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Utilizing Merbau Wood and Coconut Shell Wastes as Biofuel in the Form of Pellets

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ABSTRACT

The wood waste generated by wood industries is increasing. On the other hand, the demand for bioenergy in the form of pellets is also rapidly increasing. Converting wood waste into wood pellets can be one of the alternatives of waste management. At the same time, improving pellets quality can be implemented to keep up with the increasing pellets demand. This study investigated the characteristics of merbau (*Intsia bijuga*) wood and coconut (*Cocos nucifera*) shell wastes pellets, and effects of material combination pellets characteristics. The results showed that merbau wood and coconut shell wastes pellets proved to meet the DIN EN 15270 pellet quality standard. Moreover, a significant improvement on merbau pellets proximate properties and calorific value was investigated; however, the crush strength of pellets was significantly decreased.

Keywords: pellets, merbau, coconut shell, material combination.

INTRODUCTION

One alternative way to utilize timber waste (dust,chip, and smaller pieces) is by converting them into wood pellets [Kocsis & Csanady, 2016]. ISO (the International Organization for Standardization) no. 17225-2 defines wood pellet as densified biofuel made from woody biomass with or without additives. Several advantages can be found in the case of pellets, in comparison to other nondensified biomass. Higher bulk and energy densities result in lower cost of transportation and higher efficiency of energy. Moreover, the decreased moisture content (±10%) increases its longevity for storage capability [Holm et al., 2006]. Pellet biomass can be a possible solution for green-house gas emission due to fossil fuels usage [Min & Um, 2017]. Compared to coal, pellets (biomass) had less carbon, NO_2, and SO_2 emission [Al-Qayim et al., 2019]. Since 2011, the demand for pellets has grown rapidly [Thrän et al., 2017]. In order to gain on the rapidly grown demand for pellets, improving pellets quality could be implemented.

In this study, Merbau (*Intsia bijuga*) sawdust waste was used as a raw material for wood pellets. Gusamo & Towalis [2022] reported that merbau sawdust has 4,093 cal/g of calorific value which does not meet the pellet quality standard for example DIN EN 15270 (German pellet standard) that requires the calorific value of pellets at the minimum of 4,302 cal/g. Therefore, it is required to improve the quality of merbau sawdust pellets, especially the calorific value.

Improving the quality of pellets could be implemented in various ways. Combination of different types of biomass materials is an effective way of improving the quality of pellets [Liu et al., 2016]. Serrano et al. [2011] reported that addition of pine sawdust increased calorific value and mechanical durability of barley straw pellets. Monedero et al. [2015] also reported that the combination of poplar and pine significantly increased the physical properties of poplar pellets. To improve the calorific value of merbau pellets, coconut shell particles, a known material for its high calorific value (5,456.5 cal/g reported by Tsai et al. [2006]) were mixed to merbau sawdust with different mass ratios in the manufacturing process of merbau pellets. This study aimed to investigate the effect of mixing merbau sawdust and coconut shell particles on merbau pellet properties.

MATERIAL AND METHODS

This study was conducted to investigate the characteristics of merbau wood and coconut shell wastes, and to investigate the effect of combination of different materials to the pellets characteristics.

Raw materials

Merbau (*Intsia bijuga*) wood waste was obtained by a merbau wood industry from Semarang city named Indojati Utama. Coconut (*Cocos nucifera*) shell waste was obtained by a coconut milk industry from Sleman city named UT. Rahman.

Sample drying

Merbau wood sawdust waste and coconut shell waste were dried to a moisture content of ±12%.

Material combination

Prior to material combination, each sample were ground to pass a 60 mesh then intercepted to an 80 mesh sieve. Both samples were then mixed with different mass ratio: (1) merbau 100% (M100), (2) merbau 75%: coconut shell 25% (M75 CS25), (3) merbau 50%: coconut shell 50% (M50 CS50), and (4) merbau 25%: coconut shell 75% (M25 CS75).

Pellet formation

Pellets were manufactured using Carver 2101 hydraulic press single pelletizer with a pressure of 150 kg/m^2.

