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# PHYSICAL AND THERMAL CHARACTERISTICS OF COCO PEAT FIBRE REINFORCED POLYURETHANE COMPOSITE FOR INSULATION BOX IN MARINE APPLICATION

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**Abstract**

During fishing, there is a need for a hold as a temporary storage area for fish. Furthermore the fish hold ability to maintain cold temperatures helps retain the fish freshness. However, the right technology is required to support the cold chain system for catch quality to be maintained. The current problem is that the insulation material made of polyurethane is still expensive, which affects the price of the coolbox. So alternative materials are needed to reduce the use of polyurethane. The purpose of this study was to investigate the physical characteristics and thermal conductivity of composite materials from a mixture of cocopeat and polyurethane for the fishermen fish box insulation. The composite material composition includes the volume ratios between polyurethane and cocopeat of 1 to 0.5, 1 to 1, 1 to 1.5, 1 to 2, and 1 to 2.5. The thermal conductivity and compressive static test on materials use ASTM E1225-99 and ASTM D1621 standards, respectively. All test results were compared with 100% polyurethane material. The thermal conductivity test results for 100% polyurethane material were obtained at 0.026 W/m.K. Cocopeat can be used as a polyurethane mixture for fish box insulation, although the heat conductivity test results are still below 100%, but the test results are still in range of the recommended, which is 0.023-0.04 W/m.K. The higher the percentage of cocopeat can increase the maximum compressive strength. So that the composition of the material chosen for the isolation of fish boxes on fishing vessels is a composition of 1 to 1. In this case, there is a conductivity value of 0.037 W/m.K with a yield stress of 0.05 MPa and a maximum stress of 0.7 MPa. Therefore, this material can save the use of polyurethane by up to 50%.

Keywords: Coco peat, Composite, Conductivity, Insulation, Polyurethane.

## 1. Introduction

Maritime and fisheries are among the supporting sectors for national development due to their significant potential. For this reason, they need to be managed optimally for maximum results. However, the catch quality has decreased by up to 28% leading to unfulfilled expectations [1]. In fishing, a boat needs a hold as a temporary storage area. The fish hold ability to maintain cold temperatures is essential for preserving fish freshness. Polyurethane is one of the materials commonly used as temperature-resisting insulation in fish storage holds [2]. Currently, fishers suffer several constraints, including the increasing cost of insulation materials, due to the high raw materials price [3].

There are several studies on the use of natural fiber for insulation materials from date pit reinforce poly lactic acid and found the thermal conductivity 0.0682 W/m.K [4]. Muthuraj et al. [5] proposed the thermal insulation of bio composites from rice husk, wheat husk, wood fibers and textile waste fibers for building material application. They reported that the performance of the composite product in thermal conductivity and density in the range of 0.08-0.14 W/m.K and 378-488 kg/m$^3$ respectively. Nguyen et al. [6] studied the influence of thermo-pressing condition on fiber board from bamboo and bio-glue. The result reported that the thermal conductivity in range 0.0582 and 0.0812 W/m.K. Florea et al. [7] reported manufacture of composite board for building material from natural fiber from ship wool and hemp using white cement and gypsum as matrix. They found the thermal conductivity in range 0.046 W/m.K and 0.073 W/m.K.

In addition to the natural fiber material that has been widely used by several previous researchers. Thomas et al. [8] conducted a study on the characteristics of dry and wet cocopeat against the impact loads where 30% of the volume fraction of this fiber was able to increase the impact strength of 1,570 N-m (dry) and 1,275 N-m (wet). Several studies have been conducted to determine the physical and mechanical properties of coco peat as shown in Table 1. Studies on chemically treated coco peat to thermal and water retention properties have been carried out [9-11]. The application of coco peat as a thermal insulation material has been carried out for desiccant in the evaporative cooling systems, i.e., at 28 $^{o}$C-85% RH [12] and concrete slabs [13, 14].

