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The utilization of composite material: Water hyacinth and sugarcane bagasse fiber-epoxy for cool box thermal insulation

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Abstract

Fish serves as the primary income source for the majority of fishermen in Indonesia. In order to preserve the freshness of the fish, fishermen commonly use styrofoam cool boxes. However, the use of styrofoam results in a significant quantity of waste that doesn't naturally break down. As a solution, a study was conducted to develop an alternative thermal insulation material for cool boxes. This material takes the form of a bio composite, made from epoxy resin combined with water hyacinth and sugarcane bagasse fibers. The research's results are A1 type had the lowest density value (0,795 g/cm3) and the lowest thermal conductivity value (0,1987 W/mK). The B3 type had the highest bending strength value (395,224 kg/cm2). All type of ratio variations' density and bending strength test results are met the requirements of SNI 03-2105-2006. It can be concluded that A1 type is the best choice as a thermal insulation material purpose. After a cool box from composite (A1) manufactured, a comparison test between styrofoam cool box and composite cool box is being held. The 24-hour test result shows that styrofoam cool box still outperformed the composite cool box in terms of temperature maintenance.

Keywords*: composite; water hyacinth fiber; sugarcane bagasse fiber; cool box*

1. Introduction

Currently, fishermen use a cooler box made of styrofoam filled with ice to maintain the cold temperature of the fish. However, it is very fragile and cannot withstand heavy loads, so they are easily damaged (1). If the damaged styrofoam is thrown away, it will accumulate and become waste. Styrofoam waste is difficult to degrade as it is inorganic waste. Moreover, it has a negative impact on human health and the environment (2). Styrofoam carried into the waters can harm both river and marine ecosystems and biota (3).

One of the alternative materials that can be created for the production of thermal insulation cool boxes is composite with the addition of natural fibers. Based on previous research, the natural fibers with a potency as composite reinforcement for thermal insulation are water hyacinth and bagasse fiber. So far, there has been no research combining water hyacinth fiber and bagasse fiber as composite reinforcement for thermal insulation. The use of water hyacinth fiber as a composite reinforcement can be combined with siliceous materials to function better as thermal insulation (4) and bagasse fiber contains 62.78% silica (5).

In this research on manufacturing composites reinforced with water hyacinth and bagasse, epoxy resin was used as the matrix and the method used was the hand lay-up. This research aims to obtain the properties of composite materials including density, thermal conductivity, and bending strength of multiple composition variation. The variation with the lowest thermal conductivity test results is then manufactured to be a cool box. It is expected that the combination of these two natural fibers can produce a good thermal insulation composite with better or nearly the same performance as the styrofoam cooler.

2. METHODS

This study uses an experimental method by manipulating the values of the independent variables based on considerations so that a causal relationship can be found or the effect on the dependent variable. The results of the data are the values of the density, thermal conductivity test and bending test. The analysis was conducted with a statistical analysis. Therefore, it is a quantitative study. Figure 1. shows the procedure of this research.

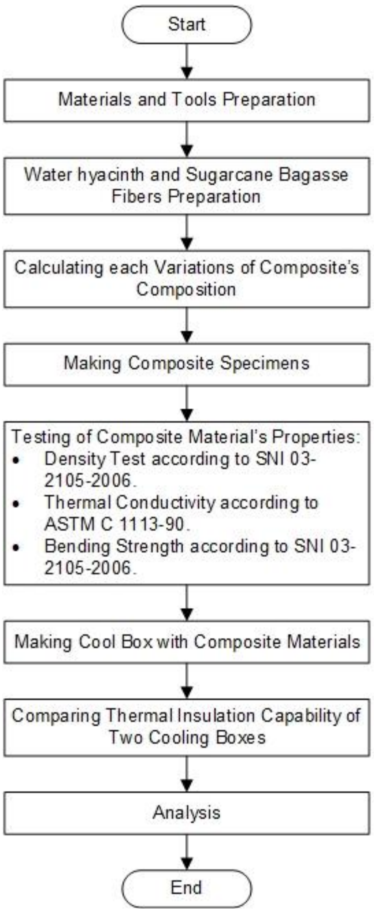


Figure 1. Research Method Flow chart

2.1 Preparation of Tools and Materials

The materials used in this study were water hyacinth fiber, bagasse, NaOH and distilled water, epoxy resin and hardener, wax, plasticine, and ice block. Meanwhile, the tools used in this study were composite molds, composite molds for forming cool box, steel wire brushes, scissors, blender, 20 mesh sieves, digital scales, mixing containers, stirrers, wooden boards and mica boards, brushes, saws, butterfly hinges, styrofoam box, digital thermometer, room thermometer, rubber gloves, thermal conductivity tool, bending test equipment.

