The Effect of Pressure on Thermal Insulation Properties of EIC Cellulose-Polyurethane Composites

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Abstract. Polyurethane and cellulose are the most frequent of material type used for insulating. The thermal properties of each materials have some disadvantages as well as the advantages. One of the methods of enhancing the thermal properties is by making a composite. A composite is produced from EIC-cellulose and polyurethane. Polyurethane with EIC-cellulose composites is pressed to produce low thermal conductivity means that it has a high insulating properties for reducing heat losses. This study is presented an insulation material of cellulose made from reeds imperata cylindrica type with the extraction process. Extraction of cellulose fibers to form a sheet by adding 3.5% Na-CMC (Sodium Cellulose Carboxsil Metyl). The production of the composite was made by pouring some polyurethane to a cellulose sheet and then put it into a cold-press and pressured for 90 minutes by varied pressures of 40517 N/m^2 and 54022 N/m^2. The isolation criterion is the value of thermal conductivity and density as low as possible but the value of the heat capacity as high as possible. The results: the lowest and the highest of thermal conductivities were 0.0735 W/m K and 0.1762 W/m K, respectively; the lowest and the highest of densities were 109 kg/m^3 and 496.5 kg/m^3, respectively; the lowest and the highest of heat capacity were 0.5217 kJ/kg K and 0.9448 kJ/kg K.

Keywords: Cellulose, isolation, polyurethane, reed, Na-CMC.

1 Introduction

Insulation is a cheap technology and can increase energy saving. Polyurethane is a material which has the lowest conductivity compared to other materials, i.e., 0.027 W/m K, based on a test that was done to 5 polyurethane samples at temperatures range from 10 to 40^{0}C [1]. The use of the insulation of Polyurethane material was one of the most efficient. Insulation with the highest performance, save the energy, and makes it possible for the use a minimal space with a density value from 30 to 100 kg/m^3 and thermal conductivity of 0.02-0.05W/m K [2]. Polyurethane Foam is used to insulate a light concrete with thermal conductivity of 0.025 W/m K and density of 60 kg/m^3 [3]. The cellulose which is used in this study is from the reeds types of imperata cylindrica which is extracted and producing fibers and lignin [4]. To lower the value of thermal conductivity is not only by making a composite of polyurethane and cellulose but also by pressing the composite. Due to the increase of pressure will homogenize the composite. Insulation characteristics is determined among others by the the thermal conductivity, the density and heat capacity.

2 Test Procedure

Material preparation

Compositing the polyurethane with EIC-cellulose by using this following method: 7 ml of polyurethane B was poured into EIC-cellulose sheet of mixture 1 and then leveled to one side. Into the polyurethane –B added sheet was then added 6.5 ml of polyurethane A rapidly, not longer than 100 seconds, because in 140 seconds the mixture of polyurethane A and B would become foam. And after the EIC-cellulose sheet and polyurethanes A and B were mixed rapidly, the mixture was then placed in a cold-press device and pressed by the pressure of 40517 N/m^2 for 45 minutes. Same steps was done to the other side, and thus a composite of EIC Cellulose - Polyurethane for mixture 1 at the pressure of 40517 N/m^2 was obtained in the total pressuring time of 90 minutes. The same steps was conducted for the mixtures 2 and 3 at the same pressure and with the same time. To determine the effect of pressure on thermal properties by the same method, the mixture was placed on a cold-press at the pressure of 54022 N/m^2 in the pressuring time of 90 minutes.

Thermal testing

The properties which tested are thermal conductivity, density and heat capacity. For thermal conductivity testing, the equipment used was a series of systems consisting of a Voltage Source device, a Digital Thermometer, and a Joulmeter. The material was tested in the size of 4.2 cm x 3 cm and 0.1cm in thickness.

Measurement was started after steady conditions and will be obtained the temperature data. From the temperature data, thermal conductivities value were calculated by,

$$q = kxA\frac{(T_1 - T_2)}{\Delta x} \qquad (1)$$

Where:

A = surface area, m^2
K = thermal conductivity of the material, W/m K
q = heat transfer rate, W
T_1 = temperature at left surface, ^0C
T_2 = temperature at right surface, ^0C
Δx = direction of heat flow, m

A Pycnometer was utilized to measure the density. The mass data was obtained using this instrument. From these data, the density was calculated using an equation,

$$\rho_s = \frac{m_{p+s} - m_p}{V_p - V_{alc}} \qquad (2)$$

Where:

m_{p+s} = mass of picno and sample, g
m_p = mass of picno, g
V_p = $(mass_{picno+alc.} - mass_{picno})/\varrho_{alc.}$, ml
$V_{alc.}$ = $(mass_{picno+alc\ +sample.} - mass_{picno+sample})/\varrho_{alc.}$, ml

