Mechanical and physical properties of rice straw fiber-reinforced polypropylene composite

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Abstract. In this study, the composite made of rice straw fiber and polypropylene as the adhesive has been produced. The mechanical properties (modulus of rupture, modulus of elasticity, compressive strength) and physical properties (density and thickness swelling) of composite samples have been examined for various compositions of rice straw fibers. The highest modulus of rupture of our composite is found to be 113 kgf/cm² obtained at the composition of rice straw fiber 40 wt. % and polypropylene 60 wt. %. The highest modulus of elasticity of our composite is 3.5×10⁴ kgf/cm² obtained at the composition of rice straw fiber 30 wt. % and polypropylene 70 wt. %. The modulus of elasticity tends to decline when the composition of rice straw is increased. The highest compressive strength and density are 8.9 MPa and 0.6 g/cm³, respectively, which are obtained at the formation of rice straw 60 wt. % and polypropylene 40 wt. %. Both compressive strength and density tend to increase when the composition of rice straw fiber is increased. The thickness swelling of the sample was obtained in the range of 0.5 to 1.0 %. Our composites (for all rice straw fiber compositions) have met Indonesian National Standard requirements for particleboard. Based on our results, we recommend producing a composite of rice straw fiber and polypropylene adhesive with an arrangement of 60 wt. % rice straw fiber and 40 wt. % polypropylene.

1. Introduction

The need for wood for furniture and building materials increases continuously in line with economic growth in the world. Unfortunately, wood availability in the forest is limited. Therefore, it is necessary to find out alternative wood materials that can be used as furniture and building materials. One solution is to make composite materials that can be used as wood substitutes such as particleboard and fiberboard. Research on particleboard and fiberboard composites has been carried out intensively. The researchers keep looking for a durable composite, but it is inexpensive. Currently, researchers are trying to develop a composite made from agricultural waste materials such as from bagasse, rice straw, palm bunches, etc. [1-7].

Indonesia is an agricultural country that produces a lot of rice every year. In 2017, rice production in Indonesia was 73.9 million tons [8]. The production increased to 74.5 million tons in 2018 [8]. Besides Indonesia, some other Asian countries also produce a lot of rice, such as China, India, and Thailand. A side product of rice production is rice straw. Assuming the amount of rice straw produced is around 20% of the total rice production, Indonesia produced approximately 15 million tons of rice.

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straw in 2018. This rice straw is agricultural waste that has not been used optimally. On the other hand, rice straw contains cellulose, which is a very potential material to be made for composite [4].

Plastic is a material that has been used by many people today, such as plastic wrapping, plastic bags, plastic cups, children's toys, and so on. Unfortunately, used plastic materials become chemical wastes that can damage the environment because the plastic material cannot be decomposed. China is a country that contributes so much plastic waste. In 2010, there were about 8.8 million tons of plastic wastes in China [9]. Indonesia produced around 3.33 million tons of plastic waste in 2010 [9]. McArthur estimated that there is about 8 million tons of plastic waste dumped into the ocean every year [10]. Polypropylene is one type of plastic waste, a thermoplastic material that can be used as an adhesive in making composites.

Several studies on composites from rice straw using polypropylene have been done previously. Sudkhar et al. studied the mechanical properties of composites made from rice straw fiber with a polypropylene matrix. However, their study was only for 0 to 25 wt. % of rice straw composition [11]. Majid et al. conducted a study of composite rice straw fiber using polypropylene as an adhesive. They did the sandwich method only for the composition of rice straw up to 10 wt. %. [12]. However, they found that the mechanical properties of their composite were rather poor [12]. Vu et al. made a composite of cellulose fibers using a polypropylene matrix for cellulose compositions from 0 to 50 wt. %. The mechanical properties of their composite materials were excellent [13]. However, they did not use rice straw directly for composites, but they extracted cellulose from rice straw. Gultom et al. used rice straw fiber directly to make a composite using urea-formaldehyde as an adhesive. However, the mechanical properties of their composites were rather poor [14].

In connection with the above discussion, it is interesting to conduct a study of composite made from rice straw fiber using a polypropylene matrix from plastic waste for the various compositions of rice straw fibers. The objective of this work is to study the mechanical and physical properties of composite made of rice straw fiber and polypropylene matrix from plastic waste for various compositions.

