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The Effect of Compacting Pressure On Physical And Thermal Properties of Cocoa Pod Briquette

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Abstract
In the present work, compacting pressure on cocoa pod briquettes' physical and thermal properties is investigated. The work is initiated by collecting the cocoa pod waste from the local plantation in Yogyakarta. After crushing, the 10 mesh size cocoa pod is compacted at different pressure, i.e., 5, 7.5, and 10 bar. The physical properties of the briquette investigated are density, compressive strength, and water resistance. Meanwhile, the thermal property of the briquette investigated is a higher heating value. The result shows that the 10 bar briquette is the best in the present work. The 10 bar briquette has the highest stable density, compressive strength, water resistance index, and higher heating value. The values are 715 kg/m^3. 9.82 N/m^2, 98.8%, and 3660.8 Cal/g, respectively. The value of stable density and higher heating value of the 10 bar cocoa pod briquette is comparable to other biomass briquettes. Thus the cocoa pod has a good potential as a raw material in making biomass briquettes under low compacting pressure.

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Keywords - *briquette, cocoa pod, densified, pressure, properties.*

I. INTRODUCTION

In recent years, many efforts on searching for an alternative source of fuel have been conducted worldwide, including Indonesia. Biomass waste, one of many potential sources of alternative fuel, has got more attention nowadays. Wastes of biomass from crop residues and wood processing industries have a huge potential for an alternative energy source for heating purposes. The waste is used in densified briquettes instead of direct use to encounter a low bulk density of biomass waste. The densified briquettes can be produced either from single raw material or blended raw material by the compacting technique. Rice straw briquettes (Rahaman & Salam, 2017), corn crop residues briquettes (Kaliyan & Morey, 2010; Miranda et al., 2018; Okot et al., 2018; Wongsiriamnuay & Tippayawong, 2015), and soda weed briquettes (Yumak et al., 2010) are the example of single raw material briquettes. Meanwhile, several blended raw material briquettes are rice husk-corn cob (Muazu & Stegemann, 2015), sawdust-neem powder briquettes (Rajaseenivasan et al., 2016), and bamboo-rice straw briquettes (Liu et al., 2013).

The quality of the densified briquettes can be evaluated in terms of their mechanical and thermal properties. Mechanical properties are density, compressive strength, water resistance, and friability. Whereas the thermal properties of the briquettes can be evaluated in terms of heating value. Various factors can affect the quality of the densified briquettes, such as compacting pressure and temperature. The density of the briquettes increases as applied compacting pressure increases (Rajaseenivasan et al., 2016). Increasing density means reducing briquette size for the same mass content and increasing energy content per volume. High compacting pressure impacts better connection at inter-particle contact points, resulting in denser and more durable briquettes (Bazargan et al., 2014). It was also found that higher compacting pressure affected the resistance and compressive strength of the briquettes significantly (Okot et al., 2018). Pellets formed at higher pressures, were more uniform in shape, having defined dimensions, which were retained over time (Gilbert et al., 2009).

Meanwhile, the temperature has a dominant effect than compacting pressure on the briquettes' quality (Gilbert et al., 2009). The thermal-compression process can promote the densification of the biomass briquette (Chou et al., 2009). The lignin present in the biomass feedstock softened and acted as a binding agent at elevated temperature (Gilbert et al., 2009), which improves cohesion force and compressive strength of the briquettes.

Although many biomass briquettes have been produced worldwide, none of those briquettes are made from cocoa pod wastes with low pressure densified methods**.** Thus, the present work aims to figure out the feasibility of cocoa pod wastes as a feedstock of low pressure densified briquettes and investigate the effect of compacting pressure on the physical and thermal properties of the briquettes.

II. MATERIALS & METHODS

A. Characterization of the feedstocks

In the present work, a waste of cocoa pods is collected from a cocoa plantation at Yogyakarta. The cocoa pod's proximate and heating value are analyzed on an air-dried basis (adb) at Universitas Gadjah Mada. Table 1 shows the cocoa pod's proximate properties and heating value in weight percentage (wt.%).