**Table 1. Physical and mechanical properties of cocopeat.**

| Avg. Diameter (mm) | Density (g/cm$^3$) | E (GPa) | $\sigma_T$ (MPa) | Elongation at break (%) | Ref. |
|---|---|---|---|---|---|
| 0.01-0.46 | 1.15-1.46 | 2.2-6 | 95-230 | 15-15.4 | [15] |
| 0.1-0.45 | 1.3-1.5 | 4-6 | 105-175 | 17-47 | [16] |
| 0.1-0.45 | - | 3-6 | 106-175 | 47 | [17] |
| 0.2 | 1.3 | 3.1 | 144.6 | 32.3 | [18] |
| 0.25 | 1.2 | 2.74 | 286 | 20.8 | [19] |
| 0.38 | 1.2 | 2 | 144 | 4.5 | [20] |
| 0.4 | 1.2 | 4-6 | 175 | 30 | [21] |

Currently, there is no single research conducted on the mixture of cocopeat and polyurethane as an insulation material in fish storage coldbox. The use of cocopeat can reduce the domination of polyurethane which is still difficult to afford by fishermen because the price is relatively expensive.

So, the main objective of this work was to investigate the physical and thermal characteristics of coco peat reinforced polyurethane composite for insulation boat hatch construction.

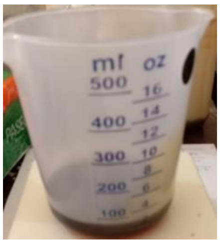
## 2. Materials and Methods

### 2.1. Material preparation

The initial step involves material preparation, followed by a specimen moulding tool. The material preparation involves sieving and drying the coco peat sourced from the coconut fibre processing industry in South Aceh, Indonesia. Another material (polyurethane) consists of Polyol and Isocyanate in a ratio of 2 to 3. The moulding tool is made of multiplex coated with a cube-shaped iron plate measuring 200×200×200 mm.

The material is made in stages based on predetermined composition between polyurethane and coco peat powder at 1:0.5, 1:1, 1:1.5, 1:2, and 1:2.5, as shown in Fig. 1. The composition ratio is measured by volume. The mixture of those materials is started by polyol and cocopeat, when it was all blended together, isocyanate should be added and quickly mix them before it is poured into the mold. The materials would have swelled and hardened in the mold. The moulding result material is cubic based on the tool dimensions. This is then reshaped based on material size and shape following ASTM E 1225-99 for thermal conductivity with cylindric shape dimension Ø52×35 mm and ASTM D 1621 for compressive tests with cubic shape dimension 50x50x50 mm, respectively [22, 23].

**(a) Measuring Polyol**



**(b) Measuring Isocyanate**

**(c) Measuring Coco peat**

**(d) Material mixing process**

**(e) Pouring the mixture into the mold**

**(f) Drying Process**

**(g) Releasing the mold**

**(h) Specimen 200×200×200 mm**

**Fig. 1. Polyurethane dan coco peat mixture specimen.**

## 2.2. Density testing

Density measurement of the specimen carried out by using a digital scale with an accuracy of 0.1 gram. Each specimen was cut into squares with dimensions Ø25x35 mm in accordance with ASTM C721 standard which is the same as the dimensions of the heat conductivity test specimen which is Ø25x35 mm. Density values were then recorded for all samples and presented in the form of graphic.

## 2.3. Thermal conductivity testing

Before testing, specimens with different compositions were formed, each Ø52×35 mm. Each material should have a flat surface since it should contact the reference material (brass and stainless steel). Furthermore, these materials are made of holes for the temperature sensor, each 10 mm and 25 mm from the top surface, as shown in Fig. 2 ant the tested materials are shown in Fig. 3.

