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RESEARCH ARTICLE

Enhancement of the mechanical properties of sawdust briquette using mung beans waste

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Abstract: This research was undertaken to enhance the efficiency of sawdust briquette using mung beans waste. Mung beans waste (MB) was blended with sawdust briquette to investigate the effect on the mechanical properties (hardness, porosity index, durability, compressive strength, bulk density and mass). Prior to the blending of the sawdust and mung beans waste, proximate analyses (moisture content, fixed carbon, ash content, volatile matter content and calorific value) were carried out on the mung beans waste and the sawdust to ascertain their suitability for biofuel production. The analyses were carried out using standard methods. The briquettes were produced at different sawdust to biomass ratios (100%:0%, 70%: 30%, 50%:50%, 30%:70% and 0%:100%) using cassava starch binder. The result of the analysis shows that the moisture content was 7.1796±0.00% for mung beans waste and 31.479±0.00 for the sawdust. Ash content was 8.25±0.002% for mung beans waste and 1.070±0.001% for the sawdust. The volatile matter was 16.610±0.01%) for sawdust and 22.976±0.00% for mung beans waste.The fixed carbon content of the sawdust was (50.841±0.00%) and 61.57±0.00% for mung beans waste.The calorific value was 18.60 MJ/kg for mung beans waste and 20.30 MJ/kg for the sawdust. The mass of the briquette increased with an increase in biomass load, ranging from 44.1±0.01 (70% sawdust and 30% biomass) to 61.1±0.90 (100% biomass). The bulk density of the sawdust briquette increased with increase in biomass load ranging from 0.234±0.00 g/m^3 (70% sawdust+ 30% biomass) to 0.421±0.007 g/m^3(100% biomass). Hardness of the sawdust briquette increased with increased in biomass load with value ranging from 366±0.57 (70% sawdust + 30% MB) to 394±0.00 (100% MB). The porosity of the briquette decreased with increased in biomass load ranging from 0.20±0.01 (100% MB) to 0.97±0.01 (30% MB + 70% sawdust). The durability of the briquettes decreased with increase in biomass load ranging from 0.89±0.00 (70% sawdust + 30% biomass) to 0.79±0.01 (100% biomass). The compressive strength of the briquettes increased from 70% sawdust + 30% biomass (2.78±0.01 N/mm^2) to 30% sawdust + 70% biomass (3.42±0.38 N/mm^2) before decreasing at 100% biomass (2.44±0.02 N/mm^2). It can be concluded that Mung beans waste can effectively enhance the efficiency of sawdust briquettes by improving the mechanical properties.

Keywords: briquette, compressive strength, durability, mechanical properties

1 Introduction

Agro waste is the most promising energy resources for developing country like Nigeria by the virtue of its available all year round at almost zero cost. Sawdust on the other hand is produced in large volume in timber industries and during construction activities. Proper management of agro waste is important for controlling environmental pollution. Solid wastes, when improperly deposited, can impair the quality and availability of water; contaminate the soil; cause unpleasant odours; and endanger public health [1–3].

Mung beans is mainly grown in pan-tropical region of south Asia, Australia, North and South America, Central Africa and parts of China [4]. The world mung beans production is worth around 7.3 million ha and an average of 5.3 million tons of mung beans are harvested from it [5]. In Nigeria, efforts are being made to mass produce mung beans and move it into the Nigerian markets due to its nutritional benefits. As a result, mung beans wastes are being generated from time to time in a large quantity. In order to avert the environmental consequences that might occur when this waste is improperly managed, this waste can be converted to an alternative source of energy.

Due to the low density of this mung waste, there is need for its densification before use as energy source. Biomass is a renewable source of energy. According to Onchieku *et al*. [6], biomass accounts for about 14% of the total world energy compared to coal (12%), natural gas (15%), and electric energy (14%). One of the major driving forces behind the researches being carried out on production of fuel briquettes for domestic use is the need to address the environmental consequences and health hazards associated with the use of solid fuel and burning of agricultural waste or allowing them to decay in a bid to use them as organic manure [7]. These biomasses can be incorporated into sawdust using binders to form briquettes. This will help to put them into good use, improve the properties of the sawdust briquettes and reduce environmental pollution.

