Thermal conductivity of coconut shell particle epoxy resin composite

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Abstract. Coconut shell is one of the agricultural wastes that are widely available in Indonesia and other tropical countries. Unfortunately, the coconut shell waste has not been used optimally for new materials, especially for thermal insulation material. In this work, the composite from coconut shell particles using epoxy resin adhesives has been prepared. The particle sizes of coconut shells for composite samples were 60, 80, 100, and 120 mesh. The compositions of samples for each particle size (ratio between coconut shell and epoxy resin) were 70/30, 75/25, 80/20, and 85/15 (vol %). The thermal conductivity of each composite sample has been examined by using a single-plate method. The density of each sample has also been measured. The results showed that the thermal conductivity of composite sample for 60 mesh of particle size with 70/30 vol.% composition was 0.071 W/m K. As the composition of coconut shell was increased to 85 vol.%, the value of thermal conductivity decreased to 0.062 W/m K. It was found that the thermal conductivity of composite sample decreased as the composition of coconut shell was increased. For the composition of 70/30 vol.%, the thermal conductivity increased to 0.078 W/m K for 120 mesh of particle size. This behavior was also the same for other compositions, where the value of thermal conductivity of composite increased as the coconut shell particle size decreased. The density of the composite was found in the range of 0.799 – 0.938 g/cm³. As the particle size of the coconut shell was reduced, the density of the composite increased. This study revealed that both thermal conductivity and density of coconut shell epoxy composite are dependent on the particle size of the coconut shell. The thermal conductivity of all samples was less than 0.1 W/m K indicating that the coconut shell epoxy composite is quite potential for thermal insulation.

1. Introduction

Indonesia is the world leader in coconut production. In 2018, the production of coconut in Indonesia was 19 million tons [1]. Coconut shells are agricultural waste from coconut production, which is quite a lot in Indonesia. Until now, coconut shells have not been used optimally. On the other hand, several studies have shown that coconut shells have the potential to be used for composites [2, 3, 4, 5, 6, 7, 8]. Bledzki et al. found that the barley husk and coconut shell could be used as alternative fillers for composites material [2]. Leman et al. argued that the coconut shell powder could be used as filler in concrete [3]. A very recent study found that nanoparticles of coconut shell significantly improved the

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performance of composite [8]. So, it is very interesting to study composites from coconut shells.

Heat insulation materials are very important in automotive, aircraft, electronic equipment, industry, and daily life. Researchers are continuously looking for heat insulation materials, which are cheap, strong, and safe for the environment. Those materials are from renewable materials such as composites made of agricultural wastes. Several studies on the thermal conductivity of composites have been conducted [9, 10, 11, 12, 13, 14]. Jolanta et al. found that the thermal conductivities of Bentgrass, Reed, and Cattail were 0.060 W/m K, 0.080 W/m K, and 0.055 W/m K, respectively [9]. The thermal conductivity of bamboo composite was found to be 0.185 – 0.196 W/m K [10]. Papyrus fiberboard had a thermal conductivity of 0.030 W/m K [11]. The lowest thermal conductivity of bamboo fiber composite using epoxy resin binder was 0.111 W/m K [12]. Kimura et al. showed that the coconut fiber composite using tapioca starch and polyvinyl alcohol as binders had a thermal conductivity of 0.104 W/m K [13]. The thermal conductivity studies of coconut shell composites are very few reported in the literature. Din et al. found that the thermal conductivity of coconut shell composite using binders was 0.143 W/m K. However, this study did not report the effect of composition and the size of coconut shell particle on thermal conductivity [14]. Meanwhile, the previous studies found that the particle size and composition significantly influence the properties of the composite [8, 15]. Burger et al. argued that the thermal conductivity in composite was affected by certain parameters such as particle size and the ratio of the filler [16].

In this work, the composite made of coconut shell and epoxy resin has been prepared. Epoxy resin has been used as a binder since it provides a good bond between the fillers [8]. The composition and particle size of the coconut shell particles were varied. The thermal conductivity and density of the composite have been measured.