The heat capacity was measured using a differential scanning calorimetry (DSC). The results of this testing is data of the heat flow in the scoreless dishes, called the S1 signal, whereas the data output of heat flow with an empty dish - standard samples, called the S2 signal. Furthermore, the data of heat flow to the dish containing the test material- standard sample, named the S3 signal. These data were calculated using regression. The value of heat capacity of a material is not a constant, but a function of temperature. Empirical equation for the heat capacity is as follow,

$$C_p(T) = a + bT + cT^{-2} \qquad (3)$$

Where a, b and c are constant, the values depending on the type of material. For example, for high purity Alumina, the values of a = 114.8, b = 12.8 x 10-3 and c = 35.4 x 105

3 Results and Discussion

The main characteristic of insulating material are determined by the thermal conductivity value. In order to minimize heat flows from a high to a low temperature, the thermal conductivity of a material must be as small as possible. Measurement of the thermal conductivity for the standard material 4,2 cm x 3 cm and 0,1 cm in thickness. Calculation of thermal conductivity uses equation (1) and temperature data listed in Table 1, whereas the results are shown in Table 2.

Table 1. Thermal conductivity test data.

Material	Pressure N/m^2	Time minutes	T1 K	T2 K	q W
Composite 1	40521	90	315.9	300.7	3
Composite 2	40521	90	326.4	302.2	3,5
Composite 3	40521	90	340	308.9	4
Composite 1-1	54022	90	320.5	301.7	3,5
Composite 2-1	54022	90	330.9	302.8	3,5
Composite 3-1	54022	90	340.1	303.2	3,5

Table 2. Measurement results of thermal conductivity.

Material	Pressure N/m²	Time minutes	k W/m K
Composite 1	40521	90	0.1529
Composite 2	40521	90	0.112
Composite 3	40521	90	0.0997
Composite 1-1	54022	90	0.124
Composite 2-1	54022	90	0.0966
Composite 3-1	54022	90	0.0735

The smallest value of thermal conductivity was occurred in a composite of 3-1 at the pressure 54022 N/m², i.e. of 0.0735 W/m K. The value of thermal conductivity was decreased by both reducing the size of the particle and increasing the pressure. The size of the material with controlled geometry size composed of at least one component of nano products below 100 nm will produce physical effects. It can be seen from the result of a research of nano material [5] at a value of thermal conductivity smaller than micro material [3,6].

Table 3. Density testing data.

Material	Pressure N/m²	Time minutes	Mp g	Mp+al g	Mp+s g	Mp+al+s g
Composite 1	40521	90	29.8857	52.4816	30.0309	52.5934
Composite 2	40521	90	29.8857	52.4816	30.0078	53.0021
Composite 3	40521	90	29.8857	52.4816	29.9865	53.0941
Composite 1-1	54022	90	29.8857	52.4816	29.9899	52.5747
Composite 2-1	54022	90	29.8857	52.4816	30.0921	53.0845
Composite 3-1	54022	90	29.8857	52.4816	30.0681	53.6482

Table 4. Measurement results of density.

Material	Pressure (N/m²)	Time (min)	ϱ(kg/m³)
Composite 1	40521	90	455.5
Composite 2	40521	90	217.4
Composite 3	40521	90	113.9
Composite 1-1	54022	90	426
Composite 2-1	54022	90	205.6
Composite 3-1	54022	90	109

Table 3 shows the mass measurement results are used to calculate density using equation (2), and the results are shown in Table 4. To obtain specific tensile strength as big as posible, the value of density has to be as small as possible. Based on the measurement, the value of the smallest density in a composite of 3-1 at the pressure of 54022 N/m² is 109 kg/m³. This value is among 100 - 125 kg/m³[7] that has been widely used as rockwool density, but smaller than calcium silicate density 225 kg/m³ [8].

The heat capacity in the form of heat flow will be calculated using linear regression, and the results is shown in Table 5.

Table 5. The results of the regression calculation of heat capacity.

Material	Pressure N/m²	Time minutes	a	b	c
Composite 1	40521	90	61.0062	0.03332	143006
Composite 2	40521	90	82.9709	0.04532	194493
Composite 3	40521	90	160.956	0.08791	377300
Composite 1-1	54022	90	94.4485	0.05159	221398
Composite 2-1	54022	90	121.57	0.06641	284973
Composite 3-1	54022	90	164.494	0.08984	385593

Based on data in Table 5 and using Eq. (3),

A equation of thermal capacity in pressure-40521 N/m^3 90-minute composite 1,

$$Cp = 61.006209 + 0.03332T + 143005.65 \times 10^6 T^{-2} \quad (4)$$

The equation of thermal capacity in pressure-40521 N/m^3 90-minute composite 2,

$$Cp = 82.970884 + 0.045317T + 194493.39 \times 10^6 T^{-2} \quad (5)$$

The equation of thermal capacity in pressure-40521 N/m^3 90-minute composite 3.