This work presents studies on the enhancement of the efficiency of sawdust briquettes by blending it with mung beans waste generated at Bioresource Development Centre, Abagana, using a locally made briquetting machine produced at Nnamdi, Azikiwe University, Awka. (Figure 1)

Figure 1 Mung Beans waste

2 Materials and method

2.1 Proximate analysis of the materials

2.1.1 Moisture content

The procedure of ASTM E1871-82 [8] was used in determining the moisture content of the samples. Each 2.0g sample was carefully measured into different beakers of known weight and kept in an oven at 105°C for 5hrs to enable the sample to dry (to constant weight). The beakers were transferred to a desiccator, allowed to cool to room temperature and weighed. The moisture content was calculated using the following formula:

$$\mathrm{MC} = \frac{\text{initial weight of sample} - \text{final weight of sample}}{\text{initial weight}} \times 100 \quad (1)$$

2.1.2 Volatile matter

The procedure of ASTM E872-82 [9] was used in determining the volatile matter content of the samples. The residual dry samples from moisture content determination were weighed and heated at 400°C in a furnace for 2 h. The samples were removed from the furnace, cooled and re-weighed. The volatile matter was calculated using

$$\mathrm{VM}(\%) = \frac{\mathrm{W3} - \mathrm{W\ 4}}{\mathrm{W3}} \times 100 \quad (2)$$

where, W_3 = Weight of the residual Sample, W_4 = weight of the sample after cooling.

2.1.3 Ash content

The ash content was determined following the procedure of ASTM E1755-01 [10]. Each 2 g dry sample was measured into different beakers of known weights. The beakers and their contents were placed in a furnace and heated at 590°C for 3 hours. The beakers and their contents were put in a desiccator to cool and then weighed. The ash content was calculated using:

$$\mathrm{AC}(\%) = \frac{\mathrm{W5}}{\mathrm{W6}} \times 100 \quad (3)$$

Where, W_5 = weight of ash W_6 = initial weight of dry sample.

2.1.4 Fixed carbon

The fixed carbon was calculated using the method of Garcia *et al.,* [11] using the formula

$$\%\mathrm{Fc} = 100 - (\%\mathrm{Ac} + \%\mathrm{Vm} + \%\mathrm{Mc}) \tag{4}$$

Where, Ac = ash content, Vm = volatile matter, Mc = moisture content.

2.1.5 Calorific value

An oxygen bomb calorimeter, model XRY-IA was used in determining the calorific values of the raw materials. The heating value of the briquette was calculated using the formula:

$$\mathrm{Calorificvalue(J/kg)} = \frac{\mathrm{Edt} - \mathrm{Q} - \mathrm{V}}{\mathrm{M}} \tag{5}$$

where, M = mass of the sample (kg), dt = change in temperature (Tf-To), E = energy equivalence of calorimeter per degree Celsius (E = 13039.308 J Q = change in the length chromium wire, V = titre value (i.e., volume of alkali solution used).

2.2 Preparation of the samples

Sawdust was gathered from timber shade, Umuokpu, Awka. The mung beans shell was sourced from Bioresource Development Centre Abagana (production unit). The sawdust and the mung beans waste were air dried to reduce the moisture content, cut into smaller sizes, pulverized, sieved with 2.8mm standard mesh sieve size and properly labelled for briquette production. (Figure 2)

Figure 2 Briquettes produced

2.3 Briquette formulation

The specifications used in the formulation of the briquettes are shown in Table 1.

Table 1 The quantity of the materials used for briquette formulation

Materials	Ratio of sawdust to biomass				
	100:0	70:30	50:50	30:70	0:100
Sawdust	210 g	147 g	105 g	63 g	0
Biomass	0	63 g	105 g	147 g	210 g
Starch	21 g	21 g	21 g	21 g	21 g
Water	10 ml	10 ml	10 ml	10 ml	10 ml

2.4 Characterization of the briquette

2.4.1 Shape, height and diameter

The height and diameter of the briquettes were measured using a vernier calliper and the average height diameter recorded.

2.4.2 Mass

The mass of each briquette composition was measured using an electronic weighing balance Model MB 2610. The average mass of each briquette composition was recorded.

2.4.3 Bulk density

The bulk density of the briquette was calculated using the equation described by Birtwatker e*t al*. [12]

$$\mathrm{Dbulk(g/cm^3)} = \frac{\text{mass of the sample}}{\text{volume of the sample}} \tag{6}$$

The Volume of the briquette was calculated using the formular πR^2h-πr^2h. Where, R = radius of the outer circle, $r^2$is the radius of the inner circle, h- height of the briquette.

