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Full Length Research Article

Influence of Activated Charcoal Addition on the Adhesion, Emission, Physical, Mechanical, and Biological Properties of Particleboard

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ABSTRACT

The objective of this study was to evaluate the use of bagasse-activated charcoal for reduced formaldehyde emissions and their effect on the physical, mechanical, and biological properties of particleboard. Activated charcoal was made by carbonizing bagasse at 300°C for 2.5 h, followed by carbon activation using a 0.1M HCl solution for 24 h. Particleboards were made of a mixture of bagasse and wood particles with a ratio of 100:0, 75:25, 50:50, 25:75, and 0:100. The concentrations of activated charcoal used in manufacturing particleboards were 2, 4, and 6% based on the dry weight of the particles. Particleboards were made with a target density of 0.7 g/cm³ and hot-pressed at 140°C for 10 min with a pressure of 35 kg/cm^2. The observed parameters were formaldehyde emission levels, physical properties, mechanical properties, and biological properties of particleboards. The results showed that the more activated charcoal added in the manufacture of particleboards decreased formaldehyde emissions of the panel. Based on the SNI 5008.2:2016, the overall formaldehyde emission value of particleboard in this study with activated charcoal is in the F* category. The addition of activated charcoal improved the physical, mechanical, and biological properties of particleboards in terms of increased density, decreased water content, water absorption, and thickness swelling, increased modulus of elasticity, modulus of rupture, internal bonding, and screw withdrawal, as well as increased resistance to termites. The particleboard with the addition of 6% activated charcoal showed better mechanical, physical, and biological properties. All physical and mechanical properties of particleboard met the JIS A 5908-2003 Type 8 standards, except for the modulus of elasticity.

1. Introduction

The sugar industry produces large amounts of solid waste that has not been optimally utilized, so it becomes an environmental problem (Nonaka et al. 2013). One approach to reducing the amount of waste is to recycle waste into valuable products. For example, sugarcane waste or bagasse is rich in compounds containing cellulose, hemicelluloses, and lignin (Thamara et al. 2018), making it suitable to be used as a raw material for making particleboards. Particleboard is a composite product made of wood wastes bonded with synthetic adhesives or other adhesives and compacted with pressure at high temperatures (Asha 2017).

Particleboards are generally made using the synthetic adhesive urea-formaldehyde (UF). Its relatively low price makes this adhesive widely used in the composite industry. The use of UF adhesive has been modified to produce a low molar ratio of Urea-Formaldehyde to improve the quality of the UF adhesive with low emissions (Lubis and Park 2018). Other advantages of UF adhesives are resistance to high humidity and fast-curing (Roffael et al. 2010), high reactivity, and water-soluble (Rowell 2012). In addition, formaldehyde-based adhesives can increase cross-bonding (Kumar et al. 2013). However, the urea-formaldehyde adhesive has a detrimental impact that causes formaldehyde emissions which interfere with human health. According to WHO (2010), formaldehyde emission at a concentration of 0.1 mg for 30 min can cause health problems. Other health problems due to formaldehyde emissions are natural disorders, irritation of the skin and eyes (Wolkoff and Nielsen 2010), irritation of the nose and throat (Aydin et al. 2014), cancer, and leukemia (Antov et al. 2020).

Formaldehyde in composite products can last for five years when used indoors (Wolkoff and Nielsen 2010). Some countries have specified permissible formaldehyde emission limits based on the impact caused by formaldehyde emissions. For example, the Japanese Standard (JSA 2015) requires a maximum formaldehyde emission value of 2.1 mg/L and 5 mg/L for the Indonesian Standard (BSN 2016). Formaldehyde emission can be reduced in several ways, such as using urea, ammonia, ammonium salts, tannin, and wood bark (Antov et al. 2020). A recent study by Lubis and Park (2018) proved that low molar ratio UF resin adhesives could decrease formaldehyde emissions. Another material that can lower formaldehyde emissions is activated charcoal. Activated charcoal is charcoal activated by activation. This activation process aims to enlarge the area of the active charcoal surface pores to increase adsorption power. A newly discovered material that can be used to reduce formaldehyde emissions is nanoclay (Lubis and Park 2021).

Studies on reduction in formaldehyde emissions using activated charcoal have been conducted by some researchers using various materials such as sawdust (Trisatya et al. 2018), small diameter wood waste (Santoso and Pari 2012a), *Cryptomeria japonica* wood (Asano et al. 1999), and rayon fiber (Rong et al. 2002). Furthermore, the manufacture of activated charcoal from bagasse has also been done. However, its use is limited as an adsorption medium to improve the quality of water (Nurhayati et al. 2015), as an adsorbent to reduce iron and manganese mine acid waste (Imani et al. 2021), as an adsorbent color of river water (Apriani et al. 2014), and to reduce free fatty acids in used cooking oil as biodiesel (Sari and Kembaren 2019). Nevertheless, up to now, there is no study has been reported on activated charcoal from bagasse to reduce formaldehyde emissions of particleboards. Therefore, this study aimed to produce low formaldehyde emission particleboard by adding bagasse-activated charcoal to the particleboard, mixing bagasse and wood powder with a urea-formaldehyde adhesive, and to evaluate its effect on the physical, mechanical, and biological properties.

2. Materials and Methods

2.1. Materials

The bagasse collected from Pontianak City were used as raw materials for particleboard and activated charcoal production. In addition, waste sawdusts obtained from the furniture industry around Pontianak City were used as material for manufacturing particleboard.

2.2. Preparation of Bagasse Particles

Bagasse was washed with water to remove dirt, and then it was soaked in hot water at 100ºC for 2 h and left in the room at room temperature for two weeks. Bagasse was then cut, measuring 2-3 cm, and then milled using a hammer mill (R175A Diesel Engine 7 HP/2600RPM) and sieved with a pass size of 8 mesh retained of 10 mesh. Afterward, bagasse was dried in an oven at a temperature of 60 ± 3ºC until the water content reached ± 5%.

