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THERMAL CONDUCTIVITY OF PARTITION BOARD BY POLYMER COMPOSITE WITH FILLER EMPTY FRIUT BUNCHES FIBRES

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Abstract

Utilization and management of Empty Fruit Bunches (EFB) fibre continue to develop as the main ingredient and additional material used in various industrial products. The technological breakthrough targeted in this study is the developed EFB fibre as a filler in polymer composite partition boards which are used as heat retainers in the interior construction of buildings. The partition board is a heat insulator, and its thermal conductivity is affected by mass density and porosity. The purpose of this study was to determine the heat resistance of partition board products to reduce the heat entering the room from outside by propagating through walls exposed to direct sunlight. The test method used is adopted from ASTM C177-13, namely the measurement of heat propagation with a modification of the heat source of 40 watts. In addition, mass density tests (referring to SNI 03-2105-2006) and water absorption (referring to ASTM D5229M-12) were also carried out on the product. The specimens were based on the formation of Singapore Highpolymer Chemical Product (SHCP) 2667 WNC polyester resin matrix partition board with weight fractions of 25%, 30%, and 35% chop strand mat (CSM). The test results show that the highest thermal conductivity value is found on the board with a weight fraction of 25%, namely 0.153 W/m.°C with a mass density of 1.16 g/cm^3 and a water absorption capacity of 3.38%. However, the lowest thermal conductivity value was found in the fibre with weight fraction of 35%, namely 0.147 W/m. °C at a mass density of 1.24 g/cm^3 and a water absorption capacity of 3.75%.

Keywords: *Composite Partition Board, EFB Fibres, Thermal Conductivity, Heat Retardant Material.*

1. INTRODUCTION

The Utilization and management of Empty Fruit Bunch (EFB) waste have increased. In general, it is still used in the development of compost, partly as a fuel and biomass energy source. The research conducted by Pandapotan indicates that the EFB of palm oil mill waste has not been utilized optimally, since the EFB is still used as compost. After all, it has humus and nutrient content [1]. According to Noerrizki, solid palm oil waste in the form of EFB can be used as fertilizer, fuel for biomass power plants, raw material for making bioenergy by various processes, and concrete additives [2]. Meanwhile, Pujari developed EFB fibres into a composite materials for brake pad and concluded that if EFB fibres are handled properly, it is possible that they would get added value [3].

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Heat insulation is a method or process used to reduce the rate of heat transfer. Heat or heat energy can be transferred using conduction, convection, and radiation or when changes occur. Heat flow can be controlled by a heat insulation process, depending on the properties of the material used. The material used to reduce the rate of heat transfer is called an insulator. Heat can escape despite attempts to prevent it from doing so, but insulators reduce the escape rate [4].

The insulation ability of a material is measured by its thermal conductivity (k). Low thermal conductivity equates to high insulation capability (thermal resistance or R-value and sound absorption coefficient, a). In heat transfer and sound absorption techniques, other properties of insulation or insulating material are density (ρ), yield (water absorption), and specific heat capacity (c) [4].

The density and porosity of a material affect the value of thermal conductivity. Density (ρ) is a measure of the compactness of a material, so the greater the density value, the greater the value of its thermal conductivity. Whereas porosity refers to the holes or spaces in a material. Porosity is always inversely proportional to density (ρ), so porosity is also inversely proportional to the value of thermal conductivity. The different values of thermal conductivity of various materials are shown in Table 1.

Table 1. Thermal conductivity values of various materials [5].

MATERIALS	THERMAL CONDUCTIVITY (W/m ºC)
Pure Silver	410
Pure Aluminium	202
Pure Nickel	93
Pure Iron	73
Oak wood	0.17
Raw rubber	0.15
Wood charcoal	0.08
Atmosphere	0.024

The technological breakthrough targeted in this research is the development of a polymer composite product with EFB fibre as a heat retardant that can be used in various engineering fields and as the interior in building construction.