2.4.4 Compressive strength

The compressive strength of the briquettes was determined using a compressive strength testing machine, Model 2914.

$$\text{Compressive strength } (\text{N/mm}^2) = \frac{\text{compressive force}}{\text{cross sectional area of the sample}} (\text{mm}^2) \quad (7)$$

2.4.5 Porosity index

This was determined as described by Onuegbu *et al.* [13] Each briquette sample was weighed and the weight recorded (w_1). The briquettes were immersed in a beaker containing 500 cm^3 of water for 2 mins.

$$\text{Porosity index} = \frac{\text{mass of water absorbed by the sample}}{\text{mass of the sample immersed in water}} \quad (8)$$

2.4.6 Durability

The durability of the briquettes was determined following the procedure of Birtwarker *et al.* [12] Each briquette sample was weighed into a metallic box with a cover. The cover of the box was closed, and the box was shaken for 3 mins. The cover of the box was opened and the remaining briquettes weighed. Durability was calculated using the equation;

$$\text{Durability} = \frac{\text{W2}}{\text{W1}} \quad (9)$$

Where, W_2 = weight of the briquette after shaking the box, W_1 = weight of the briquette before shaking the box.

The durability of each briquette was rated based on durability rating proposed by BRL [14] and Karunanithy *et al*. [15]

2.4.7 Hardness

Eseway hardness testing machine (type DVRB-P) was used in determining the hardness of the briquettes and values were read directly from the machine.

3 Results and discussion

Table 2 and Figure 3 showed that the moisture content was 7.1796±0.00% for mung beans waste and 31.479±0.00 for the sawdust. The moisture content of the wastes was lower than that of the sawdust. Lower moisture content of the wastes shows that they will serve as a better feedstock for biofuel (briquette) production. Ash content of the biomass was 8.25±0.002% for mung beans waste and 1.070±0.001% for the sawdust.

Table 2 Mean proximate analyses results of the materials

Parameters	Mung Beans Shell	Sawdust
Mean Mc (%)	7.1796±0.000	31.479±0.000
Mean Ac (%)	8.255±0.002	1.070±0.001
Mean Vm (%)	22.976±0.001	16.610±0.010
Mean Fc (%)	61.573±0.000	50.841±0.00
Calorific value (MJ/Kg)	18.600±0.000	20.300±0.010

Note: MC = moisture content, AC = Ash content, VM = Volatile matter and FC = Fixed carbon content, CV = Calorific value, MB = mung beans waste.

Ash is a by-product of combustion and therefore is not desired in large quantity. The ash content of a good fuel is expected to be low. Therefore, low ash content of the materials presents them as a good feed stock for biofuel production, sawdust showed the lower volatile matter of 16.610±0.01% than mung beans with a value of 22.976±0.00%. High volatile matter content of the wastes poses them as a good feed stock for biofuel production. According to Oyelaran and Tudunwada [16], the higher volatile matter content of the wastes shows that they will ignite more readily and burn fast. The fixed carbon content of the sawdust was (50.841±0.00%) and was lower than that of the mung beans waste which was 61.57±0.00% Higher fixed carbon is an indication that the wastes will serve as a good feedstock in biofuel production.

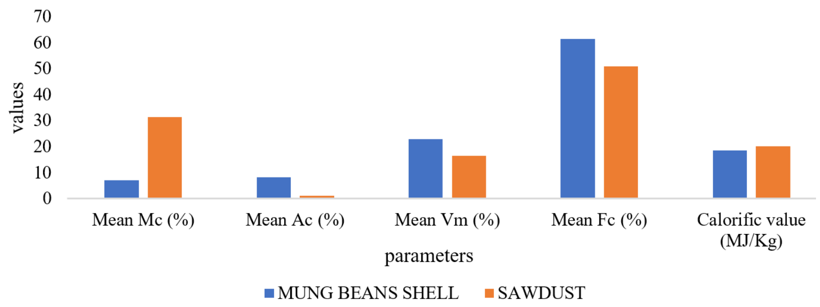

Figure 3 Proximate analysis of the materials

Calorific value is an important factor in determining the energy efficiency of a biomass. The calorific value was 18.60 MJ/kg for mung beans waste and 20.30 MJ/kg for the sawdust. The higher calorific value of sawdust shows that it will release more heat during combustion than the mung beans. According to Akpenpuun *et al.* [17], the higher the calorific value, the easier and better burning efficiency.