2.3. Preparation of Sawdust

Wood powder in the form of waste sawdust was obtained from the furniture industry. The sawdust was soaked with hot water at 100ºC for 2 h to reduce the extractive substances. After that, the sawdust was placed outside under the sunlight for 8 h, then sieved to 8 mesh and retained 10 mesh. Sawdust was then oven-dried at 60 ± 3ºC until the moisture content reached ± 5%.

2.4. Activated Charcoal Manufacturing

Activated charcoal was made from bagasse particles that were dried in the oven at 105°C until a constant weight was obtained. Furthermore, the carbonization process was carried out by inserting bagasse particles into the homemade furnace with a length of 1 m and a diameter of 10 cm made of stainless-steel tube equipped with a coolant and electrical elements as a thermocouple at a temperature of 300°C for 2.5 h. Bagasse charcoal was sieved to get a particle size of 200 mesh. The process was continued with activated carbon activation by soaking bagasse charcoal in HCl 0.1 M activator for 24 h. Then the activated charcoal was filtered and washed using distilled water until the pH reached seven and then dried in an oven at 150°C for 2 h.

2.5. Particleboard Manufacturing

Particleboards were made measuring 30 cm x 30 cm x 1 cm with a target density of 0.7 g/cm^3. Urea formaldehyde with 52% solids content was used as a binder with a concentration of 12%, mixed with NH_4Cl of 0.1% as a catalyst, and liquid paraffin of 1%, each weighed based on the dry weight of the particles. The manufacture of particleboards was done by mixing activated charcoal, sawdust, bagasse, and adhesive. The compositions of bagasse and sawdust were 75:25, 50:50, and 25:75, while the levels of activated charcoal were 2%, 4%, and 6% based on the dry weight of the particles. After well mixed, the mixture was put into a mold and pre-pressed for 1 min, and then the board was compressed at a temperature of 140ºC for 10 min with a pressure of 35 kg/cm^2 (Iskandar and Supriandi 2013). The resulting particleboard was conditioned for seven days at room temperature before testing.

2.6. Particleboards Evaluation

2.6.1. Formaldehyde emission

The formaldehyde emission of PB was determined based on the Indonesian National Standard SNI 01-7140-2005 (BSN 2006) on testing the formaldehyde emissions of wood panels using the desiccator method. The test samples were arranged and clamped with wire clamps, placed on a cup containing distilled water in a desiccator, and closed (**Fig. 1**). The desiccator was then conditioned at a temperature of 20 ± 1ºC for 24 h.

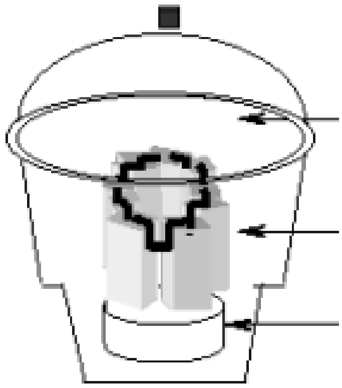

Fig. 1. Formaldehyde emission test according to SNI 01-7140-2005 (BSN 2006).

2.6.2. Physical properties

The physical properties tested included moisture content (MC), water absorption (WA), and thickness swelling (TS). The physical test was based on the JIS A 5908:2003 standard (JSA 2015). MC was measured using a test sample of 10 cm × 10 cm × 1 cm. The test sample was weighed in air-dry conditions to obtain the initial weight, then put into an oven at 103 ± 2ºC until it reached a constant weight. The MC value was calculated as follows:

$$MC\ (\%) = \frac{Initial\ weight\ (g) - Oven\ dry\ weight\ (g)}{Oven\ dry\ weight\ (g)} \times 100\% \quad (1)$$

The test sample used for the water absorption test measured 5 cm × 5 cm × 1 cm. WA was calculated based on the difference in weight before and after soaking for 24 h. Before immersion, the test sample was weighed to obtain the initial weight. After immersion for 24 h, the test sample was weighed again to obtain the weight after immersion. As a result, the WA was calculated using the following formula:

$$WA\ (\%) = \frac{Weight\ after\ immersion\ (g) - Weight\ before\ immersion\ (g)}{Weight\ before\ immersion\ (g)} \times 100\% \quad (2)$$

The test sample used for the TS test measured 5 cm × 5 cm × 1 cm. The thickness of the air-dry sample was measured at 5 points (before immersion in distilled water). After immersion in distilled water for 24 h, the test sample was measured again at 5 points. The TS value was calculated as follows:

$$TS\ (\%) = \frac{Thickness\ after\ immersion\ (g) - Thickness\ before\ immersion\ (g)}{Thickness\ before\ immersion\ (g)} \times 100\% \quad (3)$$

2.6.3. Mechanical properties

The mechanical properties tested included modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding (IB), and screw withdrawal (SW). According to JIS A 5908:2003 (JSA 2015), a mechanical test was carried out. The test sample for the MOE test measured 20 cm × 5 cm × 1 cm. The MOE test was carried out using a universal testing machine, which is first determined by the distance of the rebuttal on the test equipment. At the time of testing, the amount of deflection that occurs at each change in a specific load is recorded. The MOE value was calculated as follows:

$$MOE\ (kg/cm^2) = \frac{PL^3}{4Ybh^3} \quad (4)$$

where P is the load proportion limit (kg), L is the support distance (cm), Y is bending at load P (cm), b is the width of the test sample (cm), and h is the thickness of the test sample (cm).

The MOR was a continuation of the MOE test with a similar test sample by giving a load up to the fracture limit of the test sample. The MOR value was calculated as follows:

$$MOR\ (kg/cm^2) = \frac{3PL}{bh^2} \quad (5)$$

where P is the load proportion limit (kg), L is the support distance (cm), Y is bending at load P (cm), b is the width of the test sample (cm), and h is the thickness of the test sample (cm).