2.2 Preparation of Sample

2.2.1 Preparation of Water Hyacinth and Bagasse Fiber

The water hyacinth is cleaned and dried before the fibers are separated using a steel wire brush. Furthermore, the water hyacinth fiber is soaked in a 5% NaOH solution for 2 hours to remove oil, dirt and others. Then, the water hyacinth fiber was rinsed with water and dried for 35 hours. The dried water hyacinth fibers were cut into small pieces with a length of 5-10 mm. Moreover, it is milled, and the results were filtered through a 20-mesh sieve. The same procedure is also conducted on the bagasse.

2.2.2 Calculation of Composite Specimen Composition

The volume fractions of epoxy, water hyacinth fiber and sugarcane bagasse fiber are as follow:

1. **A1**: 60% epoxy resin, 30% water hyacinth fiber, 10% sugarcane bagasse fiber.
2. **A2**: 60% epoxy resin, 20% water hyacinth fiber, 20% sugarcane bagasse fiber.
3. **A3**: 60% epoxy resin, 10% water hyacinth fiber, 30% sugarcane bagasse fiber.
4. **B1**: 70% epoxy resin, 22,5% water hyacinth fiber, 7,5% sugarcane bagasse fiber.
5. **B2**: 70% epoxy resin, 15% water hyacinth fiber, 15% sugarcane bagasse fiber.
6. **B3**: 70% epoxy resin, 7,5% water hyacinth fiber, 22,5% sugarcane bagasse fiber.

To determine water hyacinth fiber, bagasse fiber and epoxy based on the volume fraction of the dimensions of the mold can be calculated using equations.

$$m_f = V_{Cetakan} \times V_f\% \times \rho_f \text{ and } m_m = V_{Cetakan} \times V_m\% \times \rho_m$$

Table 1 is the mass of each materials used to make each variation of the specimen.

Table 1. Composite Mass Composition for Each Sample Code

No.	Sample Code	Mass for Thermal Conductivity Test Mold (gr)			Mass for Bending Test Mold (gr)		
		Epoxy resin	**Water Hyacinth Fiber**	**Sugarcane Bagasse Fiber**	***Epoxy resin***	**Water Hyacinth Fiber**	**Sugarcane Bagasse Fiber**
1	A1	240,77	26,4	12,672	205,2	15	21,6
2	A2	240,77	17,6	25,344	205,2	22,5	10,8
3	A3	240,77	8,8	38,016	205,2	7,5	32,4
4	B1	240,77	19,8	9,504	239,4	11,25	16,2
5	B2	240,77	13,2	19,008	239,4	16,875	8,1
6	B3	240,77	6,6	28,512	239,4	5,625	24,3

2.2.3 Making Composite Specimens

At this stage, the composite specimens were made using the hand lay-up method. The advantage of this method is that it is easy to use and work with.

First procedure that must be done is to weigh the epoxy resin material, water hyacinth fiber and bagasse in accordance with the calculation of the mass composition. then Prepare a composite mold with a size of 11 cm x 16 cm x 2 cm to make 2 thermal conductivity test specimens (The size of one specimen is based on BRIN regulation, which is 10 cm x 5 cm x 2 cm). after that Prepare a composite mold with a size of 20 cm x 15 cm x 1 cm to make 3 tensile test specimens (The size of one specimen is based on the SNI 03-2105-2006 which is 20 cm x 5 cm x 1 cm). Prepare wax, wooden board and plastic mica. Apply wax evenly with the help of a brush to the entire surface of the mold and plastic mica. Place the mica plastic on the wooden board as a base, then place the composite mold on the mica plastic. Epoxy resin and epoxy hardener were mixed in a 1:1 ratio, then stirred until mixed. After the water hyacinth fiber and bagasse weighed according to ratio, put it into the epoxy mixture. Furthermore, stir it until completely mixed. Pour the mixture into the mold and leave it for 12 hours to harden it. Cut the composite with a saw based on the standard provisions of the specimen for testing.