An analysis of variance (ANOVA) test was performed to assess the variation in proximate analysis among the materials. The significance level was set at $\alpha = 0.05$. The F-statistic was found to be 58.582, with a corresponding p-value of 0.000. This indicates a statistically significant difference in proximate analysis among the materials.

Following the significant findings of the ANOVA test, a multiple comparison test was conducted to identify specific differences between pairs of proximate analysis parameters in various materials. The significance level was set at $\alpha = 0.05$. Significant difference was observed between the following pairs of proximate analysis of the materials: Moisture content and fixed carbon content, Ash content and volatile matter, Ash content and fixed carbon content, Volatile matter and fixed carbon content, and Fixed carbon content and calorific value.

Table 3 and Figure 4 show that the mass of the briquettes increased with increase in biomass load. 100% sawdust had a mass of 41.1±0.17. The mass ofthe briquettes ranged from 44.1±0.01 (70% sawdust and 30% MB) to 61.1±0.90 (100% MB). The mass of the briquettes may depend on the initial weight of the materials used in their production. Some materials are lighter than others. Sawdust appeared to be the lighter than mung beans waste. This led to increase in the mass of the briquettes with an increase in biomass load. This increase in mass with an increase in biomass load presented mung beans waste as good blends for sawdust briquette production because this increase in mass will eventually result in increased the density of the briquettes.

Table 3 The results for the characterization of the briquettes

Ratio	Mass (g)	Bulk density (g/m^3)	Compressive strength (N/mm^2)	Porosity index	Durability	Hardness
100%sawdust:0% biomass	41.1±0.17	0.211±0.001	2.43±0.03	1.09±0.00	0.96±0.00	300±0.57
70% sawdust:30% biomass	44.1±0.01	0.234±0.00	2.78±0.01	0.97±0.01	0.89±0.00	340±0.57
50% sawdust:50% biomass	51.4±0.59	0.248±0.002	2.92±0.03	0.63±0.00	0.83±0.01	365±1.00
30% sawdust:70% biomass	54.7±0.10	0.368±0.001	3.42±0.38	0.34±0.01	0.81±0.00	381±1.15
100% biomass	61.1±0.90	0.421±0.007	2.44±0.02	0.20±0.01	0.72±0.01	394±0.00

Table 3 and Figure 5 show that the briquettes had a bulk density ranging from 0.234±0.00 g/m^3 (70% sawdust+ 30% biomass) to 0.421±0.007 g/m^3(100% biomass). lowest bulk density (0.211±0.001) was recorded with 100% sawdust briquette. The bulk density increased with increase in biomass load. The observed values for the bulk density are comparable to the findings of Jayappa and Narayana [18], who reported 0.0619+4.72 (g/cm^3) for castor seed cake, 0.0423+1.83 (g/cm^3) for jatropha seed cake, 0.03337+1.92 for tamarind fruit shell and 0.014+0.048(g/cm^3) for sawmill dust.

Table 3 and Figure 6 show that the compressive strength of the briquettes increased with increase in biomass load.The compressive strength of the briquettes increased from 70% sawdust+ 30% biomass (2.78±0.01 N/mm^2) to 30% sawdust+ 70% biomass (3.42±0.38 N/mm^2) before decreasing at 100% biomass (2.44±0.02 N/mm^2). 100% sawdust briquette had a compressive strength of 1.57±0.06 N/mm^2. The observed increase in the compressive strength of the briquettes with increase in biomass load could be as a result of the nature of the added biomass (MB). According to Onuegbu *et al*. [19], the acceptable compressive strength in industry is 0.38 MPa. The result of compressive strength of the briquettes presented in Table 2 shows that the

