Evaluation possibilities to utilize rice straw and plastic waste for particleboard

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Abstract. Rice straw is an abundant waste from almost rice field in Asia. Plastic is also an abundant waste in many countries which damages the environment seriously, while the need for wood continues to increase. To overcome these environmental problems we have developed a particleboard from rice straw by using plastic waste polypropylene as a matrix with the rice straw compositions of 30, 40, 50, 60, and 70 wt. %. Some physical properties (density and thickness swelling) and mechanical properties (modulus of rupture, modulus of elasticity, and compressive strength) of the particleboard have been measured. Our results showed that the density of rice straw polypropylene particleboard is found to be 0.56 g/cm³ to 0.8 g/cm³. Its thickness swelling after immersion in the water for 24 hours is less than 5%. Its modulus of rupture is found to be 83 to 134 kgf/cm². The modulus of elasticity is 3.3x10⁴ to 4.5x10⁴ kgf/cm² and the compressive strength is about 6.7 MPa. Our analysis revealed that the rice straw polypropylene particleboard with the rice straw compositions of 30, 40, 50, and 60 wt. % meets the Indonesian National Standard and Japanese Industrial Standard requirements for particleboard.

1. Introduction

The rice production in the world has been improved recently. According to FAO, the total rice production in the world is about 500 million tons in 2017 [1]. Most paddy production is from Asia such as China, India, Indonesia, Bangladesh, Vietnam, etc. The paddy production in Indonesia is about 70 million tons in 2017 [1]. Rice straw is an abundant agriculture residue from a rice field in Indonesia and some other places in the world. Until now, only a small amount of rice straw waste in Indonesia is used for animal feed and compost fertilizer, while farmers leave others in the fields. Meanwhile, the previous study found that agricultural residues have a great prospect for the global panels industry [2-7]. This material contains 32-47% of cellulose, 19-27% of hemicelluloses, and 5-24% of lignin [8], which is potential to be a filler in the composite material. Akyildiz et al. found that rice straw by using urea formaldehyde resin has possibilities for making particleboard [9]. Another study found that the rice straw-wood particleboard has reasonable values of mechanical and physical properties [10]. Xianjun Li found that the properties of particleboard highly depend on the type of adhesive [11]. These findings are very important for furniture industries to substitute a natural wood with agricultural residues such as a rice straw for particleboard.

There is a lot of plastic waste in the world including in Indonesia which damages the environment seriously. There is about eight million tons of plastic waste entering into the ocean each year [12].
Thus, plastic must be recycled or reused for other purposes in order to save our earth. Meanwhile, recent studies show that plastic which is a polymer could be used as a matrix to produce a composite [13-14]. Consequently, to overcome the environmental problems discussed above, it is necessary to develop a particleboard by using rice straw and plastic wastes. In this study, we have evaluated the possibilities to utilize rice straw and plastic waste polypropylene to produce a particleboard. Both the mechanical and physical properties of this particleboard have been examined. Detail results are presented in this paper.

2. Experimental Details
The sample of particleboard was prepared as described the following. Rice straw was dried, milled, and sieved with 20 mesh siever. Polypropylene (PP) was obtained from bottle plastic waste. The bottle of plastic waste was cut by 1 cm x 1 cm, mixed with a coupling agent, and melted at 170 °C to produce a matrix. After that, the rice straw particle was mixed with that matrix with the various compositions. The compositions of rice straw particle : PP matrix were 40 : 60; 50 : 50; 60 : 40; and 70 : 30 wt. %. The mixture of rice straw particle and PP matrix was pressed at 170 °C with 3.5 tons of load to produce the particleboard samples. The sample was cut as the Indonesian Standard for particleboard (SNI). Mechanical properties of rice straw particleboard were measured by using Universal Testing Machine Hung Ta.

