Physical and chemical properties of particleboard made of rice straw and plastic waste

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Abstract. Rice straw is agricultural waste which hasn’t been used optimally yet, especially in Indonesia. Meanwhile, rice straw contains cellulose that can be used form composite such particleboard. In this study, the physical and chemical properties of particleboard made of rice straw particle and polypropylene from plastic waste as adhesive were investigated. The rice straw and polypropylene compositions were varied: 30:70, 40:60, 50:50, and 60:40 wt.%. The rice straw particle sizes were varied for 40 mesh, 50 mesh, and 60 mesh for each composition. X-Ray Fluorescent has been used to measure the chemical composition of our particleboard. The density of particleboard is 0.59 - 0.77 g/ cm³. Its thickness swelling is less than 2%. Both density and thickness swelling has met the requirement for Indonesian Standard of particleboard. Our results showed that the density of particleboard strongly depends on rice straw particle size. As the particle size decreases, the density increases. The particle size of rice straw affects the thickness swelling of particleboard. The thickness swelling decreases as the particle size decreases. The major constituents of our particleboard are the \( \text{SiO}_2 \), \( \text{CaO} \), \( \text{K}_2\text{O} \). Our finding showed that the particle size has an essential role in the physical properties of particleboard.

1. Introduction
The wood usage in the world increases from time to time to meet development needs, including for building construction, furniture, household appliances, etc. On other hands, the availability of natural wood is limited, which has caused a lot of illegal logging in many countries, including in Indonesia. According to the problem, particleboards have been developed to replace natural wood. Particleboards are usually made from a mixture of wood chips or wood particles, mixed with synthetic resin glue and pressed into a sheet for a certain thickness. However, the availability of wood fiber and wood particles is limited. Therefore, alternative wood particle substitutes are needed to overcome this problem. Substitutes for alternative wood particles or wood chips can be from agricultural wastes such as rice straw, rice husk, bagasse, etc. Previous studies showed that agricultural residues could be used to produce composites [1-5].

One of the agricultural wastes is rice straw. As an agricultural country, rice straw is an abundant agricultural waste in Indonesia. According to the Central Bureau of Statistics, Indonesia produced 79.36 million tons of dried paddy in 2016 and 81.38 million tons in 2017 [6]. So, Indonesia produced a lot of rice straw. However, the rice straw in Indonesia has not been used optimally yet. Meanwhile, the rice straw contains about 40% of cellulose, 27% of hemicellulose, and 24% of lignin [7]. Cellulose is a
fiber which can be used as a filler to produce a composite material such as particleboard. Thus, rice straw is a potential material for making particleboard [8].

There is a plentiful of waste from plastic bags, plastic packaging, etc. which can damage our environment severely. There are approximately eight million tons of plastic waste, including polypropylene type plastic which enters the ocean every year [9]. Therefore, plastic waste must be immediately recycled or reused with another purpose to save our earth's nature. Some plastic can be classified as a thermoplastic which can be recycled again with a reheating process. In the meantime, some recent studies showed that plastic (thermoplastic) could be used as a matrix to produce composites [10-11]. Accordingly, it is interesting to produce a composite or particleboard from plastic waste and agriculture waste.

There are several studies which have been conducted on the development of composites using plastic adhesives [10-11]. Fie Yao et al. studied the composite made of rice straw fiber and high-density polyethylene [11]. They found that high-density polyethylene worked well as adhesive to form a composite. Several other studies have also shown that polypropylene can be used as an adhesive to produce composite [12]. Recent work indicated the possibilities to make particleboard from rice straw and plastic waste [13]. Nonetheless, this recent work only studied for 20 mesh of rice straw particle size. It is fascinating to research composite from rice straw using used plastic for other particle sizes. In this paper, we studied the physical properties of particleboards made of rice straw and plastic waste for various particle sizes. The chemical composition of particleboard was also examined.

