An effect of blending ratio on mechanical and thermal properties of the sawdust-cocoa pod briquettes

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Abstract: - The present work aims to utilize wastes of sawdust and cocoa pod as the raw materials of low pressure densified briquettes and to investigate an effect of blending ratio on mechanical and thermal properties of the briquettes. The weight ratio between sawdust and cocoa pod are 3:1 (SD75CP25), 1:1 (SD50CP50), and 1:3 (SD25CP75). The compaction process is performed at room temperature and under low compacting pressure of 0.1 MPa. The quality of the briquettes is evaluated in terms of their mechanical properties (relaxed density, stable density, water resistance index, and compressive strength), and their thermal properties (higher heating values). The results indicate that waste of sawdust and cocoa pod have the potential as the raw material of low pressure densified sawdust-cocoa pod briquettes. Based on the stable density and the higher heating value, the SD50CP50 briquette has the best properties in the present work. The stable density and the higher heating value of the SD50CP50 briquette are 452.74 kg/m^3 and 16.34 MJ/kg, respectively. The values are comparable to the values of other densified briquettes obtained by other researchers.

Key-Words: - Blend, Briquette, Cocoa pod, Densified, Mechanical, Sawdust, Thermal
Received: May 21, 2021. Revised: March 14, 2022. Accepted: April 12, 2022. Published: May 6, 2022.

1 Introduction

Shortage of crude oil based fuel and global warming consideration triggered the intensive utilization of alternative renewable energy sources, i.e. biomass. Loppinet-Serani et al [1] stated that biomass is all organic materials which come from plant and animal. Meanwhile, Basu [2] divided biomass source as virgin biomass and biomass waste. Virgin biomass is classified as terrestrial and aquatic biomass. Meanwhile, based on sources, biomass is shared into agricultural solid residue, forestry residue, industrial disposal, and municipal disposal. Table 1 shows the classification of biomass wastes and their sources [2].

Table 1: Classification of biomass waste, their sources and examples [2]

Biomass classification	Sources

Agricultural solid residue	Crop residue, manures and livestock
Forestry residues	Floor residues leaves, bark
Industrial wastes	Oil, fat, demolition wood; sawdust
Municipal disposal	Landfill gas, MSW (Municipal Solid Waste), sewage, bio-solids

Prior to be used as a feedstock, it is important to perform proximate and ultimate analysis to obtain thermochemical properties of the biomass waste. Proximate analysis gives composition of the biomass in terms of volatile matter (VM), fixed carbon (FC), moisture content (MC), and ash content. Proximate analysis can be conducted on air dry basis. Whereas, ultimate analysis provides typical elemental composition of hydrocarbon fuel, that are Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), and Sulphur (S) which are presented in weight percentage. Ultimate component of biomass is useful for determination of stoichiometric air for combustion.

Wastes of biomass from crop residues and wood processing industries have a huge potential for alternative energy source for heating purpose. However, these wastes have a low bulk density that make them difficult to handle and also have a low energy content per volume. Instead of the direct use, the wastes are used in a form of densification briquettes by compacting or pressing single raw material or blended raw material in the press machine under particular pressure. For example, briquette made of single material are corn crop briquettes [3-6], rice straw briquettes [7], and soda weed briquettes [8] and briquette made of blended material are sawdust-neem powder briquettes [9], bamboo-rice straw briquettes [10], and rice husk-corn cob [11].

To figure out briquette's quality, mechanical properties (i.e. density, water resistance, durability, compressive strength) and thermal properties (i.e. heating value, combustion rate, and ash content) are commonly used. The briquette's quality can be affected by various factors. These factors can be broadly divided into compacting factor (pressure and temperature) and preparation factor (size of a raw material and blending ratio). Briquette's density improves as stepping up pressing pressure [9]. More mass contains per volume when density is higher, thus more energy content of the briquette. Moreover, inter particle connection is better at high compacting pressure, which in turn give denser and more reliable briquettes [12]. Compressive strength increases significantly by increasing compacting pressure [5]. By applying higher compacting pressures, it was able to obtain uniform in shape as well as withstand over time briquette [13]. Another important parameter is compacting temperature. Compared with pressure, temperature give more impact on briquette's quality [13]. The thermal-compression technique promotes densification process [14] which is able to soften a lignin in biomass and turns it as a binder [13]. The binder enhances a cohesion force of which results in increasing compressive strength.