The test sample used for testing the IB measured 5 cm × 5 cm × 1cm, which was glued to two iron plates and then pulled perpendicular to the test sample until damage occurred. The IB value was calculated as follows:

$$IB\ (kg/cm^2) = \frac{P}{2bL} \quad (6)$$

where P is the maximum load (kg), b is the length of the test sample (cm), and L is the width of the test sample (cm).

The SW test used a sample measuring 5 cm × 10 cm × 1 cm. The surface of the test sample was installed with a screw diameter of 2.7 mm with a length of 16 mm, which was installed perpendicular to the center of the surface of the test sample until it reached a depth of 8 mm. Then, the test sample was clamped on the right and left, and the screw was pulled up to the maximum load limit until the screw was pulled out. The maximum load achieved is expressed in kg.

2.6.4. Termite resistance

The subterranean termite method in No-Choice Test and Choice Test refers to Ohmura et al. (2000) with modifications. In the No-Choice Test method, the subterranean termite test containers used a plastic cup measuring 5 cm in diameter and 6 cm high. Each cup was filled with sand with a size of 30 retained of 50 mesh as much as 10 g, which had previously been sterilized using an autoclave for 30 min at a temperature of 120ºC with a pressure of 1 atm. Sand is moistened with water as much as 2 mL to maintain moisture. A plastic gauze measuring four cm in diameter was given on the top of the sand to prevent the test sample from coming into direct contact with the sand. Then, one sample of particleboard with known oven-dry weight and 55 subterranean termites *Coptotermes curvignathus* were added into the plastic cup with a ratio of 50 worker caste and five soldier caste.

Meanwhile, the Choice Test method used a test container measuring 20 cm in diameter and 10 cm in height. Sterile sand was inserted into the test container as high as one cm in the No Choice Test method and moistened with 10 mL of water into the test container, test samples of all treatments and termites *C. curvignathus* as many as 150 workers castes and 15 castes of soldiers. The test units were kept in the darkroom at a temperature of 26.9-28.3°C and humidity of 70-82% for 21 days. The study was conducted in five replications.

At the end of the test, the sample was removed from the test container, cleaned of adhering dirt, dried in the oven, and weighed to determine the weight after testing. The experimental parameters included weight loss of filter paper and termite mortality.

2.7. Data Analysis

Analysis of formaldehyde emission data, physical, mechanical, and biological properties was analyzed using Completely Randomized Design (CRD) with two factors. The two factors were the amount of activated charcoal (2%, 4%, and 6%) and the composition of sawdust and bagasse (75%:25%, 50%:50%, 25%:75%). Each factor was repeated three times. Samples codes used in this study are as follows:

a = Solid wood control,
b = Particleboard control composition 50% sawdust:50% bagasse without any addition of activated charcoal,
c1 = 2% activated charcoal with particleboard composition 75% sawdust:25% bagasse,
c2 = 2% activated charcoal with particleboard composition 50% sawdust:50% bagasse,
c3 = 2% activated charcoal with particleboard composition 25% sawdust:75% bagasse,
d1 = 4% activated charcoal with particleboard composition 75% sawdust:25% bagasse,
d2 = 4% activated charcoal with particleboard composition 50% sawdust:50% bagasse,
d3 = 4% activated charcoal with particleboard composition 25% sawdust:75% bagasse,
e1 = 6% activated charcoal with particleboard composition 75% sawdust:25% bagasse,
e2 = 6% activated charcoal with particleboard composition 50% sawdust:50% bagasse,
e3 = 6% activated charcoal with particleboard composition 25% sawdust:75% bagasse.

3. Results and Discussion

3.1. Activated Charcoal Quality

Bagasse activated charcoal with HCl 0.1M activator has met the quality standard of activated charcoal according to the SNI 06-3730-1995 standard (BSN 1995). The results of the analysis of bagasse-activated charcoal are presented in **Table 1**.

Table 1. Analysis of bagasse-activated charcoal

No	Parameters	SNI 06-3730-1995	Analysis results
1	Volatile matter at 950°C (%)	Max. 25	16.67
2	Moisture content (%)	Max. 15	10.54
3	Ash content (%)	Max. 10	6.12
4	Fix carbon (%)	Min. 65	66.68
5	Iodine adsorption (mg/g)	Min. 20	23.80

Volatile matter is volatile compounds other than water in activated charcoal (Sahara 2017). **Table 1** shows that volatile matter is 16.67%. The content of this volatile matter met the SNI 06-3730-1995 standard, showing value of < 25%. With the same carbonization temperature as in this study (300°C), the bagasse-activated charcoal's volatile matter content was lower than the bagasse-activated charcoal research by Nurhayati et al. (2015), which is 97%. It was due to the differences in the activator materials used. Nurhayati et al. (2015) used $CaCO_3$ as an activator, while this study used HCl. Imani et al. (2021) used the same activator material as this study (HCl 0.1 N) and reported a volatile matter of activated charcoal from bagasse was 18.80%, higher than this study. However, the volatile matter content of this study is higher than that of Kurniasih et al. (2020), which is 15.77% which also made bagasse activated charcoal with an activator material of wuluh starfruit solution with 24 h of immersion. Differences in the activator material are thought to cause differences in the levels of these volatile matters.

The moisture content of bagasse-activated charcoal is 10.54% (**Table 1**). This value met the the SNI 06-3730-1995 standard because it is less than 15%. The lower the moisture content of the activated charcoal caused the bigger pores and increased the surface area of the activated charcoal. The increase in the surface area led to an increase in activated charcoal adsorption so that the quality of the activated charcoal improved (Idrus et al. 2013).

