Mechanical and physical properties of the rice straw particleboard with various compositions of the epoxy resin matrix

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Abstract. The rice straw has been utilized to form particleboard by using an epoxy resin matrix. The rice straw particle (20 mesh) was mixed with epoxy resin with the various compositions, pressed with 5 ton of load to produce the rice straw particleboard samples. Mechanical and physical properties of rice straw particleboard were measured. Our results showed that the modulus of rupture (MOR) of rice straw particleboard is in the range of 2.07 to 3.31 kgf/mm², the bending modulus of elasticity (MOE) is found to be 408 to 1490 kgf/mm², and the density (ρ) is in the range of 0.360 to 0.480 g/cm³. We found that the MOR, MOE, and ρ have the exponential function of the resin composition with the equations of MOR=2.0668+6.5604e^{-0.3327x} (kgf/mm²), MOE=344.55+3159.5e^{-0.203x} (kgf/mm²), and ρ=0.4414-0.3338e^{-0.2183x} (g/cm³), where x is the epoxy resin composition (%). This finding will help manufacture to produce rice straw particleboard for desired values of MOR, MOE, and density.

1. Introduction

Wood is one of the main materials in building construction and furniture manufacturing. Wood usage continues to rise from year to year as the population grows in the world. However, the availability of natural wood is very limited. The high rate of forest damage followed by increasing public demand for wood makes wood materials in rare conditions so that the price of natural wood rises sharply. Thus, an alternative wood substitute is needed to overcome this problem. An alternative wood substitute is a particleboard made of agricultural wastes [1-4]. One of the potential organic wastes that can be used as raw material for particleboard manufacturing is rice straw [5-6]. Previous research has shown that rice straw contains 32-47% cellulose, 19-27% hemicellulose, and 5-24% lignin [6]. Cellulose is a fiber that has the potential to be filler in the manufacture of composite materials. The previous study by Akyildiz et al. found that rice straw with urea formaldehyde adhesive was potentially made for particleboard [7]. The results of Akyildiz et al. showed that particleboard of rice straw using urea formaldehyde adhesive with a density of 428 kg/m³ had the flexural strength of 1.48 N/mm² and the modulus of elasticity of 380.43 N/mm² [7]. Yang et al. also studied rice straw wood particle composite recently. By using a commercial urea-formaldehyde adhesive, they found that the rice straw-wood particle composite board has reasonable values of bending modulus of rupture and density [8].

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Xianjun Li et al. found that the performance of particleboard is highly dependent on particle size and type of adhesive. The rice straw particleboard bonded using urea-formaldehyde resin exhibits rather poor performance compared to the sample using polymeric diphenylmethane diisocyanate resin [9]. Most previous studies used urea-formaldehyde resin to form particleboard from rice straw where the hot press is needed to produce the particleboard samples. Moreover, the use of urea formaldehyde is not good for health. Meanwhile, the epoxy resin can be found easily in the commercial market and no hot press is needed to form the particleboard sample. It is safer for health than formaldehyde.

The mechanical properties of particleboard (composite) strongly depend on the filler or fiber as reinforcement in the composite [10]. The matrix is a constituent of the composite body which is part of the cover and binder of the composite structure. It is found that the mechanical property such as elastic modulus is dependent on the volume fraction of fibers and matrix [10]. Nonetheless, the correlation between the mechanical properties of rice straw particleboard and matrix composition is still unknown.

Indonesia has a lot of rice fields which produce abundant rice straw. Until now, only a small amount of rice straw waste was used for animal feed and compost fertilizer, while farmers left others in the fields. Even some people burn these rice straw, causing air pollution around the rice fields. This situation is the same in other Asian countries. Thus, it is necessary to consider the utilization of rice straw waste so that it has economic value. In this study, particleboard (particle reinforced composite) has been made from rice straw with an epoxy resin matrix. The mechanical and physical properties of rice straw particleboard have been examined. Furthermore, the correlation between its mechanical properties and epoxy resin composition has been investigated. Detail results are reported in this paper.

2. Experimental Details

Rice straw obtained from a rice field in Aceh Besar, Indonesia was cleaned, dried, milled, and sieved with 20 mesh siever. The rice straw particle was mixed with epoxy resin with the various compositions. The compositions of epoxy resin were 5 vol. % (36.8 wt. %), 10 vol. % (53.2 wt. %), 15 vol. % (63.7 wt. %), and 20 vol. % (70.1 wt. %). The total percentage of rice straw particle and epoxy resin remained 100% for all samples. Then, the mixture of rice straw particle and epoxy resin was pressed with 5 ton of load to produce the particleboard samples. Mechanical properties of rice straw particleboard were measured by using Universal Testing Machine Hung Ta.