Particle size is an important influencer of briquettes durability. Earlier works indicated that raw material particle size inversely proportional the strength of the densification briquettes. Small particles size has large contact area per unit volume and more contact points during compaction [12]. Generally, the finer the particle, the higher the durability [15]. Fine particles usually absorb more moisture than large particles and, therefore, undergo a higher degree of conditioning. Smaller particles resulted in more dense packing of particles at constant pressure [16]. Blending ratio also plays an important role on quality of the densified briquette. Impact resistance test showed that the strength of a sawdust-neem briquettes enhanced by increasing the neem content [9]. It was stated that blending different types of raw biomass materials was able to improve the properties of pellets [10].

Biomass combustion consists of two main steps, i.e. the first is the de-volatilization process and burning of light organic volatiles and the second is a mass loss resulting from the oxidation of char. Meanwhile, two ignition steps of homogeneous volatile ignition and heterogeneous surface ignition were observed by Shan et al. [17] during their experimental work of single biomass pellet ignition and combustion. High volatile biomass is easier to be ignited but the flame generated are smoky flame. Volatile matter contains methane and other hydrocarbons which are combustible gases [18]. Duration of ignition and combustion stage are also affected by particle size or density and shape [19]. Ignition of small particles is faster than that of large particles. High burning rate as well as thin reaction zone can be observed during small particle combustion [20].

Indonesia has a large amount of cocoa pod waste which can be utilized as a feedstock of biomass briquette. Indonesia is the 3rd largest cocoa producer countries in the world behind Ivory Coast in the 1st and Ghana in the 2nd [21]. Figure 1 shows anatomy of cocoa fruit (*Theobroma cacao* L). Almost ¾ of the fruit is a pod, where 73.63% is a pod, 24.37% is a beans, and the rest of 2% is a placenta [22]. Bestowing to Ministry of Agriculture of Republic of Indonesia [21], almost 750,000 ton a year of cocoa was harvested in Indonesia. This means that almost 552,225 ton of cocoa pod waste is available for a raw material for densification briquette. However, this waste of cocoa pod has not yet utilized for useful energy sources. In order to utilize this waste into useful energy source, the cocoa pod waste is utilized as a raw material of densification briquette in the present work.

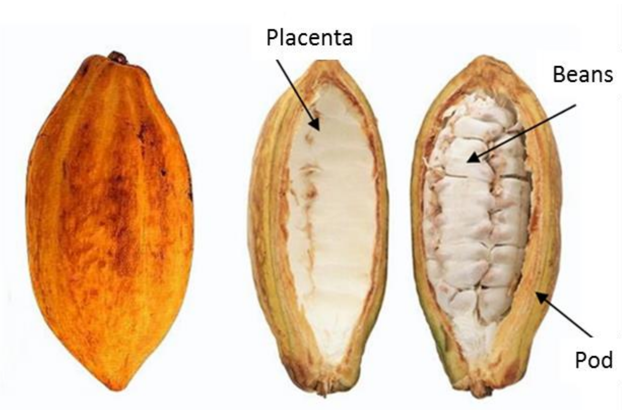

Figure 1: Cocoa fruit

Novelty statement

Although many biomass briquettes have been produced worldwide, but none of those briquettes are made from cocoa pod waste using low pressure densification method so far**.** Thus, the present work aims to figure out the feasibility of cocoa pod as feedstocks of low pressure densified cocoa pod-sawdust briquettes and to investigate an effect of blending ratio on the briquette's mechanical and thermal characteristic.

