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Experimental Study of Heat-absorbent Foam Concrete Wall based Macro-encapsulation of Beef Tallow/Damar Gum in Building

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Abstract. Generally, the foam concrete that designs as the current building wall is without considering the heat absorbent. Therefore, it is necessary to find additional materials that able to absorb the heat energy. One of them is Phase Change Material (PCM). Beef tallow is an organic material of PCM that has a high heat storage capability. Commonly, an aggregate requires in the manufacture of foam concrete as reinforcement materials. This aggregate can be changed with macro-encapsulation of PCM. This study aimed to find the ability of foam concrete based macro-encapsulation of beef tallow/damar gum in absorb heat energy that will be applied in building walls. This research was conducted experimentally with the primary materials of cement, fine sand, water, foam agent, catalyst, sika, and macro-encapsulation of beef tallow/damar gum. This foam concrete wall was made with the dimension of 80 x 80 x 10 cm and varied with a mixture of beef tallow/ damar gum of 0%, 1%, 3%, and 5%, respectively. The wall concrete heater was simulated with using four lamps with the power of 200 watts. The type-K thermocouple was placed on samples at 2 points, inside and on the surface which connected with Agilent 34970A. The results showed that the effect of adding PCM resulted in a decreasing of the temperature inside and on the surface of foam concrete walls. The amount of temperature decrease due to the addition of 5% PCM is from 51.9 °C to 44.7 °C or decreased by 13.87% inside of foam concrete walls and 75.64 °C to 51.9 °C or down to 21.87% on the surface of foam concrete walls. Overall, this foam concrete based macro-encapsulation of beef tallow/damar gum is better to use as heat-absorbent in building wall application compare with foam concrete wall without using macro-encapsulation of beef tallow/damar gum.

1. Introduction

Most of the buildings and infrastructure facilities in urban areas use concrete as the primary material of buildings [1]. Along with the rapid growth of knowledge and technology, the necessary materials of the buildings are transferred to foam concrete [2]. This foam concrete has a lower density compared to concrete in general, and it also has other advantages that not owned by ordinary concrete [3], but on the other hand, this foam concrete has disadvantages in its design without considering heat-absorbent materials. One of the heat-absorbent materials can be overcome by adding PCM to a foam concrete



mixture [4]. The advantage of using PCM is it has a high latent storage capability and better than foam concrete/conventional concrete[5]. The fundamental work of PCM is it will absorb the excess heat which is passing through the concrete so that the heat is stored in PCM [6]. This act will influence the thermal comfort in the room. Indirectly, the heat in the room can be controlled. Therefore, if the room is not too hot, then the thermal load is lower, and this act can produce an efficient thermal management system. The higher efficiency will provide the better condition because it can reduce the electricity consumption. By reducing the electricity consumption, greenhouse gas emissions will also be reduced automatically.

PCM consists of several groups such as organic, inorganic and eutectic [7]. Besides these three groups, there are also commercial PCM materials [8]. Of all types of PCM groups, organic PCM is available to be used in building applications. This organic PCM can be obtained by utilizing the potential of local ingredients such as beeswax[9], [10], beef tallow[11], palm oil [12], coconut oil [12], and soybean oil [12]. Amin et al. tested the beeswax as a local material, and it has excellent potential as thermal energy storage and can be applied to the building walls[9]. Hamdani et al. also tested beeswax and damar gum that applied to buildings [11]. Fauzi et al. [13] in his research showed that damar gum could be potentially increasing the thermal conductivity when mixed into PCM base materials. All of this potential local materials can be used as the new material as a bio PCM to be applied in the building walls.

In the manufacture of foam concrete, an aggregate is usually needed to be used as reinforcement material from foam concrete. This aggregate can be replaced by macro-encapsulated PCM as performed by Zhang et al.[14]. Besides, Mohseni et al. [15] also made macro-encapsulated PCM which consists of paraffin as a core and lightweight aggregate (LWA) as a container. Next, Tie-lin et al. [16] made encapsulation of ceramsite and the PCM of paraffin and stearic acid. The adding of PCM to foam concrete using either PCM encapsulation or without encapsulation can reduce room temperature as evidenced by some researchers such as; Memon et al. [17]. They conducted thermal testing on lightweight aggregate concrete using PCM containing macro-encapsulation. The results obtained that the effect of macro-encapsulated PCM on lightweight aggregate concrete can reduce the indoor temperature. Lim and Choi [18] tested the foam concrete based light material (lightweight foamed concrete) mixed with PCM, and the result was the indoor temperature could be reduced by 1°C with the mixture of PCM with only 10%. Bamonte et al. [19] carried out the testing of foam concrete which was added by PCM as a heat absorbent, and the results showed that with the addition of PCMs, it could reduce up to 20% of the energy needed for cooling in the summer.

