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# Properties of Thermal Conductivity Hybrid Epoxy Resin Composite Reinforced Natural Fiber as Alternative Insulator Material

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## Abstract

*The properties of hybrid composite materials depend highly on the constituents used as reinforcement, such as natural fibers with a matrix. This study aims to determine the effect of the chemical solution of NaOH and Silane solution on the fiber's thermal conductivity properties. Fibers were treated at 3% and 6% concentrations, had a length of 5 mm, and were in random orientation. Hybrid composite materials manufacture using the hand lay-up molding method. The nettle fiber reinforced resin matrix to fiber weight ratio was 10, 15, 20, and 25%. Immersion was carried out for 2 hours in NaOH solution (Merck, 98%) and Silane coupling agent solution (Merck, 99.5%). The results of this study indicate the highest thermal conductivity with a fiber composition of 25% in a chemical solution treatment of 6% Silane of 0.1995 Watt/m˚K.On the other hand, the lowest with a composition of 10% natural fiber with 3% NaOH treatment of 0.1099 Watt/m°K. The hybrid resin composite can significantly influence the thermal conductivity properties. The thermal conductivity properties obtained from hybrid composite materials are of low value, so they can be used as insulators.*

**Keywords:** *composite; NaOH, silane; thermal conductivity*

## 1. Introduction

Current developments in science and technology have resulted in the use and utilization of materials that initially only came from fossil raw materials, shifting to materials that come from natural raw materials. So far, the existence of metal materials dominates the industrial sector. However, materials with particular properties have yet to be fulfilled in industrial applications, so alternative materials have been developed. A Composite is a material formed from a combination of two or more materials where the mechanical properties of the constituent materials vary (Putra et al., 2019). One of the natural fiber reinforcements is from nature, such as plants and animals. This natural fiber is mainly formed from cellulose with a small amount of extractive. Vegetable fiber is the most widely used fiber because it is abundant in nature, inexpensive, and easy to obtain. Types of natural fibers are cotton, hemp, nettle, and other cellulose fibers derived from plants and animal fibers, which are types of materials that have the potential to be used as composite reinforcement materials. Silk and wool are often used as animal fibers (Rahmayanti et al., 2019). Compared with synthetic inorganic reinforcement such as glass and carbon fiber, natural fibers provide many advantages and relatively high tensile and flexural modulus (Xie et al., 2010).

The immersion of natural fibers in a solution containing silicon (Si) is carried out as a chemical treatment of natural fibers, called silane treatment (Kushwaha & Kumar, 2010). Mixing silane agent with ethanol/distilled water solution is a silane processing process that can be done. Silica can be moved with the resin matrix due to the silane coupling agent. Silane coupling agent has hydroxy groups that can be attracted to the hydroxy groups on the surface of the natural fiber, causing the organo-functional groups to react with the resin matrix, forming strong bonds.

Silane is an intermediate used to make between two special materials. The silane treatment was carried out by mixing the Silane with ethanol solvent or distilled water in a ratio of 80:20, which the mixing could be carried out in a container. Silane works at the interface between the parts of inorganic and organic materials to combine two types of materials. Using Silane as a hardener will also improve the resistivity on the insulator's surface, making it more difficult to flow or reducing the leakage current (Utami et al., 2021).

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Adhesion between the fibers and the matrix increase can be done by chemical modification of the natural fibers. The interface of each composition variation binds or provides reinforcement which causes the mechanical properties to increase (Suarsana et al., 2021).

Composites can be made in hybrid composites or biocomposites. Determination the mechanical properties of hybrid composites influenced by graphene/epoxy with alumina (Shetty, 2019), while the degradable natural fiber in polymer also influenced mechanical properties. (Alex & Retnam, 2014). Researchers revealed that the properties of nettle fiber are technically strong, so this material is promising to be used as a composite reinforcement. Good properties of this strong nettle fiber have Young's modulus of 87 GPa, a tensile strength of 1594 MPa, a breaking strain of 2.11%, and an average diameter of 19.9 m (Bodros & Baley, 2008). Researchers have proven that nettle fiber has a high strength to strengthen composite materials. Special treatment is required to produce strong, fine nettle fibers and high tensile strength (Bacci et al., 2009). Studies on the thermal conductivity of natural fiber-reinforced hybrid composites resulted in high strength (Nikmatin et al., 2017). Another study on thermal conductivity and its relationship to wear resistance used natural fiber-reinforced epoxy resin composites (Patnaik et al., 2010). Using natural fiber (luffa) as a concrete mixture and adding 1% and 2% luffa with a compressive test resulted in increased flexural stress (Sen & Ankit, 2018).