The density of rice straw particleboard was obtained by using the equation (1) below.

$$\rho = \frac{m}{V}$$

Where, \( \rho \) is density (g/cm\(^3\)), \( m \) is the mass of sample (g), and \( V \) is the volume of sample (cm\(^3\)). The water absorption of rice straw particleboard was obtained by using the equation (2).

$$WA = \frac{m_2 - m_1}{m_1} \times 100\%$$

Where, \( WA \) is water absorption (%), \( m_2 \) is the mass of the sample after immersing in water for 2 hours or 24 hours, and \( m_1 \) is mass of sample before immersing in water. The bending modulus of elasticity of rice straw particleboard was determined by using the equation (3) the following.

$$E = \frac{\Delta P}{\Delta y} \times \frac{S^3}{4bd^3}$$

Where \( E \) is the bending modulus of elasticity (MOE) (kgf/mm\(^2\)), \( S \) is the distance between the support points (mm), \( b \) is the width of the sample (mm), \( d \) is the thickness of the sample (mm), and \( \frac{\Delta P}{\Delta y} \) is the slope of deformation force (kgf/mm). The modulus of rupture of rice straw particleboard was determined by using the equation (4) the following.

$$\sigma = \frac{3P_{\text{max}}S}{2bd^2}$$
Where $\sigma$ is the modulus of rupture (MOR) (k gf/mm$^2$), $P_{\text{max}}$ is maximum load (kgf), $S$ is the distance between the support points (mm), $b$ is the width of the sample (mm), and $d$ is the thickness of sample (mm).

3. Results and Discussions

Our result of the modulus of rupture (MOR) of rice particleboard with various rice straw compositions is shown in figure 1. At the 80 vol. % (29.9 wt. %) of rice straw composition, the MOR is found to be 2.072 k gf/mm$^2$. As the rice straw composition is increased, the MOR is also increased. At the 95 vol. % (63.2 wt. %) of rice straw composition, the MOR is 3.310 k gf/mm$^2$. Clearly, the value of MOR depends on the rice straw composition. However, we cannot obtain a simple equation for the relationship between MOR and rice straw composition. Then, we tried to plot the MOR as a function of the resin composition as shown in figure 2. At 5 vol. % of the resin composition, the MOR is found to be 3.31 kgf/mm$^2$. As the resin composition is increased to 10 vol. %, the MOR is decreased to 2.30 k gf/mm$^2$. Surprisingly, the MOR has an exponential function of the resin composition with the following equation: $y = K_0 + K_1 e^{-K_2 x}$, where $y$ is MOR, $x$ is resin composition, $K_0 = 2.0668$, $K_1 = 6.5604$, and $K_2 = 0.3327$. The solid line in figure 2 is the best fit for those parameters.

The results of the bending modulus of elasticity (MOE) of rice straw particleboard are shown in figures 3 and 4. The MOE is found to be 409 k gf/mm$^2$ at the 80 vol. % (29.9 wt. %) of rice straw composition. Similar to MOR, the MOE is increased as the rice straw composition is increased as shown in figure 3. The MOE is 1490 k gf/mm$^2$ at the 95 vol. % (63.2 wt. %) of rice straw composition. Again, it is difficult to fit the experimental data to find a simple equation which represents the relationship between MOE and rice straw composition. Alternatively, we plotted the MOE as a function of the resin composition as shown in figure 4. At 5 vol. % of the resin composition, it was found that the MOE is 1490 k gf/mm$^2$. As the resin composition is increased to 10 vol. %, the MOE is decreased to 769 k gf/mm$^2$, etc. It was found that the MOE has an exponential function of the resin composition with the following equation: $y = K_0 + K_1 e^{-K_2 x}$, where $y$ is MOE, $x$ is resin composition, $K_0 = 2.0668$, $K_1 = 6.5604$, and $K_2 = 0.3327$. The solid line in figure 4 is the best fit for those parameters.

Figure 1. Modulus of rupture (MOR) of rice straw particleboard with various rice straw compositions

Figure 2. Modulus of rupture (MOR) of rice straw particleboard with various epoxy resin compositions (filled squares are the experimental data and the solid line is the best fit)
composition with the following equation: \( y = K_0 + K_1 e^{-K_2 x} \), where \( y \) is MOE, \( x \) is resin composition, \( K_0 = 344.55 \), \( K_1 = 3159.50 \), and \( K_2 = 0.2030 \). Those parameters have a good fit for the MOE experimental data as shown in solid line in figure 4.

