The Effect of Variation of Volume Fraction on Polyester-Team Wood Fiber Composite (Melaleuce leucandendra) on Thermal Conductivity Value

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Abstract. The current use of the gelam tree is only found in wood processing. On the other hand, gelam bark is not optimally utilized so as to produce unused bark waste even though the natural fiber of gelam bark is of high economic value. The purpose of this study was to determine the effect of volume variations on the value of thermal conductivity in gelam fiber wood composite materials with a filler ratio of each volume variation ratio of 10%, 30%, 50% and 70% using polyester resin and alkalinizing skin fiber using 5% NaOH in 2 h of immersion time and knowing the effect of microstructure on gelam bark fiber composites. Based on the results of the research, the value of thermal conductivity is strongly influenced by variations in the fraction of different volumes in each sample given 5% alkaline treatment which increased from a low fiber composition of 10% to 70% fiber composition from 0,059 W/m°C to 0,107 W/m°C. Composite composition (10% sera - 90% resin, 30% fiber - 70% resin, 50% fiber - 50% resin and 70% fiber - 90% resin) with alkalization 5% shows that there is density and density between the matrix and fiber so that this sample does not have a cavity that inhibits the distribution of heat flow and faster conduction.

Keywords: alkalization · gelam · composite · thermal conductivity · volume fraction

1 Introduction

The gelam tree is usually found in tropical climates such as Indonesia, especially in Kalimantan. The Galam tree (Melaleuce Leucadendra) can grow to a height of 10 to 20 m and has an appearance as shown in Fig. 1. The utilization of the gelam tree is currently only found in its wood processing, due to its tenacity and durability against conditions in various regions. On the other hand, gelam bark is not used optimally so that it produces unused bark waste even though the natural fiber of gelam bark has high economic value.

When viewed visually, the physical form of gelam bark is in the form of thin sheets that have fibers. In general, fiber is widely used as a mixture to strengthen composite materials.

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Fig. 1. Gelam tree (melaleuce leucadendra).

Composite materials have the advantage that they are rust-resistant and the manufacturing process is easier so that they are suitable for use as building construction materials. Utilization of natural fiber from unused gelam bark is expected to help the community to find out more about the use of natural fiber with high selling value.

Composite materials with structured testing of mechanical bonding and mechanical properties are well known. Research on composites has been very diverse with artificial fiber reinforcement or natural fibers. Composites with natural fiber reinforcement are now very much needed because the mechanical properties of natural fiber composites are strong, lighter and the price is relatively cheaper.

Composite materials that will be used for building construction are not only known for the physical strength and mechanical properties of the composite but, the ability of composite materials to conduct heat must also be considered. This research is shown to determine the value of the thermal conductivity of a composite because each material used has a different thermal conductivity value.

1.1 Composites

Composite is a material formed from a combination of two or more materials, where the mechanical properties of the composition material vary. Due to the different composition characteristics, new materials will be produced, namely composites that have different mechanical properties and characteristics from the constituent materials [1].

Classification of composite materials can be distinguished from their properties and composition. Composite materials can be grouped into several types as shown in Fig. 2. Classification of composites based on reinforcement composites are classified into four namely:

1. Fiber Composite
2. Particle Composite
3. Laminate Composite
4. Flake Composite

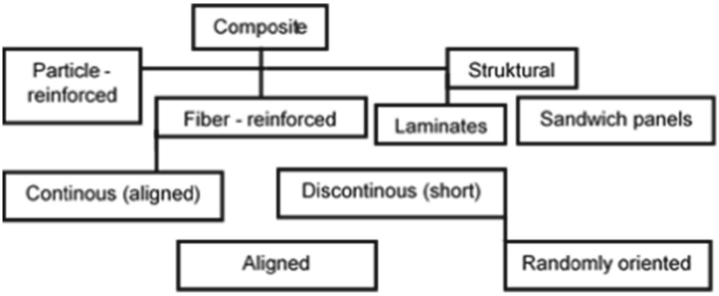

Fig. 2. Classification of composites based on their structure.