Research on the effect of treating NaOH and Silane solutions to determine the thermal conductivity has never been done before. This study aims to analyze the thermal conductivity properties of the NaOH and Silane solutions with solution concentrations: of 3% and 6% and the composition of nettle fiber: of 10%, 15%, 20%, and 25%. The results and discussion section will present and analyze the test results.

## 2. Materials and Methods

### 2.1. Materials

Taking fiber in natural plants is done as follows: plant stems are cut with a length of 50 cm and dried for 3-5 days using sunlight. Dry plant stems are followed by soaking the fiber in water for 4-5 days at free air temperature until the fibers are visible. Naturally separating from the stems in a not-so-dry and not-so-wet condition, a manual sorting process between the stems and fibers was carried out by hand. The nettle plant fibers that had been recovered were dried again for two days, which the manufacturing process referred to in Figure 1.

After drying, the fibers were again treated with 3 and 6% NaOH (Merck 98%) and Silane (Merck 99,5%) chemical solutions, respectively. The treatment aims to remove lignin, increase fiber and matrix adhesion, and dry. Finally, the fibers were cut to a length of 5 mm, shown in Figure 2.

### 2.2. Methods

The hand lay-up molding process is done by pouring resin into the fibers arranged randomly and then applying pressure and leveling the surface using a brush. In this process, the resin is directly in contact with air, and the molding process is carried out at room temperature. The manufacture of hybrid resin composites begins with chemical treatment variations of nettle fiber on NaOH and Silane 3% and 6% with natural fiber composition as reinforcement of 10, 15, 20, and 25%, respectively. Glycerin is applied thinly and evenly on the inside of the composite mold. The resin and catalyst were mixed with a proportion of 1% catalyst in a measuring cup. After which the two components were stirred until well mixed. The nettle fiber is added to the resin mixture and stirred until well blended. The mixture of fiber and resin is poured into the mold, leveled, and given a pressure of 10 psi so that the reinforcement and binder are evenly distributed throughout the mold (Suryawan et al., 2020).

The hand lay-up process is illustrated in Figure 3. The order of the sequence is designed as follows [A1/B1]; [A1/C1], [A2/B1]; [A2/C1] and [A3/B1]; [A3/C1]. Capital letters [A] function as an abbreviation of the variation of natural fiber composition, [B] function as NaOH alkali treatment, [C] function as Silane treatment. The suffix number is used as a code for differences in fiber immersion and chemical treatment duration. Comparison of fiber composition and chemical treatment were: 10% (A1)/3%NaOH (B1) and 15% (A2)/3%Silane (C1). Epoxy resin printed without fiber reinforcement as a control. The difference in natural fiber composition is 10, 15, 20, and 25%. For the composition, the concentration

**Figure 1.** Natural Fiber Working Process

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(a) (b)

**Figure 2.** (a) NaOH (Merck 98%), (b) Silane (Merck 99,5%)

of NaOH is 3% and 6%, and Silane is also 3% and 6%.

**2.2.1 Thermal conductivity**

Thermal conductivity testing can determine the value of thermal transfer in the hybrid composite. The thermal conductivity value is calculated using the equation from ASTM E 1225, with the Equation 1.