2. Method
The rice straws were collected from rice farm near Banda Aceh. The plastic wastes (code five that is polypropylene) were obtained in Banda Aceh. The samples were prepared as the following steps. First, the rice straws were cleaned and milled to produce rice straw particles. Second, the rice straw particles were sieved with a filter of 40 mesh, 50 mesh, and 60 mesh. Third, the recycled plastic waste was cut to a size of about 1 cm x 1 cm and mixed with Anhydride Maleic, Benzoyl Peroxide, Xylene, and Methanol (Coupling Agent). After that, the compound melted at a temperature of ±170 °C, which becomes a matrix. Subsequently, rice straw particles were mixed with the matrix for several compositions. The samples used in this study for several compositions and particle sizes are shown in Table 1.

| Sample no | The particle size of rice straw (mesh) | Rice straw (wt. %) | Polypropylene (wt. %) |
|-----------|--------------------------------------|--------------------|-----------------------|
| S1        | 40                                   | 30                 | 70                    |
| S2        | 40                                   | 40                 | 60                    |
| S3        | 40                                   | 50                 | 50                    |
| S4        | 40                                   | 60                 | 40                    |
| S5        | 50                                   | 30                 | 70                    |
| S6        | 50                                   | 40                 | 60                    |
| S7        | 50                                   | 50                 | 50                    |
| S8        | 50                                   | 60                 | 40                    |
| S9        | 60                                   | 30                 | 70                    |
| S10       | 60                                   | 40                 | 60                    |
| S11       | 60                                   | 50                 | 50                    |
| S12       | 60                                   | 60                 | 40                    |
The filler mixture (rice straw) and matrix (PP) were then cast with a size of 20 cm x 5 cm x 1 cm and then pressed using a Hot Press with a constant pressure of 3 tons for 1 hour to produce particleboard samples. Particleboard samples were cut according to the standard particleboard reference, namely SNI 03-2105-2006. Physical properties of samples to be tested are density and thickness swelling.

The density test was carried out after the sample was cut to a size of 5 cm x 5 cm x 1 cm, then the sample was weighed using a digital scale and recorded the mass. The volume of the sample was measured by using a digital caliper. The density value was calculated using the equation (1).

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

(1)

Where, \( V \) is the volume of sample (cm\(^3\)), \( m \) is the mass of sample (g), and \( \rho \) is the density of the sample (g/cm\(^3\)).

The sample size of 5 cm x 5 cm x 1 cm was prepared for the thickness swelling measurement. The sample thickness was measured by using a digital caliper before and after the sample was immersed in water for 2 and 24 hours. The value of thickness swelling was obtained from equation (2).

\[ PT = \frac{T_2 - T_1}{T_1} \times 100\% \]  

(2)

Where PT is the thickness swelling of the sample (%), \( T_1 \), and \( T_2 \) are the sample thickness before and after immersing into the water, respectively. The swelling in thickness was measured for 2 hours and 24 hours immersing the sample into water.

The chemical property of particleboard was also evaluated in this study. The chemical property of particleboard was investigated by using X-Ray Fluorescent (PANalytical MiniPal Type 4). The experiment was performed at room temperature with the sample size of 1 cm x 1 cm x 1 cm for sample S7 (rice straw particle size 50 mesh, 50 wt. % of rice straw and 50 wt. % of polypropylene).

3. Results and discussions

The density of particleboard made of rice straw and recycled polypropylene has been measured. The results are shown in figures 1 and 2.

![Figure 1. The particleboard density for various rice straw compositions.](image-url)
Figure 1 is a density plot for a variety of straw compositions for several particle sizes. For 40 mesh of rice straw particle size, the particleboard density is 0.71 g/cm$^3$ for 30 wt. % of rice straw. When the composition of rice straw is increased to 40 wt. %, the density is found to be 0.70 g/cm$^3$. However, the density decreases to 0.65 g/cm$^3$ for 50 wt. % of rice straw composition. The density continues to reduce to 0.57 g/cm$^3$ for 60 wt. % of rice straw composition. For particle size 50 mesh, the density is 0.73 g/cm$^3$ for the rice straw 30 wt. %. As the rice straw composition is increased, the density does not change significantly for this particle size. However, for particle size 60 mesh, the density decreases when the rice composition increases that is the same behavior for 40 mesh particle size as shown in figure 1. This behavior could be due to the density of rice straw is lower than those of polypropylene (density of polypropylene is about 0.9 g/cm$^3$). The density of particleboard versus particle size of rice straw is shown in figure 2. For rice straw 30 wt. % and polypropylene 70 wt. %, the density is 0.71 g/cm$^3$ for 40 mesh of particle size. As the particle size decreases to 50 mesh and 60 mesh, the density increases a little bit to 0.73 g/cm$^3$. For the composition of rice straw 40 wt. %, the density is 0.71 g/cm$^3$ for 40 mesh of particle size. The density slightly increases to 0.74 g/cm$^3$ for 60 mesh of particle size. This behavior is similar to the case of 50 wt. % rice straw composition. While for 60 wt. % of rice straw, the particle size effect on the density is significant, but it somewhat fluctuates. The density is 0.76 g/cm$^3$ for the particle size 50 mesh. In general, the particle size does not affect the density significantly. However, the density tends to increase as the particle size decreases.