Pellets compressive strength

Physical characterization of pellets was illustrated by compressive strength. Compressive strength (CST) were inspected using Universal Testing Machine. Compressive strength is expressed as the maximum force of compression applied before failure for pellets with the same weight (N) in accordance to ASTM D4179-01.

Pellets proximate characteristics

Proximate characterization conducted were moisture content (MC), volatile matter content (VMC), ash content (AC), and fixed carbon content (FCC). Moisture content, volatile matter content, ash content, and fixed carbon content were determined using these following equations in which followed the ASTM D3172-89:

$$\text{Moisture Content (\%)} = \frac{a-b}{a} \times 100\% \quad (1)$$

where: a – air-dry sample (g);
b – sample after dried at 105 °C (g).

$$\text{Volatile matter content (\%)} = \frac{b-c}{b} \times 100\% \quad (2)$$

where: c – sample after dried at 950 °C (g).

$$\text{Ash content (\%)} = \frac{d}{b} \times 100\% \quad (3)$$

where: d – sample after dried at 750 °C (g).

$$\text{Fixed carbon content (\%)} = \\ = 100\% - (\text{moisture}, \% + \text{ash}, \% + \\ + \text{volatile matter}, \%) \quad (4)$$

Pellets calorific value

Calorific value (CV) was determined using IKA C-200 automated bomb calorimeter in accordance to ASTM-D5865.

Experimental design

The effect of material combination was analyzed with analysis of variance (ANOVA) conducted using SPSS program (version 20 IBM, New York USA) and the significance differences were set at 95%. The effects which were proven to have a significant effect to the quality of the pellets, would then proceed to a Tukey Honestly Significant Difference (HSD) analysis to investigate the genuine difference between each effects.

RESULTS AND DISCUSSION

Pellets compressive strength

From Table 1 it could be seen that the compressive strength of merbau wood and coconut shell waste pellets varied between 332.31 N and 598.06 N. Larsson and Samuelsson [2017] showed that compressive strength has strong correlation with the durability of pellets. Thus, it is possible to portray compressive strength as the durability of pellet. Highly durable pellets are more preferred, since they could withstand long pressure while in storage or transportation.

Table 2 showed that material combination significantly affected the pellets compressive strength. Figure 1 showed that combination between merbau sawdust and coconut shell particle decreased the pellets compressive strength. This occurance was similar to a study by Hasna et al. [2019] which reported that combination of sengon (*Falcataria mollucana*) and coconut shell particles decreased the pellets compressive strength. Coconut shell contained 40–45% of lignin [Lim & Kosnan, 2015], and high concentration of lignin in biomass generates stiffness [Sajith et al., 2017]. Liu et al. [2016] stated that stiffness resulting in easier destruction of the natural binding between particles in the pelletization process. It would require an elevated temperatures for lignin to soften and help the binding process [Kaliyan & Morey, 2009], while in this study pelletization was not using any heat. Hence, pellet compressive strength decreased as the coconut shell proportion increased.

Table 1. The properties of different types of pellet

Parameter	Material combination				DIN EN 15270
	M100	M75 CS25	M50 CS50	M25 CS75	
CST (N)	598.06±53.38 c	431.34±8.81 bc	347.55±28.25 a	332.31±7.79 a	
MC (%)	10.70±0.29 b	9.70±0.51 a	9.66±0.23 a	9.49±0.32 a	<10
VMC (%)	80.29±0.25 c	80.06±0.67 c	75.11±0.64 b	73.78±0.59 a	
AC (%)	1.82±0.04 c	1.75±0.05 c	1.43±0.07 b	1.26±0.09 a	<0.5
FCC (%)	17.89±0.24 a	18.08±0.66 a	23.46±0.65 b	24.95±0.63 c	
CV (cal/g)	4,758.2±36.44 a	4,763.2±6.91 a	4,813.4±48.50 ab	4,852±32.80 b	>4,302

Note: Average of five pellets ± the standard deviation; The same letters in the same row are not significantly different at p < 5% by Tukey HSD test.