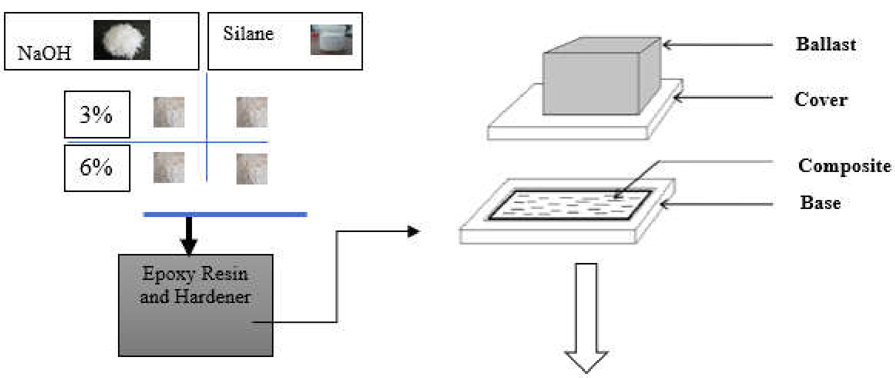
$$Q_x = -kA\frac{dT}{dX} \quad (1)$$

Where: Heat flux Qx [W], thermal conductivity **k** [W/m$^o$K], temperature difference dT [$^o$K], thickness difference dX [m], and sample cross-sectional area A [m$^2$].

The value of thermal conductivity (**k**) is calculated by Equation 2.

$$k = -\frac{Q_x\, dX}{A\, dT} \quad (2)$$

Thermal conductivity testing is conducted using a Thermal Conductivity Measuring Tool, namely: (1) Preparation of the specimen to be tested; (2) Cylindrical-shaped test material with a diameter of 30 mm and a thickness of 20 mm with three repetitions of the test; (3) The specimen is mounted on two copper cylindrical sections, which are loosened according to the thickness of




| Fiber variety | NaOH | Silane | | Thermal conductivity |
|---|---|---|---|---|
| A1 | 0,03 | 0,03 | | |
| | 0,06 | 0,06 | | |
| A2 | 0,03 | 0,03 | | |
| | 0,06 | 0,06 | | |
| A3 | 0,03 | 0,03 | | |
| | 0,06 | 0,06 | | |
| A4 | 0,03 | 0,03 | | |
| | 0,06 | 0,06 | | |

**Figure 3.** Hand Lay-Up Procedure for Making Composites

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**Table 1**. Thermal Conductivity Testing Data (Watt /mºK)

| Fiber composition (%) | Chemical Treatment | | | |
|---|---|---|---|---|
| | NaOH | | Silane | |
| | 3% | 6% | 3% | 6% |
| 10 | 0.1099 | 0.1163 | 0.1185 | 0.1204 |
| 15 | 0.1353 | 0.1424 | 0.1506 | 0.1589 |
| 20 | 0.1555 | 0.1689 | 0.1725 | 0.1801 |
| 25 | 0.1735 | 0.1824 | 0.1885 | 0.1995 |

the specimen; (4) Then the top nut of the tube is tightened; (5) When the test took place, the ambient temperature was at 19oC, and the heating power was 66 Watts.

The thermal conductivity testing is carried out at the Laboratory of the Basic Phenomena of Mechanical Engineering, Udayana University, as shown in Figure 4.

**2.2.2. Scanning Electron Microscope (SEM) Test**

Underwent a thermal conductivity test; the specimen was observed with SEM. The steps in taking pictures in the SEM test are: (1) Prepare the specimen to be analyzed; (2) Specimens were cleaned using an ultrasonic cleaner with acetone media to remove impurity dust before sticking to the specimen holder; (3) Attach the specimen to the specimen holder using a double sticky tip to obtain a rigid specimen position; (4) Specimens are inserted into the specimen chamber on the SEM tool to observe the test specimens before taking pictures; (5) Photographs were taken using the desired magnification to determine fiber distribution, debonding, pullout, and voids: (6) The results of taking SEM images are then analyzed.

Scanning Electron Microscope (SEM) is an electron microscope that is widely used to analyze the microstructure of composite materials. SEM can also be used to analyze the crystallographic structure and morphology so that it can be developed to determine elements or compounds of materials. The working principle of SEM is that two electron beams are used simultaneously. One strike specimen is used for testing, and the other is a cathode ray tube (CRT) providing image display. SEM uses X-rays that have a wavelength of 4x10-3 nm or about 100,000 times shorter than the wavelength of visible light. This is why SEM can analyze tiny objects that ordinary microscopes cannot separate. The detector used in this SEM is a secondary electron. SEM schematic diagram can be seen in Figure 5.