2 Material and Method

2.1. Characterization of the waste

The cocoa pods waste and sawdust waste are obtained from cocoa farming in Kulon Progo and wood furniture industry in Bantul, respectively. Proximate property and heating value of those raw materials are analyzed at Universitas Gadjah Mada and Tekmira, Bandung. Proximate property and heating value of the pod and sawdust are tested on air dried basis (adb), The results are presented in weight percentage (wt.%) as shown in Table 2.

Table 2: Properties of cocoa pod and sawdust

Properties	**Sawdust**	**Cocoa pod**
Fixed Carbon (adb, wt%)	23.63	9.54
Volatile Matter (adb, wt%)	68.20	19.60
Ash Content (adb, wt%)	1.66	2.15
Moisture (adb, wt%)	6.51	68.76
HHV (MJ/kg)	20.09	15.92

2.2. Densification work

Figure 2 shows a diagram of densification process of sawdust-cocoa pod (SD-CP). After sun drying, the pods are sliced in the crusher machine till its size reaches 10 meshing size, followed by blending the crushed pod with the sawdust. Three different blending ratios (wt.%) between sawdust and cocoa pod are 75%:25% {SD75CP25), 50%:50% (SD50CP50), and 25%-75% (SD25CP75). The mixture is fed into the die and pressed using manual hydraulic press under low pressure of 0.1 MPa for 60 second holding time. The die has a diameter of 40 mm and height of 50 mm. The product of low pressure densification briquettes of SD-CP for each blending ratio are shown in Figure 3.

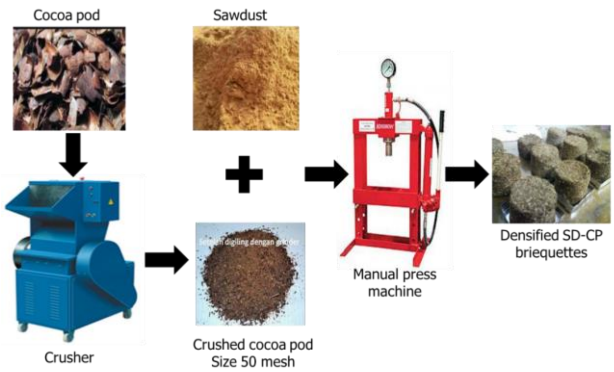

Figure 2: Diagram of briquetting process

Figure 3: Sawdust-Cocoa pod (SD-CP) briquettes

2.3. Evaluation of briquette's properties

The quality of the briquettes is figured out in terms of mechanical properties (i.e. density, compressive strength, durability, and water resistance) and thermal properties (i.e. higher heating value). Density is a ratio between a mass and a volume of the briquettes. The density obtained just after the compacting is called compacting density. When density is obtained within a period of time after compacting, it is called relaxing density. Compacting and relaxing densities are calculated using Eq. (1).

$$\rho = \frac{4\,x\,m}{\pi\,x\,D^2\,x\,h} \quad (1)$$

where ρ is the density of the briquette (g/mm³), m is the mass of the briquette (g), D is the diameter of the briquette (mm), and h is the height of the briquette (mm).

The briquettes could be able to withstand the compressive force during their transportation. The parameter is evaluated using Universal Compressive Machine and Eq. (2)

$$\sigma = \frac{4\,x\,F}{\pi\,x\,D^2} \quad (2)$$

where σ is the compressive strength (kg/mm²), F is the compressive force that breaks the briquette (kg), and D is the briquette's diameter (mm²)

Resistance of the briquette to water is commonly defined in terms of Water Resistance Index (WRI). The WRI indicates the respond to the water absorption, especially when the briquettes contact with water. The WRI is investigated using immersion technique. The briquettes are submerged in the water for 30 second [9] followed by calculating the WRI using Eq. (3).

$$WRI = \frac{m_f - m_i}{m_f} \quad (3)$$

where WRI is the water resistance of the briquette, m_f is the mass of the briquettes after immersion (g), and m_i is the initial mass of the briquette (g).