Table 2. One-way ANOVA analysis result

Source of variation	df	CST	MC	VMC	AC	FCC	CV
Material combination	3	*	*	*	*	*	**
Error	16						
Total	19						

Note: df – degree of freedom; * P<0.01; ** P<0.001

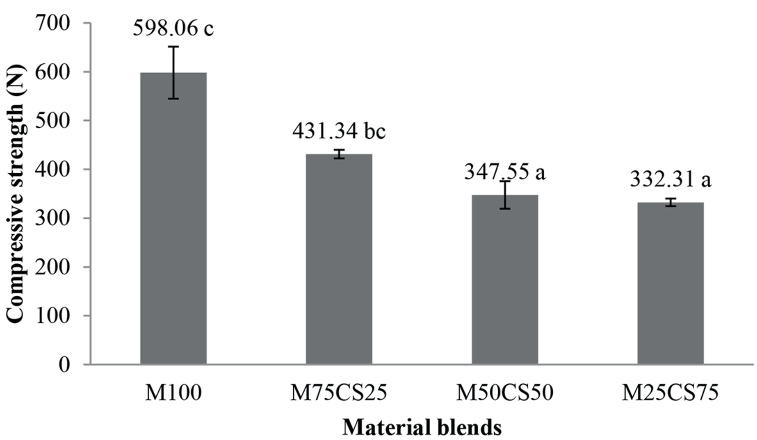

Figure 1. Compressive strength of pellets

Pellets proximate properties

Table 1 showed that The moisture content of merbau wood and coconut shell wastes pellets varied between 9.49–10.70 %, volatile matter varied between 73.38–80.29 %, ash content varied between 1.26–1.82 %, and fixed carbon content varied between 17.89–24.95 %. Compared with DIN EN 15270 pellet quality standard, all of the combination failed to meet the ash content minimum requirement, while only M100 pellets failed to meet the moisture content minimum requirement.

Table 2 showed that material combination significantly affected the proximate properties (MC, VMC, AC, FCC) of merbau wood and coconut shell wastes. Figure 2 showed a significant improvement on the proximate properties of pellets due to combination of merbau sawdust and coconut shell particles. Moisture content, ash content, and volatile matter content decreased as the coconut shell proportion increased, while fixed carbon content increased.

Moisture content

Figure 2 showed that the moisture content of merbau wood and coconut shell wastes pellets was significantly decreasing as the proportion of the coconut shell increased. In other words, it showed that moisture had struggled more to penetrate pellets with higher coconut shell proportion. Low moisture content of pellets is preferrable, since it has a low possibility to attract fungi and pests. Moreover, low moisture content generates higher calorific value. High moisture content of pellets takes more energy, since the energy is firstly used to evaporates the moisture, hence it has lower calorific value (Obernberger & Thek, 2004).

Volatile matter content

Figure 2 showed that as the proportion of coconut shell increased, merbau wood and coconut shell wastes pellets volatile matter content were significantly decreased. Volatile matter influenced the combustion characteristics of pellets. High amount of volatile matter eases ignition process, thus it is easier to start a fire. Generally, volatile matter consisted of short chain and long chain of hydrocarbon in which are evaporated if burned [Chaney, 2010].

Ash content

The ash content depended on the composition of mineral contained in the source of fuel [Dick et al., 2007]. Moreover, the ash content caused slagging or fouling in the combustion chamber which resulting a technical difficulties [Wiloso et al., 2020]. Figure 2 showed that as the proportion of coconut shell significantly increased, the ash content of merbau wood and coconut shell wastes pellets were decreased. Merbau sawdust contained 3.94% of ash [Khasri and Ahmad, 2018], while coconut shell contained 2.28 % of ash [Ewansiha et al., 2012]. Since the coconut shell ash content was less than merbau sawdust, therefore pellet ash content decreased as the coconut shell proportion increased. A similar effect has been reported by Wistara et al. [2017] whereas the increasing bark content of oil palm trunk pellets was generating high content of ash pellets because oil palm bark consisted more ash content than oil palm trunk.

Fixed carbon content

Figure 2 showed that as the proportion of coconut shell increased, the fixed carbon content (FCC) of merbau wood and coconut shell wastes pellets were increased. High amount of FCC resulting in high calorific value. Fixed carbon is a solid carbon which has the role of being the main source of energy [Sukarta et al., 2018], hence the high amount on FCC resulting in high calorific value.