The fibres are generally much stronger than the matrix and provide tensile strength, while the matrix functions to protect the fibres from environmental effects and damage caused by impact. Many fibres can be used to improve the properties of composites. Natural fibres can be fillers in composites because of their cellulosic content; some natural fibres that have cellulose include kenaf, sugar cane, corn, abaca, rice, hemp, EFB, and others [6]–[8].

The initial treatment in the form of soaking the fibre in alkaline or silane can remove impurities that stick to them. This treatment can increase the interfacial bonding of fibres and their matrices. This is due to an increase in the surface roughness of the empty fruit bunches of oil palm [9].

According to Jamilah, ramie fibres that were not treated with alkaline had the smallest tensile strength of 39.25 MPa. However, after being giving alkaline treatment (4% NaOH), the tensile strength of the fibres increased to 43.86 MPa. From the test, it was found that the maximum average tensile strength of 57.37 MPa was obtained in the fibres that were given alkaline treatment with 8% NaOH, while after being given alkaline treatment with 9% NaOH, the average tensile strength tended to decrease to 41.19 MPa. The decrease in fibre strength could be caused by damage to the fibre structure due to an excessive amount of NaOH concentration, so it is necessary to know the exact concentration to obtain the optimum result [10].

The EFB fibre can be used as an ingredient for the manufacture of composite boards for application in furniture making. Water absorption is one of the important characteristics of natural fibre-polymer composites that determine the end-use application of the fibre. Although water absorption may lead to a reduction in the end-use application of the composites under study, there is reason to believe that by understanding the limitations and benefits of EFB fibre filled High Density Polyethylene (HDPE), fillers (EFB fibres) are unlikely to be overlooked by the composite industry for use in automotive, building tools, and other applications [11], [12].

In general, the mechanical properties of natural fibre reinforced thermoplastic and thermoset composites showed improvement with the addition of natural fibres as reinforcement [13]. Polylactic acid (PLA) composites showed significant improvements in both tensile and flexural strength. However, the low thermal stability of PLA has limited its use in certain applications. Polystyrene (PS) and epoxy (EP) composites were hardly affected or only slight improvement in mechanical properties was observed. Kenaf (KE) fibre is stronger than Oil Palm Empty Fruit Bunch (OPEFB) fibre because of the advantages of KE’s higher aspect ratio. KE fibre also exhibits strength comparable to E-glass fibre. Scanning Electron Microscopy (SEM) analysis showed the interaction between fibre and matrix. The natural fibre reinforced PLA composites possessed excellent adhesion leading to higher strengths compared to PS and EP composites [14].

The amount of heat absorbed/released by an object is directly proportional to the mass of the object, the specific heat of the object and changes in temperature. Energy transfer will occur when an object has a temperature gradient. It can be said that the energy moves by conduction, and the rate of heat transfer is proportional to the normal temperature gradient [15].

The measurement of thermal conductivity aims to determine the effect of the rate of thermal conduction on several types of materials [6]. The transfer of heat energy in insulating materials at high temperature takes place in several ways: conduction through air confined in a cavity and conduction through hollow or solid materials [5]. The value of thermal conductivity can be calculated by indirect measurement by measuring directly from several other quantities, the thermal conductivity of each sample used in this research [16].

The greater the gradient of a material flowing with heat, the greater the heat flow [17]. Thus, the heat flow is proportional to the cross-sectional area through which the heat is passed as shown in Figure 1.

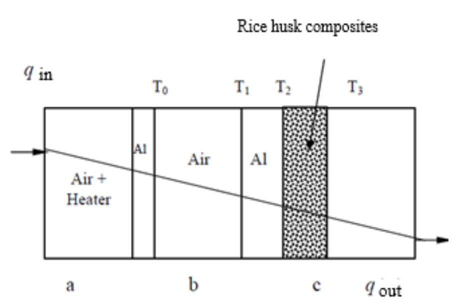


Figure 1. Heat resistance test scheme

2. MATERIALS AND METHODS

2.1. EFB Fibre Composite Production

In producing the sample, the mass composition ratio was used. The composite comparison was based on different percentage weight fractions of the fibre to the polyester matrix, i.e. 20, 30, and 35 %. The pressing process was carried out until it hardens using a screw press with a pressure of 0.0255 – 0.0306 khf/mm^2. Then the sample was removed from the die and allowed to dry naturally. A schematic of composite board production is shown in Figure 2.