Ash content is the remaining minerals after the sample is burned. The SNI 06-3730-1995 standard requires the ash content of activated charcoal not to exceed 10%. The ash content of the bagasse-activated charcoal in this study is 6.12%, so it complied with the SNI 06-3730-1995 standard. However, ash content can affect the quality of activated charcoal, where the presence of excessive ash can cause clogging of pores resulting in reduced surface area of activated charcoal (Asbahani 2013).

Pure activated charcoal is carbon resulting from decomposition other than ash and water does not evaporate during testing of volatile matter at high-temperature heating. This study's pure activated charcoal content complied with the SNI 06-3730-1995 standar because it is greater than 65%, which was 66.68%. According to Tadda et al. (2009), volatile matter factors affect pure activated charcoal content. Therefore, the smaller volatile matter content caused the higher pure activated charcoal content.

The iodine adsorption is a parameter to determine the quality of activated charcoal because it indicates the amount of iodine absorbed in 1 g of activated charcoal (Nurhayati et al. 2015). Based on the analysis results, the iodine adsorption value met the SNI 06-3730-1995 standard because it was greater than 20 mg/g, which is 23.80 mg/g. However, even though it meets the standards, the iodine adsorption value was lower than the research of Nurhayati et al. (2015) of 285 mg/g. This can be explained because the carbonization process at temperatures below 350°C causes the bagasse not to be fully carbonized (Nurhayati et al. 2015).

3.2. Formaldehyde Emission

The disadvantage of using formaldehyde-based synthetic adhesives is that they produce formaldehyde emissions which at certain levels can interfere with human health. The average value of particleboard formaldehyde emission in this study ranged from 3.95 – 3.05 mg/L (**Table 2**). **Table 2** shows that the more activated charcoal added in the manufacture of particleboards leads to low formaldehyde emission levels. This tendency can be explained because the activated charcoal contains chemical compounds that are polar and positively charged, absorbing free formaldehyde (Kumar et al. 2013). The results of this study are supported by the previous studies (Darmawan et al. 2010; Resmi and Narayanankutty 2017; Santoso and Pari 2012a; Trisatya et al. 2018).

Table 2 shows a significant difference between the control particleboard and the particleboard with the addition of activated charcoal. There is no significant difference among all particleboards with the addition of activated charcoal. The composition of sawdust and bagasse powder has no effect on the formaldehyde emission on the board.

Based on the SNI 5008.2:2016, the overall formaldehyde emission value of particleboard in this study with activated charcoal is in the F* category, namely particleboard which has an average value of formaldehyde emission of 5.0 mg/L. On the other hand, the control particleboard made without activated charcoal had a formaldehyde emission of 5.03 mg/L, showing a value that exceeded the limit required by the SNI 5008.2:2016 standard. These results prove that the activated charcoal of bagasse added in the manufacture of bagasse and sawdust particleboards can absorb free formaldehyde from adhesives released during hot pressing so that formaldehyde emission is lower (Santoso and Pari 2012b).

Table 2. Emission formaldehyde content of bagasse and sawdust based-particleboard with the addition of bagasse-activated charcoal

No	Samples	Average formaldehyde emission levels (mg/L)	Formaldehyde emission requirements SNI 5008.2:2016	
			Average value (mg/L)	Maximum value (mg/L)
1	a	0	F**** 0.3	0.4
2	b	5.03 (0.54)	F*** 0.57	0.7
3	c1	3.95 (0.07)	F** 1.5	2.1
4	c2	3.38 (0.68)	F* 5.0	7.0
5	c3	3.31 (0.66)		
6	d1	3.2 (0.64)		
7	d2	3.19 (0.36)		
8	d3	3.61 (0.40)		
9	e1	3.15 (0.46)		
10	e2	3.28 (0.51)		
11	e3	3.05 (0.48)		

Notes: Numbers in parentheses indicate the value of the standard deviation.

Even though it met the SNI 5008.2:2016 standard, the particleboard formaldehyde emissions in this study are still high because it is in the F* category with an average formaldehyde emission value of 5.0 mg/L. It might be due to the high level of UF adhesive used, which is 12%, that caused the high formaldehyde emission of particleboards. Christensen et al. (1981) explained that the high value of formaldehyde emissions could be caused by the high levels of free formaldehyde in the adhesive used. In addition, the use of low molar ratio urea-formaldehyde resin adhesives can also reduce formaldehyde emissions (Lubis and Park 2020).

3.3. Physical Properties

The particleboard with activated charcoal was darker in color than the control particleboard (**Fig. 2**). In comparison, particleboard with more activated charcoal added has a darker color than particleboard with fewer amounts of activated charcoal (**Fig. 2**). Darmawan et al. (2015) supported these results, reporting that MDF given activated charcoal has a darker color than the control MDF.

The average moisture content of particleboard ranged from 6.83-8.31%, where the board moisture content tends to decrease with the increase in the amount of activated charcoal used (**Fig. 3**). Tristaya et al. (2018) and Santoso and Pari (2012a) reported similar results to this study. The entire particleboard of this study has a moisture content value that meets the JIS A 5908-2003 Type 8 standard with a maximum moisture content requirement of 13%. Statistical analysis shows that the addition of activated charcoal had a significant effect on the value of moisture content of particleboard. The moisture content value was not significantly different between particleboard with the addition of activated charcoal but substantially different from control particleboard without the addition of activated charcoal.