1.2 Composite Main Part

The main parts of the composite, namely:

1. Filler is the main part of the composite which functions as a guarantor of the main load on the composite.
2. The matrix is the element in the composite which has the largest part or volume fraction that functions as an adhesive or binder and guards the filler. Another function of the matrix is as follows [2]:

   a. Delivers tension to the fiber evenly.
   b. Keeps the fibers from coming into contact with pressure and friction.
   c. Grasp and hold the fiber in position.
   d. Protects from spaces that can cause damage.
   e. Remains firm after the manufacturing process.

   The properties of the matrix are as follows:

a. Good mechanical properties.
b. Good strength of component elements.
c. Good physical endurance.
d. Can adapt to temperature.

1.3 Alkaline Treatment of Natural Fibers

The rationalization treatment of natural fiber aims to remove impurities or lignin contained in the fiber. In addition, the alkalizing treatment aims to be able to blend with the liquid and can be called hydrophilic. The effect of alkaline treatment on the texture properties of natural fibers has been investigated where the optimal water content can be reduced so that the hydrophilic nature of the fiber can provide maximum interfacial bonds with the matrix [3]. The alkali used in this research is NaOH.

1.4 Catalyst

Catalysts are materials used to shorten the setting time of resins. Catalyst is a chemical additive that is mixed in a polyester resin matrix for the purpose of solidifying the matrix. The addition of excessive catalyst will produce a brittle composite. The recommended addition of a catalyst is 1% to 2% by weight of the resin.

1.5 Thermal Conductivity

Thermal conductivity can be defined as the level of a material's ability to generate heat. Thermal conductivity numbers indicate how much heat can flow to a given material. The more the particle moves, the faster it can transfer energy. So the thermal conductivity depends on the temperature of the heat. Thermal conductivity can occur due to the transfer of heat sent from one point to a different point through one of three heat transfer methods, namely:

1. Heat transfer by conduction is a heat transfer process if heat moves from a place with a high temperature to a place with a lower temperature, but the connecting container for heat transfer remains.
2. Convection is the transfer of heat by the motion of a heated substance. The process of heat transfer by flow/convection is a phenomenon that occurs in surface textures.
3. Radiant heat transfer is the transfer of heat that occurs due to radiation from electromagnetic waves. Radiant heat transfer takes place with wavelengths at intervals across various heat-conducting machines.

The thermal conductivity value of a material can be obtained by direct measurement of several component quantities, so that the general thermal conductivity value can be calculated through the equation:

$$k = \frac{\Delta Qh}{A \Delta T \Delta t} \tag{1}$$

Or we can calculate the conductivity value using Fourier's law:

$$q''_{cond} = k\frac{(T_1 - T_2)}{L} = k\frac{(T_{in} - T_{out})}{L} \tag{2}$$

The heat flow rate per unit heat (q/A = q") can be calculated by the convection formula in the equation:

$$q''_{cond} = (T_s - T_\infty) = h_c(t_{out} - T_{out}) \tag{3}$$

where:

T_{in} = Inner air temperature (°C)
T_{out} = Outside air temperature (°C)
t_{in} = Inner wall temperature (°C)
t_{out} = Outside wall temperature (°C)

L = Sample thickness (m).
k = Heat transfer coefficient (W/m°C)
hc = Heat transfer coefficient (W/m2°C)
q/A = Heat flow rate per unit area (W/m2)

There are several factors that can affect the thermal conductivity of a material, including the following [3]:

1. Temperature
   The value of thermal conductivity is inversely proportional to the influence of temperature, in general when the temperature increases, the thermal conductivity decreases.
2. Water vapor content
   The thermal conductivity will be higher as the humidity value increases. If the value of (k) increases, it becomes a good conductor, but if the value of (k) decreases, it becomes a good insulator.
3. Specific gravity
   The value of thermal conductivity also depends on the specific gravity of the material. The greater the specific gravity of the feed, the better the conductivity of the conductor.
4. Density and porosity of materials
   The more cavities contained in the mahan, the worse the thermal conductivity.

2 Research Methods

This research was conducted at the Mechanical engineering Laboratory, Faculty of Engineering, University of Lambung Mangkurat, and was only limited to testing the thermal conductivity and physical characteristics of composites viewed with micro-photos up to 500× magnification. Material preparation includes gelam bark fiber, polyester resin, MEKPO catalyst and NaOH solution.