TABLE 1
Proximate and heating value of the cocoa pod

Properties	Cocoa pod
Fixed Carbon (adb, wt%)	9.54
Volatile Matter (adb, wt%)	19.60
Ash Content (adb, wt%)	2.15
Moisture (adb, wt%)	68.76
HHV (MJ/kg)	15.92

B. Densification work

Fig. 1 shows a process diagram of cocoa pod briquette production. Dry cocoa pods are crushed using the crushing machine and sieved using 10 meshing size. The cocoa pod-water mixture is fed into the die and pressed using manual hydraulic press under low pressure of 5, 7.5, and 10 bar for 60 seconds holding time. The die has a diameter of 40 mm and a height of 50 mm. The product of the cocoa pod briquettes (P5, P7.5, and P10) are shown in Fig. 2. P5, P7.5, and P10 indicate the pressure applied during compaction, such that 5, 7.5, and 10 bar, respectively.

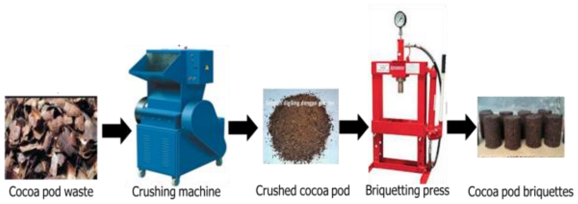

Fig. 1. Process diagram of making the densified cocoa pod briquettes

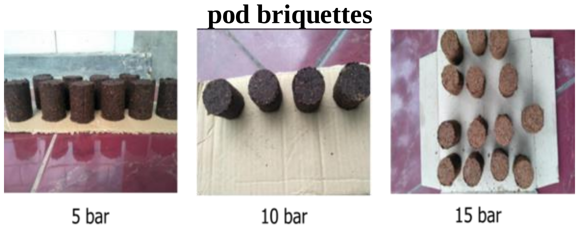

Fig. 2. Cocoa pod briquettes

C. Evaluation of physical and thermal properties

Their physical properties and thermal properties figure out the quality of the briquettes. The physical properties observed are density, compressive strength, and water resistance. Meanwhile, the thermal property investigated in the present work is a higher heating value.

Density is defined as the amount of mass content per unit volume of the briquettes. 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).

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

Where ρ is the density of the briquette (g/mm^3), 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 stand compressive force during their transportation. The strength is measured under Universal Compressive Machine to figure out their compressive strength. The compressive strength is calculated using Eq. (2).

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

where σ is the compressive strength of the briquette (kg/mm^2), F is the force applied when the briquette breakup (kg), and D is the diameter of the briquette (mm^2)

The Water-resistance index of the briquettes also has to be considered in briquettes production. It shows the response of the briquettes during rainy seasons or while in contact with water. The water resistance is obtained by immersed the briquettes in the water container for 30 s (Rajaseenivasan et al., 2016). Eq. (3) is used to calculate the water-resistance of the briquettes.

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

WRI is the briquette's water resistance, mf is the briquettes' mass after immersion (g), and mi is the briquette's initial mass (g). Meanwhile, the higher heating value of the briquettes was obtained by bomb calorimeter test. The test is conducted at PAU-Universitas Gadjah Mada.

II. RESULTS & DISCUSSION

Fig. 3 and Fig. 4 present the briquettes' relaxed and stable density within 10 days after production. The graph in Fig 3 indicates that the briquettes' density reduces till day 4 and remains constant from day 5. This means that stable densities of all three briquettes were obtained after 4 days. Reduction in density is caused by moisture loss and volume expansion of the briquettes. Volume expansion is lower at higher compacting pressure. This is obvious that bonding strength increases with increasing compacting pressure. Assuming moisture released is similar for the three briquettes, the 10 bar briquette has the highest density since it experiences the lowest volume expansion. The briquettes' stable density is 0.609, 0.663, and 0.715 g/cm^3 for 5, 7.5, and 10 bar compacting pressure, respectively.