**Figure 3.** Bending modulus of elasticity of rice straw particleboard with various rice straw compositions.

**Figure 4.** Bending modulus of elasticity of rice straw particleboard with various epoxy resin compositions (filled circles are the experimental data and the solid line is the best fit).

**Figure 5.** The density of rice straw particleboard with various rice straw compositions.

**Figure 6.** The density of rice straw particleboard with various epoxy resin compositions (unfilled circles are the experimental data and the solid line is the best fit).
The density of rice straw particleboard with various rice straw compositions is shown in figure 5. At 80 vol. % of rice straw composition, the density of particleboard is found to be 0.480 g/cm³. As the rice straw composition is increased, the density of particleboard is decreased. At 95 vol. % of rice straw composition, the density of particleboard is 0.369 g/cm³. The same for the MOR and MOE cases, we have plotted the density of particleboard versus the resin composition as shown in figure 6. The density of rice straw particleboard is increased when the resin composition is increased. It is an exponential function of resin composition with the following equation: \( y = K_0 + K_1 e^{-K_2 x} \), where \( y \) is density, \( x \) is resin composition, \( K_0 = 0.4414 \), \( K_1 = -0.3338 \), and \( K_2 = 0.2183 \). The solid line in figure 6 is the best fit to the experimental data (density) by using those parameters.

The water absorption of rice straw particleboard was also measured after immersing the particleboard in water for 2 hours and 24 hours. The results are shown in figures 7 and 8. At 80 vol. % of rice straw composition, the water absorption is 51.3% for after immersing the sample in water for 2 hours. The water absorption is increased to 88.6% after immersing the sample for 24 hours. The percentage of water absorption is increased as the increasing of rice straw composition or decreased as the increasing of the resin composition. However, it is difficult to fit the experimental data to find a relationship between water absorption and rice straw composition or resin composition.

The density of rice straw particleboard is found to be in the range of 0.360 to 0.480 g/cm³. Based on the density, our rice straw particleboard can be classified as a low-density board (\( \rho < 0.64 \) g/cm³). According to the Indonesian National Standard (SNI) for particleboard, the density should be in the range of 0.4 to 0.9 g/cm³ [11]. Therefore, our rice straw particleboards for rice straw compositions of 80 vol. %, 85 vol. %, and 90 vol. % are met for SNI requirement. The MOR of our rice straw particleboard is between 2.07 to 3.31 kgf/mm² (207 to 331 kgf/cm²) which can be classified as a medium density board. The MOR requirement for SNI is in the range of 82 to 184 kgf/cm² [11]. Thus, our rice straw particleboards are met for SNI requirement. The MOE of our straw particleboard is between 408 to 1490 kgf/mm² (4.08x10⁴ to 14.9x10⁴ kgf/cm²) which can be classified as a high-

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**Figure 7.** Water absorption of rice straw particleboard with various rice straw compositions

**Figure 8.** Water absorption of rice straw particleboard with various epoxy resin compositions (filled squares and circles are the experimental data and solid lines are the best fit)
density board. The MOE requirement for SNI is in the range of $2.04 \times 10^4$ to $3.09 \times 10^4$ kgf/mm$^2$ [11]. Again, our rice straw particleboards are met for SNI requirement.

The mechanical properties (MOR and MOE) of this study by using epoxy resin are better than those of previous study using urea formaldehyde adhesive where its MOR is 0.15 kgf/mm$^2$ and MOE is 38.79 kgf/mm$^2$. This finding agrees with the previous study where the mechanical properties of rice straw particleboard with urea-formaldehyde resin are rather poor [9]. Nonetheless, the percentage of water absorption of our rice straw particleboard is rather high. Our results show that the MOR has the exponential function of the resin composition with the equation $MOR = 2.0668 + 6.5604 \cdot e^{-0.3327x}$ (kgf/mm$^2$). Similar to the cases of MOE and density; $MOE = 344.55 + 3159.5 \cdot e^{-0.203x}$ (kgf/mm$^2$), and $\rho = 0.4414 - 0.3338 \cdot e^{-0.2183x}$ (g/cm$^3$), where $x$ is the epoxy resin composition (%). This new finding is very important for particleboard manufactory where the MOR, MOE, and density of rice straw particleboard with epoxy resin can be tuned for the desired value by adjusting the percentage of the resin composition.

4. Conclusions

Our results showed that the rice straw with epoxy resin matrix has a great potential composite for particleboard. Based on the density, MOR, and MOE, our rice straw particleboard for rice straw compositions of 80 vol. %, 85 vol. %, and 90 vol. % are met for SNI requirement. There is a strong correlation between the mechanical properties of rice straw particleboard and epoxy resin composition. The MOR, MOE, and density of rice straw particleboard with epoxy resin have an exponential function of the resin composition.

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