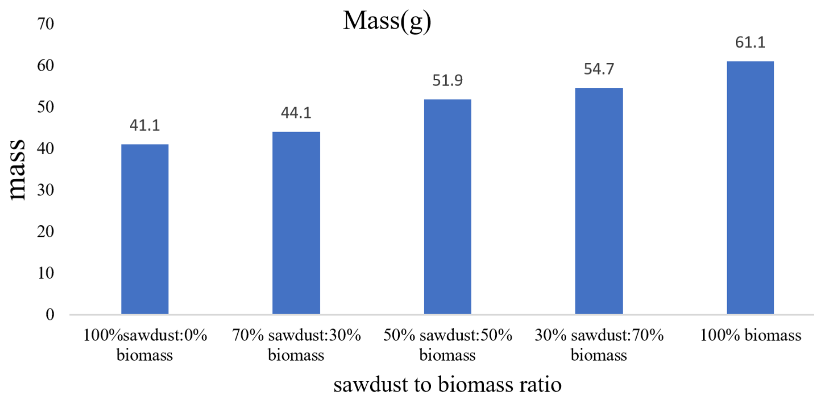

Figure 4 The effect of biomass on the mass of sawdust briquettes

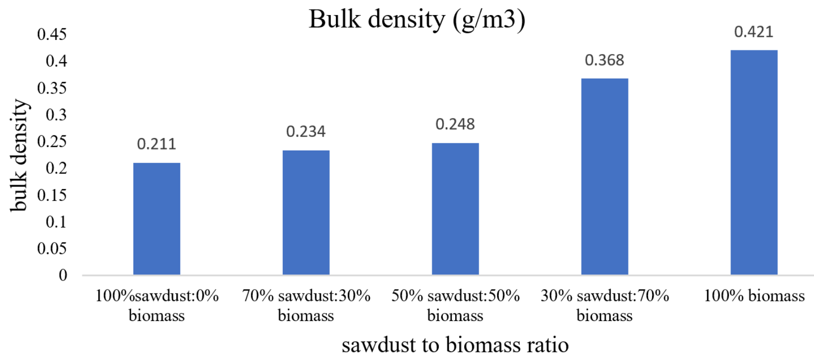

Figure 5 The effect of biomass on the bulk density of sawdust briquettes

compressive strength of the briquettes at different ratio exceeded 0.38MPa which implies they would not easily break during transportation and storage. The result of the compressive strength is comparable to the result obtained by Onuebgu *et al*. [19] 0.92 N/mm2 for coal briquette and 1.09-7.45 N/mm2 for coal-*pennisetumpurpurem* briquette blends.

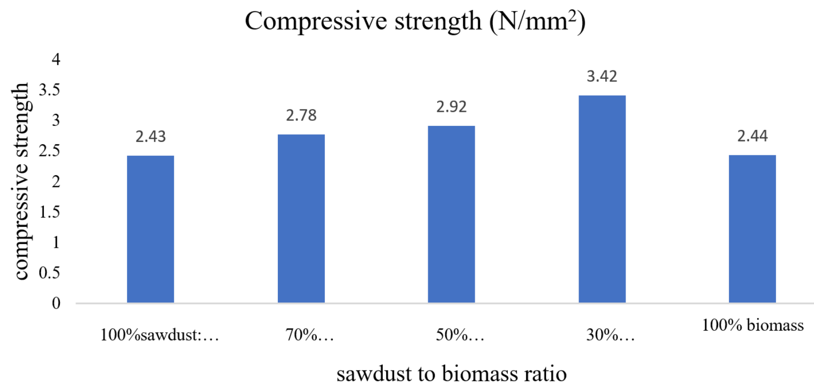

Figure 6 The effect of biomass on the compressive strength of sawdust briquettes

Table 3 and Figure 7 showed that porosity of the briquettes reduced with increase in biomass load. The result obtained shows that 100% sawdust briquette had a porosity index of 1.09±0.00, while the blended briquettes had a porosity index ranging from 0.20±0.01 (100% MB) to 0.97±0.01 (30%MB + 70% sawdust). High porosity in briquettes can lead to high water absorption, increased burning rate, low burning time and reduced durability of the briquettes, so it's an undesirable quality in briquettes. Ikelle *et al.* [20] and Karunanithy *et al.* [15] observed increase in porosity of coal briquette with an increase in biomass load.

Table 3 and Figure 8 show that the durability of the briquettes decreased with increase in biomass load. 100% sawdust had the highest durability value of 0.96±0.00. The blended briquettes had a durability ranging from 0.89±0.00 (30% MB + 70% sawdust) to 0.79±0.01 (100% MB). Mechanical durability is the property briquettes which show their resistance level to destruction during transportation and storage [21,22]. It is important to note that the lower