## 3. Result and Discussion

Thermal conductivity testing was carried out on four composite fiber compositions with three samples in each composition, and then the average was searched. Thermal conductivity testing is done by taking data from the specimens of each composite-forming material to the total volume made. The average data of test results through calculations with equation (2) can be shown in Table 1.

**3.1. Thermal Conductivity Test Results**

The thermal conductivity test is shown in Figure 5, which includes a description of the material and thermocouples T1 - T7 with a sensor reading distance from each thermocouple. Tests were carried out on each test material with different composition variations. The test results then calculated the value of the thermal conductivity. When the test took place, the ambient temperature was at 19°C, and the heating power was 66 Watts according to the ability of the test machine.

It can be seen in Figure 6 that graphs show the results of the thermal conductivity test without and with chemical solutions treatment and composite compositions, which provide data on the relationship between fiber composition, NaOH, and silane solutions concentration. Based on Figure 6, the results showed an increase in thermal conductivity from each without and with chemical solution treatment of fiber composition and

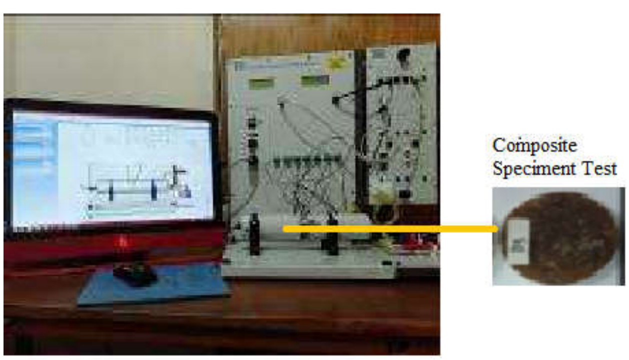


**Figure 4.** Heat Conductivity Testing Materials and Equipment

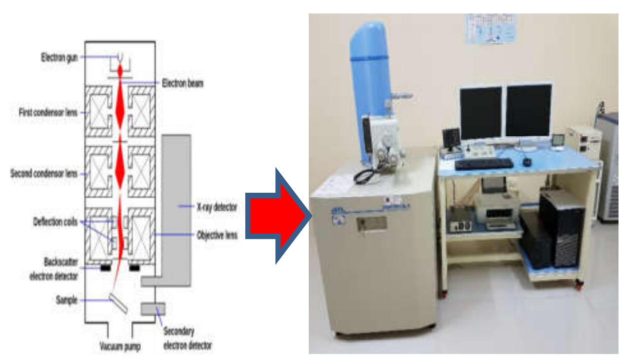


**Figure 5.** SEM Schematic Diagram and SEM Testing Tools (Choudhary & ka, 2017)

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at each different concentration of NaOH and Silane solutions. The thermal conductivity of the epoxy resin composite without chemical solution treatment on the fiber was 0.0958, 0.1225, 0.1425, and 0.1655 W/m°K. The composition of 10% fiber with a concentration of 3%, 6% NaOH and 3%, 6% Silane, respectively, produced thermal conductivity (0.1099 Watt/m°K and 0.1163 Watt/m°K) NaOH and (0.1185 Watt /m°K and 0.1204 Watt/m°K) Silane. The composition of 25% fiber with a concentration of 3%, 6% NaOH and 3%, 6% Silane, respectively, produced thermal conductivity (0.1735 Watt/m°K and 0.1824 Watt/m°K) NaOH and (0.1885 Watt /m°K and 0.1995 Watt/m°K) on Silane. So it can be seen that there is an effect of fiber composition and chemical solution treatment of NaOH and Silane on the results of increased heat conductivity in each test. Where each composition has the effect of increasing the ability of thermal conductivity because it is influenced by the density and hardness increases with each treatment temperature (Suryawan et al., 2020). Increasing the addition of fiber particles processed by immersion in Silane solution can reduce the pores so that the density of the material increases, which can affect the conductivity of the composite material as a heat conductor (Patnaik et al., 2010).