2.1 Research Variable

This research is using experimental method. The variables used in this study are as follows:

1. The independent variable used is the volume fraction variation, namely:

   a. Polyester 90% and fiber 10%.
   b. Polyester 70% and fiber 30%.
   c. 50% polyester and 50% fiber.
   d. 30% polyester and 70% fiber.

2. The dependent variable used is the composite sample test, namely: thermal conductivity test.

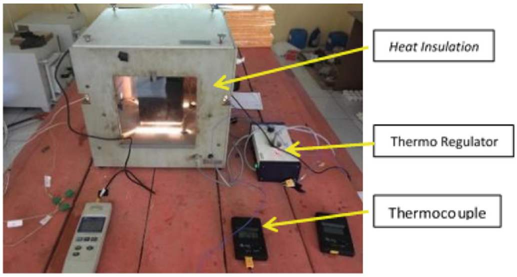

Fig. 3. Heat insulation/heat conduction PHYWE.

Fig. 4. Results of sewing gelam bark fibers.

3. Observational variables used include:
4. The temperature of the heat source in the test apparatus by heating for 40 min is 70–80 °C as shown in Fig. 3.

The procedures in the study are as follows:

1. Gelam bark fiber treatment;

   a. The gelam bark fibers that have been obtained from nature are then cleaned, and cut to a length of 25 cm for variations of straight fibers.
   b. Boiling gelam bark fibers to remove the natural substances contained in it for ± 20 min.
   c. Prepare a solution with a NaOH concentration of 5%.
   d. The gelam bark fiber that has been prepared is then put into a NaOH solution for ± 2 h for the alkalization process.
   e. Then the gelam bark fibers were dried in the sun for 2 days.
   f. Then make gelam bark fibers with volume fractions of 10%, 30%, 50% and 70%. Gelam bark fibers are arranged as shown in Fig. 4 to facilitate the next process.

Fig. 5. Test sample.

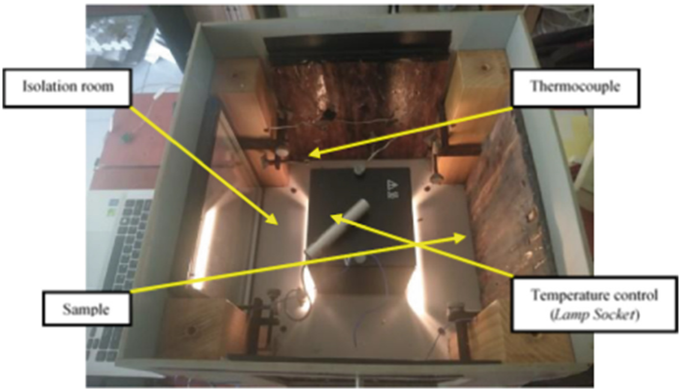

Fig. 6. Procedure for installing the sample and thermocouple on the heat insulation house.

2. Composite manufacturing

   a. Prepare a sample mold of glass with a size of 250 mm x 250 mm x 50 mm and apply wax/kit to the prepared mold.
   b. Preparing resin
   c. Preparing the catalyst
   d. Mixing resin and catalyst (catalyst as much as 1% of the resin volume)
   e. Prepare the fibers that have been dried, then put the fibers that have been assembled into a mold.
   f. Then pour the resin over the fibers until evenly distributed.
   g. After ± 24 h remove the sample from the mold.
   h. Finally, dry the sample for ± 48 h at room temperature.

3. Thermal conductivity test sample testing

   a. Prepare 3 samples with the same composite material (1A, 1B, and 1C) to be tested for thermal conductivity as shown in Fig. 5.
   b. Install samples on each side of the Heat Insulation House tool and also install thermocouples on each wall (inside and outside) samples 1A and 1B to measure the temperature as shown in Fig. 6.
   c. Turn on the heat conduction device for 40 min of heating.

d. After heating for 40 min, take the temperature data of the outer and inner walls of samples 1A and 1B and also the temperature of the air inside and outside (environment) every 5 min for 30 min.
e. After that, attach the thermocouple to the 1C sample, then turn it on again for 15 min of heating. After that take the temperature data of the inner and outer walls, as well as the temperature of the air inside and outside of the 1C sample.
f. The tests for the first composite test sample were completed. Repeat steps (a) to (f) for all composite test samples.