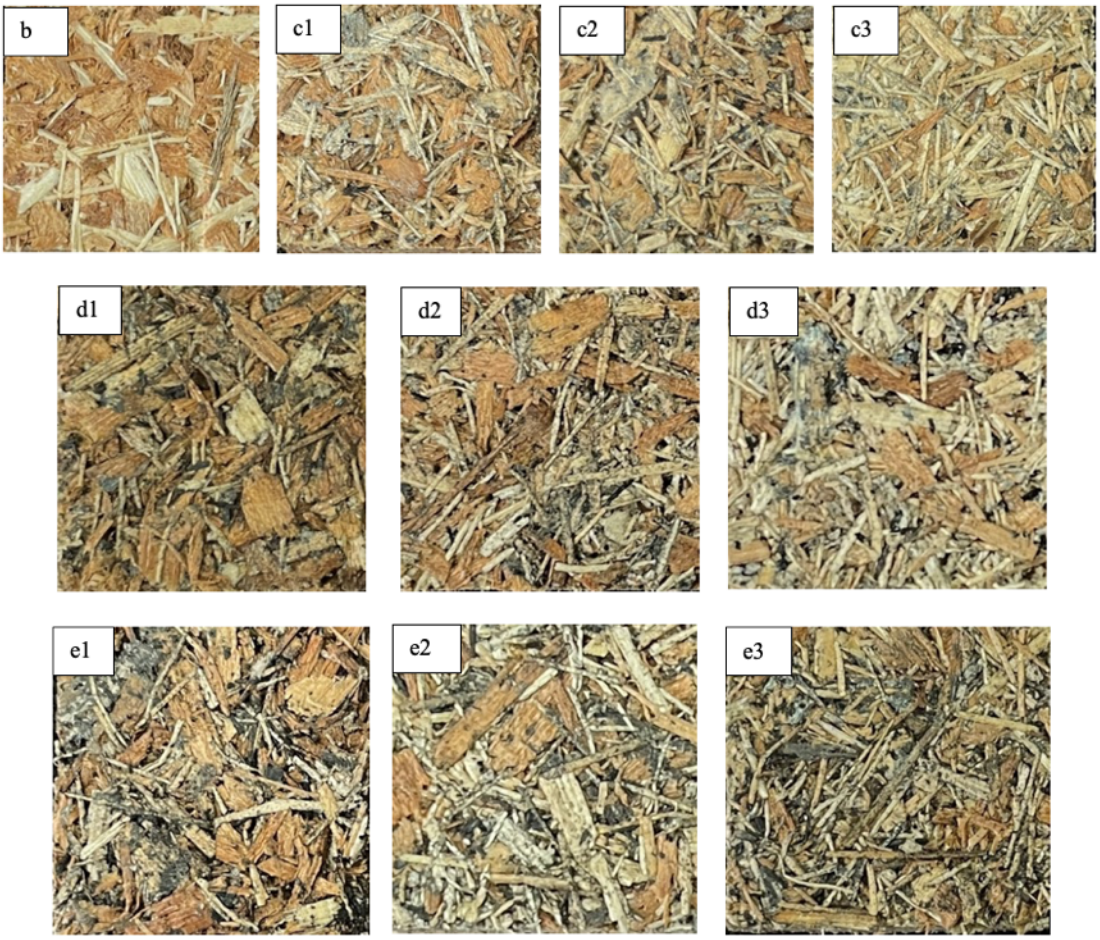

Fig. 2. Visual observation of the surface of particleboard.

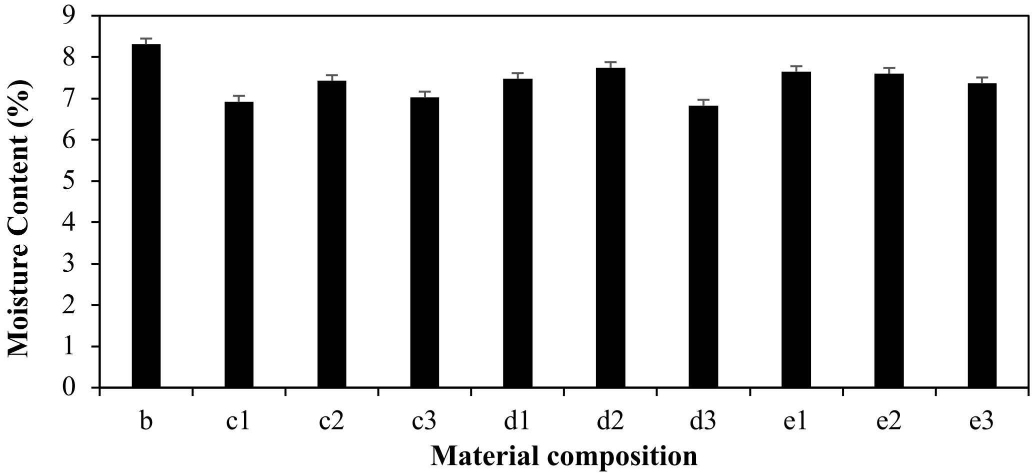

Fig. 3. The moisture content of bagasse and sawdust particleboard at various levels of activated charcoal.

The thickness swelling value of particleboard varies from 5.90-10.93% (**Fig. 4**). The value of thickness swelling of the particleboard with the addition of activated charcoal is smaller than that of the control particleboard (without activated charcoal), which is 22.60%. The overall thickness swelling value of particleboard in this study (except control board) complies with the JIS A 5908-2003 Type 8 standard with a maximum thickness swelling requirement of 12%. The analysis of variance showed that the amount of activated charcoal and the composition of the material had a significant effect on the thickness swelling and water absorption.