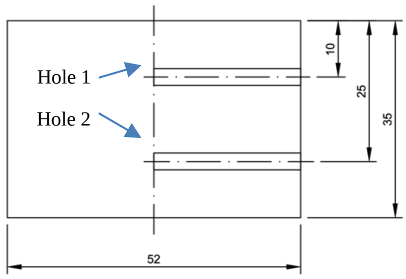



**Fig. 2. Position of the thermocouple.**

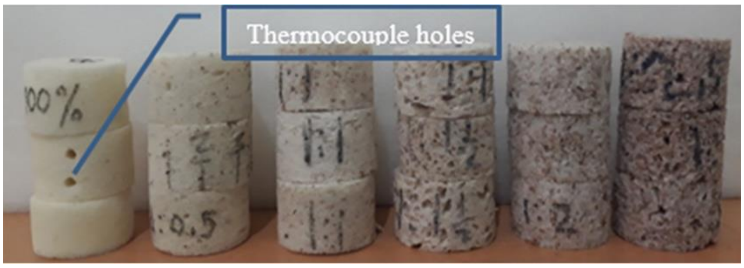



**Fig. 3. Conductivity test specimens with various compositions.**

The specimens are tested on a heat conductivity tester, as shown in Fig. 4. This test device is designed based on ASTM E 1225-99 (Standard Practice for Calculating Thermal Transmission Properties under Steady-State Conditions) for the material.

This test equipment has a data logger that records the temperature passing through the material every 30 seconds. The data is sent to a computer and displayed in Microsoft Excel in real-time through the PLX_DAQ for Excel application, a connecting software between computer devices and test tools. This test tool has 6 heat measuring sensors, specifically T1, T2, T3, T4, T5, and T6. Channels T1 and T2 are placed on a stainless-steel reference material with a thermal conductivity value of 0.24 W/m.K used a heater place. The T3 and T4 channels are embedded in the material, and T5 and T6 are placed in a brass reference material with a heat conductivity value of 1.09 W/m.K [24]. After arranging and installing the thermocouple, all material is inserted in the tube to prevent external factors from affecting the temperature reading. Figure 5 shows the arrangement of the test tool.

**Fig. 4. Heat conductivity testing tool.**

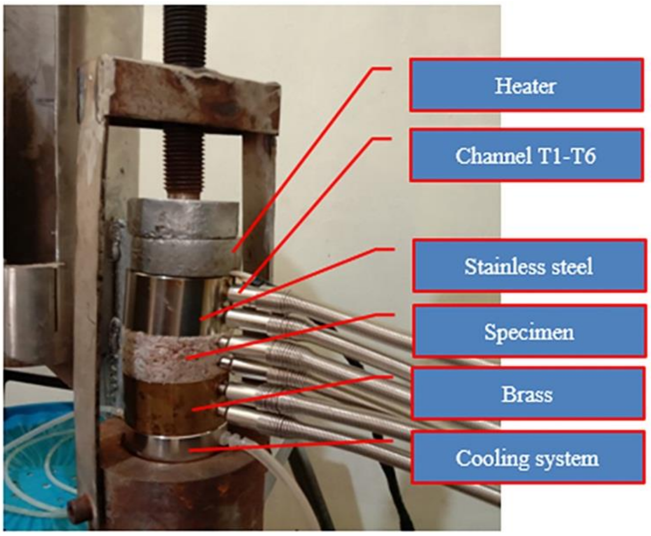



**Fig. 5. Arrangement of conductivity test tool.**

The thermal conductivity value is calculated based on ASTM E1225-99. The conductivity calculation is carried out on the reference material for Stainless Steel ($k_T = 0{,}24$ W/m.K) and brass ($k_B = 1{,}09$ W/m.K), including the following specimens.

Stainless Steel Heat Rate $$q'_T = k_T.\frac{T_2-T_1}{Z_2-Z_1} \quad (1)$$

Brass Heat Rate $$q'_B = k_T.\frac{T_6-T_5}{Z_6-Z_5} \quad (2)$$

The temperature reading distance for each material is:

$T_1$-$T_2$ = Stainless Steel $Z_2$-$Z_1$ = 15 mm

$T_3$-$T_4$ = Test Material $Z_4$-$Z_3$ = 15 mm

$T_5$-$T_6$ = Brass $Z_6$-$Z_5$ = 15 mm

Thermal conductivity

$$k_s' = \frac{(q_T' + q_B')(Z_4 + Z_3)}{2(T_4 - T_3)} \quad (3)$$

## 2.4. Compressive static testing

The investigation was conducted on 100% polyurethane material and a mixture of polyurethane and coco peat made from rigid polyol polyester with medium density and closed cells of 32 kg/m$^3$. The experiments' material sizes are with the nominal dimensions of 50×50×50 mm, as shown in Fig. 6 and the specimens are shown in Fig. 7. In all experiments, the loading was in an upward direction. The compressive strength test is conducted based on the ASTM D 1621 standard [23].

