Thermal conductivity of rice straw polypropylene particleboard

I Ismail¹*, N Fitri¹, Mursal¹, S H S Md Fadzullah²

¹Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, Banda Aceh 23111, Indonesia
²Centre for Advanced Research on Energy, Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

*Email: ismailab@unsyiah.ac.id

Abstract. The availability of rice straw in Indonesia, including in some other Asian countries, is very abundant. However, it has not been used optimally. One possibility of using rice straw is for heat insulation in buildings. This study aims to analyze the thermal conductivity of rice straw polypropylene composite/particleboard. In this study, particulate composites from rice straw have been produced by using recycled plastic polypropylene (homopolymer) as adhesive. The particle size of rice straw used in this study was 20 mesh. The composition of rice straw and polypropylene were varied (the ratio of rice straw particle to polypropylene is 30/70 wt. %, 40/60 wt. %, 50/50 wt. %, and 60/40 wt. %). The composite samples were produced by using a hot press with 3 tons of load. The thermal conductivity of rice straw composite samples has been measured. We found that our composite thermal conductivity is 0.223 (±0.015) W/m °C for rice straw 30 wt.% and polypropylene 70 wt. %. For rice straw composition 60 wt. %, its thermal conductivity reduces to 0.191 (±0.002) W/m °C. The composite thickness swelling is found to be 0.76 (±0.26) % for rice straw 30 wt.% (after 24 hours immersing in water). The percentage of thickness swelling is 1.80 (±0.10) % for rice straw 60 wt. %. The results of our study revealed that the thermal conductivity of rice straw composite decreased as the thickness swelling increased. This behavior is related to the porosity of the composite.

1. Introduction

Indonesia is one of the agricultural countries in Asia that produces around 70 million tons of rice in 2018 [1]. Therefore, there is a lot of rice straw in the field of rice in Indonesia. If we assume the ratio of rice to straw is about 80:20, then there are about 14 million tons of rice straw produced in Indonesia in 2018. Almost all of these rice straws become waste in the rice fields; they have not been used optimally. Only a few are used for animal feed. Besides Indonesia, several other Asian countries such as China, Vietnam, and India also produce a lot of rice. The situation is the same as in Indonesia, where there is abundant rice straw waste in the rice fields. Meanwhile, a previous study found that there was about 36 - 39 % of cellulose contained in the rice straw [2].

Some previous studies have been conducted on rice straw composites. Yang et al. made a composite of rice straw particles mixed with wood particles using a urea-formaldehyde adhesive, which is potential for acoustic panel [3]. Akyildiz et al. showed that the particleboard could be made from rice straw and urea-formaldehyde matrix [4]. Zhongli Pan et al. prepared rice straw fiber particleboard by using polymeric methylene diphenyl diisocyanate (PMDI) mixed with rice bran as adhesive. The rice bran adhesive can be used up to 30 % to substitute PMDI to form particleboard [5]. Reasonable particleboard can also be formed by using rice straw and epoxy resin adhesive [6]. Besides urea-formaldehyde, PMDI, and epoxy resin, several researchers have used plastic as an adhesive in manufacturing composite. Yao et al. formed a rice straw fiber composite by using high-density
polyethylene as a matrix [7]. Some other studies have used rice straw and polypropylene as a matrix in producing reasonably strong composites [8], [9], [10].

The application of composite material is extensive. One of them is for thermal insulation. Research on the thermal properties of composites has been conducted continuously [11], [12], [13], [14], [15]. Researchers continue to look for strong composite materials, low cost, and have low thermal conductivity (good thermal insulator). Jolanta Vejeliene et al. evaluated the thermal conductivity of several renewable resources. They found that the thermal conductivity of cattail, bentgrass, reed, and barley are in the range of 0.055 to 0.085 W/m °C [11]. Mounika et al. showed that the bamboo fiber polyester composite has a thermal conductivity of 0.185 W/m K. They found that bamboo fiber composite has better thermal insulator properties than glass fiber composite [12]. Tangjuank et al. found that the conductivity of papyrus fiberboard is 0.029 – 0.030 W/m °C [13]. Chandana et al. reported that the thermal conductivity of composite made of bamboo fiber using epoxy resin as a matrix is 0.173 – 0.197 W/m °C [14]. Raju and Kumarappa showed that the thermal conductivity of groundnut shell particle epoxy resin composite is 0.076 to 0.348 W/m °C [15].

A recent study proposed the particleboard made from rice straw particles (20 mesh) and polypropylene plastic waste as a matrix. It was found that the particleboard composite has excellent mechanical properties where its modulus of rupture and modulus of elasticity fulfill the Indonesia National Standard [10]. Nonetheless, the thermal conductivity of this particleboard composite is still unknown. On the other hand, thermal insulator panel having excellent mechanical properties is very important which can be used in building such wall and ceiling panels to prevent heat flow from outside building to reduce the consumption of electricity for air conditioner, especially in the tropical country. Based on the discussion above, we have investigated the thermal conductivity of rice straw polypropylene composite.