4. Sample testing macro structure test

   a. Prepare macro structure test samples with 1 sample for each variation.
   b. Cut the sample at the thermal conductivity test point.
   c. Prepare a digital microscope and laptop/notebook.
   d. Place the test sample in the macro structure test stand.
   e. Take a sample image at the thermal conductivity test point.

3 Result and Discussion

3.1 Thermal Conductivity

Analysis of the thermal conductivity value was carried out on 12 samples from 4 different composite composition variations and to obtain the thermal conductivity value of the composite sample in this test was measured by several parameters such as:

1. For the first step we must know the value of the heat transfer rate (qconv = q/A) for each material as shown in the calculation below:

$$q''_{conv} = h_c(t_{out} - T_{out}) = 8{,}1(36{,}0 - 28{,}2) = 63{,}18\, W/m^2$$

   The above calculations were carried out for all types of samples.

2. In the second step calculate the thermal conductivity value (qcond" = qconv") of each sample in the manner shown below:

$$q''_{conv} = k\frac{(t_{in} - T_{out})}{L}$$

$$63{,}18 = k\frac{(44{,}8 - 36{,}0)}{0{,}008}$$

$$k = 0{,}57\, W/m^{\circ}C$$

From the two steps above, the thermal conductivity value of each sample is obtained as shown in Table 1 (Table 2).

Table 1. Table test result data and thermal conductivity values.

Alkalization (%)	Volume/Sample Fraction	L (m)	T in (°C)	T out (°C)	t in (°C)	t out (°C)	hc (W/m²°C)	q/A (W/m²)	k (W/m°C)
5	**10% fiber – 90% resin**								
	Sample 1A	0,008	44,5	28,2	44,8	36,0	8,1	63,18	0,057
	Sample 1B		53,5	28,6	44,9	35,5		55,89	0,048
	Sample 1C		53,3	27,6	44,8	36,6		72,90	0,071
	30% fiber – 70% resin								
	Sample 2A	0,008	48,8	29,2	43,3	35,9	8,1	54,27	0,059
	Sample 2B		52,2	31,3	44,9	39,2		63,99	0,066
	Sample 2C		52,4	29,3	44,9	39,4		81,81	0,119
	50% fiber – 50% resin								
	Sample 3A	0,008	49,2	28,2	43,5	37,0	8,1	71,28	0,088
	Sample 3B		50,7	29,7	45,0	37,9		66,42	0,75
	Sample 3C		53,9	29,2	45,8	39,7		85,05	0,112
	70% fiber – 30% resin								
	Sample 4A	0,008	48,9	28,6	43,6	37,6	8,1	72,90	0,097
	Sample 4B		53,9	29,3	44,8	38,9		77,76	0,105
	Sample 4C		52,1	28,6	44,8	39,1		85,05	0,119

3.2 Effect of Volume Fraction Variation on Thermal Conductivity Value

Figure 7 shows the value of thermal conductivity is strongly influenced by the variation of the fraction of the volume itself so that there is an increase in the value of thermal conductivity. In each sample treated with 5% alkalinization, there was an increase from a low fiber composition of 10% to 70% fiber composition from 0.059 W/m °C to 0.107 W/m °C.

In addition, the change in value is due to the high specific gravity of the fiber compared to other fibers. The higher the specific gravity of the fiber, the better the fiber as a conductivity conductor. The higher the thermal conductivity value is because the constituent material of gelam wood skin fibers is more cohesive and produces fewer cavities in the composite which causes friction between particles which causes heat conductivity to increase. The thermal conductivity value is also strongly influenced by the matrix used in the composite, and the composite material in this study is a poor conductor of heat, causing the composite thermal conductivity value to increase relatively low.