3 Results and Discussion

Figure 4 and Figure 5 show relaxed and stable density of the briquettes within 7 days, respectively. The graph in Figure 4 reveals the density of the briquettes reduce up to 6th day and remain stable at 7th day. It indicates that all three type briquettes get their stable size after 6 days. Decreasing density occurs due to moisture lost and volume expansion of the briquettes. SD75CP25 briquette experiences the highest mass loose and volume expansion and on the other hand mass loose and volume expansion of SD50CP50 briquettes are the lowest. Higher mass loose and volume expansion lead to lower the stable density of the briquettes. From Figure 5, stable density of SD75CP25, SD50CP50, and SD25CP75 briquettes after 6 days are 390.87, 452.74, and 442.68 kg/m³, respectively. Density of the briquette increases as increasing percentage of cocoa pod from 25% to 50%. Compaction ratio increases as increasing percentage of cocoa pod from 25% to 50%. Increasing compaction ratio results more compact the briquette, hence lower volume expansion in the SD50CP50 briquette. Increasing cocoa pod reduce volume expansion of the briquette. The cocoa pod able to increase the bonding force of the briquette (i.e. cocoa pod is also as a binder). Better bonding force impacts lower volume expansion of the briquette. Thus higher stable density of the SD50CP50 briquette is obtained compared to that of the SD75CP25 briquette. Meanwhile, the stable density of the SD25CP75 briquette is lower than that of the SD50CP50 briquette. Volume expansion of SD25CP75 briquette should be lower than volume expansion of SD50CP50 briquette, thus the stable density should be higher. This can be explained as follows. Moisture content in the SD25CP75 briquette is also higher than that in SD50CP50 briquette. During the 7 days observation, more moisture loose from SD25CP75 briquette that results in higher mass loss. This leads lower stable density of the SD25CP75 briquette than SD50CP50 briquette.

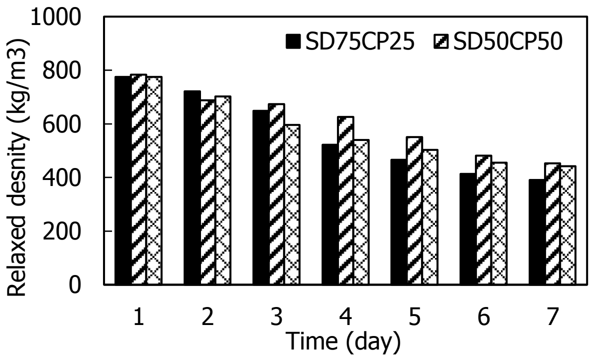

Figure 4: Relaxed density within 7 days

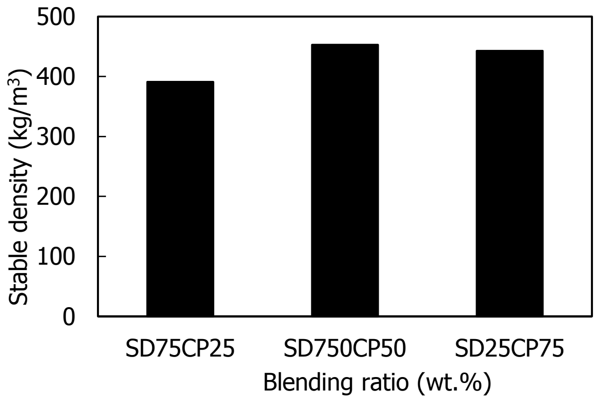

Figure 5: Stable density after 7th day.

