Utilization of Mixture of Teak Wood Sawdust and Bagasse Fiber using Treatment of Fiber Variations and Alkali NaOH Immersion as A Refrigerator Insulation Material

Alam Baheramsyah[1], Ede Mehta Wardhana[2], Achmad Taufik Rendi Kisserah[3]

Abstract— this research modified the insulation of coolbox material by utilizing a mixture of teak wood sawdust (*Tectona grandis L.f.*) and previously immersed bagasse fiber (*Saccharum officinarum*) into an alkali NaOH solution to improve the mechanical properties of the fiber and reduce the value of material thermal conductivity. The most optimal test and analysis results were obtained by composing 50% teak wood sawdust with 50% of previously immersed bagasse fiber in an alkali NaOH solution at a level of 15%. The obtained conductivity value is 0.2907 W / mK, the density is 0.4901 gram / cm3. Experiments on changes in temperature of ice, fish, and coolbox chamber as well as experiments on the duration of fish preservation in the coolbox with variations in the composition of straight fibers have better performance compared to the variation of random fiber which is able to preserve fish for 34 hours with minimum temperature of 0, 2 ° C. For fishing duration of two days, coolbox with a variety of straight fiber has almost the same performance as coolbox made from styrofoam and has the potential to replace styrofoam because it is more environmentally friendly.

Keywords— alkali NaOH, coolbox, insulation, thermal conductivity, styrofoam.

I. INTRODUCTION

The type of coolbox that commonly used by fishermen is a coolbox made of Styrofoam. Styrofoam has disadvantages such as being dangerous both for human health and the environment, thus it needs an effort to reduce the use of Styrofoam. Styrofoam can be replaced with material that has properties as an insulator and low thermal conductivity [1]. Teak wood sawdust (*Tectona grandis L.f.*) and bagasse fiber (*Saccharum officinarum*) are natural materials which have low thermal conductivity values between 0.022 W / mK to 0.082 W / mK [2-9].

Bagasse fiber is insoluble in water and consists mainly of cellulose 37.65%, pentosan 27.97%, and lignin 22.09%. Lignin ($C_9H_{10}O_2(OCH_3)n$) is one of the constituent components of plants which is insoluble in water and stable in nature but useful as an adhesive that connects cellulose to hemicellulose [10]. While cellulose is a polysaccharide with chemical formulas similar to starch $(C_6H_{10}O_5)_n$ it is not easily soluble in air and is not easily degraded either chemically or mechanically. [2-7]. Natural fibers have hydrophilic properties, resulting in a low value of adhesion force between fiber and matrix. To optimize cellulose properties and increase the adhesion force between fibers and polymers, both physical and chemical treatments are needed.

Chemical treatment of fibers can change the physical and chemical structure of the fiber surface. One of the chemical treatment processes is alkalization which is the most widely used method for removing the content of lignin and oil that covers the outer surface of the fiber. The impact caused by doing alkalization treatment is the change in hydrogen bonds in the structure of the fiber tissue which changes the surface of the fiber becoming rough. thus, it can reduce the value of thermal conductivity in natural fibers [8-14]. In this research, the alkalization process was carried out by immersing the fiber in an alkali NaOH. NaOH is chosen because it is widely used on the industrial scale is given relatively lower in price and is a strong base solution classified as easily soluble in water that can be perfectly ionized. The chemical reaction that occurs during the process of soaking the fiber using an alkali NaOH solution is shown in figure 1.

Lignin reacts with a solution of NaOH which dissociates into Na^+ and OH^-. OH^- ion reacts with an H group on lignin and then forms H_2O. This causes the O group to become free radicals and reactive to C then form an epoxy ring (C-O-C) resulting in a series of groups releasing bonds to group O and producing two separate benzene rings. Both benzene rings each have an O group that is reactive and reacts with Na^+ and then dissolves in a base solution so that the lignin disappears when rinsed and the fiber diameter decreases [15-18].