3.3 Microstructural Observation

Microstructural observations in this study used a digital microscope up to 500x magnification to make it easier to analyze the effect of volume fraction variations on the thermal conductivity value and to make it easier to analyze the cause of the increase in the thermal conductivity value.

Table 2. Table Test Result Data and Thermal Conductivity Values.

Alkalization (%)	Volume Fraction/Sample	Thermal Conductivity (W/m°C)	Average Thermal Conductivity (W/m°C)
5	**10% fiber – 90% resin**		
	Sample 1A	0,057	0,059
	Sample 1B	0,048	
	Sample 1C	0,071	
	30% fiber – 70% resin		
	Sample 2A	0,059	0,081
	Sample 2B	0,066	
	Sample 2C	0,119	
	50% fiber – 50% resin		
	Sample 3A	0,088	0,091
	Sample 3B	0,075	
	Sample 3C	0,112	
	70% fiber – 30% resin		
	Sample 4A	0,097	0,107
	Sample 4B	0,105	
	Sample 4C	0,119	

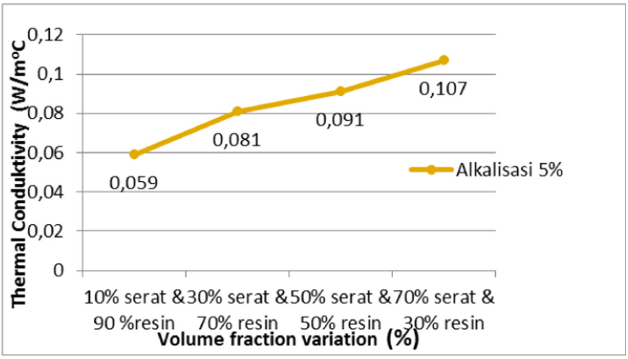

Fig. 7. Graph of average thermal conductivity.

Figure 8 shows that the composite sample with 5% alkalinization has a density and density between the matrix and fiber so that this sample does not have cavities that hinder the distribution of heat flow and conduction more quickly.

If there are many pores in the composite material, the thermal conductivity will be smaller. Porous materials can store gases in their pores. It is well known that gases are poor conductors of heat than liquids or solids. The low thermal conductivity is caused by the low conductivity of the air trapped in the pores [4].

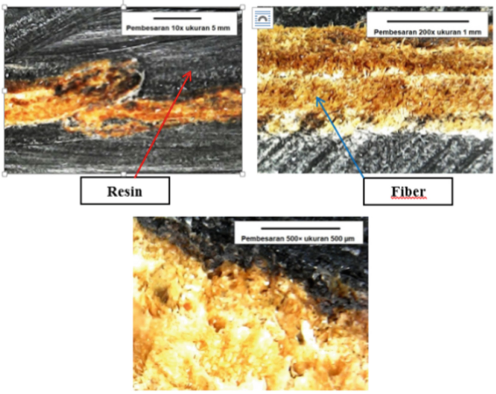

Fig. 8. Microstructure photo of the polyester resin-gelam bark fiber composite with 5% alkalization.

The distribution of the matrix greatly determines the toughness of the matrix in loading the empty voids between the reinforcement to reach the dense volume and will ultimately determine the magnitude of the porosity and strength [5]. A good material for heat insulator has a thermal conductivity value of about 0.1 W/m °C [6].

4 Conclusion

The conclusions of this study are as follows:

1. The thermal conductivity value is strongly influenced by the variation of the fraction of the volume itself so that the conductivity value increases. The change in value was due to the high specific gravity of the fiber compared to other fibers. The higher the specific gravity of the fiber, the better the fiber as a conductivity conductor.
2. The value of thermal conductivity is also strongly influenced by the matrix used in the composite. The polyester composite material made from gelam bark fiber that can be applied as a heat insulator is a composition (70% fiber-30% resin) with 5% alkalinization of 0.107 W/m °C.
3. Composite composition (10% t fiber - 90% resin, 30% fiber - 70% resin, 50% fiber - 50% resin and 70% fiber - 90% resin) with 5% alkalinization indicates that there is density and density between the matrix and fibers so that this sample does not contain cavities that hinder the distribution of heat flow and conduction more quickly.

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