Figure 6 and Figure 7 display an effect of blending ratio on compressive strength and WRI, accordingly. Cocoa pod content of the briquette impacts bonding force of the briquette. High lignin content of cocoa pod may act as a binder which soften and bond the particles during compression [11]. Thus, compressive strength increases as increasing cocoa pod content of the briquette as shown by Figure 6. The compressive strength of the SD75CP25, SD50CP50, and SD25CP75 briquettes are 2.75, 3.17, and 3.52 N/cm^2, respectively. These reveal the SD25CP75 briquette is more durable than SD75CP25, SD50CP50 briquette with impact force that may occur during the storage and transportation.

On the other hand, the SD25CP75 briquette has the lowest WRI as can be seen in Figure 7. Cocoa pod is fibrous which high water adsorptive property. Thus, briquette with higher cocoa pod content absorbs more water (i.e. low water resistance index). The WRI of the SD75CP25, SD50CP50, and SD25CP75 briquette are 0.75, 0.72, and 0.70, respectively. It can be stated that the WRI of SD-CP briquettes decrease with increasing percentage of cocoa pod.

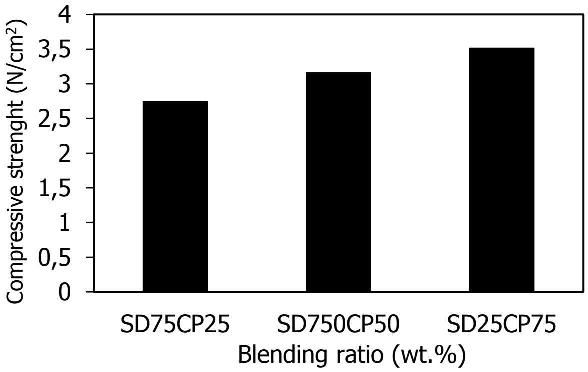

Figure 6: Compressive strength

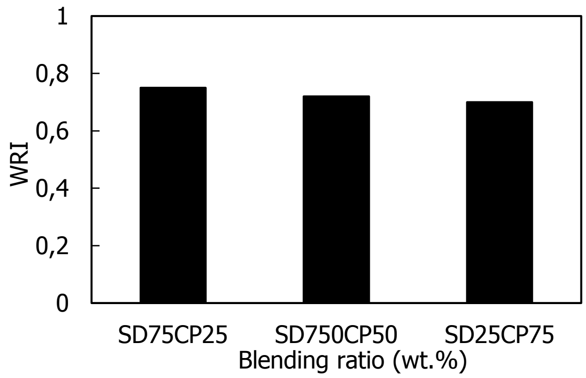

Figure 7: Water Resistance Index

Meanwhile, Figure 8 displays an effect of blending ratio on higher heating value (HHV) of the briquettes. The HHV of SD75CP25, SD50CP50, and SD25CP75 briquettes are 17.97, 16.34, and 14.65 MJ/kg, accordingly. Increasing cocoa pod percentage from 25% to 75% reduces HHV of the briquettes. This because HHV and volatile content of the cocoa pod are lower than that of sawdust. Thus, the HHV decreases as sawdust percentage reduces in the briquette (i.e. cocoa percentage increases).

According to mechanical properties and thermal properties of the SD-CP briquettes, the SD50CP50 is the best briquette in this work. The SD50CP50 briquette has maximum stable density. Although it has slightly lower HHV that SD75CP25, but the current work aims to utilize cocoa pod waste for making densified briquettes, thus the SD50CP50 is acceptable briquette. The stable density and HHV of the SD50CP50 briquette is comparable to stable density and HHV of other densified briquettes obtained by other researchers.