Alam Baheramsyah, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia, Email : abaheramsyah@gmail.com

Ede Mehta Wardhana, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia, Email : edewardhana123@gmail.com

Achmad Taufik Rendi Kisserah, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya 60111, Indonesia, Email : taufikrendikisserah@gmail.com
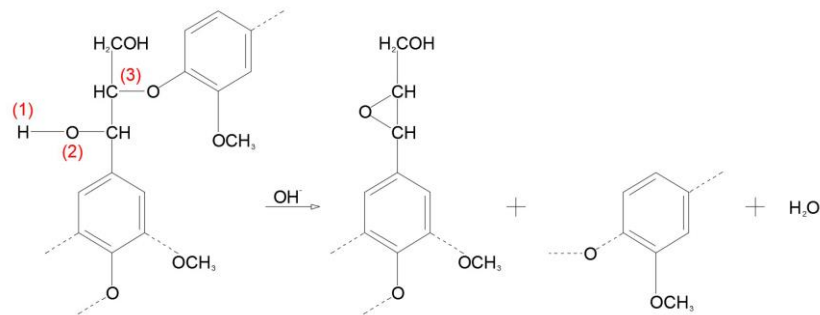
International Journal of Marine Engineering Innovation and Research, Vol. 4(2), Sept. 2019. 78-86
(pISSN: 2541-5972, eISSN: 2548-1479)

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Figure. 1. The Chemical Reaction During the Process of Soaking the Fiber Using An Alkali NaOH

II. METHOD

A. Specimen Making

The making of specimens is carried out using a mixture of teak wood sawdust (*Tectona grandis L.f.*) with bagasse fiber (*Saccharum officinarum*). The purpose of making these specimens is to determine the value of the thermal conductivity of the material and the density of the material. Before the specimen is made, bagasse fiber is given a chemical treatment by immersing it into an alkali NaOH solution which then is mixed with polyurethane adhesive. The specimens are formed according to the mold made of PVC pipe with a diameter of 3.8 cm and a height of 5 cm. While making an alkali solution is done by reacting the distilled water solution with NaOH solids according to the variation of the level of 0% (without soaking an alkali NaOH solution), 15%, and 30%. There are nine specimens that are being tested for the value of thermal conductivity and density for each variation of the fiber arrangement with the same chemical composition and consist of nine specimens of variations in random fiber arrangement, and nine specimens of variations in straight fiber arrangement. However, this research does not cover the test of nine specimens of variations in the straight fiber arrangement due to manufacturing difficulties and less supportive test equipment (specimens were difficult to make). To continue research on variations of straight fibers arrangement, researchers directly compared the performance of the test results with random fibers when making a prototype or coolbox model without testing thermal conductivity and mass type specimens.

The composition of nine specimens with variations in the random fiber arrangement to be tested are as follow:

1. Specimen 1 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber without soaking NaOH (0%)
2. Specimen 2 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber with soaking NaOH (15%)
3. Specimen 3 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber with soaking NaOH (30%)
4. Specimen 4 = 50 grams of teak wood sawdust: 50 grams of bagasse fiber without soaking NaOH (0%)
5. Specimen 5 = 50 grams of teak wood sawdust: 50 grams of bagasse fiber with soaking NaOH (15%)
6. Specimen 6 = 50 grams of teak wood sawdust: 50 grams of bagasse fiber with soaking NaOH (30%)
7. Specimen 7 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber without soaking NaOH (0%)
8. Specimen 8 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber with soaking NaOH (15%)
9. Specimen 9 = 70 grams of teak wood sawdust: 30 grams of bagasse fiber with soaking NaOH (30%)

B. Specimen Testing

1. Density Test

The equation to calculate the density of an object is :

$$\rho = \frac{m}{V} \qquad \text{.......... (1)}$$

Where : ρ = density (gr/cm³)
m = mass of specimen (gr)
V = volume of specimen (cm³)

The tested specimens have cylindrical shape thus, the volume value can be calculated by multiplying the cross-sectional area of the specimen in a circle with a high specimen. The mass of specimens can be known by weighing using digital scales.

