JBAT 12(1) (2023) 32 – 38

Jurnal Bahan Alam Terbarukan

Accredited SINTA 2 by Ministry of Research and Technology/National Research and Innovation Agency
SK No. 200/M/KPT/2020
http://journal.unnes.ac.id/nju/index.php/jbat

p-ISSN 2303 0623
e-ISSN 2407 2370

New Thermal Insulation Materials Based on Mahogany Sawdust and Polyurethane Foam for Buildings

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DOI: https://doi.org/10.15294/jbat.v12i1.40569

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Article Info

Article history:
Received
2 December 2022
Revised
15 January 2023
Accepted
17 January 2023
Online
8 May 2023

Keywords:
Thermal insulation material;
Mahogany sawdust;
Polyurethane foam;
Thermal conductivity;
Composite

Abstract

Global energy consumption has increased in the last few decades and is the third largest contributor to global energy consumption and one of the causes of increased carbon dioxide emissions. Therefore, in this study utilizing sawdust mahogany as a thermal insulation material to overcome the above problems. Sawdust material is combined with polyurethane foam to produce optimal physical, mechanical, and thermal insulation properties. From the study results it was found that the density of the thermal insulation material increased with the addition of sawdust. The value of the density is in the range of 0.041-0.052 gr/cm^3. Observations using the secondary electron image (SEI) on thermal insulation materials show that the amount of sawdust added will affect the formation of an open pore cell structure which is directly proportional to the addition of sawdust. In addition, the more sawdust that is added will change the arrangement of cells and reduce the mechanical properties of the thermal insulation material. This is confirmed by the results of the hardness test which decreases with the addition of sawdust with the lowest value of 16.6 shore C for the addition of 10% sawdust. The thermal conductivity of the thermal insulation material has a value of 0.052, 0.038, 0.033, 0.032, and 0.033 W/mK for the addition of 0.2.5%, 5%, 7.5% and 10% sawdust, respectively. This shows that the thermal insulation material made in this study can be used as an alternative to thermal insulation material.

INTRODUCTION

Energy consumption for household application is one of the three largest contributors to global energy consumption and a contributor to carbondioxide (CO_2) gas emissions (Geng et al., 2018). One of the effective method to reduce energy consumption and CO_2 gas emissions is to utilize thermal insulation materials on the interior or exterior of a building (Huang et al., 2020; Liu et al., 2019). The ability of this material to reduce energy consumption is to reduce heat transfer between the inner and outer walls of the building. Several studies indicate that materials properties are important and the main concern for researcher to develop insulation material, such as thermal conductivity, thermal energy storage, acoustics, thermal mass, hygroscopic, fire resistance, ability to dynamic loading, and production level of CO_2 emission during operational process (Cetiner & Shea, 2018).

Until now, there are three types of insulation materials that are often used, namely those based on organic, inorganic, and mortar (Lin et al., 2021; Tiuc et al., 2019). Organic thermal

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insulation materials, including polyurethane, polyethylene, and polystyrene, are often used because of their good thermal insulation properties and affordable prices. However, the organic material is highly flammable and not friendly to the environment. Thermal insulation mortars, such as vitrified microspheres and adhesive polyethylene particles (APP), have good thermal insulation and also fire resistant. However, due to its poor water resistance and relatively high price, thermal insulation mortar is not widely used as an insulation material. Inorganic materials such as mineral wool and glass fiber also have good thermal insulation properties and are relatively affordable, but health problems such as skin and lung irritation make users rethink using these materials.

Recently, the development of insulation materials based on renewable materials and biomass sources has attracted particular interest among researchers. These renewable materials are not only cheap but also friendly to the environment. The use of these renewable materials can certainly reduce CO_2 emissions and waste to the environment. Among the renewable materials that have been developed, only a few materials are quite effective as insulation materials. These materials include cellulose, cotton waste, straw, bamboo, and other agro-industrial waste.

The wood processing industry is one of the major contributors to environmental pollution in Indonesia. Some waste is generated from the wood processing industry, one of which is sawdust from cutting which in the process of disposal, the wood sawdust is often carried out by a combustion process (Merli et al., 2021). To reduce the problem of sawdust waste, it is necessary to use sawdust waste into materials with high economic value and support policies to reduce CO_2 emissions in the environment. One of its uses is as a raw material for the manufacture of thermal insulation materials used in building application.