2. Material and method
Rice straw was collected from rice fields near Banda Aceh city. Then, the rice straw was cleaned and dried under the sun until the water content of rice straw was around 2%. The polypropylene used in the study was plastic bottle waste (code 5). The used plastic bottles were cut into pieces with a size of about 0.5 × 0.5 cm. Then, used plastic was melted using a coupling agent at a temperature of 170°C so that it became matrix or adhesive. The length of rice straw fiber for all samples was 0.5 cm with randomly oriented.

The rice straw fibers were mixed with the polypropylene at a temperature of 170°C. The compositions of rice straw fibers and matrix (polypropylene) were 30 : 70, 40 : 60, 50 : 50, and 60 : 40 wt. %. Furthermore, the mixture of rice straw fiber with polypropylene was poured into a sample mold and then pressed for 50 min with a load of 3 tons at a temperature of 170°C to obtain the composite.

Mechanical testing (modulus of rupture, modulus of elasticity, and compressive strength) of the composite was carried out using a machine manufactured by Hung Ta. In addition to measuring mechanical properties mentioned above, we also measure the physical properties of samples that are thickness swelling and density. Detailed procedures to determine the physical and mechanical properties of samples have been described in the previous study [6].

3. Results and discussion
The modulus of rupture (MOR) which is also known as bending strength or flexural strength has been measured. Our results are shown in Figure 1. For 30 wt. % composition of rice straw fiber, the MOR is obtained to be 98 kgf/cm². When the composition of fiber is 40 wt. %, the MOR is 113 kgf/cm². Its value decreases to 84 kgf/cm² when the rice straw fiber is 50 wt. %. However, its error-bar is rather large, which could be due to less homogeneity of mixture between rice straw and polypropylene. The MOR increases to 101 kgf/cm² for 60 wt. % of rice straw fiber. If we fit the experimental data by
using a linear function (solid line in Figure 1), it is found that the MOR decreases a little bit when the fiber is increased. This trend is the same as the trend found in the previous study (rice straw particle polypropylene composite), as shown in Figure 1 (unfilled squares and dashed line) [6].

![Figure 1. MOR of rice straw fiber-reinforced polypropylene composite (filled circles) and a previous study (unfilled squares).](image1)

![Figure 2. MOE of rice straw fiber-reinforced polypropylene composite.](image2)

The comparison between MOR from this study with several previous studies is listed in Table 1. The MOR of our composite is significantly higher than those of composite made of rice straw fiber using urea-formaldehyde matrix. The MOR of rice straw fiber (0.5 cm) is about the same as the MOR of composite made of rice straw particle (20 mesh). The Indonesian National Standard (SNI) requires that the MOR of composite for particleboard should be larger than 82 kgf/cm² [15]. Based on MOR, our composites fulfill the SNI requirement for all compositions of rice straw fiber.

**Table 1. The modulus of rupture of several composites.**

| Composite                                | MOR (kgf/cm²) | Ref. |
|-------------------------------------------|---------------|------|
| Rice straw particle (20 mesh) & epoxy resin | 210 – 330     | [5]  |
| Rice straw particle (20 mesh) & polypropylene | 72 - 134      | [6]  |
| Rice straw fiber (0.5 cm) & urea formaldehyde | 13 – 28       | [14] |
| Rice straw fiber (3 cm) & urea formaldehyde      | 15 - 33       | [4]  |
| Rice straw fiber (0.5 cm) & polypropylene     | 84 - 113      | This study |

Figure 2 shows our results of the modulus of elasticity (MOE) for various compositions. The MOE of composite with rice straw fiber composition 30 wt. % is $3.5 \times 10^4$ kgf/cm². When the number of rice straw fiber is increased to 40 wt. % and 50 wt. %, the MOE values decrease to $3.2 \times 10^4$ kgf/cm² and $2.2 \times 10^4$ kgf/cm², respectively. For the rice straw composition, 60 wt. %, the MOE value increases slightly ($3.3 \times 10^4$ kgf/cm²). The dashed line (see Figure 2) is a linear function fit to the experimental data, whereas the rice straw fiber is increased, the MOE decreases. The composite becomes less elastic when the composition of rice straw fiber is increased. Similar to MOR, this trend is the same as previously found in the rice straw particle polypropylene composite [6]. As shown in Table 2, the composite using urea-formaldehyde matrix has a lower value of MOE compared to those using polypropylene and epoxy resin matrixes. The MOE of our composite is almost the same value as the composite of rice straw particle (20 mesh) using polypropylene adhesive. SNI requires that MOE
value of a particleboard composite must be greater than 20400 kgf/cm$^2$ [15]. Our composite in this study has met the SNI requirement for MOE.