2. *Thermal Conductivity Test*

Testing of thermal conductivity in this study uses the ASTM E1225 standard. The specimen is tested by placing it between two copper metal pieces. To find out the temperature of the specimen points, a thermocouple is installed. After obtaining temperature data, the calculation is then carried out with the following steps:

a. Copper Average Temperature Calculation

$$Tc_{avg} = \frac{T_1 + T_2}{2} \qquad \text{.......... (2)}$$

Where:
$T_{AVG\ copper}$ = Average copper temperature (K)
$T1$ = Temperature 1 (K)
$T2$ = Temperature 2 (K)

b. Copper Thermal Conductivity Calculation

The value of copper thermal conductivity can be calculated using the interpolation method in the thermal characteristics table of some solid metals or better known as table A-1 (table 1).

TABLE 1.
THERMAL CONDUCTIVITY OF COOPER

Material	Thermal Conductivity (W/mK)		
	300 K	400 K	500K
Pure Cooper	401	393	388

International Journal of Marine Engineering Innovation and Research, Vol. 4(2), Sept. 2019. 78-86
(pISSN: 2541-5972, eISSN: 2548-1479)

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c. Heat Value Calculation

The heat value of copper can be calculated using the equation (3)

$$Q_c = \frac{c \times A_c \times \Delta T_c}{L_c} \qquad \ldots\ldots\ldots (3)$$

Where :

Q_c = Heat in Cooper (W)
K_c = Thermal Conductivity of copper (W/mK)
A_c = Area of Cooper Surface (m^2)
ΔTc = Temperature differences (°C)
L_c = Length of copper (m)

In this experiment, the amount of incoming heat (heat in copper) is assumed to be equal to the amount of heat that comes out (heat on the specimen).

$$Q_{in} = Q_{out}$$
$$Q_{cooper} = Q_{specimen}$$

d. Thermal Conductivity Calculation

The amount of incoming heat (Qc) is calculated by equation (3) and the thermal conductivity of the specimen is calculated by equation (4).

$$K_{sp} = \frac{Q_{sp} \times L_{sp}}{A_{sp} \times \Delta T_{sp}} \qquad \ldots\ldots\ldots (4)$$

Where :

Q_{sp} = Heat in Cooper (W)
K_{sp} = Thermal Conductivity of the specimen (W/mK)
A_{sp} = Area of Specimen Surface (m^2)
ΔT_{sp} = Temperature differences (°C)
L_{sp} = Length of specimen (m)

C. *Specimen Selection*

Specimen selection is done by giving ranks, scores, and weights. The percentage of the greatest value from the weighting results is used as a reference for making the coolbox. In this research, the fifth specimen has the highest final value. Thus, the manufacture of coolboxes with a variation of a random straight and random fiber is using the reference of the fifth specimen which has a composition of 50 grams of teak wood sawdust: 50 grams of previously immersed bagasse fiber in 15% of NaOH solution.

D. *Coolbox Making*

After selecting the specimen with the highest percentage value, then it is used as a recommendation for making a prototype of coolbox with the following dimensions:
Length : 33,5 cm
Width : 24,5 cm
Height : 27 cm
The specification of coolbox can be seen in table 2.

E. *Full-Scale Experiment*

The experiment is conducted by comparing the performance of the cool box with the selected composition for random fiber and straight fiber arrangement and cool box made of Styrofoam. The three Coolboxes will be treated the same as given by layers of plywood and resin. The experiment was carried out by inserting tuna with a mass of 500 grams and 2.5 kg of ice into the coolbox.

a. *Cooling Time*

The cooling time observed is the duration of the coolbox containing fish and wet ice reaches a temperature of 20°C.

b. *The Lowest Temperature Achieved by Each Coolbox*

The observation scoop was the lowest temperature value achieved by the cool box within 24 hours with the time span of data collection every 30 minutes. The observation was carried out by observing the temperature at a number of conservation points, namely the first point below the wet ice surface, the second point in the fish body, and the third point in the space inside the cool box. In addition to these three points, data of surrounding temperature is also taken every 30 minutes.

