Preliminary investigation of thermal conductivity testing equipment for composite materials utilizing the axial flow method.

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Abstract. Thermal conductivity is a material property that indicates its ability to conduct heat. The purpose of making this test tool is to determine the thermal conductivity value of the composite material and to find out the test results of the tool. The method for evaluating the thermal transmission resistance of a material uses the axial flow method, namely the flow of heat energy from the high temperature side to the low temperature side in a vertical direction. The heat source received by the material comes from a heater that is supplied with electric current. The measurement process focuses the heat that is conducted from the surface of the material at a higher temperature to the surface at a lower temperature. From the test results, the measurement thermal conductivity value for the ramie fiber composite at a temperature optimization of 35°C was 11.55 W/m K; for a temperature optimization of 40°C, it was 4.16 W/m K. While for the banana stem fiber composite at a temperature optimization of 35˚C it was 3.34 W/m K, and for a temperature of 40˚C it was 10.10 W/m K.

Keywords: Thermal conductivity, axial flow method, composite material.

1.1 Introduction

Technology and science are advancing and transforming swiftly with each successive year. Indonesia possesses extensive natural resources, especially indigenous flora. Natural fibers have attracted significant attention as a substitute for synthetic fibers in reinforcing various resins for composite applications, owing to their characteristics such as low density, high specific strength, sustainability, and environmental friendliness. The development of composite materials derived from natural fibers and agricultural waste will contribute to environmental protection. These composites are frequently employed in industrial and aerospace applications. Numerous Indonesian firms and research organizations necessitate equipment to support material development research. Procurement is a significant difficulty encountered by industry and research groups in Indonesia in their efforts to advance research.

Thermal conductivity is one of the most essential physical factors to consider when selecting materials. Thermal conductivity refers to a material's capacity to conduct heat. A material medium with measurable conductivity facilitates heat transfer. This research intends to develop a thermal conductivity tester for composite materials. Furthermore,

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Indonesia's extensive natural resources offer a high potential for obtaining natural fibers, thereby encouraging the development of composite materials that incorporate these fibers. Researchers have researched the thermal conductivity of natural fibers, including ramie, coconut, and banana stem fiber. The values are as follows: 1.25-1.46 (W/m. K.) for ramie fiber , 0.17-0.22 (W/m. K.) for coconut fiber, and 0.45-0.49 (W/m. K.) for banana stem fiber [1], [2], [3] .

The thermal conductivity values previously discussed pertain to the original fiber material; however, the corresponding value for the composite material, incorporating the aforementioned components, remains undetermined. This research endeavors to develop a testing apparatus for assessing the thermal conductivity of composite materials derived from the aforementioned fibers.

2. Methodology

The research begins with the construction of thermal conductivity test equipment, drawing upon various references, particularly those using the axial flow method [4], [5], [6]. The subsequent phase involves the creation of a composite material utilizing natural fibers, specifically ramie fiber and banana stem fiber.

2.2 Thermal conductivity test equipment

Axial Flow Method is the most widely used method to measure the value of heat conductivity at low temperatures. In this method, the temperature gradient is made by placing the test material in the middle of the standard material whose heat conductivity value has been known and on one side of the test tool there is a heater and the other side there is a cooler [5]. A schematic illustration of measurement with axial flow can be seen in Figure 1.

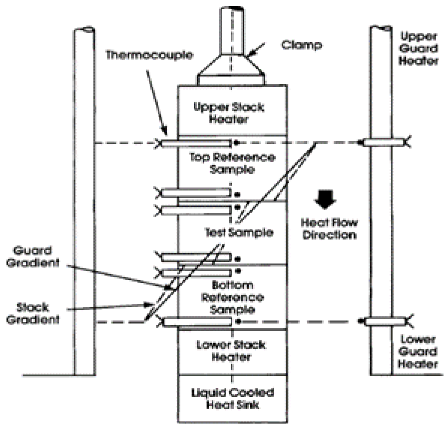

Fig.1 Schematic illustration of measurement with axial flow [7]

There are three forms of heat transport in a medium: conduction, convection, and radiation. The axial flow approach employs the conduction mode. Conduction is the movement of heat or energy from a high-temperature component to a low-temperature component that occurs in a specific medium and does not include the transfer of material particles. The fundamental equation of conduction is Fourier's Law, which is as follows [8]:

$$q = -k.A.\frac{dt}{dx} \tag{1}$$

Where q is the heat transfer rate (W), k is thermal conductivity value (W/m.K), A is the heat transfer cross-sectional area [m^2], dx is the thickness of the wall where the heat flows (m) and dt is the temperature difference (K).