2.2.4 Properties of Composite Materials

Tests to the specimens are thermal conductivity testing with ASTM C 1113-90 standard at the Badan Riset dan Inovasi Nasional (BRIN) and Bending testing with SNI 03-2105-2006 standard at the Center for Materials Processing and Failure Analysis, Universitas Indonesia. The composition of the variation with the best thermal conductivity test results will be continued to be made as cool box with a size of 28 cm x 15,5 cm x 16,5 cm. Bending tests were also conducted on all composition variations to determine whether they were in accordance with particleboard standards based on SNI 03-2105-2006.

The mix composition with best test results, especially the lowest thermal conductivity will be selected to make the cool box. The procedures are the same to make the composite specimens. After the composite hardens and is removed from the mold, the composite boards will be assembled into a box shape by being glued together by a mixture of epoxy resin, hyacinth and bagasse fiber following the composition of the selected mixture. On the lid, butterfly hinges are installed to facilitate opening and closing of the box.

2.2.5 Comparison Test of Thermal Insulation Capability of Cooling Box

The first procedure is to prepare tools and materials (both cooler boxes, room thermometers, and digital thermometers, paper, pens, cellphones, ice block). Put the ice block in both boxes, insert digital thermometer probes into both boxes, and record temperature changes that occur every 30 minutes for 24 hours.

This stage is conducted to determine the thermal insulation capability of the cool box made from the composite by comparing its temperature changes of the styrofoam cool box. The temperature of this experiment is the temperature inside of the composite cooler box and the Styrofoam cooler box and room temperature. Measurements were taken using a room and digital thermometer for 24 hours, it is conducted every 30 minutes. The temperature measurement in the cooling box was conducted by using a digital thermometer. The probe's thermometer is placed in an area that is not in contact with water or ice blocks, so that the temperature obtained is the temperature of the cool box. The weight of ice block per box is 1 kg.

3. Result and Discussion

3.1 Thermal Conductivity Test Specimen Results

The following are specimens used in thermal conductivity testing.

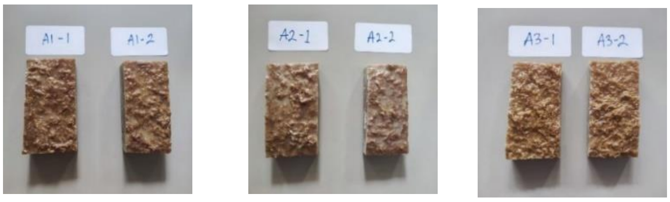


Figure 2. Thermal Conductivity Test Specimens A1, A2, A3

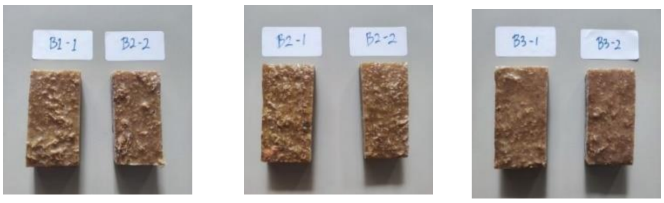


Figure 4. Thermal Conductivity Test Specimens B1, B2, B3

3.2 Results of Bending Test Specimens

The following are the specimens used in the bending test.

Figure 5. Bending Test Specimens A1, A2, A3

Figure 6. Bending Test Specimen B1, B2, B3

3.3 Material Properties of Composite Specimens

3.3.1 Density of Specimens

The test specimen used is a specimen measuring 10 cm × 5 cm × 2 cm, so it has a volume of:

$$Volume = p \times l \times t = 10 \times 5 \times = 100 \ cm^3$$

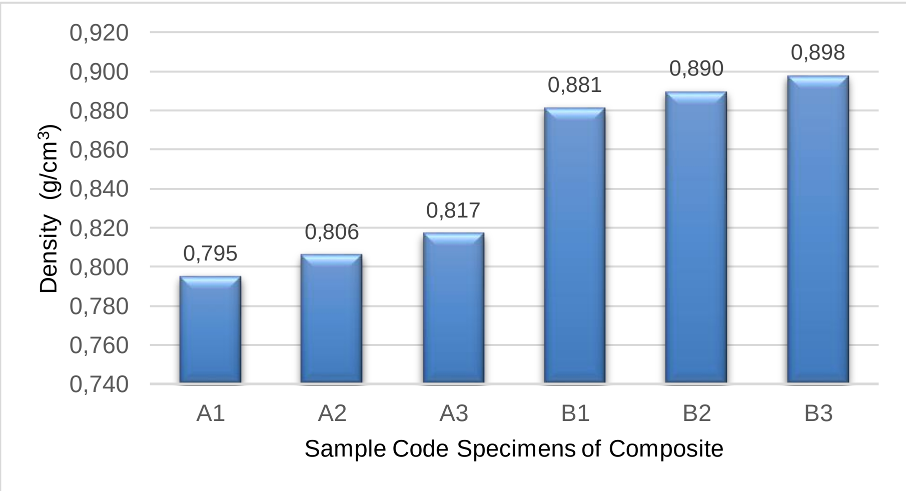
The density value of each specimen variation can be calculated using equation:

$$\rho = \frac{m}{v}$$

The following data is the result of density calculations on each specimen variation.

Table 2. Density Measurement Data of Composite Specimens

No.	Sample Code	Volume of Specimen (cm^3)	Massa of Specimen (gr)	Density (gr/cm^3)	SNI 03-2105-2006
1	A1	100	79,500	0,795	
2	A2	100	80,600	0,806	
3	A3	100	81,700	0,817	0,40 - 0,90 gr/cm^3
4	B1	100	88,125	0,881	
5	B2	100	88,950	0,890	
6	B3	100	89,775	0,898	



Graph 1. Density Value of Composite Specimens

Graph 1 shows the specimens with less epoxy resin matrix, which is 60% of the composite's volume (samples A1, A2, A3) have lower density values than specimens with 70% epoxy resin (samples B1, B2, B3). The results show that the more epoxy matrix used, the higher the density value will be. This is because the higher the matrix composition, the higher the total mass of the resulting composite at a similar volume. This statement is in line with Sembiring et al who stated that the density value decreases the more fiber composition is used (6).

In specimen samples with 60% epoxy resin, it can be seen that the lowest density is obtained by A1 (60% epoxy resin + 30% water hyacinth fiber + 10% bagasse fiber) which is 0.795 gr/cm^3 and the highest density is obtained by A3 (60% epoxy resin + 10% water hyacinth fiber + 20% bagasse fiber) which is 0.817 gr/cm^3. This shows that the composition of water hyacinth and bagasse also determines the value of density. The more water hyacinth composition in the specimen, the lower the density value and vice versa. This statement also applies to specimen samples with 70% epoxy resin. This is due to the density value of water hyacinth is indeed lower than the density value of bagasse (7).

Mass of Water hyacinth = $\rho_{eg} = 0{,}25\ gr/cm^3$
Mass of Sugarcane Bagasse = $\rho_{at} = 0{,}36\ gr/cm^3$
$\therefore \rho_{eg} < \rho_{at}$

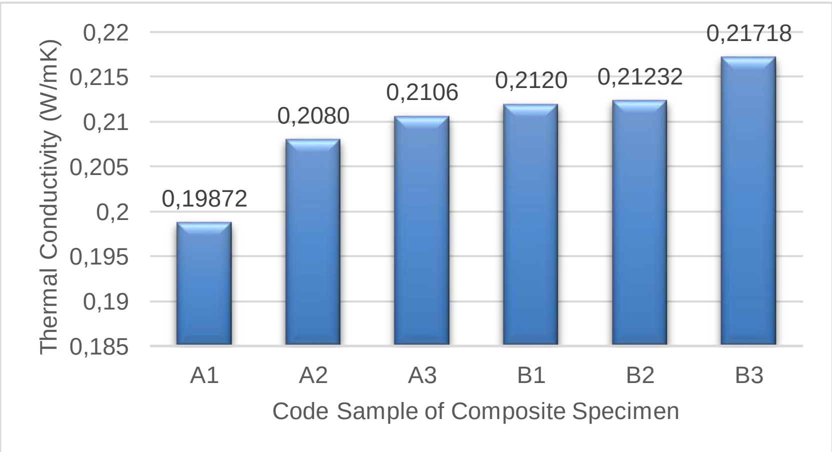
But overall, the density data from each sample variation has met the SNI 03-2105-2006 particleboard standard, which is 0,40 – 0,90 gr/cm^3 (8).