The modulus of rupture (MOR) of the samples was determined by using the equation below.

\[ MOR = \frac{3P_{\text{max}} S}{2bd^2} \]  

Where MOR is the modulus of rupture (kgf/cm²), \( P_{\text{max}} \) is maximum load (kgf), \( S \) is the distance between the support points (cm), \( b \) is the width of the sample (cm), and \( d \) is the thickness of sample (cm). The bending modulus of elasticity (MOE) of the samples was determined by using the equation below.

\[ MOE = \frac{\Delta P}{\Delta y} \frac{S^3}{4bd^3} \]  

Where MOE is the bending modulus of elasticity (kgf/cm²), \( S \) is the distance between the support points (cm), \( b \) is the width of the sample (cm), \( d \) is the thickness of the sample (cm), and \( \Delta P/\Delta y \) is the slope of deformation force (kgf/cm). The compressive strength of particleboard was also measured by using the equation (3) below.

\[ \sigma = \frac{P_{\text{max}}}{A} \]  

Where \( \sigma \) is the compressive strength (kgf/mm²), \( P_{\text{max}} \) is maximum load (kgf), \( A \) is the cross-sectional area (mm²). The unit of compressive strength \( \sigma \) can be also in MPa where 1 kgf/mm² is equal to 9.8067 MPa. The density of rice straw particleboard was obtained by using the equation below.

\[ \rho = \frac{m}{V} \]  

Where, \( \rho \) is density (g/cm3), \( m \) is the mass of sample (g), and \( V \) is the volume of sample (cm³). The thickness swelling of rice straw particleboard was obtained by using the equation (5) below.

\[ TSW = \frac{D_2 - D_1}{D_1} \times 100\% \]  

Where \( TSW \) is thickness swelling (%), \( D_2 \) is the thickness of the sample after immersing into the water for 2 hours or 24 hours, and \( D_1 \) is the thickness of the sample before immersing into the water.

3. Results and Discussions
We have measured some mechanical properties of rice straw polypropylene particleboard. Our results of the modulus of rupture (MOR) of rice straw polypropylene particleboard for several rice straw
compositions are shown in figure 1. The MOR of this particleboard is found to be 114 kgf/cm\(^2\) at 30 wt. % of rice straw composition. As the rice straw composition is increased to 40 wt. %, its MOR decreases to 83 kgf/cm\(^2\). At the 50 wt. % of rice straw composition, its MOR increases to 134 kgf/cm\(^2\). However, as the composition of rice straws are increased to 60 and 70 wt. %, the MOR decreases to 96 and 72 kgf/cm\(^2\), respectively. In general, as the rice straw composition is increased the MOR of rice straw polypropylene particleboard decreases as shown in figure 1 (thick line). Our results showed that the modulus of elasticity (MOE) of rice straw polypropylene particleboard is found to be 45.19x10\(^3\) kgf/cm\(^2\) at the 30 wt. % of rice straw composition. The MOE decreases as the rice straw composition is increased which is a linear trend as shown in figure 2 (thick line). It was found that the MOE is 35.09x10\(^3\) kgf/cm\(^2\) at the 70 wt. % of rice straw composition.

Our results showed that the compressive strength of rice straw polypropylene particleboard is found to be 8.1 MPa at the 30 wt. % of rice straw composition. The compressive strength is 7.5 MPa at 40 wt. % of rice straw composition. In general, the value of compressive strength of rice straw polypropylene particleboard slightly decreases as the rice straw composition is increased as shown in figure 3, where the thick line is a fit to the experimental data.

Some physical properties of rice straw polypropylene particleboard have also been measured. The density of rice straw polypropylene particleboard for several rice straw compositions is shown in figure 4. At 30 wt. % of rice straw composition, the density of particleboard is found to be 0.66 g/cm\(^3\). At 40 wt. % of the rice straw composition, its density is found to be 0.76 g/cm\(^3\). However, the rice straw composition is increased to 50 wt. %, its density decreases to 0.62 g/cm\(^3\). In general, the density of particleboard tends to decrease as the rice straw composition is increased as shown in figure 4 (solid line). Besides the density, the thickness swelling of particleboard is also measured, the results are shown in table 1. The thickness swelling of rice straw polypropylene particleboard after immersing the sample into the water for 2 hours is about 0% for 30 wt. %, 40 wt. %, 50 wt. %, and 60 wt. % of rice straw composition. At the 70 wt. % of rice straw composition, the swelling thickness after immersing 2 hours into water is found to be 1.8%. The thickness swelling of rice straw polypropylene
particleboard after immersing the sample into the water for 24 hours is less than 5% for all rice straw compositions (30 wt % - 70 wt. %) as shown in table 1.