2. Method

The coconut shell waste was obtained from the market in Banda Aceh. The coconut shell was cleaned and dried under the sun for several days. After that, the dried coconut shell was chopped to a small size. Then, the chopped coconut shell was milled to get coconut shell particles. Furthermore, the coconut shell particles were sieved by using sievers to obtain the coconut shell particles with sizes of 0.250 mm (60 mesh), 0.177 mm (80 mesh), 0.149 mm (100 mesh), and 0.125 mm (120 mesh). The epoxy resin as the matrix was purchased from the Avian Company, Indonesia.

The coconut shell particles were mixed with epoxy resin homogeneously by using a mixer with a speed of 300 rpm at room temperature for 30 minutes. The mixture of coconut shell particles and epoxy resin was poured into the sample mold with a size of 15 cm x 15 cm x 1 cm and then pressed at room temperature with a 9 tons load for 60 minutes to produce a composite sample. The fabrication process of the composite is shown in figure 1. The compositions of samples were varied for each particle size. The ratio of coconut shell particle to epoxy resin was 70/30, 75/25, 80/20, and 85/15 vol. %. The sample size for thermal conductivity measurement was 10 cm x 10 cm x 1 cm. The sample size for density measurement was 5 cm x 5 cm x 1 cm.

A single-plate method has been used to measure the thermal conductivity of samples. The instrument was manufactured by Leybold. The thermal conductivity of the sample was calculated by using equation (1) [17].

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

Where \( \Delta Q \) is heat flow through the sample during the time \( \Delta t \), \( A \) is the area of the sample, \( d \) is the thickness of the sample, \( \Delta T \) is the temperature difference between the sides of the sample. The density of samples was obtained by using the equation (2).

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

Where \( V \) is the sample volume and \( m \) is the sample mass. The error-bar of thermal expansion and density was determined by using the standard deviation equation.
3. Results and Discussion

The thermal conductivity of coconut shell particle (CSP) epoxy resin composite for various compositions of coconut shells and various coconut shell particle sizes is shown in figure 2. For coconut shell particle size 60 mesh, the thermal conductivity of composite was found to be 0.071 W/m K for the composition 70 vol.% of CSP (30 vol.% of epoxy resin). For 75 vol.% of CSP (25 vol.% of epoxy resin), the thermal conductivity decreased to 0.069 W/m K. For CSP composition 85 vol.%, the thermal conductivity was 0.062 W/m K. The thermal conductivity of composite decreased as the composition of CSP was increased for 60 mesh of particle size. As the particle size became smaller (80 mesh), the thermal conductivity of composite increased to 0.072 W/m K for 70 vol.% of CSP. The thermal conductivity decreased to 0.070 W/m K for 75 vol.% of CSP. Similar to the 60 mesh particle size, the thermal conductivity of composite decreased, as the composition of CSP increased.
This behavior is the same for other particle sizes (100 and 120 mesh), as displayed in Figure 2.

The comparison between the thermal conductivity from this study and previous studies is displayed in table 1. Ramsaroop et al. found that the thermal conductivity of the coconut shell was in the range of 0.030 – 0.125 W/m K [19]. The thermal conductivity from this study is in the range of these values. The thermal conductivity from this study is slightly lower than the result reported by Kimura et al. for the coconut fiber composite using tapioca and PVA matrix [13]. The thermal conductivity of coconut shell composite using epoxy resin reported by Din et al. was 0.143 W/m K [14] which is higher than the thermal conductivity from this study. The discrepancy between the result from this study and the result reported by Din et al. could be due to the particle size and composition of coconut shells. Din et al. did not report the particle size and composition of filler or matrix in their composite.

| Material/composite                   | k (W/m K) | Ref.   |
|-------------------------------------|-----------|--------|
| Coconut shell                       | 0.030 – 0.125 | [19]   |
| Coconut fiber & tapioca & PVA       | 0.105     | [13]   |
| Coconut fiber                       | 0.048 – 0.049 | [18]   |
| Coconut fiber & epoxy resin         | 0.140     | [14]   |
| Coconut shell & epoxy resin         | 0.143     | [14]   |
| Coconut shell & epoxy resin         | 0.062 – 0.078 | this study |