To improve environmental protection, the sawdust can be processed into a material with a high economic value, namely as a thermal insulation material. Zou, et al conducted research on composite materials for building materials that combine geopolymer materials as adhesives and sawdust as aggregates. The results obtained are the insulation material has a fairly good heat resistance, good thermal conductivity with value of 0.087 W/mK, density of 430.8 kg/m^3, and compressive strength of 0.97 Mpa (Zou et al., 2020). Another study also stated that the combination of sawdust and polyurethane resulted in a combination of excellent thermal insulation properties (Tiuc et al., 2019). Cetiner et al., also used sawdust in their research and placed the insulating material in the wall frame. The research resulted in thermal conductivity in the range of 0.048 to 0.055 W/mK (Cetiner & Shea, 2018). Francesca Merli et al., combined various sizes of sawdust, types of binders (vinyl and flour), and methods of fabricating composite materials. This research resulted in thermal conductivity properties in the range of 0.071-0.084 W/mK and sound attenuation up to 11 dB at 1700 Hz. These properties vary in each test sample depending on the type of wood used (Merli et al., 2021). Although several studies have shown that sawdust can be a potential material to be used as a thermal insulation material, more in-depth research is needed to be able to increase the thermal insulation ability optimally, and practical trials are needed on building walls.

In this study, mahogany sawdust from the wood cutting industry will be used as filler material. Mahogany sawdust was combined with polyurethane foam to determine the physical properties and conductivity of the thermal insulation material.

EXPERIMENTAL DESIGN

Materials

To obtain wood waste-based composites, the sawdust particles used in this study were obtained from the results of wood cutting in the Foundry Engineering workshop, Bandung Polytechnic for Manufacturing. The wood waste belongs to the type of mahogany wood with a powder size of 22-40 µm. The wood waste obtained is heated inside the furnace with temperature of 100 ^oC and then placed inside the storage box and maintained the humidity at 10%.

Polyurethane binders are used as a bonding agent between sawdust. There are two components used in the manufacture of polyurethane binders. The first component is Polyisocyanate (Millionate MR-200, Japan) with a viscosity of 150-250 mPa.S at a temperature of 25 ^oC and a density of 1.22 gr/cm^3. The second component is polymeric diphenylmethane-4,4′-di-isocyanante (JKR-7631L, Japan, density: 1.1 g/cm^3, viscosity 250 mPa.S at 25 °C). Each component is mixed in a ratio of 100:70 by weight of component A to component B.

Composite Materials Processing

Polyisocyanate and polymeric diphenylmethane-4,4′-di-isocyananante were weighed on a digital balance with accuracy 0.0001 g. The two components were poured into a polypropylene glass and mixed with a weight ratio of 100:70. The sawdust was also weighed and added to the polyurethane mixture with variations of 0, 2.5, 5, 7.5, and 10 %. The mixture is stirred for 10-12 seconds and poured into the wooden mold quickly due to the high reaction speed. The mold is left in an open state for 1 hour so that the chemical reaction takes place completely. Due to the influence of the addition of sawdust, the chemical reactions that occur also experience a slowdown than without addition (Cetiner & Shea, 2018; Tiuc et al., 2015).

Physical Properties

Samples were cut with a size of 20 mm x 20 mm x 20 mm to test the physical properties of the composite material. Prior to measurement, each sample was conditioned to achieve a constant weight. The apparent density (ρ) of the composite is calculated by using the following equation

$$\rho = \frac{m}{v} \quad (1)$$

where m is the mass of the composite and v is the volume of the composite. The mass of the composite was weighed using an digital analytical balance with an accuracy of 0.0001 g, and the volume was measured using a vernier caliper with accuracy 0.02 mm. The morphology of the composite material was observed by using a Scanning Electron Microscope (SEM, Hitachi SU-3500, Japan) using an acceleration voltage of 5 kV by using secondary electron image (SEI) method.

Mechanical Properties

Measurement of the mechanical properties of the composite materials is intended to determine the behavior of composite materials when receiving external loads. The test sample was first conditioned at a temperature of 25 °C and a humidity of 45%. Hardness test was carried out to determine the effect of sawdust addition on the mechanical properties of the composite materials. Hardness testing was carried out using a Shore C Durometer with an indentation force of 8.06 N according to the ASTM D22040 standard (ASTM, 2010).