Table 2. The modulus of elasticity of several composites.

| Composite                                  | MOE (kgf/cm$^2$)         | Ref. |
|--------------------------------------------|--------------------------|------|
| Rice straw particle (20 mesh) & epoxy resin| $4.09 \times 10^4 - 14.9 \times 10^4$ | [5]  |
| Rice straw particle (20 mesh) & polypropylene| $3.3 \times 10^4 - 4.5 \times 10^4$ | [6]  |
| Rice straw fiber (0.5 cm) & urea formaldehyde| 69 - 539                 | [14] |
| Rice straw fiber (3 cm) & urea formaldehyde| 3879 - 7125              | [4]  |
| Rice straw fiber (0.5 cm) & polypropylene  | $2.3 \times 10^4 - 3.5 \times 10^4$ | This study |

Compressive strength is the nature of the material to withstand the maximum load so that the material does not change in size or damage. We have measured the compressive strength of our composite whose results are shown in Figure 3. The compressive strength is found to be 6.9 MPa for rice straw fiber 30 wt. %. The compressive strength slightly decreases to 5.4 MPa for composition 40 wt. %, but it increases to 8.8 MPa and 8.9 MPa for 50 wt. % and 60 wt. % composition of rice straw fiber, respectively. Table 3 shows the comparison of compressive strength from this study with several previous studies. The compressive strength of our composite is larger than that of gypsum rice straw composite or wheat straw composite. However, it is about the same as that of rice straw particle composite (20 mesh).

Figure 4 shows the density of our rice straw fiber composite. For the composition rice straw fiber 30 wt. %, the density is 0.52 g/cm$^3$. When the composition of rice straw fiber is increased, the density slightly increases (see the dashed line in Figure 4). The density for 60 wt. % rice straw composition is 0.58 g/cm$^3$. The comparison between the densities of our composite with some previous studies is listed in Table 4. The density of our composite is slightly lower than those of composite made of rice straw particle and polypropylene matrix. However, the density of our composite is larger than those composite made of rice straw particle and epoxy resin matrix. The density of all our composites is larger than 0.4 g/cm$^3$, which is met the SNI requirement for particleboard [15].

The thickness swelling of our samples has been measured. The sample was immersed in the water for 24 h. For rice straw fiber composition 30 wt. %, the thickness swelling is 0.5%. When the
The composition of rice straw fiber is increased, the thickness swelling also increases. The thickness swelling is found to be 1.0% for 60 wt. % composition of rice straw. The SNI requires that the thickness swelling of particleboard should be less than 12% [15]. Thus, all our samples fulfill the SNI requirement.

### Table 3. The compressive strength of several composites.

| Composite                                      | Compressive Strength (MPa) | Ref.  |
|------------------------------------------------|---------------------------|-------|
| Gypsum & rice straw                            | 2.0 – 5.5                  | [16]  |
| Rice straw particle (20 mesh) & polypropylene  | 3.2 – 8.1                  | [6]   |
| Wheat straw & corn pith & methylene diphenyl diisocyanate | 3.0 – 4.3                 | [17]  |
| Rice straw fiber (0.5 cm) & polypropylene      | 5.4 – 8.9                  | This study |

### Table 4. The density of several composites.

| Composite                                      | Density (g/cm³) | Ref.  |
|------------------------------------------------|-----------------|-------|
| Rice straw particle (20 mesh) & epoxy resin    | 0.37 – 0.48     | [5]   |
| Rice straw particle (20 mesh) & polypropylene  | 0.61 – 0.76     | [6]   |
| Rice straw fiber (3 cm) & urea formaldehyde    | 0.40 – 0.60     | [4]   |
| Rice straw fiber (0.5 cm) & polypropylene      | 0.52 – 0.58     | This study |

4. Conclusion
The composite made of rice straw fiber and polypropylene from waste plastic has been successfully produced. The modulus of rupture and elasticity are found to be in the range of 84 to 113 kgf/cm² and 2.3×10⁵ to 3.5×10⁵ kgf/cm², respectively. The compressive strength of our composite is 5.4 to 8.9 MPa. The density values of the composite range for 0.52 to 0.58 g/cm³. The thickness swelling is found to be 0.5 to 1.0%. Compared to the rice straw particle composite, the MOR, MOE, and density of rice straw fiber polypropylene composite is slightly lower than those of rice straw particle composite. However, the compressive strength of our composite is larger than that of rice straw particle composite. Based on the mechanical and physical properties above, our rice straw fiber polypropylene composite fulfills the Indonesian National Standard for particleboard.

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