3.3.2 Thermal Conductivity Testing

The test method carried out in the form of hot wire method with ASTM C 1113 - 90 standard. Testing for each sample code is repeated 5 times to ensure the accuracy of the test results. Each specimen variation is represented by 2 samples. The data of thermal conductivity testing on each specimen variation can be seen in Table 3.

Table 3. Thermal Conductivity Test Result Data

No.	Sample Code	Thermal Conductivity (W/mK)					Average (W/mK)
		Test 1	Test 2	Test 3	Test 4	Test 5	
1	A1-1	0,2000	0,2012	0,1987	0,1991	0,1996	0,1987
2	A1-2	0,1959	0,1975	0,1989	0,1974	0,1989	
3	A2-1	0,2065	0,2086	0,2097	0,2089	0,2108	0,2080
4	A2-2	0,2065	0,2059	0,2075	0,2058	0,2096	
5	A3-1	0,2106	0,2105	0,2113	0,2094	0,2099	0,2106
6	A3-1	0,2111	0,212	0,2099	0,2104	0,2111	
7	B1-1	0,2135	0,216	0,2175	0,2184	0,2172	0,2120
8	B1-2	0,2066	0,2083	0,2071	0,2077	0,2073	
9	B2-1	0,2121	0,2122	0,2097	0,2108	0,2102	0,2123
10	B2-2	0,2146	0,2127	0,2147	0,2134	0,2128	
11	B3-1	0,2171	0,2181	0,2186	0,2206	0,2188	0,2172
12	B3-2	0,2139	0,2170	0,2159	0,2151	0,2167	



Graph 2. Thermal Conductivity Value of Composite Specimen

Graph 2 is the average of thermal conductivity test results from 2 specimens in 6 sample variations that are repeated 5 times for each sample. It shows that the specimens with less epoxy resin matrix, which is 60% of the composite's volume (samples A1, A2, A3) have a lower thermal conductivity value than specimens with 70% epoxy resin composition fraction (samples B1, B2, B3). The results show that the more epoxy matrix used, the value of thermal conductivity will increase.

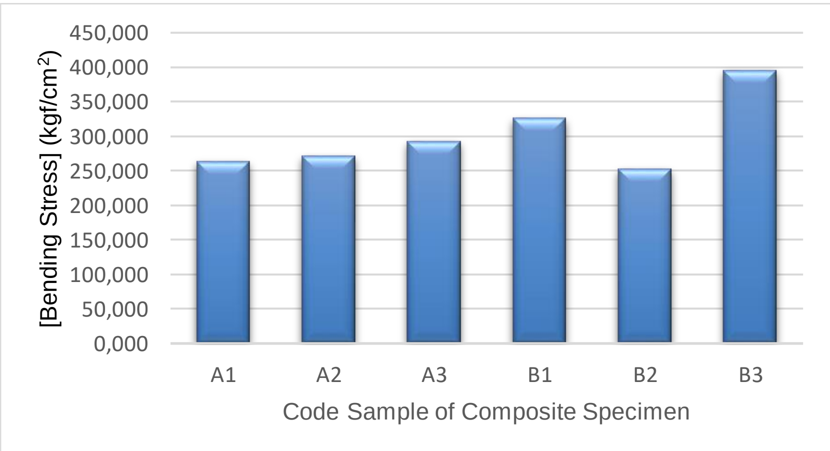
It is directly proportional to the density because density is one of the factors that affect the value of thermal conductivity. The lower the density value of a material, the amount of porosity in the material also increases. In the porosity contained gases that are worse heat insulator when compared with liquids or solids (4), (9). Therefore, in the research results, the specimen that has the lowest thermal conductivity value, which is A1 (60% epoxy resin + 30% water hyacinth fiber + 10% bagasse fiber) is also the specimen with the lowest density results. Likewise, the specimen that has the highest thermal conductivity value is B3 (70% epoxy resin + 7.5% water hyacinth fiber + 22.5% bagasse fiber) is also the specimen with the highest density results.

3.3.3 Bending Test Result

Table 4 shows the data of bending tests on each specimen variation.