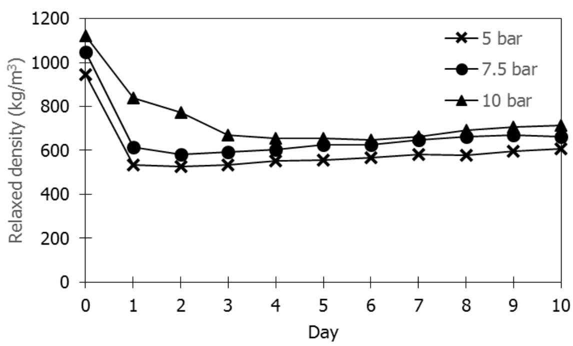

Fig. 3. Relaxed density within 10 days

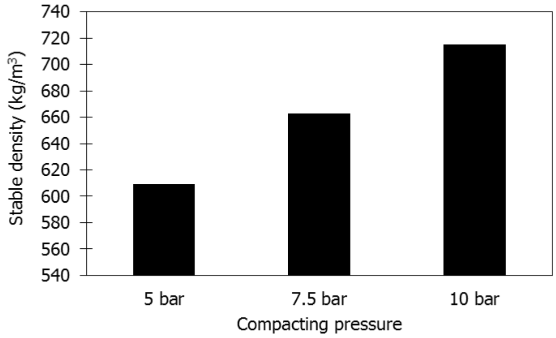

Fig. 4. Stable density after 10 days.

The density of 10 bar cocoa briquettes is comparable with other briquettes and is presented in Fig. 5. The stable density of the 10 bar cocoa pod briquette is higher than rice husk-sawdust briquette (Rahaman & Salam, 2017), rice husk-cassava waste briquette (Yank et al., 2016), and soda weed briquette (Yumak et al., 2016), but lower than corn cob briquette (Kaliyan & Morrey, 2010).

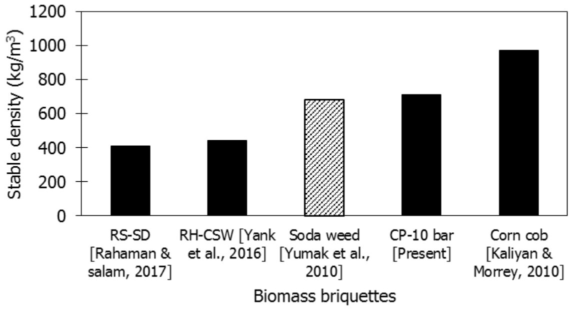

Fig. 5. The stable density of various biomass briquettes

Fig. 6 and Fig. 7 show and effect of blending ratio on compressive strength and water resistance index (WRI) of the briquettes. More amount of cocoa pod in the briquette leads to enhance bonding force between sawdust and cocoa pod. High lignin content in the cocoa pod may act as a binder. Lignin softens and bonds the particles during compression (Gilbert, 2009). Thus, the bonding of the briquette increases as increasing compaction pressure. The compressive strength of the 5 bar, 7.5 bar, and 10 bar briquettes are 5.38, 7.73, and 9.82 N/cm^2, accordingly. This means that the 10 bar briquette is more durable than the 5 bar and 7.5 briquettes with impact force during storage and transportation.

Like compressive strength, the 10 bar briquette has the highest WRI, as shown in Fig. 6. Increasing compacting pressure results in denser briquettes that reduce the pores of the briquettes. This leads to reducing water absorption of the 10 bar briquette. The higher the WRI, the more resistant the briquette to moist climate.