III. RESULT AND DISCUSSION

A. *Chemical Fiber Treatment and Test Result*
a. *Chemical Fiber Treatment Result*

The difference between the three fibers both physically and chemically can be observed virtually as shown in figure 6. Physically, there is a difference between the color and shape of the fiber. Fiber that has been soaked using 15% NaOH and 30% NaOH has a darker color, has a more regular shape, and has a smaller diameter than fiber without any immersion process.

b. *Density Test Result*

Based on table 3, the variation of random structures with a composition of 30% teak wood sawdust and 70% bagasse fiber has a mass value and volume ranging from 26.3 grams to 26.9 grams and the volume ranging from 55.16 cm3 to 58.13 cm3. The density for the specimens in this composition ranges from 0.48 g / cm3 to 0.50 g / cm3 where the 9th specimen has the smallest density value.
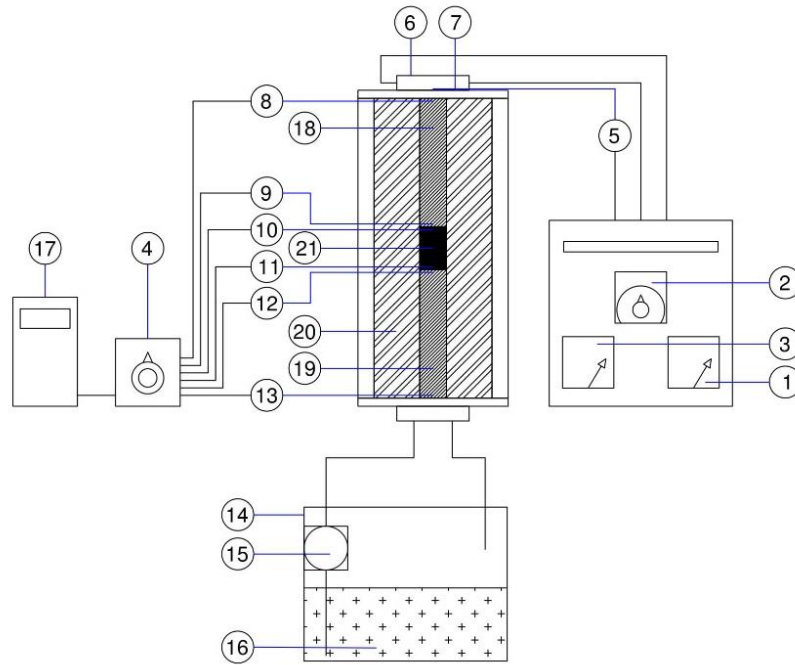
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(pISSN: 2541-5972, eISSN: 2548-1479)

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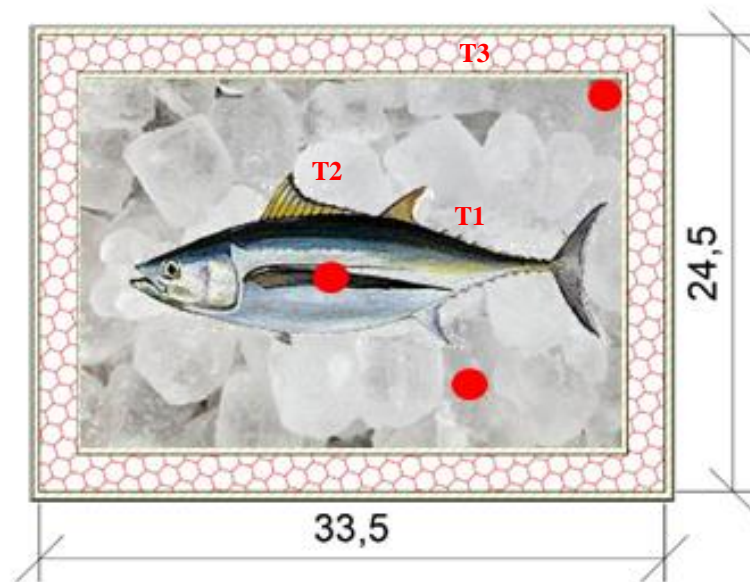**Figure. 2**. Installation of Thermal Conductivity Test