Table 4. Bending Test Result Data

No.	Sample Code	Max Bending Load. (kg)	Bending Stress (kgf/cm^2)	Average of Bending Stress (kgf/cm^2)	SNI 03-2105-2006
1	A1-1	85,3	246,651		
2	A1-2	92,5	288,312	263,245	
3	A1-3	92,4	254,771		
4	A2-1	61,4	183,934		
5	A2-2	113,2	335,407	271,304	
6	A2-3	106,1	294,571		
7	A3-1	91,3	254,526		
8	A3-2	136,3	362,484	292,207	
9	A3-3	104,5	259,612		≥ 82 kgf/cm^2
10	B1-1	123,8	319,413		
11	B1-2	114,8	326,704	325,677	
12	B1-3	107,7	330,913		
13	B2-1	71,5	177,843		
14	B2-2	129,5	278,298	252,156	
15	B2-3	140,6	300,327		
16	B3-1	176,5	409,443		
17	B3-2	152,1	403,386	395,224	
18	B3-3	155,6	372,843		



Graph 3. Bending Stress Result of Composite Specimens

In the graph of the research results in Graph 3, There is a decrease in the average bending strength in sample B2. This is due to one of the three B2 specimens, specifically B2-1, having a significantly lower bending strength value compared to the other two specimens. This considerable difference is presumed to be due to, as seen in Figure 7, the presence of numerous voids in the fracture of specimen B2-1. The significant number of voids indicates a weak bond between the matrix and fibers in this specimen (7).

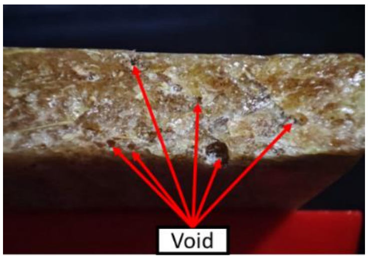


Figure 7. Macro Picture of Fracture Specimen B2-1

From the graph also can be seen that the specimens with less epoxy resin matrix, which is 60% of the composite's volume (samples A1, A2, A3) have lower bending strength than specimens with 70% epoxy resin (samples B1, B2, B3). The results show that the more epoxy matrix used, the value of bending strength will increase. These results are directly proportional to the specimen density value. Sample specimen B3 (70% epoxy resin + 7.5% water hyacinth fiber + 22.5% bagasse fiber) has the highest bending strength value, which is 395.224 kg/cm^2, is a specimen with the highest density value compared to other specimens. While specimen A1 which has the lowest density, its bending strength value is also the lowest at 252.156 kg/cm^2. This fact is in line with Luamkanchanaphan et al who stated that particleboard with high density is stronger than particleboard with low density (10). But overall, the results of the bending strength test of each sample variation have met the SNI 03-2105-2006 particleboard standard, which is ≥ 82 kgf/cm^2 (8).

3.4 Manufacturing Result of Composite Cooler Box

The sample variation selected to be made as a cool box is a specimen that has the lowest thermal conductivity value. Therefore, according to the thermal conductivity test results in Table 3, the A1 sample with an average thermal conductivity value of 0,1987 W/mK was selected. The composition of this sample variation is 60% epoxy resin, 30% water hyacinth fiber and 10% bagasse fiber.

Figure 8 is a picture of the composite cool box. The physical characteristics of the box can be seen in Table 1.

Figure 8. Composite Cool Box

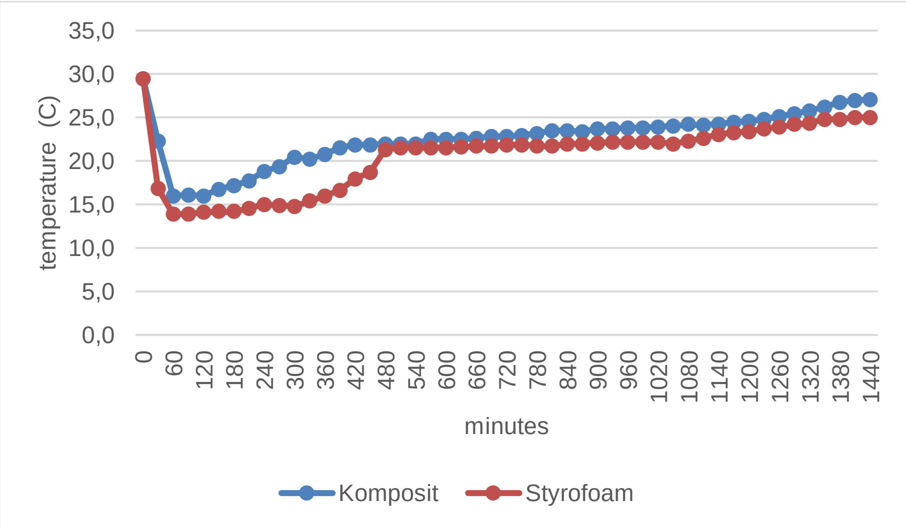
Table 1. Characteristics of The Composite Cooler box