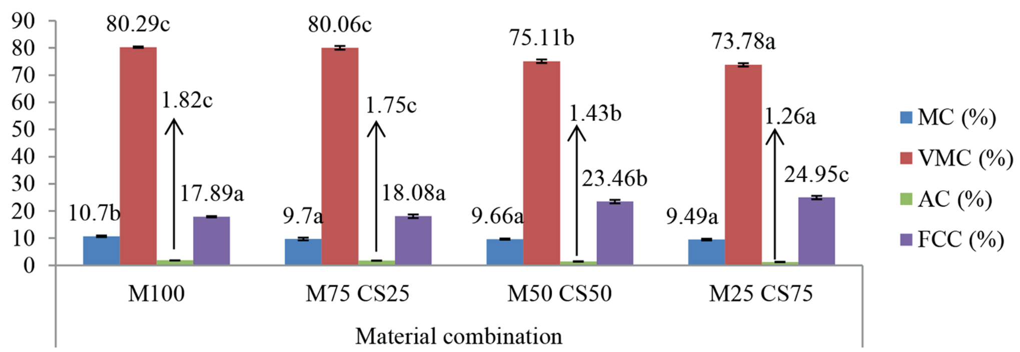

Figure 2. Proximate characteristics of pellets

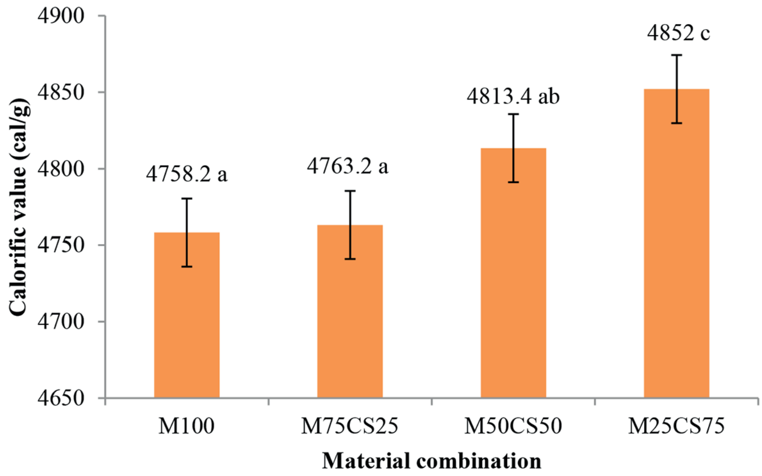

Figure 3. Calorific value of pellets

Pellets calorific value

Table 1 showed that the calorific value of merbau wood and coconut shell wastes pellets varied between 4,758.2–4,852 cal/g. Calorific value shows the energy recovery potential of biomass in the course of thermo-chemical conversion [Pradan et al., 2018].

Figure 3 showed that material combination significantly improved pelet calorific value. Calorific value increased as the coconut shell proportion increased, contrary to Figure 2 which showed decreased moisture content and ash content as the coconut shell proportion increased. Several sutdies reported there are various factors which affect calorific value. Prasetyadi and Sutapa [2022] reported that high fixed carbon content pellets had higher calorific value than lower fixed carbon content pellets, while Demirbas [2002] stated that moisture content and ash content generally decreased calorific value. The moisture content influences combustion effeciency of biomass [Zamorano et al., 2011], and ash content consist of inorganic elements and compounds that inhibit combustion process [Obernberger et al., 1997]. Therefore, higher moisture content and ash content generate lower calorific value biomass. Moreover, calorific value has a highly significant correlation with lignin [Telmo & Lousada, 2011], and coconut shell contained high concentration of lignin. Hence, the calorific value increased as the coconut shell proportion increased.

CONCLUSIONS

The majority of combination pellets characteristics met the DIN EN 15270 pellet quality standard; hence, the merbau wood and coconut shell wastes pellets had a proven quality. Material combination of merbau sawdust and coconut shell particle was an effective way to improve the properties of merbau pellets besides their compressive strength properties.

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