2. Material and Methods
Rice straw was obtained from the rice field in Aceh Besar district, which was close to the city of Banda Aceh. After cleaning, the rice straw was dried under the sun for several days. Furthermore, rice straw is chopped to a smaller size. In the next step, rice straw was dried by using an oven at 105 °C for 4 hours. Then, dried rice straw was milled then sieved to obtain a grain size of 20 mesh. Used polypropylene plastic (homopolymer) was collected from the city of Banda Aceh, which was cut by about 1 cm x 1 cm. The plastic waste was mixed with the coupling agent (methanol, xylene, anhydride maleic, and benzoyl peroxide) and heated at a temperature of 175 °C, which became a matrix. Then, the melted plastic was mixed with rice straw particles and poured into the sample mold to be pressed for 3 tons for 1 hour at a temperature of 175 °C to produce composite samples. The compositions of particleboard samples were varied: (a) 40 wt. % of rice straw and 60 wt. % of polypropylene matrix; (b) 50 wt. % of rice straw and 50 wt. % of matrix; (c) 60 wt. % of rice straw and 40 wt. % of the matrix; and (d) 70 wt. % of rice straw and 30 wt. % of the matrix.

The size of samples for thermal conductivity measurement was 10 cm x 10 cm (area) and x 1 cm (thickness). The thermal conductivity measurement was conducted by using a single-plate method instrument manufactured by Leybold. The thermal conductivity of the sample is determined by using equation (1) [16].

\[ k = \frac{\Delta Q}{\Delta t \cdot A \cdot \Delta T} \]  

Where \( d \) is the thickness of the sample, \( A \) is the area of the sample, \( \Delta T \) is the temperature difference between the heated and the cooled side of the sample, \( \Delta Q \) is heat flow through the sample during the time \( \Delta t \). The system is entirely isolated. Therefore the amount of heat flow (\( \Delta Q \)) is equal to the electrical energy (\( \Delta W \)) for the heating element. Three repetitions of measurements were made to obtain each data point of thermal conductivity. The error-bar of thermal conductivity data was calculated from the repetition data by using the standard deviation equation.

The thickness swelling of samples (\( TS \)) was determined by using Equation (2) [17].

\[ TS = \left( \frac{T_W - T_A}{T_A} \right) \times 100\% \]
Where $T_A$ is the thickness of the sample in the air (before immersing in water), $T_W$ is the sample thickness after immersion the sample in water for 24 hours. The size of the sample was 5 cm x 5 cm x 1 cm. Similar to thermal conductivity data, three repetitions of measurements of thickness swelling were made and averaged to have each data point. The error-bar of thickness swelling was also calculated by using the standard deviation equation.

3. Result and Discussion

Our results of thermal conductivity measurement of rice straw polypropylene composite are shown in Figure 1. For the rice straw composition 30 wt. % and polypropylene 70 wt. %, the thermal conductivity is 0.223 W/m °C. As the composition of rice straw increases to 40 wt. %, the conductivity of composite decreases to 0.219 W/m °C. For the composition of rice straw 50 wt. %, the thermal conductivity of composite is found to be 0.207 W/m °C. The value of thermal conductivity decreases as the composition of rice straw increases. The lowest value of conductivity of our composite is 0.191 W/m °C obtained at the rice straw composition 60 wt. %.

![Figure 1. Thermal conductivity of the composite.](image)

The comparison of thermal conductivity from the present study with other composites is displayed in Table 1. The value of thermal conductivity of rice straw polypropylene composites is almost the same value as the conductivity of the composite made from bamboo using a polyester matrix or epoxy matrix. The thermal conductivity of our composite is much larger than the thermal conductivity value of the papyrus fiber composite. However, the thermal conductivity of rice straw polypropylene composite is much smaller than the thermal conductivity of rice husk, bagasse, and corncob. Compared to concrete and glass, the rice straw polypropylene composite produced from this study has a better thermal insulator property. Thus, the rice straw polypropylene composite is a reasonable thermal insulator material.
Table 1. Thermal conductivity for selected composites.

| Material/Composite                     | k (W/m °C) | Ref.  |
|----------------------------------------|------------|-------|
| Bamboo fiber & polyester               | 0.185 – 0.211 | [12]  |
| Bamboo fiber & epoxy                   | 0.173 – 0.197 | [14]  |
| Ground nut shell particle & epoxy      | 0.076 – 0.348 | [15]  |
| Rice husk, corn cob, bagasse & starch | 0.297 – 0.494 | [18]  |
| Papyrus fiber & rubber                 | 0.029 – 0.030 | [13]  |
| Glass                                  | 0.78       | [17]  |
| Oak                                    | 0.17       | [17]  |
| Concrete                               | 0.80       | [17]  |
| Rice straw particle & polypropylene   | 0.191 – 0.223 | This study |

The thermal conductivity of our composite sample is strongly dependent on the composition of rice straw particles, and it has a linear trend, as indicated by the dashed line in Figure 1. We speculate that this behavior is related to the porosity of the composite. The porosity of the composite must be related to the water absorption or thickness swelling of the composite. The standard for composite or particleboard requires the thickness swelling. For this reason, we have measured the thickness swelling of our composite sample after 24 hours of immersion in water for several compositions. The results can be seen in Figure 2.