The density of coconut shell composites for various compositions and particle sizes has been measured. The result is displayed in figure 3. For 60 mesh particle size, the density of composite was found to be 0.861 g/cm³ for 70 vol. % of CSP composition. As the CSP composition was increased to 75 vol. %, the density decreased to 0.820 g/cm³. For 85 vol.% CSP, the density of composite was 0.799 g/cm³. The density of coconut shell nanoparticle composite using epoxy matrix was found to be 1.031 g/cm³ [8]. The density of coconut shell composite reported by Bhaskar et al. was in the range of 1.17 – 1.29 g/cm³ [20]. The discrepancy of the density from this study and the density from previous studies was due to different particle size and composition of filler. The density of composite decreased, as the CSP composition was increased. This behavior was the same for other particle sizes (80, 100, and 120 mesh). As the particle size was decreased to 80 mesh, the density was found to be 0.891 g/cm³. For the particle sizes of 100 mesh and 120 mesh, the densities of the composite were 0.893 g/cm³ and 0.938 g/cm³, respectively. The density of the composite increased, as the size of the coconut shell particle was reduced. This trend is similar to other compositions, as shown in figure 3. This behavior was observed in previous studies [8, 15].

Figure 2 shows that the thermal conductivity of composite reduces as the composition of coconut shell is increased. This trend is the same for density, as displayed in figure 3. This behavior could be related to the porosity of the composite sample. The epoxy matrix is dense, while the coconut shells have some pores. As the composition of the coconut shell is increased, the porosity of the composite increases. Then, the density of the composite decreases. The air is trapped in the pores, where the thermal conductivity of air is 0.024 W/m K [17]. Thus, the thermal conductivity decreases because of the porosity. As the particle size is reduced, the thermal conductivity of the composite increases, as shown in figure 2. This behavior could be related to the increased total surface area of filler (coconut shell particles). The density of the sample also increases as the particle size is reduced, as shown in figure 3. This behavior could be due to the porosity of composite, where the small particle size of coconut shell could reduce the porosity. Figure 4 shows the thermal conductivity against the density of the composite for various compositions of coconut shells. The result obtained is very interesting, where there is a correlation between thermal conductivity and density of composite samples. Its relation is linear, as shown (dashed line) in figure 4. As the density of coconut shell composite increases, its thermal conductivity increases. This finding suggests that the thermal conductivity of
coconut shell composite is influenced by its density. This behavior was observed in the previous study of fiber reinforced concrete reported by Nagy et al. [21].

![Figure 4. The thermal conductivity of composite versus its density](image)

The thermal insulation materials commonly used are glass wool and styrofoam. The thermal conductivity of glass wool and styrofoam are 0.038 and 0.033 W/m K, respectively [17]. The thermal conductivity of concrete or building wall is 0.760 W/m K [17]. The thermal conductivity of the composite from this study is 0.062 – 0.078 W/m K that is much smaller than the thermal conductivity of the building wall. Therefore, the composite from this work has the potential to be used as a thermal insulator material for building to reduce the heat flow from outside to inside building during the daytime.

4. Conclusion
The composite made of coconut shell and epoxy resin as a binder has been fabricated for various compositions and particle sizes of coconut shells. The thermal conductivity and density of the composite were influenced significantly by the composition and the particle size of the coconut shell. The thermal conductivity of composite decreased as the composition of coconut shell was increased. The density of composite had similar behavior, where the density also decreased as the composition of coconut shell was increased. However, the thermal conductivity of composite increased as the size of the particle of the coconut shell was reduced. This behavior was similar to the density of the composite. This finding suggests that there is a correlation between the thermal conductivity and density of composite. The thermal conductivity of coconut shell composite was found to be in the range of 0.062 – 0.078 W/m K which is less than 0.1 W/m K. Thus, the coconut shell composite using epoxy resin adhesive is a good thermal insulator.

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