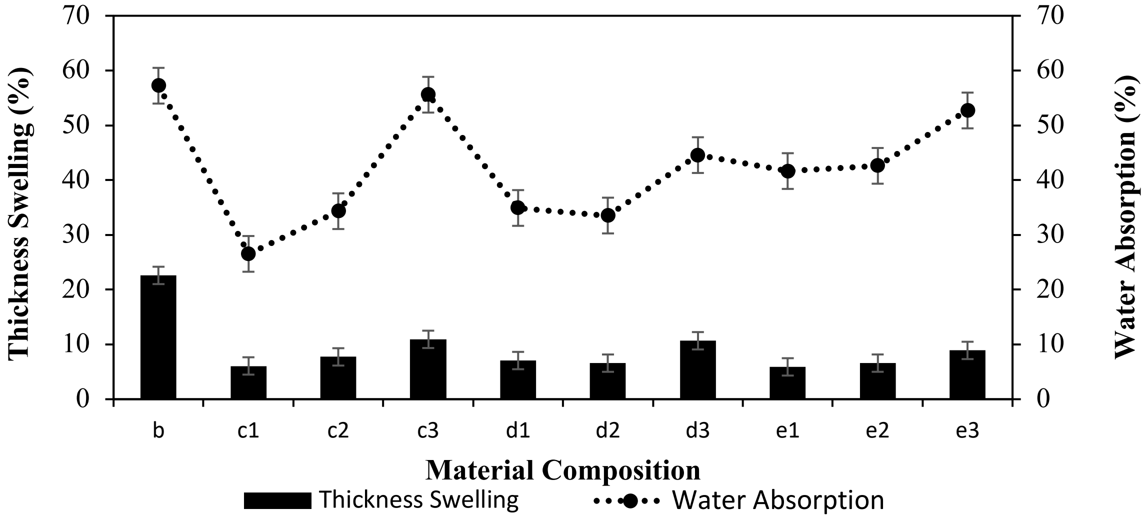

Fig. 4. Thickness swelling and water absorption of bagasse and sawdust particleboard at various levels of activated charcoal.

Fig. 4 shows that the more activated charcoal content in the particleboard causes the thickness to expand and decreases water absorption. The results of this study were supported by Darmawan et al. (2010), who examined the effect of adding activated charcoal to MDF formaldehyde emissions. The composition of the material also affects the value of thickness swelling and water absorption. The more bagasse content in the particleboard causes the higher thickness swelling and water absorption. The relationship between thickness swelling and water absorption is shown in **Fig. 4**, where the thickness expansion results in higher water absorption of particleboard. Similar results were also reported by Darmawan et al. (2010).

3.4. Mechanical Properties

The mechanical properties of modulus of elasticity (MOE) and modulus of rupture (MOR) are presented in **Fig. 5**. The MOE values varied from 599.25 – 1193.58 kg/cm^2. The overall MOE value of particleboard in this study did not meet the standard JIS A 5908-2003 Type 8 with a minimum MOE value requirement of 20400 kg/cm^2. However, this MOE value is higher than the results of Darmawan et al. (2010) research, which examined bagasse particleboard and resulted in MOE values varying from 23.32 to 34.79 kg/cm^2.

The smallest MOE value was found on particleboard with 6% activated charcoal, and the highest value was observed on particleboard with 2% activated charcoal. Similar results were reported by Santoso and Pari (2012b) and Darmawan et al. (2010). The highest MOE values were found on particleboard with a material composition of 75% sawdust and 25% bagasse. This suggests that more bagasse content causes MOE value to decrease. This result is supported by Mikael et al. (2015), who examined particleboard from bagasse and mahogany wood powder.

The MOR values of all particleboards in this study meet the standard JIS A 5908-2003 Type 8 with a minimum MOR value requirement of 82 kg/cm^2. The MOR value resulting in this study ranged from 150.29 – 286.69 kg/cm^2 (**Fig. 5**), where the smallest value was found on the control board. In contrast, the highest value was found on the board with the addition of 2% activated charcoal and material composition of 75% sawdust and 25% bagasse. This study proves that adding activated charcoal in higher amounts leads to low MOR values. It is presumably because the activated charcoal used is small. As McCabe and Walls (2008) said, a larger filler size causes a better strength and vice versa. These results align with the research of Darmawan et al. (2010) and Santoso and Pari (2012b). However, the MOR value of the particleboard in this study is higher than the previous research (Santoso and Pari 2012b) that used small diameter wood as the materials for making particleboard and activated charcoal.

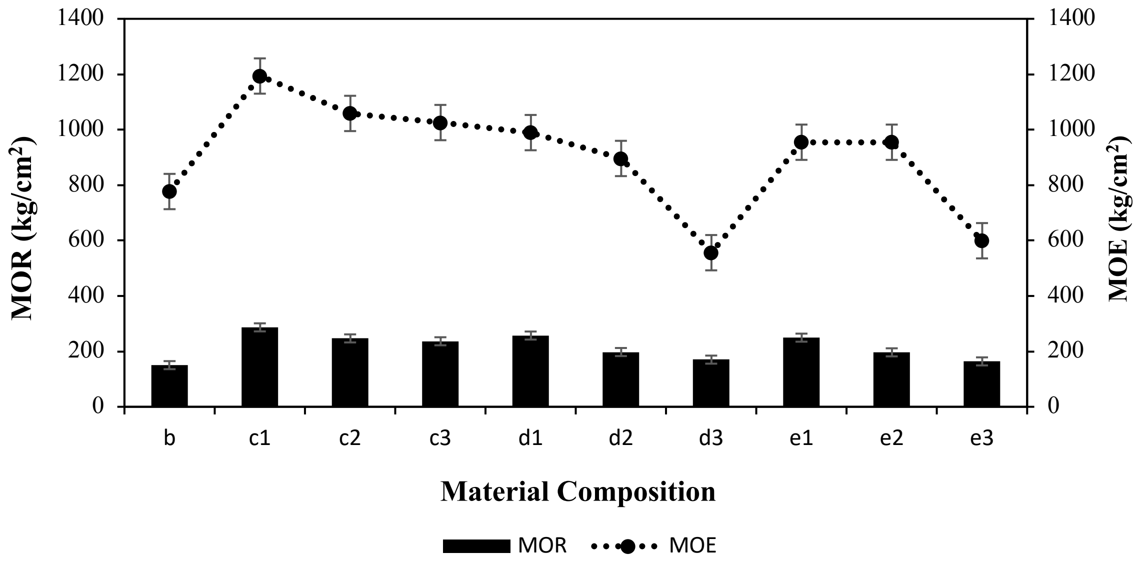

Fig. 5. MOE dan MOR of bagasse and sawdust particleboard at various levels of activated charcoal.