Based on our results discussed above, the highest density value was obtained for the composition of 60 wt. % of rice straw and 40 wt. % of polypropylene with a particle size of 50 mesh, which is equal to 0.76 g/cm$^3$. The lowest density value obtained for the composition of rice straw 60 wt. % and polypropylene 40 wt. % with a particle size of 40 mesh, which is equal to 0.58 g/cm$^3$. Based on the standard reference SNI 03-2105-2006, the density of particleboard should be in the range from 0.40-0.90 g/cm$^3$ [14]. So, the density of all our particleboards has met the requirement for the standard of SNI particleboard.
Another physical property of our particleboard that has been measured in this study was the thickness swelling of samples after immersing for 2 and 24 hours into water. For 2 hours immersing the sample into the water, the percentage of thickness swelling of our particleboard is about zero. For 24 hours immersing the sample into the water, the results of thickness swelling are shown in figures 3 and 4. The effect of the composition of rice straw on the thickness swelling of particleboard is shown in figure 3. For 40 mesh of rice straw particle size, thickness swelling is 0.60% for 30 wt. % composition of rice straw. When the composition of rice straw increases to 60 wt. %, the percentage of thickness swelling increases to 1.27%. This trend is similar to other particle sizes, as shown in figure 3. This behavior should be related to the porosity of rice straw, where the porosity of rice straw is larger than those of polypropylene. The rice straw absorbs more water than the polypropylene does. Thus, as the composition of rice straw increases, the percentage of thickness swelling increases. The particle size effect of the thickness swelling was also examined. The results are shown in figure 4. For 30 wt. % composition of rice straw, the thickness swelling is 0.60% for 30 mesh of particle size. As the particle size decreases to 60 mesh, the thickness swelling decreases to 0.42%. This tendency is the same for all compositions, where the thickness swelling decreases as the particle size decreases.

As the results described above, thickness swelling of our particleboard is found to be in the range of 0.42% to 1.80%. According to the standard reference SNI 03-2105-2006 for particleboard, the thickness swelling should be less than 12% after immersing into the water for 24 hours [14]. So, the thickness swelling of all our particleboards has met the requirement for the standard of SNI particleboard. The thickness of particleboard is influenced by the amount of adhesive, such as polypropylene. The more adhesive is given, the smaller thickness swelling of particleboard is obtained. This happens because the adhesive in the form of plastic can inhibit the absorption of water in the particleboard. Thus, polypropylene is a suitable matrix to reduce water absorption in the particleboard.

![Figure 3. The thickness swelling versus rice straw compositions.](image)
Figure 4. The thickness swelling versus particle size of rice straw.

The chemical composition of particleboard for the composition 50 wt. % of rice straw, 50 wt. % of polypropylene, for 50 mesh particle size has been measured by using X-Ray Fluorescent. Our results are shown in table 2. We found that the silicon dioxide (SiO$_2$), the potassium oxide (K$_2$O), and the calcium oxide (CaO) are the major constituent of our particleboard. These compounds contained in the particleboard comes from the rice straw. The previous study found that the rice straw ash contains 74.67 % of SiO$_2$, 12.30 % of K$_2$O, 3.01 % of CaO, 1.41 % of P$_2$O$_5$, and 1.75 % of MgO [15]. Our results indicate that our particle board is safe from harmful chemicals.

Table 2. Oxide compound contained in particleboard sample.

| Compound   | Weight (%) |
|------------|------------|
| SiO$_2$    | 35         |
| K$_2$O     | 28         |
| CaO        | 15         |
| Fe$_2$O$_3$| 8          |
| P$_2$O$_5$ | 3          |
| MnO        | 3          |
| TiO$_2$    | 1          |

4. Conclusions

In this research, the highest density of particleboard made of rice straw particle and plastic waste (polypropylene) is found to be 0.76 g/cm$^3$. This value was obtained at the rice straw 60 wt. % (polypropylene 40 wt. %) and 50 mesh of rice straw particle size. For this condition, the thickness swelling is less than 2%. Based on density and thickness swelling, particleboard has met the SNI requirement for industrial particleboard. Our study shows that the density of particleboard increases if the rice straw particle size decreases. The thickness swelling of particleboard tends to decreases as the particle size decreases. The major constituents of our particleboard are the potassium oxide (K$_2$O), the
silicon dioxide (\(\text{SiO}_2\)), and the calcium oxide (CaO) which indicate that our particle board is safe from harmful chemicals.

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