the combustion rate comparable that of coal and hence can be used in residential, commercial, and industrial heating systems. These briquettes may be gasified to producer gas which could find application in thermal and electric power generation.

5. Acknowledgement
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