![Figure 2. Thickness swelling of our composite.](image)

For rice straw 30 wt. %, the swelling of thickness is 0.76 %. For rice straw 40 wt. %, the thickness swelling increases to 1.24 %. The swelling of thickness increases with the increasing of rice straw composition, as shown in Figure 2. The relationship between the thermal conductivity and the thickness swelling is shown in Figure 3. As the percentage of thickness swelling increases, the thermal conductivity decreases. Higher percentage thickness swelling means that this composite has a bigger percentage of porosity. So, the thermal conductivity is influenced by the porosity of the composite.
Since the thermal conductivity is influenced by the porosity as shown above, then we believe that the thermal conductivity should also be related to the density of the composite. The density of rice straw polypropylene composite for 20 mesh particle size has been measured and reported in the previous study [10]. Now let’s plot the thermal conductivity against the density of our composite, as shown in Figure 4.

The dashed line is the linear fit to the data. The density data is from the previous work [10], while the thermal conductivity data is from this work. From Figure 4, we can see that the thermal conductivity is also influenced by the density of the composite. The higher density of rice straw polypropylene composite, the greater its thermal conductivity is. We believe this behavior applies to other composite materials.

4. Conclusion
The thermal conductivity of rice straw particle composite (20 mesh) using polypropylene matrix has been measured for various rice straw compositions. For 30 wt. % of rice straw composition, the thermal conductivity was found to be 0.223 W/m °C. The thermal conductivity of composite
decreased as the composition of rice straw was increased. This behavior is related to the porosity of the composite. The lowest thermal conductivity was obtained at 60 wt. % composition of rice straw that was 0.191 W/m °C. Our finding indicates that the composite made of rice straw particles and polypropylene is potential for a thermal insulator.

5. Acknowledgment
This work was partially funded by the Research Grant (Hibah Laboratorium 2018) from the Universitas Syiah Kuala, Banda Aceh, Indonesia.

References
[1] Food and Agriculture Organization (FAO) 2018 Food Rice Market Monitor. 2018. XXI. Available at: http://www.fao.org/3/i9243en/i9243EN.pdf.
[2] Lu P, Hsieh Y L 2012 Carbohydr. Polym. 87 pp. 564-573.
[3] Yang H S, Kim D J, Kim H J 2003 Bioresour. Technol. 86 117 – 121.
[4] Akyldiz M H, Kesik H I, Oncel M, Olgun C 2015 PRO LIGNO 11 130 – 137.
[5] Pan Z, Cathcart A, Wang D 2006 Ind. Crops Prod. 23 40–45.
[6] Ismail I, Aini Q, Zulfalina, Jalil Z, Md Fadzullah S H S 2018 J. Phys. Conf. Ser. 1120 012014.
[7] Yao F, Wu Q, Lei Y, Xu Y 2008 Ind. Crops Prod. 28 63–72.
[8] Grozdanov A, Buzarovska A, Bogoeva G G, Avella M, Errico M E, Gentille G 2006 Agron. Sustain. Dev. 26 251–255.
[9] Mohammadi H, Mirmehdi S, Hugen L N 2016 CERNE 22 449-456.
[10] Ismail I, Fitri N, Zulfalina, Md Fadzullah S H S 2018 J. Phys. Conf. Ser. 1120 012015.
[11] Vėjeliene J, Gailius A, Vėjelis S, Vaitkus S, Balčiūnas G 2011 Mater. Sci 17 208 – 212.
[12] Mounika M, Ramaniah K, Prasad R A V, Rao K M, Chandra Reddy K M 2012 IOP Conf. Ser. Earth Environ. Sci. 3 1109 – 1116.
[13] Tangjuan S, Kumfu S 2011 J. Appl. Sci. 11 26402645.
[14] Chandana E, Hussain S A 2013 J. Mech. Civil Eng. 9 7-14.
[15] Raju G U, Kumarappa S 2012 Polym. Renew. Resour. 3 117 – 138.
[16] Holman J P 2010 Heat Transfer. New York: Mc Graw Hill.
[17] Japanese Standards Association 2003 Japanese Industrial Standard for particleboard JIS A 5908. Tokyo: Japanese Standards Association.
[18] Kyauta E E, Dauda D M, Justin E 2014 Am. J. Eng. Res. 03 34-40.