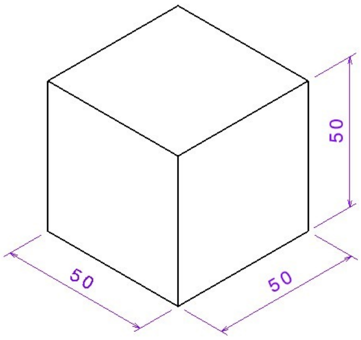



**Fig. 6. Specimens of compressive static test.**


**Fig. 7. Specimens of compressive static test.**

# 3. Results and Discussion

## 3.1. Density testing

The density tests were conducted to determine weight changes of the material mixed with coco peat and compared with the density of 100% polyurethane. This test also serves to validate the 100% polyurethane density made in the laboratory within the market. Figure 8 shows the test results on the material density.

Figure 8 shows that the density of 100% polyurethane material is 32.3 kg/m$^3$ [13] and increases to 83.4 kg/m$^3$ as the ratio of the coco peat increases, where the coco peat itself has a density of 0.23 g/cc or 230 kg /m$^3$ [25].

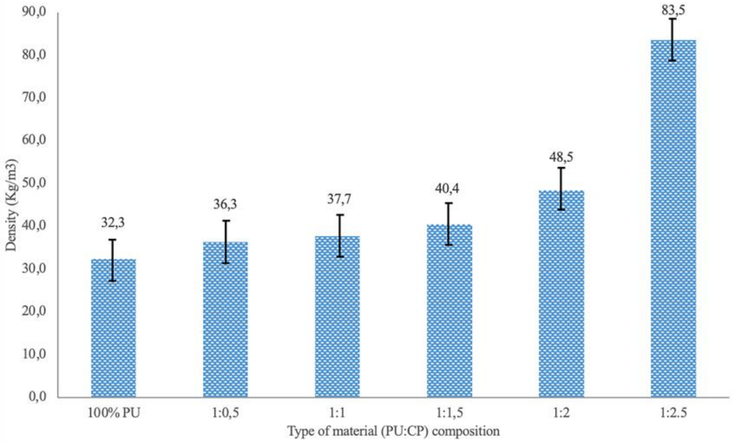



**Fig. 8. The density of each material composition.**

## 3.2. Thermal conductivity testing

The heat conductivity test was conducted for the first time on 100% Polyurethane material as comparative data with coco peat mixture. Each material was tested 3 times to get the average conductivity value. The test data was taken 36 times at intervals of 100 seconds for 60 minutes. The test data is displayed in graphical form, as shown in Fig. 9.

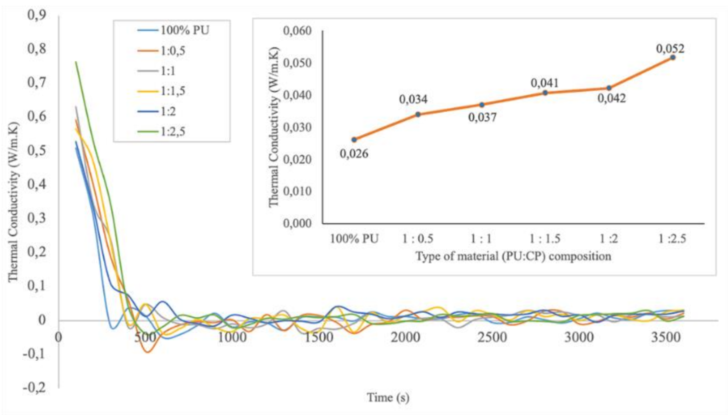



**Fig. 9. Thermal conductivity of each material composition.**

The average thermal conductivity test for 100% polyurethane material is 0.026 W/m.K. The results obtained are in line with the standard heat conductivity values for polyurethane materials, specifically 0.023-0.040 W/m.K [24]. Furthermore, the composite material was tested with a polyurethane and coco peat composition of 1 to 0.5.