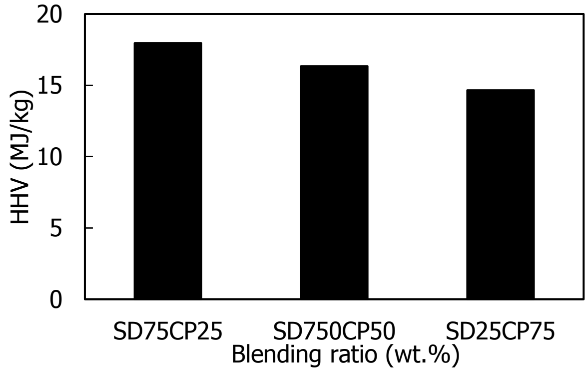

Figure 8: Higher Heating Value

Figure 9 and Figure 10 comparing the stable density and HHV of the SD50CP50 briquettes to other densified briquettes. The SD50CP50 briquette has higher stable density than rice husk-sawdust briquette [9] and rice husk-cassava waste briquette [23], but lower than soda weed briquette [8] and corn cob briquette [3]. Meanwhile, the HHV of SD50CP50 briquette is higher than the HHV of the rice husk-sawdust briquette and the rice husk-cassava waste briquette, but lower that HHV of the rice straw-sugarcane leaves [24] and the Mapani leaves-cow dung [25].

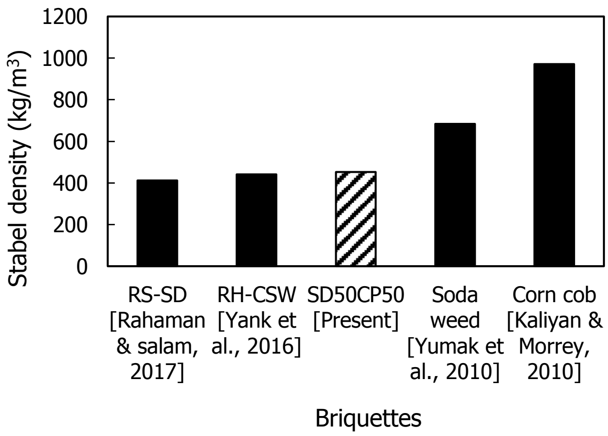

Figure 9: Stable density of various densified briquettes

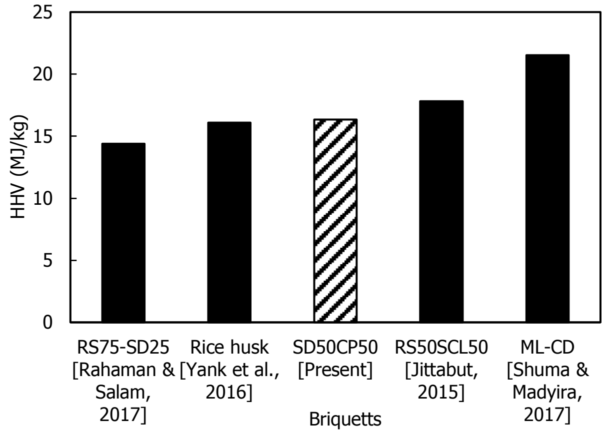

Figure 10: HHV of various densified briquettes

4 Conclusion

The wastes of rice husk and cocoa pod are utilized to make the densification sawdust-cocoa pod briquettes with different blending ratio, i.e. SD75CP25, SD50CP50, and SD25CP75. The briquettes are investigated in terms of mechanical and thermal properties. It can be concluded that:

1. The waste of sawdust and cocoa pod are used successfully to make densification briquettes using manual hydraulic press of 0.1 MPa. Crushing of cocoa pod is required prior to be blended with the sawdust.
2. According to mechanical and thermal properties, the SD50CP50 briquette is the best briquette in the present work. The SD50CP50 briquette reaches stable after 6 days and the value is 452.74 kg/m^3. Meanwhile, the HHV of the SD50CP50 is found to be 16.34 MJ/kg
3. The stable density and HHV of the SD50CP50 briquette are comparable to stable density and HHV of other densified briquettes obtained by other researcher. It can be stated that cocoa pod is good potential as a raw material of densification briquette.

Acknowledgement:
The authors sincerely thank to Mechanical Engineering Department, Institut Sains & Teknologi AKPRIND Yogyakarta for the support given during the experimental work

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