The mechanical properties of the screw holding strength indicate the particleboard strength to having screws of a specific size. The average value of screw holding of particleboard in this study ranged from 57.6-81.15 kg (**Fig. 6**).

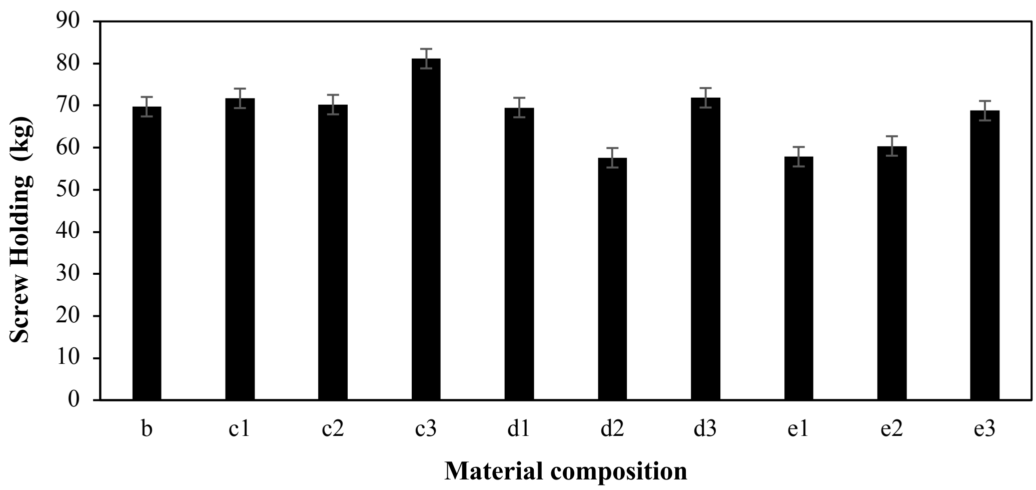

Fig. 6. Screw holding of bagasse and sawdust particleboard at various levels of activated charcoal.

The value of screw holding strength met the JIS A 5908-2003 Type 8 standard which requires a minimum screw holding strength of 31 kg. The value of the screw holding of this study was higher than that of Santoso and Pari (2012b), which resulted in the holding strength of particleboard with the addition of activated charcoal, which was 42.12-78.41 kg. **Fig. 6** shows that the higher amount of activated charcoal added causes the particleboard screw holding strength value to be lower. A large amount of activated charcoal caused a decrease in the bonding strength between the particles and the adhesives, thereby reducing the value of the screw holding strength.

Internal Bonding (IB) tests were conducted to determine the quality of the adhesive in binding the sawdust and bagasse. The average value of IB in this study ranged from 2.87-4.2 kg/cm^2 (**Fig. 7**). This IB value meets the JIS A 5908-2003 Type 8 standard, requiring a minimum IB value of 1.5 kg/cm^2. The results of this study are in line with those of Santoso and Pari (2012b) and Darmawan et al. (2010). However, the IB value of this study is higher than that of Santoso and Pari (2012b), which was 1.54-2.64 kg/cm^2.

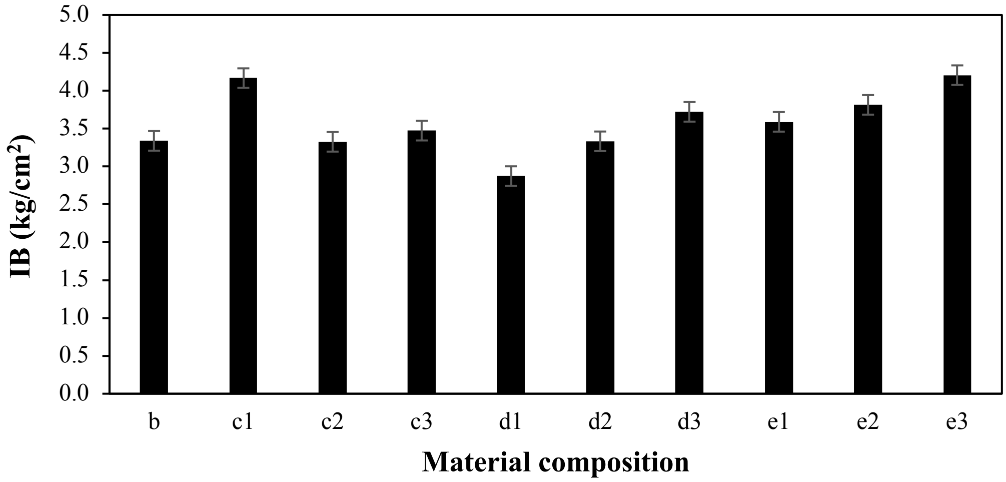

Fig. 7. Internal bonding (IB) strength of bagasse and sawdust particleboard at various levels of activated charcoal.

3.5. Termite Resistance

The average value of particleboard and solid wood weight loss using the no-choice and choice-test methods is presented in **Fig. 8**. The weight loss of particleboard in both the No-choice test and Choice-test has the same trend, namely, the higher the activated charcoal content, the lower the particleboard weight loss.