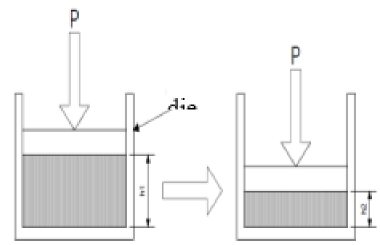


Figure 2. Schematic of producing a composite board

2.2. Preparation of Test Specimen

The dimensions and shape of the test specimens were chosen based on the standards of each test, i.e. SNI 03-2105-2006 for mass density test, ASTM D5229M-12 for water absorption test, and ASTM C177-13 for thermal conductivity test. Water absorption and mass density were tested using a square shape with the size of length (l) x width (w) x height (h) is (10 x 10 x 1) cm. Furthermore, for the thermal conductivity, the test sample also had a square shape with the size of length (l) x width (w) x height (h) is (20 x 20 x 1) cm, and a point was given for temperature readings; this is so that the sample can be precisely entered into the heat conductivity test box to determine the temperature gradient.

2.3. Testing

2.3.1. Mass density test

Density testing is a test of the physical properties of the specimen. In this mass density test, the specimens used refer to the SNI 03-2105-2006 standard [18].

2.3.2. Water absorption test

Water absorption testing is carried out by weighing the dry mass of the sample and the wet mass. Dry period is the mass when the sample is dry, and the wet mass is obtained after the sample has been immersed for 24 hours at room temperature. In this water absorption test, the specimens used refer to the ASTM D5229M-12 standard [19].

2.3.3. Thermal conductivity testing

The problem-solving method used in this study is the experimental method. In this study, the measurement was focused on measuring the temperature gradient to determine the conductivity at various measurement times, 5, 10, and 15 minutes. The sample and tool set-up is presented in Figure 3.

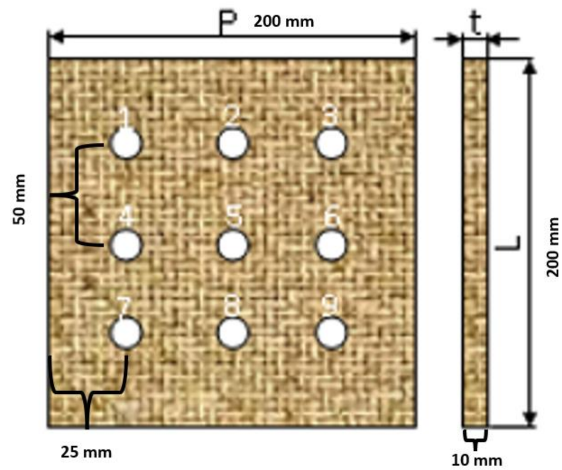


Figure 4. Set-up of test heat conductivity

Information:

1. Heat source.
2. Heat source insulation room.
3. Hot plate (heat source temperature measurement point)
4. EFB fibres composite board tested.
5. The temperature measurement point on the test object (to determine the temperature gradient)
6. Isolation room

The thermal conductivity test was carried out by adopting the ASTM C177-13 standard, namely the Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus [20]. This method uses the hot plate insulating method. The test specimen is placed on the parallel side of the aluminium plate, which is close to the heat source, and the temperature in the hot and cold rooms is measured using a digital thermometer (Figure 4).

To get the value of the thermal conductivity (k) of the test specimens of the EFB fibre composite board, a re-set-up of the thermal conductivity test (k) is done. The process is carried out in the following manner:

1. The walls of the box are made of 3 layers, namely a layer of wooden planks on the outside, a layer of sterofoam and Teflon on the inside.
2. The heat source used is a heater from a 40 watt incandescent light bulb connected to a thermostat and a switch. The end of the thermostat temperature gauge sensor is installed in the insulation chamber of the heating source.

As a temperature gauge in the test box, a digital thermometer that has the ability to read temperatures from -50 oC to 110 oC is used. For more details, the size and shape of the box for the thermal conductivity test (k) are shown in Figure 5.