The major components of this design are listed below: Figure 2 shows the cartridge heater, copper, material coating, rockwool, coolside mounting, heatsink, iron hinge, and Peltier. Figure 3 shows the thermal conductivity test equipment and its supporting equipment.

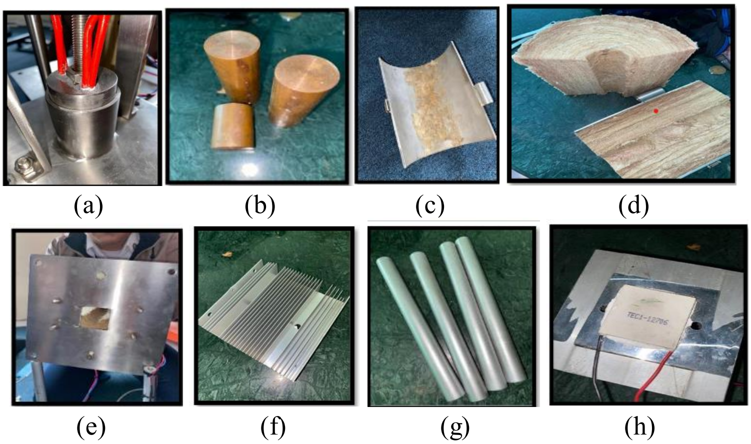

Fig. 2 Cartridge heater (a), copper (b), material coating (c), rockwool (d), coolside mounting (e), heatsink (f), iron hinge (g), and Peltier (h).

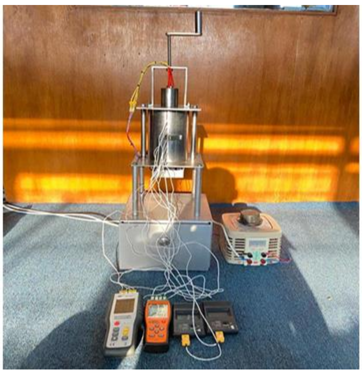

Fig. 3 Thermal conductivity test and Supporting Equipment

The purpose of this device is to produce a temperature difference between the two ends of the material. One end is heated, while the other end is kept at a constant temperature by flowing cooling water. As stated earlier in equation 1, the conductivity of a material can be calculated using basic heat transfer calculations.
This device's heater is a 200 W cartridge heater with copper as a reference material. A solid rockwool insulator is employed to keep heat from leaving the system. The cooler has a heat sink and a peltier. Figure 4 depicts the ten locations where we attached a digital thermometer to gather temperature data.

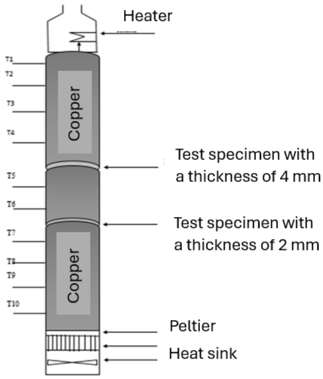

Fig. 4 Schematic of Thermocouple Point Location at Temperatures T1 to T10 Thermal Conductivity Test Equipment

2.1 Composite material of ramie fiber and banana stem fiber.

Generally, composites consist of two elements, namely reinforcement and binding material (matrix). The main element of composite materials is fiber, where fibers determine the characteristics of composite materials such as stiffness, strength and other mechanical properties [9] . Research on numerous composite materials' thermal conductivity has been conducted [10], [11], [12]

The composite under examination in this investigation has natural fiber reinforcement. Ramie fiber and banana stem fiber are the two natural fibers used. The test specimens have a diameter of 25.4 mm and thicknesses of 4 mm and 2 mm, respectively (refer to Figure 5). The test specimens that are to be tested must be sanded prior to being cut with a grinder to the specified thickness. The test specimen is subsequently coated with thermal paste prior to being inserted into the measuring instrument. Thermal paste is employed to optimize heat transfer and reduce the vacant space between the two surfaces.