Figure 6 shows the results of the thermal conductivity test in the form of a bar graph comparing the NaOH solution treatment with the Silane treatment on each fiber composition. The results showed that in the NaOH treatment at each composition, there was an increase in thermal conductivity, and in the Silane treatment at each fiber composition an increase in thermal conductivity. In this study, the NaOH and Silane treatments affect the thermal conductivity properties. The study found that chemical treatment influenced the thermal conductivity properties, whereas the Silane treatment had a more significant effect than the NaOH treatment. The data results and discussion of the effect of fiber composition and chemical treatment of natural fibers show a significant effect in increasing the percentage of

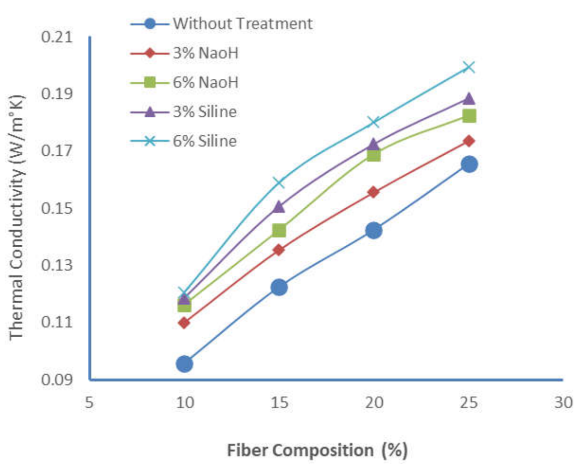



**Figure 6.** Thermal Conductivity Test Results

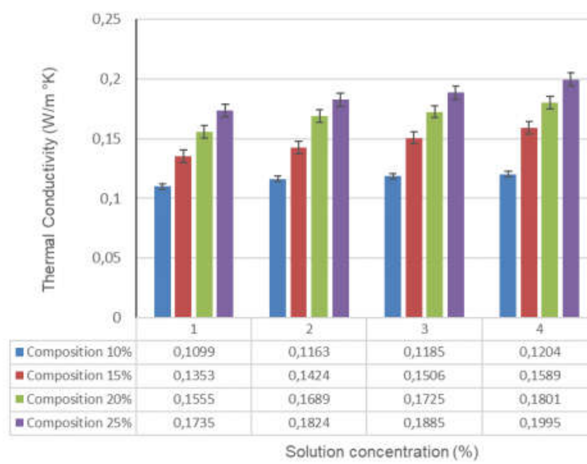
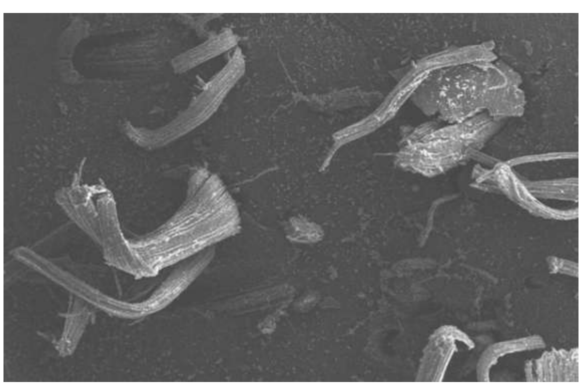
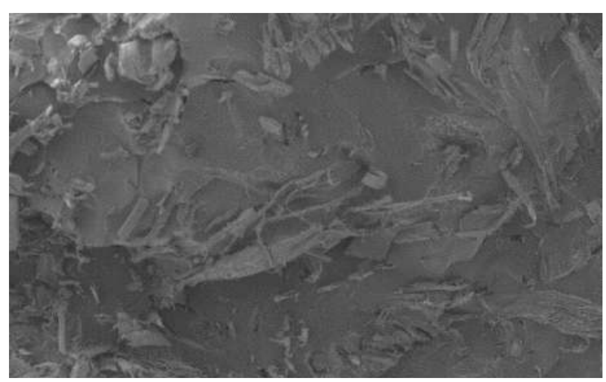



**Figure 7.** Graph of the Relationship Between Fiber Composition and Chemical Treatment



(a)