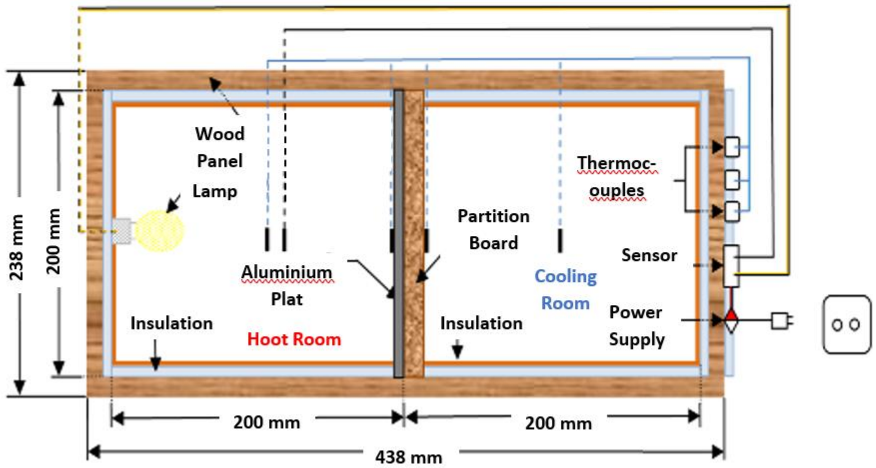


Figure 5. The shape of the thermal conductivity tester box (k)

3. RESULT AND DISCUSSION

From the process of making a polymer composite partition board reinforced with EFB fibers by printing on a hot screw press, a square shape with dimensions (40 x 40 x 1) cm is obtained, as shown in Figure 6.

Figure 6. Partition boards with variations in weight fraction of 25%, 30%, and 35%.

Furthermore, the mass density and water absorption capacity testing were carried out using SNI 03-2105-2006 and ASTM D5229M-12 test standards, so the physical property test results of the EFB fibre partition board were obtained, as shown in Table 2.

Table 2. The results of testing the physical properties of the EFB fibres partition board

NUMBER	PHYSICAL PROPERTIES OF PARTITION BOARDS	PERCENTAGE WEIGHT FRACTION OF EFB FIBRE COMPOSITES		
		25 (%)	30 (%)	35 (%)
1	Weight (gram)	1859.2	1928	1987.2
2	Mass density, ρ (gr/cm^3)	1.162	1.205	1.242
3	Water absorption (%)	3.38	3.42	3.75

From Table 2, there is an increase in water absorption due to the increase in the volume of EFB fibre in the composte. Calculation of water absorption can use the Equation 1 below:

$$WA = \frac{w_w - w_d}{w_d} \times 100\% \qquad (1)$$

where WA is water absorption, Ww is the weight of wet sample and Wd is the weight of the dry sample.

In addition to the composition of the EFB fibre, the choise of the will have an affect because there are several types of matrix that have water-resistant properties. The random distribution, position, and orientation of the powder surface on the composite also influence the ability of the composite to absorb water. The powder on the surface of the board will be a source of water absorption [21].

The amount of heat absorbed/released by an object is directly proportional to the mass of the object, the specific heat of the object and changes in temperature. The amount of heat is formulated in Equation 2 as follows [15]:

$$Q = mc\Delta T \qquad (2)$$

where the constant Q is the amount of heat absorbed/released (J); m is the mass of the object (kg); c is the specific heat of the object (J/kg.ºC); and ΔT is the change in temperature (ºC). Energy transfer will occur when an object has a temperature gradient. It can be said that the energy moves by conduction, and the rate of heat transfer is proportional to the normal temperature gradient, in Equation 3 [15]:

$$\frac{q}{A} = \frac{\partial T}{\partial \chi} \qquad (3)$$

If the proportionality constant is entered, it can be formulated as follows, Equation 4:

$$q = -kA\frac{\partial T}{\partial \chi} \qquad (4)$$

where the coefficient q shows the rate of heat transfer, and is the temperature gradient towards heat transfer. The positive constant k is called thermal conductivity. The minus sign in Equation 4 is inserted to comply with the second law of thermodynamics, namely heat flows from a higher point to a lower point on the temperature scale [5].