Fig. 5. Test Specimen after Sanding

3. Results and Discussions

The composites of ramie fiber and banana stem fiber were tested at heating temperatures of 35˚C and 40˚C respectively and cooling temperatures at 26˚C. From the test results, the graphs obtained are as shown in Figures 6 and 7.

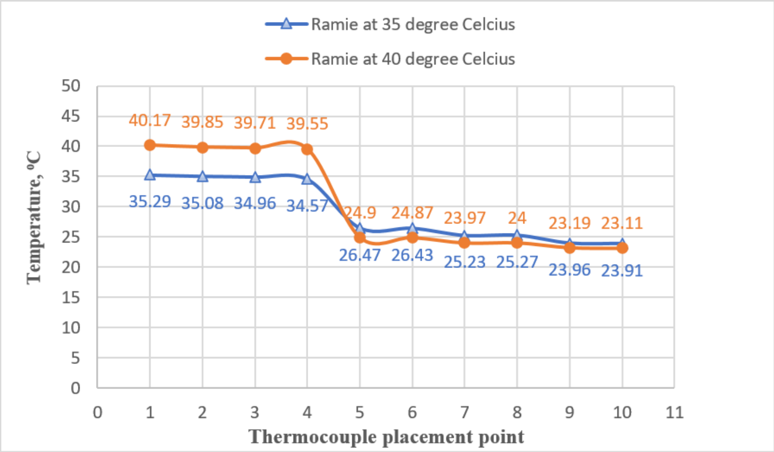

Fig. 6 Ramie fiber's temperature graph at 35˚C and 40˚C observations.

Based on the graph on the ramie fiber composite, it can be seen that the test results at high temperatures produce a high-temperature difference. Calculations are then carried out to obtain the thermal conductivity value based on the temperature difference from the test results by referring to the Fourier equation. The calculations for the ramie fiber composite show that testing at a higher temperature will produce a lower thermal conductivity value.

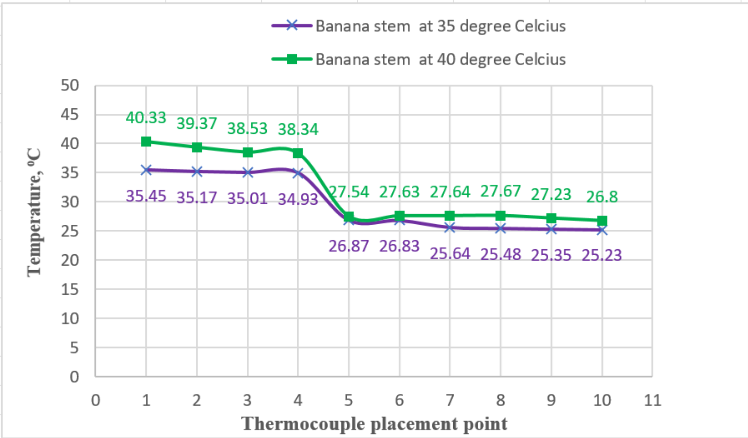

Fig. 7 Banana stem fiber's temperature graph at 35˚C and 40˚C observations.

However, the test results of banana stem fiber revealed a distinct trend. Testing at higher temperatures resulted in high thermal conductivity values.
The thermal conductivity values from all test results are summarized in table 1.

Table 1. Thermal conductivity values .

Reinforcement material	Heating temperature, °C	Thermal konductivity , W/m.K
Ramie fiber	35	11.55
	40	4.16
Banana stem fiber	35	3.34
	40	10.1

4. Conclusion

This thermal conductivity device is 85 cm high and weighs 18.5 kg. It consists of two cartridge heaters, each with a diameter of 10 mm, a length of 44.5 mm, and a power of 100 W. In addition, the test specimen itself has the same diameter of 25.4 mm and dimensions of 2 mm and 4 mm for the thickness of the test material. The cooling component is Peltier, and solid rock wool serves as an insulator. This helps to prevent the heat transfer process from becoming axial or spreading to the right and left.

The measured thermal conductivity value for the ramie fiber composite at 35˚C is 11.55 W/m K, for 40˚C it is 4.16 W/m K. Meanwhile, for the banana stem fiber composite at 35˚C it is 3.34 W/m K, and for 40˚C it is 10.10 W/m K. The thermal conductivity value of the ramie fiber and banana stem fiber composite has an increase compared to the thermal conductivity value of the fiber itself.

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