Size	28 $\boldsymbol{cm}$ length × 15,5 $\boldsymbol{cm}$ width × 16,5 $\boldsymbol{cm}$ height
Volume	7161 cm^3
Height	1,8 cm
Density	0,795 gr/cm^3
Thermal Conductivity	0,1987 W/mK
Bending Strength	263,245 kg/cm^2

3.5 Comparison Test Result of Thermal Insulation Capability of Cooling Box

This comparison is done to determine the thermal insulation ability of the cool box in maintaining the cold temperature inside. The test was conducted by looking at the temperature changes inside the composite and Styrofoam cool box that had been filled with 1 kg of ice block each for 24 hours. Recording of temperature changes that occur is done every 30 minutes, so the total test time is 1440 minutes. Measurements were made of the temperature inside the box (not contacting the ice block) and the ambient temperature where the test was conducted.

During the observation and recording of temperature change data for 24 hours, the average temperature of the environment outside the box was 30,9ºC. After the data is obtained, a comparison is made of the temperature change data that occurs in both cool boxes. From the results of the analysis, it will be known which thermal insulation performance is better. The following are the test results in graphical form.



Graph 4. Temperature Changes in Both Cool Box

Graph 4 shows the lowest temperature data achieved in the cool box from epoxy resin, water hyacinth and bagasse fiber were 16°C at the 60th minute after the test started. The results of the last collected data in the 1440th minute (24 hours) showed that the temperature in the composite cool box was 27,1°C with the room temperature of 31°C. Furthermore, the lowest temperature data achieved in the styrofoam cool box is 13,9°C at the 60th minute after the test begins. The results of the last collected data in the 1440th minute (24 hours) showed the temperature in the composite cooler box was 25°C.

In general, the decrease in temperature in both boxes continued until between 90 and 120 minutes. After that, the temperature in both boxes increased with occasional small decreases (≥0,3°C) until the end of the observation. In the last temperature collected data, at the 1440th minutes, the temperature in the styrofoam cool box showed a lower value than the composite coolbox. From the mentioned results, the composite cool box is not superior in its ability to withstand heat transfer into and out of the box's wall than the styrofoam cool box.

As previously known, the smaller the value of a material's thermal conductivity, the longer the heat transfer process takes place. Therefore, for use in a cool box, the cooling process becomes more effective. Based on the results of the thermal conductivity test of composite specimens in this research, the lowest thermal conductivity value that then be made as cool box is 0,1987 W/mK, that thermal conductivity value is still higher than the thermal conductivity value of styrofoam, which is 0.095 W/mK (11).

4. CONCLUSION

Results of the analysis showed that A1 sample (60% epoxy resin + 30% water hyacinth fiber + 10% bagasse fiber) had the lowest density and thermal conductivity values compared to other specimens. The bending strength value also exceeded the standard value of bending strength in SNI 03-2105-2006. So, specimen code A1 is chosen as the specimen code made as a cooler box. In a test time of 24 hours (1440 minutes), the lowest temperature obtained from the experiment using a cool box made of epoxy resin, water hyacinth and bagasse was 16°C and the last collected data result at the 1440th minute was 27.1°C, while the lowest temperature from the experiment using a cool box made of Styrofoam was 13.9 ° C and the last collected data result at the 1440th minute was 25°C.. So, it can be seen that the composite cool box is not better at maintaining temperature than the styrofoam cool box.

The suggestions are made based on experience aimed at researchers in similar fields, or who want to develop the research. First is to obtain more uniform specimen dimensions, it is necessary to perform machining using CNC. Furthermore, it is to fulfil the overall mechanical standard of SNI 03-2105-2006, it is necessary to conduct other tests such as moisture content.

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