The 1 to 0.5 material's conductivity test shows that the average heat value is 0.034 W/m.K. Compared to the test results of 100% polyurethane material, the addition of 0.5 coco peat from the polyurethane volume does not affect the conductivity value with a difference of 0.008 W/m.K. The test results for 1 to 1 material were obtained at 0.037 W/m.K with a difference of 0.003 W/m.K from material 1 to 0.5 or higher than 100% polyurethane of 0.011 W/m.K.

The fourth test was conducted on 1 to 1.5 material, which explained that the conductivity value was obtained at 0.041 W/m.K. Compared to the test results of 100% polyurethane material, the addition of 1.5 coco peat from the total volume of polyurethane affects the conductivity value of 0.014 W/m.K. The result of the thermal conductivity test on the material is strongly influenced by several large porosities on its surface. For this reason, it affects the rate of heat transfer to the material. Furthermore, the 1 to 2 and 1 to 2.5 materials were tested and had an average conductivity value of 0.042 and 0.052 W/m.K. In both of these materials, coco peat is dominant, hence its conductivity value greatly affects the performance of other material, apart from being higher than the previous one.

### 3.3. Compressive static testing

The compressive static test was conducted on 100% polyurethane material with an average density of 32.3 kg/m$^3$. The test results were compared with previous studies [27, 28]. Figure 10 shows the average value of the three tests.

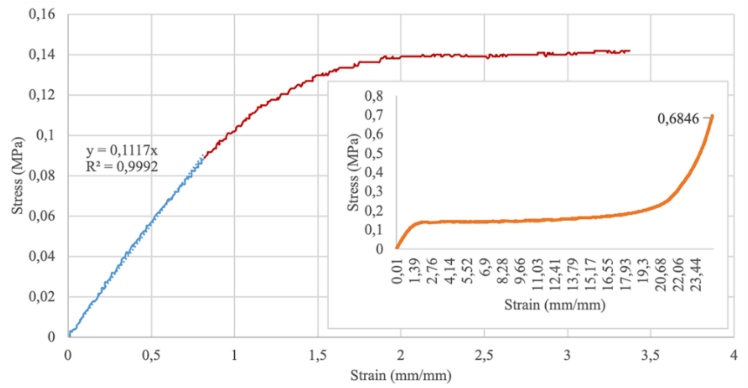



**Fig. 10. Stress-strain curve of 100% polyurethane material.**

According to Fig. 9, there is a strength in the elastic region (Yield Strength) of 0.11 MPa with a modulus of elasticity by 9.18 MPa. The maximum compressive strength (U Strength) is obtained at 0.68 MPa. The test results for this material are compared to the one mixed with coco peat, as shown in Fig. 11.

According to Fig. 10, the addition of coco peat in a polyurethane mixture reduces the elastic region (Yield Strength). However, it can increase the value of the maximum compressive strength (Ultimate Strength). The compressive strength test results of the composite material 1 to 0.5 have a density of 36.3 kg/m$^3$, while the compressive strength value in the elastic region is 0.08 MPa. The elastic modulus is 17.09 MPa, while the maximum compressive strength is 0.54. MPa. The compressive strength test of 1 to 1 material with a density of 37.6 kg/m$^3$ was conducted three times before calculating the test's average value. This material's compressive strength value is 0.04 MPa with a modulus of elasticity at 23.3 MPa and a maximum compressive strength value of 0.7 MPa. Additionally, there is a compressive strength decrease in the elastic region compared to 100% polyurethane material. The decrease is caused by mixing more coco peat into the material. After crossing the plateau boundary, this material can increase the maximum compressive strength value over the previous one.