(b)

**Figure 8.** SEM specimens at 10% fiber composition with (a) 6% naoh and (b) 6% silane

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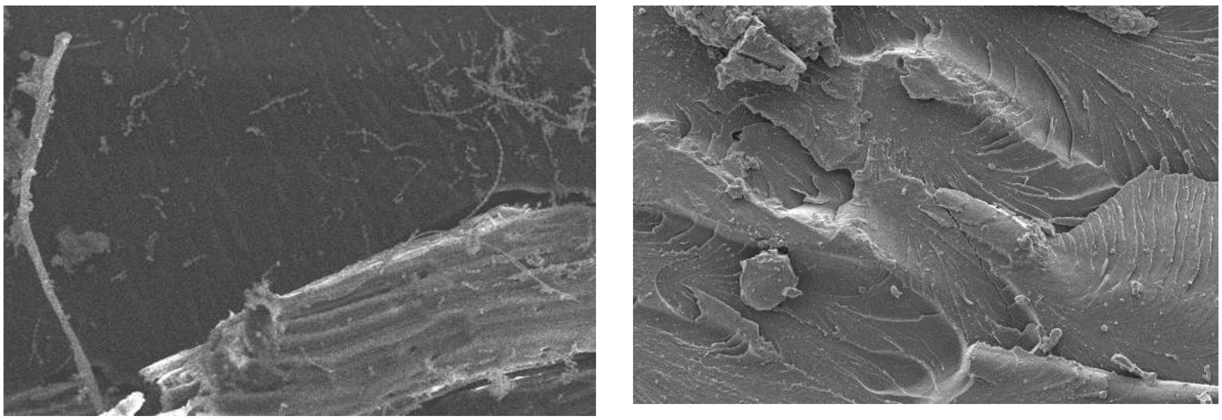
fiber in the hybrid composite. Likewise, the effect of soaking the fiber with a chemical solution of NaOH and Silane showed increased thermal conductivity. So for insulators, low thermal conductivity is needed with a thermal conductivity value under 0.42 W/m°K. Therefore it is better to choose the result of low thermal conductivity. (Subagia et al., 2017)

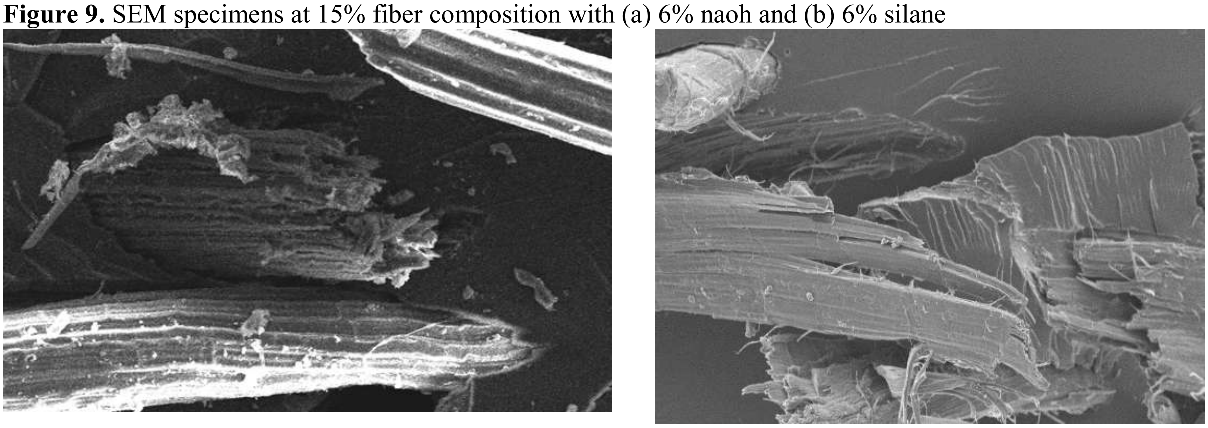
### 3.2. SEM Result

SEM (Scanning Electron Microscope) test is performed on specimens that have been subjected to thermal conductivity on the specimens. The test was carried out with SEM photos of materials with different fiber compositions and a chemical solution of NaOH and Silane with a composition of 6% with each magnification