Figure. 3. Illustration of Coolbox from Top View

Annotation:
T1 = Ice Temperature in Coolbox
T2 = Fish Temperature in Coolbox
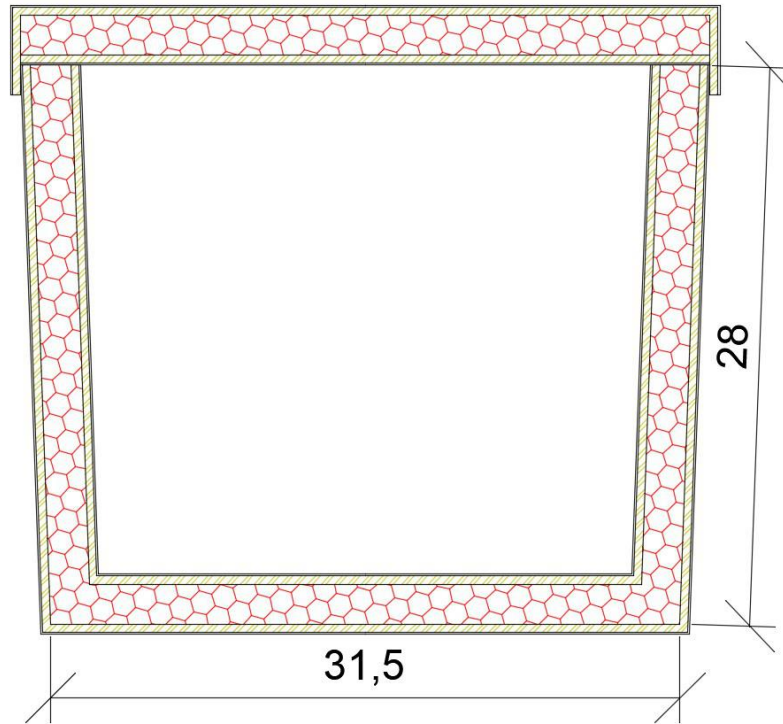T3 = Temperature of Coolbox Chamber

International Journal of Marine Engineering Innovation and Research, Vol. 4(2), Sept. 2019. 78-86
(pISSN: 2541-5972, eISSN: 2548-1479)
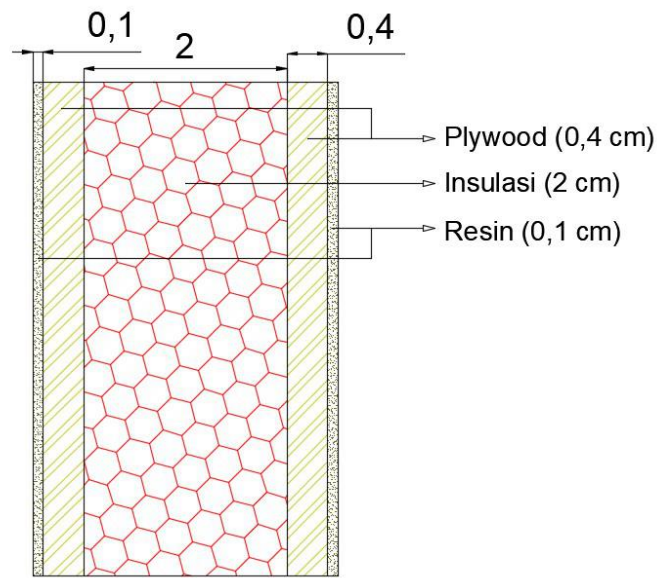
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Figure. 4. Illustration of Coolbox from Side View

Figure. 5. Illustration of the insulation material layer in the coolbox

Figure. 6. Result of immersing fiber that has been dried

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(pISSN: 2541-5972, eISSN: 2548-1479)