To evaluate the possibilities to use the rice straw polypropylene particleboard for furniture (base particleboard) or decorative particleboard, its physical and mechanical properties are compared to Indonesian National Standard (SNI) [15] and Japanese Industrial Standard (JIS) particleboard [16]. According to these standards (SNI and JIS), the density of particleboard should be 0.4 g/cm$^3$ or up to 0.9 g/cm$^3$. The density of our rice straw polypropylene particleboard is in the range of 0.56 g/cm$^3$ to 0.8 g/cm$^3$ which is in the required range. Thus based on the density, the rice straw polypropylene particleboard fulfills both standard requirements (SNI and JIS) for the 30 to 70 wt. % of rice straw composition. According to SNI and JIS, the swelling in thickness after immersion in water shall be less than 25% for the sample thickness is less than 12.7 mm. The thickness of our sample is 10 mm. Our results showed that the swelling in thickness of rice straw particleboard after immersion in the water for 24 hours is less than 5% which fulfills the SNI and JIS requirement.

Figure 3. The compressive strength of rice straw particleboard for several rice straw compositions.

Figure 4. The density of rice straw particleboard for several rice straw compositions.

Table 1. The swelling in thickness of particleboard after immersing into the water for 2 and 24 hours

| No. | Composition rice straw : PP (wt. %) | The thickness swelling after 2 hours (%) | The thickness swelling after 24 hours (%) |
|-----|-----------------------------------|----------------------------------------|----------------------------------------|
| 1   | 30 : 70                           | 0                                      | 0.7 (± 0.3)                            |
| 2   | 40 : 60                           | 0                                      | 2.5 (± 0.3)                            |
| 3   | 50 : 50                           | 0                                      | 3.9 (± 0.4)                            |
| 4   | 60 : 40                           | 0                                      | 1.1 (± 0.3)                            |
| 5   | 70 : 30                           | 1.8 (± 0.6)                            | 4.1 (± 0.6)                            |
According to the SNI and JIS requirement, the MOR of particleboard should be in the range of 82 to 184 kgf/cm\(^2\) and the MOE should be in the range of 2.04x10\(^4\) to 3.06x10\(^4\) kgf/cm\(^2\). Our results showed that the MOR of rice straw polypropylene particleboard is in the range of 83 to 134 kgf/cm\(^2\) for the rice straw compositions of 30, 40, 50, and 60 wt. %. Thus, our rice straw particleboards are met for SNI requirement for those compositions. However, at 70 wt. % of rice straw composition, it is found that the MOR is 72 kgf/cm\(^2\) which is not met for SNI and JIS requirement. The MOE of our rice straw polypropylene particleboard is found to be in the range of 3.3x10\(^4\) to 4.5x10\(^4\) kgf/cm\(^2\) for all rice straw compositions (30 – 70 wt.%) which is met the SNI and JIS requirement. The compressive strength is not required for SNI and JIS. Nonetheless, the average compressive strength of our particleboard is 6.7 MPa which is good enough for commercial use.

4. Conclusions

Some physical and mechanical properties of rice straw particleboard by using polypropylene as a matrix have been evaluated for rice straw compositions of 30, 40, 50, 60, and 70 wt. %. Based on the density, thickness swelling, MOR, and MOE, the rice straw polypropylene particleboard fulfills the SNI and JIS requirements for the rice straw compositions of 30, 40, 50, and 60 wt. %. Thus, we conclude that rice straw and plastic waste polypropylene have a great potential to be used for producing a standard particleboard.

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