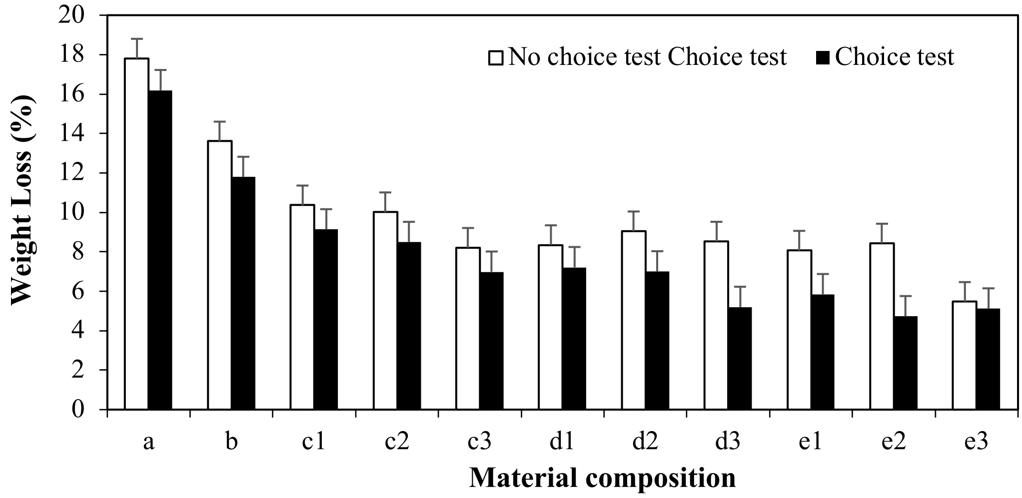

Fig. 8. Weight loss of particleboard after exposure to subterranean termite in No-choice test and Choice-test methods.

The average weight loss of particleboard in this study ranged from 5.47%-13.61% for the No-choice test method and 5.12%-11.79% for the Choice-test method, where the smallest weight loss value was found in particleboard with a composition of 25% sawdust: 75% bagasse and 6% activated charcoal content and the highest value was found in the control particleboard (without any addition of activated charcoal). The weight loss value of particleboard is lower than that of solid wood, which is 16.19% for the No-choice test and 17.80% for Choice-test methods. The low weight loss of particleboard compared to solid wood is due to the presence of UF adhesive in the particleboard. The adhesive properties of this type can inhibit the attack of wood-destroying insects, including termites.

Activated charcoal also causes this particleboard to be disliked by termites. The analysis of activated charcoal shows that the compounds in activated charcoal are ash, volatile matter, and pure activated charcoal, whereas termites do not favor these compounds. It is known that termites only degrade cellulose compounds from wood and its derivatives for survival. Therefore, the higher activated charcoal content in the particleboard causes a lower weight loss. The value of particleboard weight loss in the No-choice test method is higher than in the Choice-test method. This is because, in the No-choice test method, termites are placed in a test unit with particleboard without any other food options so that in such conditions, termites are forced to eat the bait in the test unit. Meanwhile, in the Choice-test method, termites were given a choice of food by placing all particleboards with different material compositions and levels of activated charcoal in a test unit so that termites could choose the particleboard they preferred to eat.

Termite mortality ranges from 15.15-98.79%, where the minor mortality was observed in solid wood, and the largest mortality was in particleboard is 25% wood powder: 75% sugarcane pulp with an active charcoal content of 6% (**Fig. 9**). In contrast, the mortality of the control particleboard was 21.21%. These results suggest that solid wood is preferred by termites as its food in this test, as solid wood contains less UF adhesive. In addition, Termite mortality on particle boards containing activated charcoal is higher than on control particle boards. This is because the activated charcoal used in this study includes 66.68% fix-carbon (pure activated charcoal), whereas the more active charcoal compounds can cause termite death.

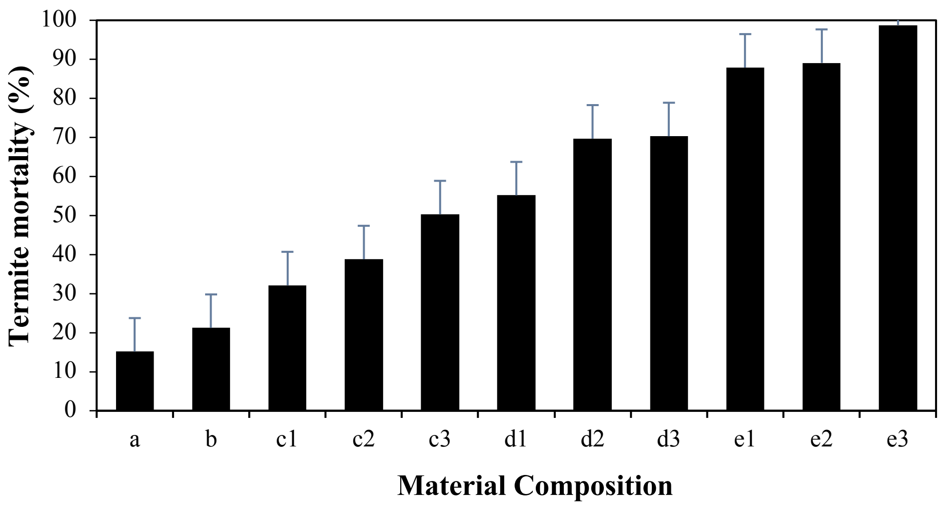

Fig. 9. Termite mortality in the No-Choice test method.

4. Conclusions

The bagasse-activated charcoal produced in this study complied with the SNI 06-3730-1995, showing a volatile matter content of 16.67%, the moisture content of 10.54%, ash content of 6.12%, fix-carbon 66.68%, and absorption capacity to I2 23.8%. Bagasse-activated charcoal can reduce formaldehyde emission from particleboard between 5.03 mg/L to 3.05-3.95 mg/L. The emission value met the SNI 5008.2: 2016 standard, which is included in the F* category with an average formaldehyde emission value of 5.0 mg/L and a maximum of 7.0 mg/L. The addition of activated charcoal could improve the physical properties of particleboard in the form of increasing density, decreasing water content, thickness swelling, and water absorption. The overall physical properties of the particleboard in this study met the JIS A 5908-2003 Type 8 standard. The addition of activated charcoal in particleboard manufacture improved the mechanical properties, including MOE, MOR, IB, and screw holding strength. However, the MOE parameters did not meet the JIS A 5908-2003 Type 8 standard, while the MOR, IB, and screw holding strength parameters met the JIS A 5908-2003 Type 8 standard. The resistance of particleboard to termite attacks increased with active charcoal, as indicated by decreased weight loss and increased termite mortality.

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