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TABLE 2.
COOLBOX SPECIFICATION

Part	Dimension		
	length (m)	Width (m)	Height (m)
Top	33,5	24,5	28
Bottom	31,5	22,5	
	Information		
	Teak Wood Sawdust	50	%
	Bagasse Fiber	50	%
	NaOH	15	%
Insulation	Density	0,4901	g/cm³
	Polyurethane	0,2171	g/cm3
	Thermal Conductivity	0,2907	W/mK
	Thick	2	Cm
	Volume	8478,84	cm³
Layer	Plywood	4	Mm
	Resin	1	Cm

TABLE 3.
DENSITY TEST RESULT

Random Fiber		Composition			Mass (gram)	Volume (cm3)	Density (g/cm3)
		Teak Wood Sawdust	Bagasse	NaOH			
Number of Spesimen	1	70	30	0%	30,9	54,97454	0,5620783
	2	70	30	15%	30,3	54,73738	0,5535523
	3	70	30	30%	30,2	54,71967	0,551904
	4	50	50	0%	29	57,95944	0,5003499
	5	50	50	15%	28,9	58,96631	0,4901104
	6	50	50	30%	28,7	58,79751	0,4881159
	7	30	70	0%	26,9	55,16636	0,487616
	8	30	70	15%	26,8	58,07402	0,4614801
	9	30	70	30%	26,3	58,13969	0,4523588

TABLE 4.
THERMAL CONDUCTIVITY TEST RESULT

Specimen	Fiber	Composition		NaOH	Thermal Conductivity (W/mK)
		Teak Wood Sawdust	Bagasse		
1				0%	0,7996
2		70	30	15%	0,7225
3				30%	0,7432
4				0%	0,5813
5	Random	50	50	15%	0,2907
6				30%	0,4069
7				0%	0,6017
8		30	70	15%	0,4733
9				30%	0,5096

c. Thermal Conductivity Test Result

Based on table 4, For specimens with the composition of 50% Teak Wood Sawdust and 50% bagasse fiber, the thermal conductivity values range from 0.2907 W / mK to 0.5813 W / mK with the smallest average conductivity value of the specimens, which is 0.4263 W / mK.

Out of three variations of alkali NaOH treatment, specimens with variations in alkali NaOH treatment at 15% levels has the lowest average thermal conductivity value of 0.4955 W / mK. This is occurring due to the process of previously immersing fiber into an alkali solution NaOH gives rise to cellulose and eliminate impurities (lignin) on the surface of bagasse fiber which results in reduced diameter of the fiber. Thus, the process of immersing fiber into an alkali NaOH solution improves the mechanical properties of the fiber and reduces the value of thermal conductivity of the fiber material compared to those without the treatment of soaking the fiber into the alkali solution.

B. Specimen Selection

The selection of specimens is chosen by selecting which specimens are the most potential, both from a technical and economic perspective.

International Journal of Marine Engineering Innovation and Research, Vol. 4(2), Sept. 2019. 78-86
(pISSN: 2541-5972, eISSN: 2548-1479)

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TABLE 5.
SPECIMEN SELECTION

Random Fiber		Composition			Score (%)				Total Score (%)	Rank
		Teak Wood Sawdust	Bagasse	NaOH	Thermal Conductivity	Density	Production Cost	Availability of Material		
Number of Specimen	1	70	30	0	6	2	19	3	30	9
	2	70	30	15	17	4	17	10	48	7
	3	70	30	30	11	7	8	9	35	8
	4	50	50	0	28	9	22	2	61	5
	5	50	50	15	50	11	14	8	83	1
	6	50	50	30	44	13	6	7	70	3
	7	30	70	0	22	16	25	1	64	4
	8	30	70	15	39	18	11	6	74	2
	9	30	70	30	33	20	3	4	60	6

Based on table 5, the 5th specimen with a composition of 50% teak wood sawdust and 50% bagasse fiber with immersion treatment using alkali NaOH 15% has the first rank with a final percentage of 83%.