The measurement of thermal conductivity aims to determine the effect of the rate of thermal conduction on several types of materials. Meanwhile, the amount of heat conduced in the material can be formulated in Equation 5 as follows:

$$\frac{\Delta Q}{\Delta t} = kA\frac{\Delta T}{\Delta \chi} \qquad (5)$$

If there is a change in temperature due to a very small change in position where $\Delta x \rightarrow 0$ then it can be written in Equation 6 as follows:

$$\frac{dT}{dx} = \frac{(T_2 - T_1)}{\chi} \qquad (6)$$

If the lines of heat flow are parallel, then each section has the same temperature gradient, the amount of heat conducted by time in this condition can be formulated in Equation 7 as follows [5]:

$$\frac{\Delta Q}{\Delta t} = kA\frac{(T_2 - T_1)}{h} \tag{7}$$

where ΔQ is the total heat energy that is conduced, Δt is the time during which conduction occurs, A is the area where conduction takes place, ΔT is the temperature difference between the two sides of the material, h is the thickness of the material and k is the value of thermal conductivity.

The transfer of heat energy in insulating materials at high temperature takes place in several ways: conduction through air confined in a cavity and conduction through hollow or solid materials [4]. The value of thermal conductivity can be calculated by indirect measurement by measuring directly from several other quantities; so in general, the value of thermal conductivity can be determined by the Equation 8:

$$k = \frac{\Delta Q h}{A \Delta T \Delta t} \tag{8}$$

A plate of material to be tested for its thermal conductivity value is clipped over the steam room and maintains a constant temperature of about 100 ^oC. An ice block is placed on top of the material, maintaining a constant temperature of 0 ^oC. Based on this information, the thermal conductivity value can be determined by the Equation 9:

$$k = \frac{M_{es} - k_l h}{A \Delta T \Delta t} \tag{9}$$

where Mes is fiber mass; the constant k is the thermal conductivity; h is the thickness of the material; A is the cross-sectional area of the ice; ΔT is the temperature difference between the two sides of the material; Δt is the time interval during thermal contact; and kl is 80 cal/g, which is the melting heat of ice in the CGS (centimetre-gram-second) system of units [4].

The thermal conductivity of each sample used in this research is calculated using the Equation 10 [16]:

$$k = \frac{(R_0)\left(80\,\frac{cal}{gram}\right)h}{(A)(\Delta T)} \tag{10}$$

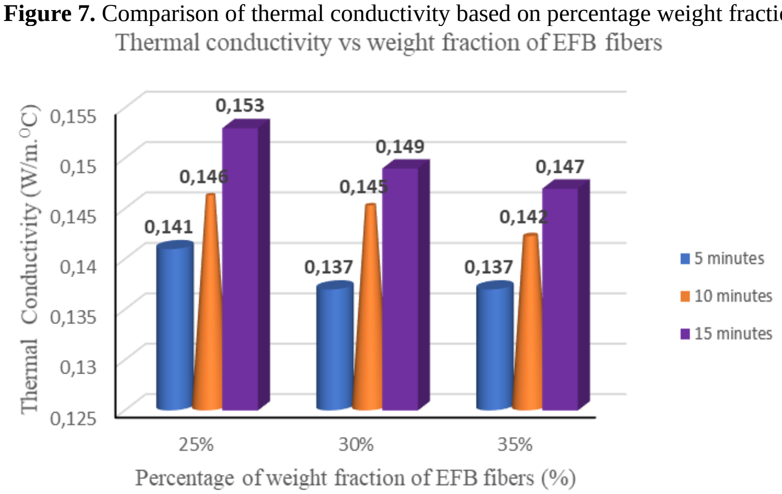
where the coefficient k is the value of thermal conductivity, Ro is the rate at which the ice melts, h is the thickness of the sample, A is the surface area of the sample, while ΔT is the temperature difference.