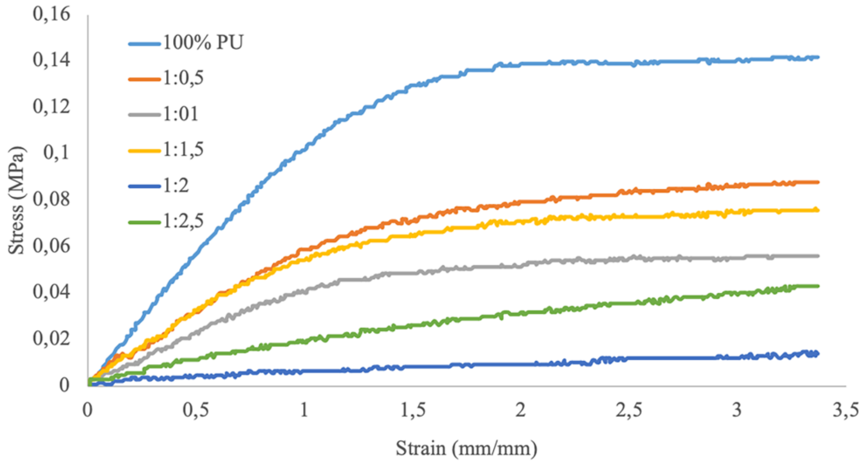



**Fig. 11. Stress-strain curve of the material.**

The compressive strength test of 1 to 5 material with a density of 40.3 kg/m$^3$ is obtained at 0.06 MPa with a modulus of elasticity at 13.02 MPa and a maximum compressive strength value of 0.67 MPa. This is higher than 1 to 1 material, though there was a decrease of 0.02 MPa compared to 100% polyurethane material. The amount of coco peat mixed into the material still affects the compressive strength in the elastic area. This material can increase the maximum compressive strength beyond 100% polyurethane material after crossing the plateau boundary.

The test results for 1 to 2 materials with a density of 48.4 kg/m$^3$ and 1 to 2.5 material with 83.4 kg/m$^3$ are different from the previous testing results. Since the test results for this material do not have a plateau, the elastic region immediately changes to plastic. The opposite reaction occurs from the load causing densification of the collapsed cell wall. This is increases stress rapidly without a significant increase in stress values. Specifically, the stresses in the elastic region include 0.003 and 0.01 MPa, respectively. The maximum compressive strength values obtained were 0.92 and 1.52 MPa higher than the maximum compressive strength of 100% polyurethane. Table. 2 and Fig. 12 show the test results on various material compositions.

**Table 2. Material test results.**

| No. | Type of Material (Volume) | Compression Test | | | | Conductivity (W/m.K) |
|---|---|---|---|---|---|---|
| | | Density (kg/m$^3$) | γ Stress (MPa) | U Stress (MPa) | E (MPa) | |
| **1.** | 100% Polyurethane | 32.3 | 0.11 | 0.68 | 9.18 | 0.026 |
| **2.** | Material 1:0.5 | 36.3 | 0.08 | 0.54 | 17.09 | 0.034 |
| **3.** | Material 1:1 | 37.6 | 0.05 | 0.70 | 23.37 | 0.037 |
| **4.** | Material 1:1.5 | 40.3 | 0.06 | 0.67 | 13.48 | 0.041 |
| **5.** | Material 1:2 | 48.4 | 0.003 | 0.92 | 163.82 | 0.042 |
| **6.** | Material 1:2.5 | 83.4 | 0.01 | 1.52 | 66.16 | 0.052 |