C. Coolbox Testing Result

Testing of the preservation time is carried out until the fish reaches a temperature of 20 ° C while testing of changes in temperature of ice, fish, and Coolbox room is carried out for 24 hours.

Based on figure 7, fish as a cooling load reaches a temperature of 20 ° C at different times for coolbox with random fiber variation, coolbox with straight fiber variation, and coolbox made of styrofoam. In the coolbox with random fiber variation, fish reaches temperatures of 20.2 ° C in a 1500th minute or in a duration of 25 hours. For coolbox with straight fiber variation, the fish reaches a temperature of 20.2 ° C in the 2040 minute or 34 hours. While in the coolbox made of Styrofoam, the fish reaches a temperature of 20 ° C in 2100 minute or 35 hours.

Based on figure 8, at the first point or at the bottom of the surface of the ice, the coolbox with random fiber variation has the lowest temperature value of 0.1 ° C and reaches temperature value that is almost unchanged or relatively stable when it reaches temperatures of 0.3 ° C in 210th to 690th minute. While the coolbox with straight fiber variation has the lowest temperature value of 0.2 ° C and reaches a relatively stable temperature value at a temperature of 0.3 ° C in the 210th to 910th minute.

Based on Figure 9, at the second point or on the body part of the fish, the coolbox with random fiber variation has the lowest temperature value of 6 ° C in 270th to 300th minute. For coolbox with straight fiber variation has the lowest temperature value of 5.8 ° C in 210th to 270th minutes.

Based on Figure 9, the third point or inside the coolbox chamber for coolbox with straight fiber variation is capable of reaching the lowest temperature of 10.4 ° C with the fastest time duration compared to the other two coolboxes. However, along with increasing environmental temperature, the temperature of the coolbox also increases significantly.
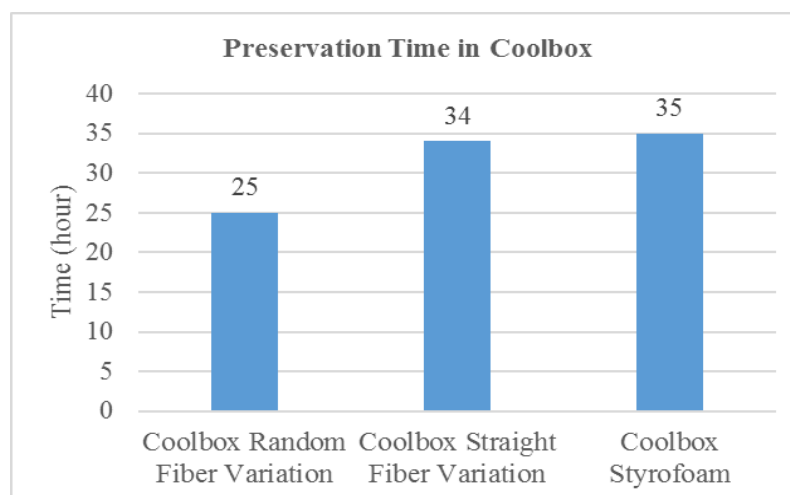

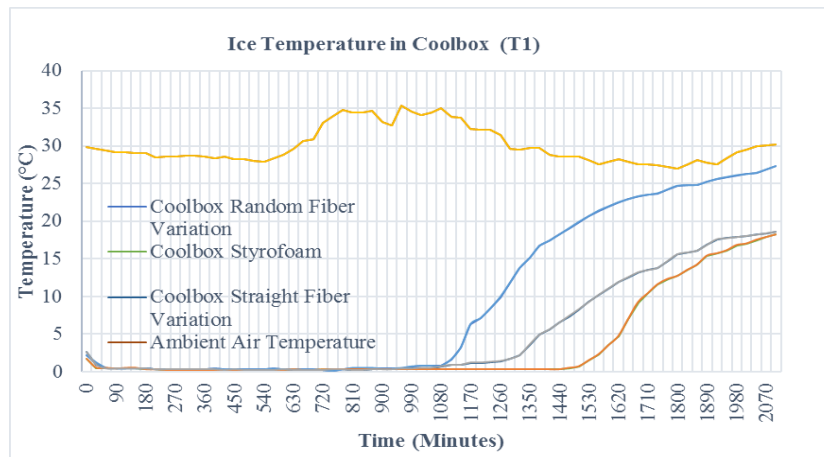**Figure. 7.** Graph of Preservation Time in Coolbox