$$Cp = 160.95601 + 0.087911T + 377299.61 \times 10^6 T^{-2} \quad (6)$$

The equation of thermal capacity in pressure-54022 N/m^3 90-minute composite 1-1,

$$Cp = 94.4484571 + 0.05159T + 221398.16 \times 10^6 T^{-2} \quad (7)$$

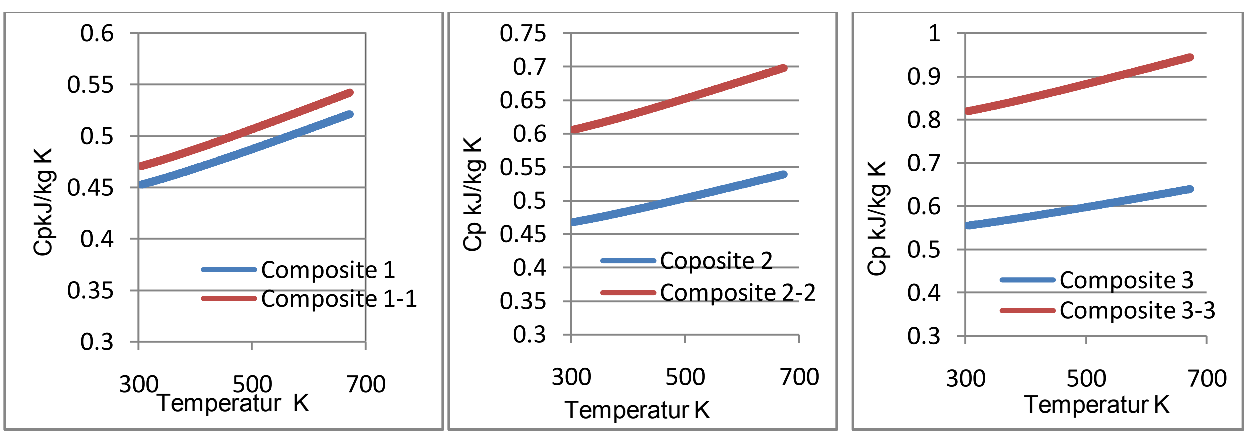
The equation of thermal capacity in pressure-54022 N/m^3 90-minute composite 2-1,

$$Cp = 121.569547 + 0.0664T + 284973.15 \times 10^6 T^{-2} \quad (8)$$

The equation of thermal capacity in pressure-54022 N/m^3 90-minute composite 3-1,

$$Cp = 164.49416 + 0.08984T + 385593.44 \times 10^6 T^{-2} \quad (9)$$

These equations are empirical equations for calculating the heat capacity when using composite materials polyurethane with cellulose, at various temperatures. Correlation between the heat capacity and temperature is shown in Fig. 2.



(a) (b) (c)

Fig.1. Relationship between the temperature and the heat capacity in pressure 40521 N/m^3 and 54022 N/m^2 (a) Composite 1 and 1-1 (b) Composite 2 and 2-2 (c) Composite 3 and 3-3

Fig.1 shows that the heat capacity of a composite of 3-1 at the pressure-54022 N/m^2 is larger than that of the heat capacity of the other composite at the pressure 40521 N/m^2 and 54022 N/m^2. For a longer mixing time and a higher pressure shows better results on the heat capacity value. For more details, heat capacity values can be seen in Table 6.

Table 6. The lowest and the highest results of heat capacity.

Material	Pressure N/m^2	Time minutes	Cp 30.17 °C Cal/mg °C	Cp 399.8°C Cal/mg °C	Cp 303.17 K kJ/kg K	Cp 672.8 K kJ/kg K
Composite 1	40521	90	72.6638	83.7411	0.3041	0.3504
Composite 2	40521	90	98.8256	113.8913	0.4135	0.4766
Composite 3	40521	90	191.7127	220.9388	0.8022	0.9245
Composite 1-1	54022	90	112.4964	129.6461	0.4707	0.5425
Composite 2-1	54022	90	144.7999	166.8743	0.6059	0.6913
Composite 3-1	54022	90	195.9269	225.7955	0.8198	0.9448

Table 6 shows that the heat capacity at 672.8 K for composite of 3-1 and at a pressure of 54022 N/m^2, i.e. 0.9448 kJ/kg.K, is larger than that of the heat capacity of calcium silicate [9] and polyurethane [10] but still below the value of the heat capacity of rockwool [11]. It shows that the mixing process in longer time and bigger pressure produces better thermal capacity value.

4 Conclusions

By increasing the pressure, the value of heat capacity is also increasing. Whereas, the value of thermal conductivity and density are decreasing. The results obtained in accordance with the criteria of insulating material. It can be concluded that the composite of 3-1 at the pressure 54022 N/m^2 was the best results, which have the lowest thermal conductivity, i.e. 0. 0.0735W/m.°C, the smallest density, i.e. 109 kg/m^{3}and the highest thermal capacity, i.e. 0.9448 kJ/kg.K.

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