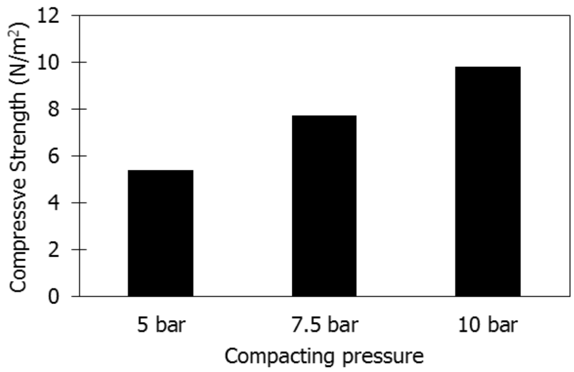

Fig. 6. Compressive strength

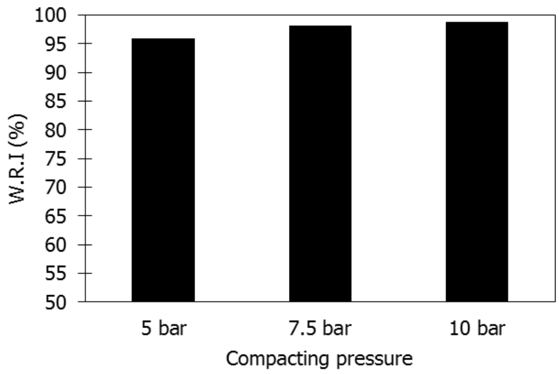

Fig. 7. Water Resistance Index

Meanwhile, Fig. 8 displays an effect of compacting pressure on the higher heating value of the briquettes. Since the 10 bar briquette has higher density, more mass content at a given volume in 10 bar briquette leads to the highest heating value observed at 10 bar briquettes. Fig. 9 compares HHV of 10 bar cocoa pod briquettes with HHV of other biomass briquettes. The HHV of the 10 bar cocoa pod briquettes is higher than the HHV of the rice husk-sawdust briquette (Rahaman & Salam, 2017) and, but lower than HHV of the rice husk briquettes (Yank et al., 2016), the rice straw-sugarcane leaves (Jittabut, 2015) and the Mapani leaves-cow dung briquettes (Shuma & Madyira, 2017).

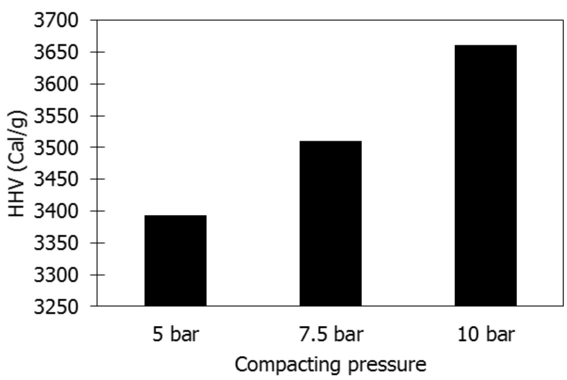

Fig. 8. Higher Heating Value

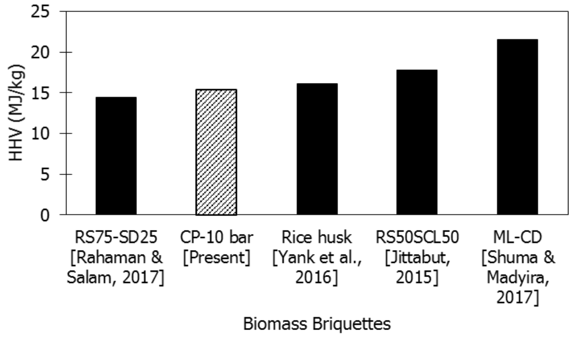

Fig. 9. **HHV of various densified briquettes**

III. CONCLUSIONS

The waste of cocoa pod is utilized to make densified cocoa pod briquettes with different compacting pressure, i.e., 5, 7.5, and 10 bar. The briquettes are investigated for their physical and thermal properties. It can be concluded that:

1. The waste of cocoa pod is successfully used to make densified briquettes using manual hydraulic press under compacting pressure of 5, 7.5, and 10 bar. The cocoa pod has to be crushed up to 10 mesh sizes before be compacted in the hydraulic press.
2. According to physical and thermal properties, the 10 bar briquette is the best in the present work. The 10 bar briquette has the highest stable density, compressive strength, water resistance index, and higher heating value. The values are 715 kg/m^3. 9.82 N/m^2, 98.8%, and 3660.8 Cal/g, respectively.
3. The value of stable density and higher heating value of the 10 bar cocoa pod briquette is comparable with other biomass briquettes. Thus the cocoa pod has a good potential as a raw material in making biomass briquettes under low compacting pressure.

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