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(pISSN: 2541-5972, eISSN: 2548-1479)

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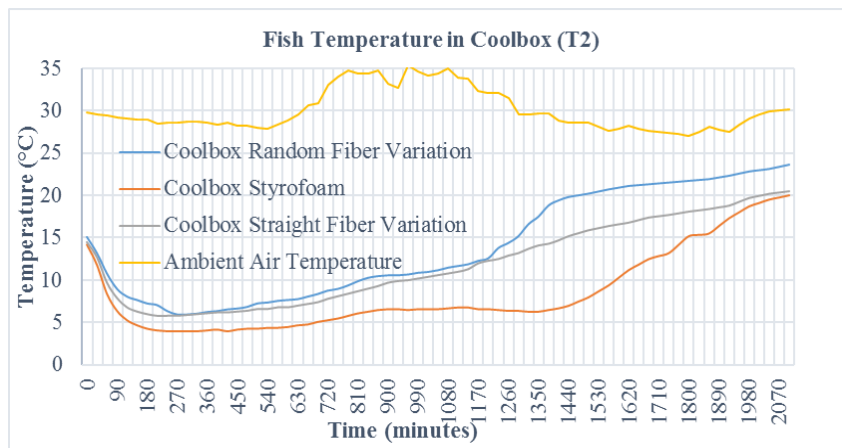**Figure. 8.** Ice Temperature in Coolbox (T1)

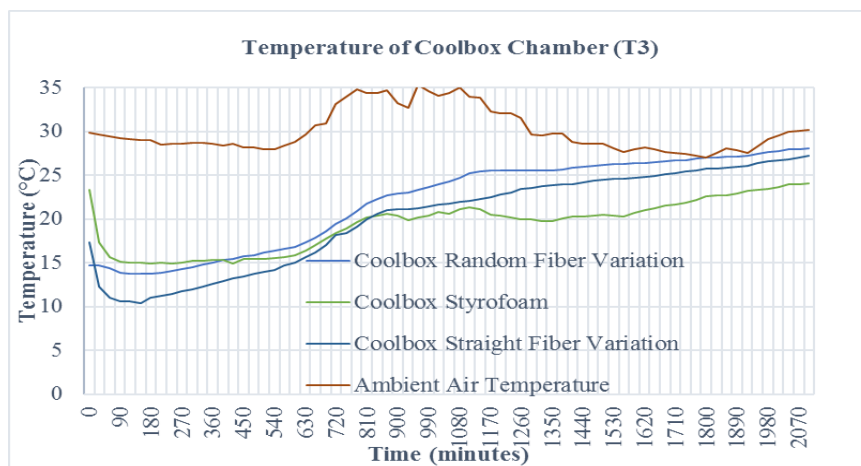**Figure. 9.** Fish Temperature in Coolbox (T2)

Figure. 10. Temperature of Coolbox Chamber (T3

IV. CONCLUSION

The fifth specimen insulation material with composition of 50% teak wood sawdust and 50% bagasse fiber treated with 15% alkali NaOH immersion has the most optimal value reviewed both technically and economically as a reference for making a coolbox. This specimen has the smallest conductivity value of 0.2907 W / mK and has a density value of 0.4901 g / cm3. For the duration of fishing for two days, coolbox with random fiber variation and coolbox with straight fiber variation have almost the same performance as Styrofoam and can be used as an alternative to Styrofoam coolboxes. Another advantage of coolbox with random fiber variation and straight fiber variation is applying materials from natural materials that are more environmentally friendly

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