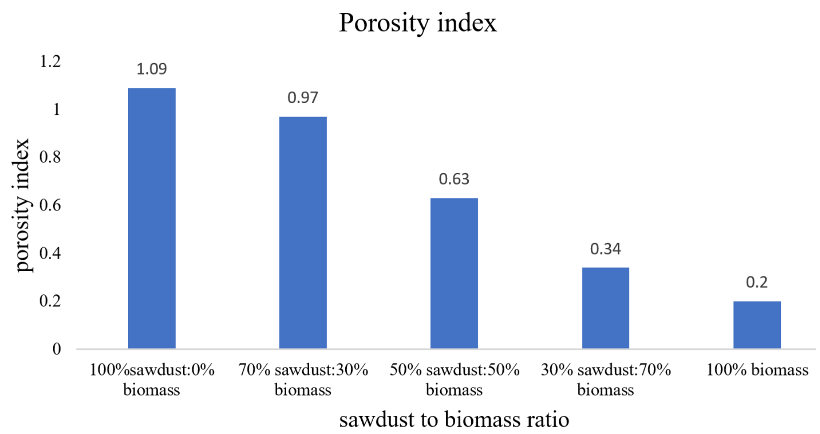

Figure 7 The effect of biomass on the porosity of sawdust briquettes

the durability, the better the quality of the briquettes.

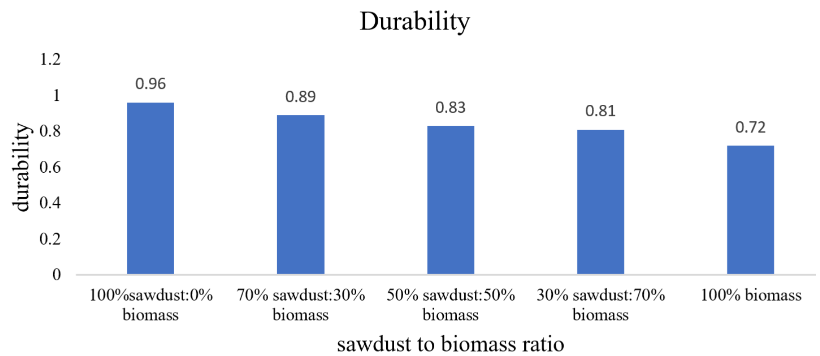

Figure 8 The effect of biomass on the durability of sawdust briquettes

Table 3 and Figure 9 show the hardness of the briquettes increased with increase in biomass load. The briquette blends had a hardness value ranging from 366±0.57 (70% sawdust+ 30% MB) to 394±0.00 (100% MB). 100% sawdust briquette had a hardness value of 300±0.57. Hardness is a desirable mechanical property in a briquette but too hard briquette is not good as they can easily break when compressed. It was observed that briquettes with higher bulk density had higher hardness.

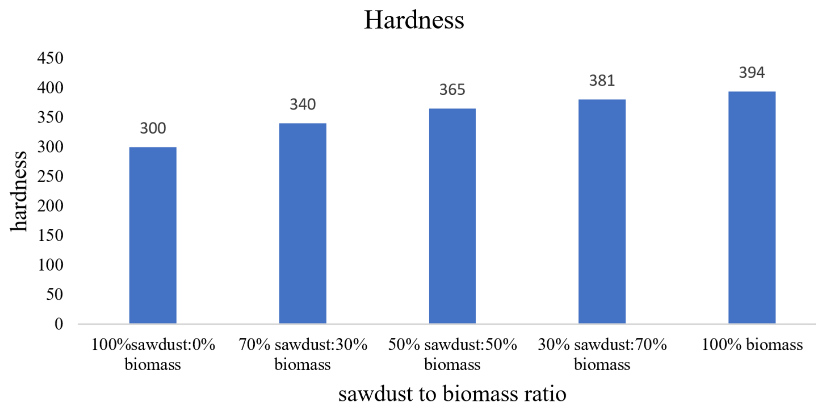

Figure 9 The effect of biomass on the hardness of sawdust briquettes

4 Conclusion

The results of the research show that blending mung beans waste with sawdust enhanced the efficiency of sawdust briquette by increasing the mass, bulk density, compressive strength, durability and hardness and reducing the porosity of the sawdust briquette. Proximate analyses of the materials showed that they can serve as a good feed stock for biofuel production even though the sawdust showed a better quality. Therefore, incorporating mung beans into sawdust briquette can give rise to improved biofuel. Moreso, researches aimed at the effect of addition of mung beans waste into sawdust briquettes should be conducted in order to determine the coal-briquette properties.

Conflicts of interest

The authors declare that they have no conflict of interest.

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