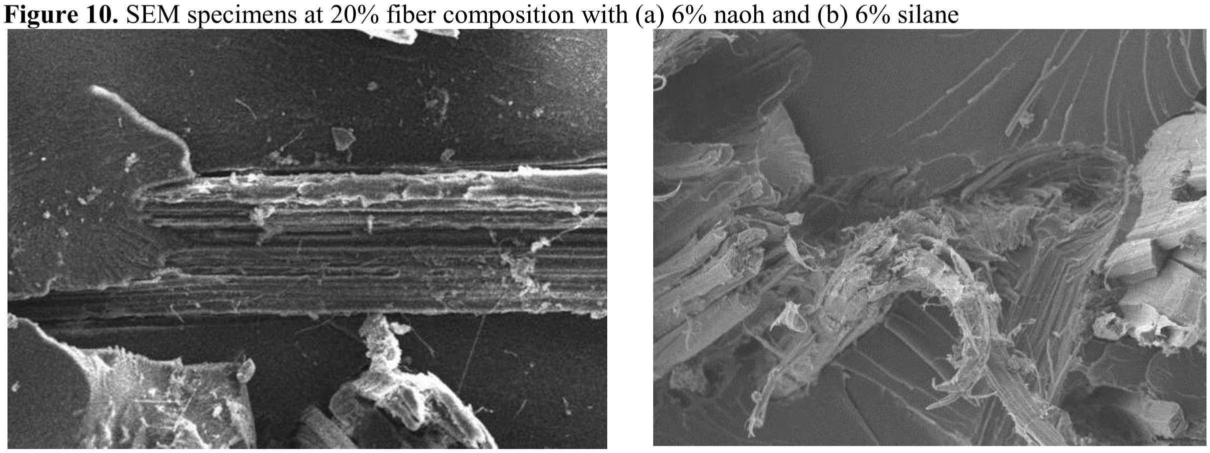
(a) (b)

**Figure 9.** SEM specimens at 15% fiber composition with (a) 6% naoh and (b) 6% silane



(a) (b)

**Figure 10.** SEM specimens at 20% fiber composition with (a) 6% naoh and (b) 6% silane



(a) (b)

**Figure 11.** SEM specimens at 25% fiber composition with (a) 6% naoh and (b) 6% silane

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of 500x. The results of the SEM (Scanning Electron Microscope) test are shown in Figure 8, Figure 9, Figure 10, and Figure 11, respectively.

In Figure 8, Figure 9, Figure 10, and Figure 11, respectively, the SEM results show the effect of the fiber composition in the hybrid composite as follows: 10%, 15%, 20%, and 25% in a solution of 6% NaOH and Silane. The results show that: the microstructure is getting tighter; the bonds are getting stronger; and the pores are reduced, both from the increase in composition with natural fibers and due to the treatment of chemical solutions of NaOH and Silane. Increasing the fiber composition percentage causes a strong bond. The function of the SEM photos with different magnifications is to support the proof and clarify the surface morphology of the hybrid composite being tested. Likewise, direct observation generally proves whether a visual difference numerically supports a difference. In the results of this study, it is true that it visually supports and proves the effect of fiber composition and NaOH and Silane treatment on the research composites. It is seen that the pores are reduced, and the bond is stronger, so the composite strength increases.

## 4. Conclusion

The study of the composition variations of natural fiber reinforcement and chemical treatment of composite hybrids on thermal conductivity properties showed that the value of thermal conductivity properties of natural fiber-reinforced epoxy resin composites increased at each composition percentage. The results of the thermal conductivity test increased in the natural fiber composition of 10% to 25% and 3% to 6% chemical treatment on NaOH and Silane, with the highest thermal conductivity value being 0.1995 W/m°K. Likewise, based on observations using a Scanning Electron Microscope (SEM), the results show that visually adding the composition of natural fiber reinforcement and chemical treatment significantly affects the thermal conductivity properties. So it can be concluded that the hybrid composite obtained still has good insulating properties, with a thermal conductivity value below 0.42 W/m°K as the maximum value for good insulating properties.

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