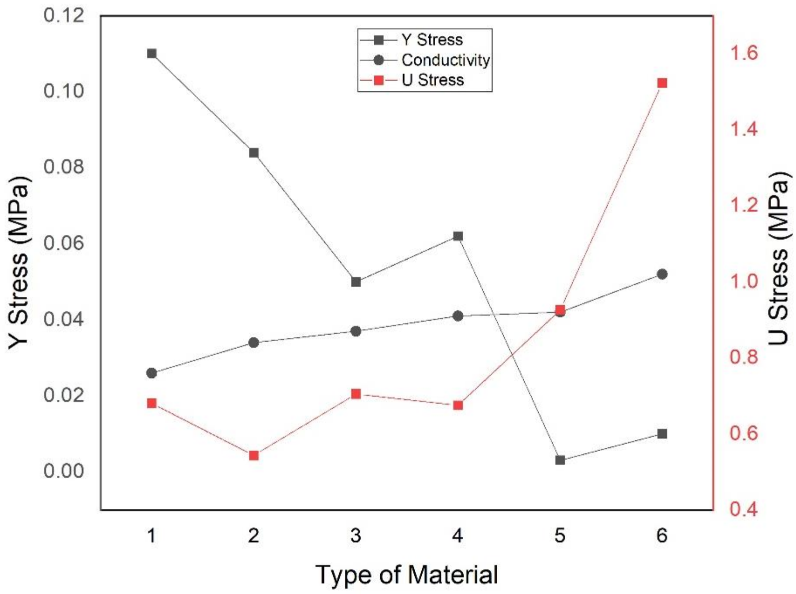



**Fig. 12. Stress vs. conductivity of a material.**

Based on all the test results, the material with a 1 to 1 composition is the most suitable material for fishing boat hold insulation. This composition has a compressive strength in the elastic region of 0.05 MPa and maximum stress over 100% polyurethane material of 0.70 MPa. Additionally, it does not affect the expansion of the polyol and isocyanate reactions. Based on materials with 1 to 2 and 1 to 2.5 compositions, there is a maximum stress value of 0.92 MPa and 1.52 MPa. This is far above polyurethane, though the amount of coco peat significantly affects the material expansion with a higher conductivity value.

Suppose a 1 to 0.5 material is used, the use of coco peat in the insulation still appears too low. Therefore, this composition does not reduce the use of polyurethane, apart from not being effective in its economic value. Contrastingly, the composition of 1 to 1.5 does not affect the expansion. It has a slightly higher conductivity value with lower maximum stress, by 0.67 MPa than the 1 to 1 composition. Therefore, the 1 to 1 composition is determined to be the most economical composition as a fishing boat holds insulation. This can save the polyurethane usage by 50% with a heat conductivity value of 0.037 W/m.K and a density of 37.68 kg/m$^3$.

The coco peat reinforced polyurethane composite materials for insulation is better than date pit reinforces poly lactic acid [4], bio composites [5], fibre board [6], and composite board from ship wool, hemp using white cement and gypsum as matrix [7]. However, the coco peat reinforced polyurethane composite material has a lower compressive strength.

## 4. Conclusions

Coco peat can be used as a polyurethane mixture for fish box insulation, though the heat conductivity test results are still below 100% polyurethane (0.026 m.K). However, the test results obtained are still within the recommended insulation material limits of 0.023-0.04 W/m.K [24]. The test results on compressive strength decreased in yield stress, while the percentage of coco peat amount increased. However, the maximum strength could increase. The material composition chosen for the fish box insulation on fishing boats is a 1 to 1 composition. In this regard, there is a conductivity value of 0.037 W/m.K with a yield stress of 0.05 MPa and maximum stress of 0.7 MPa. Therefore, this material can save polyurethane usage by 50%.

**Nomenclatures**

| | |
|---|---|
| $E$ | Young's Modulus |
| $k_T$ | Conductivity of reference material, W/m.K |
| $k'_s$ | Conductivity of composite material, W/m.K |
| $q'_B$ | Heat rate of brass |
| $q'_T$ | Heat rate of stainless steel |

***Greek Symbols***

| | |
|---|---|
| $\gamma$ | Yield |
| $\varepsilon$ | Strain |
| $\rho$ | Density, $kg/m^3$ |
| $\sigma$ | Stress strength |

**Abbreviations**

| | |
|---|---|
| ASTM | American Standard Testing and Material |

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