Thermal Conductivity

The test sample was cut into size (100 x 100 x 20) mm for thermal conductivity testing. The test sample was inserted into the thermal conductivity testing apparatus according to the ISO 8302-1991 standard (ISO, 1991). Temperature measurement is carried out using a thermocouple that has been conditioned according to the standard.

RESULTS AND DISCUSSION

Apparent Density

Figure 1 shows the density of the pu foam and wood powder composite material. The density of composite materials is in the range of 0.041-0.052 gr/cm^3. The lowest density of composite materials is owned by pu foam without the addition of sawdust with a value of 0.041 gr/cm3. While the highest density of the composite material is owned by the composite with the addition of 10 wt.% sawdust. From figure 1 it can also be seen that the more sawdust added to the pu foam, the density will also increase.

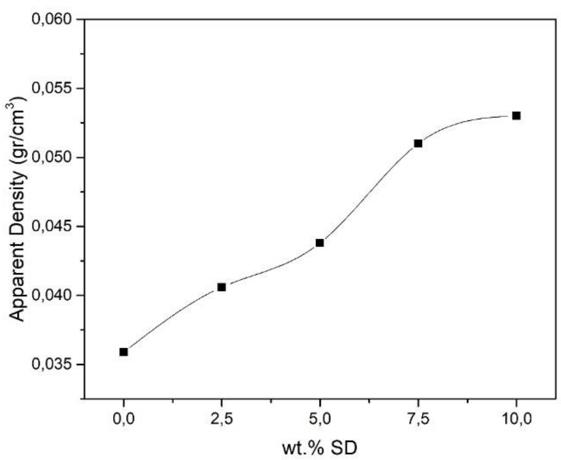

Figure 1. Apparent density of PUF+SD.

Microstructure

Figure 2 shows the morphology of the thermal insulation material for various compositions of 0 and 2.5 % sawdust. Based on observations made using SEI, it was found that the size and shape of the cells of the foam is determined by the interaction between the polyurethane foam matrix and the filler sawdust surface. The addition of 2.5 % sawdust significantly affected the cell

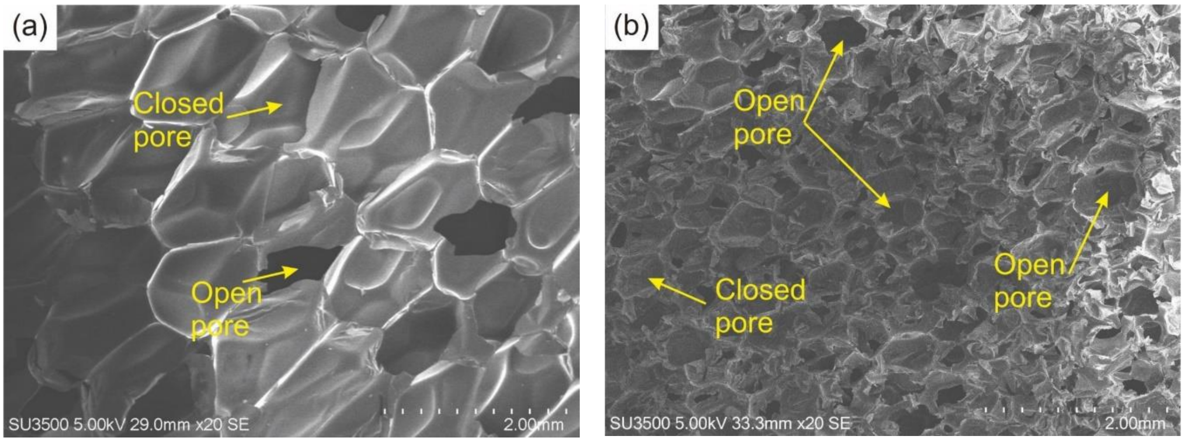

Figure 2. SEI micrograph of (a) 0% SD and (b) 2.5 % SD.

shape. The shape and size of the PU foam cells are no longer uniform due to the addition of sawdust.

Observation results using SEI from PU foam and sawdust materials show that the amount of sawdust addition will influence the formation of open pore cell structures. The open pore cell structure will affect the mechanical properties and physical properties of the material. As can be seen in the Figure 2 (a), without the addition of sawdust, the open pore cell structure only forms in a few locations. However, the addition of sawdust resulted in more formation of open pore cell structures as can be seen in Figure 2 (b). Open pore cell structure is one of the most important factors that determine the physical properties of the insulation material, especially the sound absorbing properties (Cetiner & Shea, 2018). In addition, Figure 2 (a) also clearly shows the presence of a closed pore structure in PU foam.