The thermal conductivity test was carried out by adopting the ASTM C177-13 standard; the heat source used was a heater from an incandescent light bulb of 40 watts of power connected to a thermostat [20]. The measurement results for the weight fractions of 25%, 30%, and 35% were obtained at various durations of 5 minutes, 10 minutes, and 15 minutes, shown in Table 3. Comparison of thermal conductivity on percentage weight fraction of EFB fibres can see in Figures 7.

Table 3. The results of testing the thermal conductivity of the composite partition board fraction EFB fibres

NUMBER	FIBRE WEIGHT FRACTION (%)	MEASUREMENT TIME (minutes)	THERMAL CONDUCTIVITY (W/m.^{O}C)
1	25	5	0,141
		10	0,146
		15	0,153
2	30	5	0,137
		10	0,145
		15	0,149
3	35	5	0,137
		10	0,142
		15	0,147

Figure 7. Comparison of thermal conductivity based on percentage weight fraction of EFB Fibres



The value of thermal conductivity for various materials will be different and will be influenced by physical, mechanical, and constituent factors. The differences in the value of thermal conductivity occur due to the properties and characteristics of the material itself; the constituent factors of the composite in this case are the matrix and fillers, which affect the density and porosity of the material. If the matrix has a large mass and a small volume, it will have a large density. Thus, the filling material will be compressed in the volume units, which makes the material dense and heavy. Composites like this have the ability to conduct heat better. In contrast, if the composite ratio indicates a large amount of filler, it will cause empty spaces or porosity, and porosity affects the ability to conduct heat. The empty spaces will affect the surface area of the conductor, and the surface area is proportional to the ability to conduct heat. Therefore, if the composite has high porosity, it will be more difficult to conduct heat due to the influence of its surface area. In this regard, a good impact is produced when the composite with EFB fibre is applied to the wall or room divider (partition board) as a heat barrier.

The heat-conducting property of the EFB Fibre Composite Partition Board is affected by the density of the filler fibres in the partition board. With a larger weight fraction of EFB fibres, the partition board has a low density, so it has a higher porosity than others. The pores formed on the board affects its heat conductive properties because it causes a convection process in the partition board. This is because the pores are filled with air which is a poor conductor of heat (isolator) compared to liquids or solids, resulting in reduced friction between particles in the air. This has a great influence on the heat conductive properties of the partition board.

The results of the thermal conductivity of the EFB fibre polymer composite partition board in this study were obtained based on variation of the ratio of the matrix to the filler fibre, and the comparison of the heat transfer rates of the test specimens used a 200 x 200 x 10 plate that was close to a heat source for different observation times of 5, 10, and 15 minutes. There are differences in the value of thermal conductivity for the different weight fractions of the fibre and observation times. The smallest thermal conductivity was observed at 30% and at 35% (0,147 W/m.°C at 15 minutes), while the highest value was observed at 25 % (0,153 W/m.°C at 15 minutes). This indicates that the relationship between density/porosity and the ability to conduct heat is directly proportional.

Based on the thermal conductivity values of the various materials shown in Table 1 [6], the polymer composite partition board with EFB fiber filler has a small thermal conductivity value (0.13 – 0.15 W/m.°C) like rubber and wood. Although there is an increase in the fiber weight fraction of the composite, the resulting thermal conductivity value only decreases by a small difference. It can be concluded that the polymer composite partition board with EFB fiber filler is a material with a high resistance value. So that further research is needed to create a partition board with a smaller resistance value so that it can be recommended as a good heat barrier.

4. CONCLUSIONS

The greater the percentage of filler in the composite, the smaller the value of its thermal conductivity, which is directly proportional to the value of mass density. The thermal conductivity of the polymer composite partition board with EFB fibre filler did not show a significant change in the different observation times. The heat retardant property of polymer composite partition boards with EFB fibre fillers is influenced by density and porosity. When there are more EFB fibres, they are more tightly arranged in the partition board, thereby minimizing the formation of cavities in the board, which causes a convection process in the board. This has a great effect on the insulating property of the partition board. This polymer composite partition board with EFB fibre filler is recommended as a good heat retardant material.

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