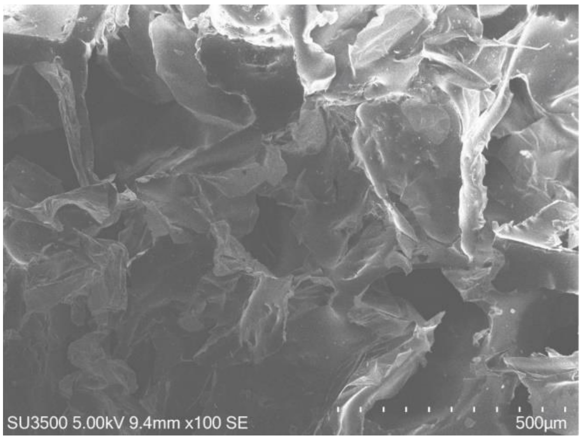

Figure 3. SEI of the PUF+7.5 % SD (an indication of a change in the PUF structure).

As can be seen in Figure 3, the sawdust is attached to the PU foam matrix where the PU foam undergoes a chemical reaction between diisocyanate from the isocyanate group and polyol from the hydroxyl group which produces urethane group (Gu et al., 2013; Muthuraj et al., 2019). In addition, the addition of sawdust also results in a reduction in cell size and disruption of the foam structure, especially at the interface as shown in Figure 3. This has the potential to reduce the strength of the cell structure and cause cracks (Dukarska et al., 2022).

Hardness

Figure 4 shows the results of the hardness test of the composite material with the addition of sawdust. Based on the above data, although the density of the composite material increases with the addition of sawdust, the hardness test results show a gradual decrease in the thermal insulation material with value of 35, 32.3, 30.4, and 23.8 shore C for addition of 0, 2.5, 5, and 7.5% sawdust, respectively. From the test results it was found that a drastic decrease in hardness was found in the composite material with the addition of 10 wt.% sawdust with a test result of 16.6 shore c durometer. This is directly proportional to the results of flexural testing and compression tests conducted by Dukarska et al. (2022). The mechanical properties of foam composites are also influenced by the type and type of filler particles, surface modifications, and interactions with the polyurethane matrix (Członka et al., 2021; Członka et al., 2020). This decrease in mechanical properties is an indication that changes in the shape of the foam cells, as can be seen in Figures 2 and 3, affect the hardness of the foam composite.

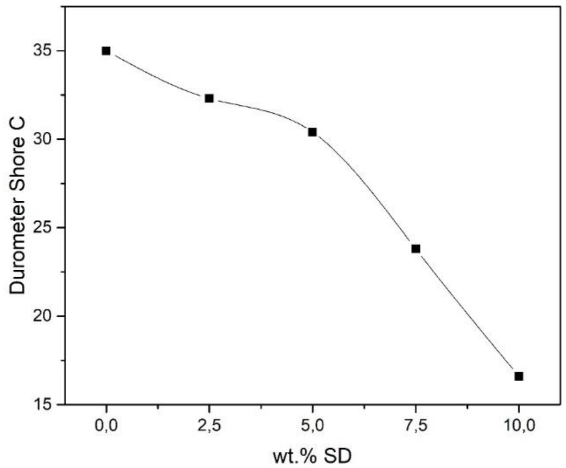

Figure 4. Hardness of PUF+SD.

Thermal Conductivity

The value of the thermal conductivity of the thermal insulation material in this study depends on changes in composition, shape of the cells (open or closed), and density. The conductivity value of this composite material is influenced by several heat transfer mechanisms including conduction from the cell wall, convection in the cell, and radiation.

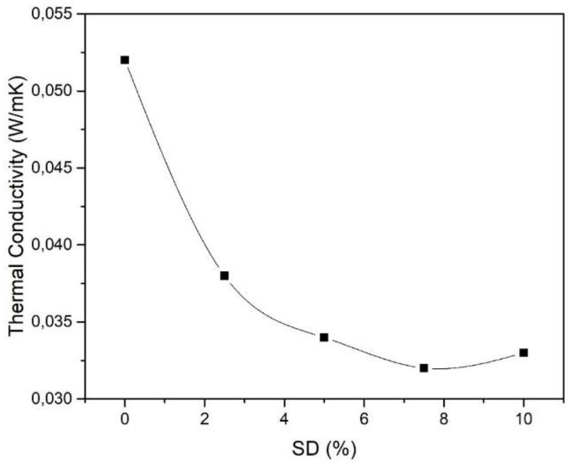

Figure 5. Thermal conductivity values for different composition of sawdust.

Figure 5 presents data regarding the effect of adding sawdust to thermal conductivity value. The PU foam made in this study has a thermal conductivity value of 0.052 W/mK. The addition of sawdust caused a decrease in the value of the thermal conductivity of the thermal insulation material with values of 0.038, 0.033, 0.032, and 0.033 W/mK for each addition of sawdust of 2.5%, 5%, 7.5%, and 10%, respectively. The addition of sawdust of 5-10% does not have any significant effect on the thermal conductivity decreasing value of the thermal insulation material and tends to have the similar value. The lowest value of thermal conductivity indicates that the composite material has very good thermal insulation properties.

Figure 6 shows the effect of heating time on the thermal conductivity of the thermal insulation material. The thermal insulation material which use in this study is heated to a temperature of 80 °C and observed at that temperature for several periods. From these results, almost all thermal insulation materials experience an increase in the value of thermal conductivity as the holding time increases. However, the increase in the value of the thermal conductivity of the composite material is not significant.

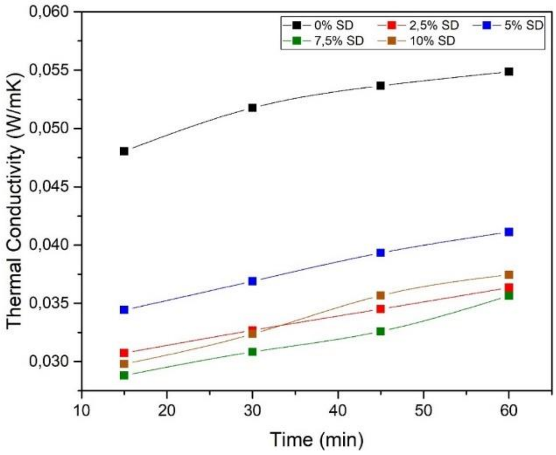

Figure 6. Thermal conductivity values for different times at 80 °C.

The results of the thermal conductivity testing of materials in this study indicate that sawdust has an important role and can be used as a thermal insulation material. The conductivity value of thermal insulation materials with the addition of sawdust in this study is still better when compared to other natural materials, namely binderless sawdust (Cetiner & Shea, 2018), wood fiber (Muthuraj et al., 2019), binderless panel oil pam wood (Mawardi et al., 2022), and sunflower/gypsum (Binici et al., 2020). Furthermore, the value of the thermal conductivity of thermal insulation material in this study are much better than the standardized value for thermal insulation materials in buildings which are in the range of 0.1-0.14 W/mK (Ross, 2010).

CONCLUSION

This study, an investigation was carried out on the use of sawdust as a thermal insulation material. Sawdust material is combined with polyurethane foam to produce optimal physical, mechanical, and thermal insulation properties. From the study results it was found that the density of the thermal insulation material increased with the addition of sawdust. The value of the density is in the range of 0.041-0.052 gr/cm3. The results of observations using the SEI of thermal insulation materials indicate that the amount of sawdust addition will affect the formation of open pore cell structures. In addition, the more sawdust that is added will change the arrangement of cells and reduce the mechanical properties of the thermal insulation material. This is confirmed by the results of the hardness test which decreases with the addition of sawdust with the lowest value of 16.6 shore C for the addition of 10% sawdust. The thermal conductivity of the thermal insulation material has a value of 0.052, 0.038, 0.033, 0.032, and 0.033 W/mK for the addition of 0.2.5%, 5%, 7.5% and 10% sawdust, respectively. This shows that the thermal insulation material made in this study can be used as a thermal insulation material

ACKNOWLEDGEMENTS

This research is supported by the ministry of education, culture, research and technology, Indonesia. The authors also wish to thank Foundry Engineering Department and Advanced Materials Engineering Department at Bandung Polytechnic for Manufacturing for the supply of the mahogany sawdust and for the help in the experimental aspects of this study.

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