Based on the analysis above, this study tried to make foam concrete by adding PCM encapsulation of beef tallow and damar gum to be applied to the building walls. This beef tallow will be used as PCM and damar gum as a shell. The purpose of this study is to determine the heat absorption performance on foam concrete wall based on macro-encapsulated PCM of beef tallow/ damar gum.

2. Methodology

2.1. Materials

The materials used in this study consisted of 2 components from the manufacture of foam concrete and macro-encapsulated PCM, respectively. The foam concrete materials used was the composed of cement, fine sand, water, foam agent, catalyst, and sika. The macro-encapsulated materials consisted of beef tallow and damar gum. Beef tallow was processed by boiling with water at 100°C until the water evaporates, and oil removes. The oil is then filtered and cooled at ambient temperature. The results of a manufacturing process of beef tallow are shown in Figure 1.



Figure 1. Beef tallow before and after treatment process.

The damar gum used has undergone a purification process which was carried out using toluene solvents. The purification process based on Hamdani et al. [11]. Thermal properties of beef tallow and damar gum were obtained using the T-history method and shown in Table 1.

Table 1. Thermal properties beef tallow and damar gum [11].

Material	Melting temperature [°C]	Specific heat [kJ/kg.°C]	Thermal conductivity [W/m.K]	Latent heat [kJ/kg]
Beef Tallow	38 – 41	3.19 – 4.16	0.181	112
Damar Gum	46 – 49	2.54 – 3.57	0.256	86

Macro-encapsulated PCM consists of beef tallow as the core material and dammar gum as its shell. The process of inserting beef tallow into the shell was used by the vacuum impregnation method as did by Zhang et al. [14] and the results are as shown in Figure 2.



Figure 2. Macro-encapsulation PCM of beef tallow/damar gum.

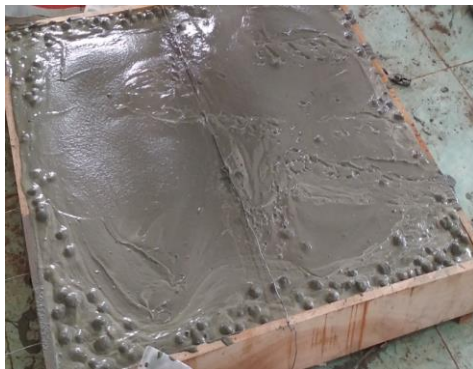
2.2. The process of making foam concrete based on macro-encapsulated PCM

Foam concrete based on macro-encapsulated PCM was prepared with a size of 80 cm x 80 cm x 10 cm. This foam concrete based on macro-encapsulation was made as a sample of foam concrete walls in absorbing good heat without using PCM or using PCM. The foam concrete walls mixed with macro-encapsulated PCM varied by 1%, 3%, and 5%, respectively. Each variation and the percentage of foam

concrete mixture are shown in Table 2. The process of making foam concrete walls based on macro-encapsulated PCM and samples ready to be tested are shown in Figure 3.

Table 3. The mixture proportion of foam concrete based macro-encapsulated PCM of beef tallow/damar gum

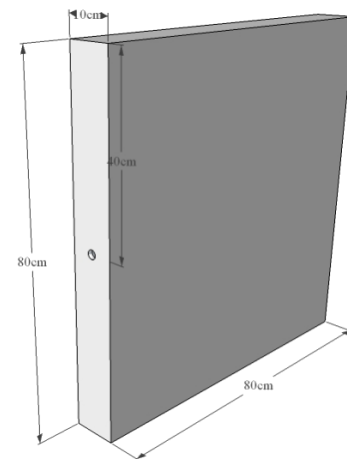
Mixture	Sand [kg]	Cement [kg]	Macro-encapsulated PCM [kg]	Water [L]	Foam agent [mL]	Catalyst [mL]	Sika [mL]
Without PCM/ references	64	38.4	-	51.2	25.6	76.8	76.8
With PCM 1%	64	38.4	0.64	51.2	25.6	76.8	76.8
With PCM 3%	64	38.4	1.92	51.2	25.6	76.8	76.8
With PCM 5%	64	38.4	3.2	51.2	25.6	76.8	76.8



(a) The mixing process of foam concrete with macro-encapsulation of beef tallow/damar gum



(b) The final result of foam concrete based macro-encapsulated PCM



(c) Schematic view of foam concrete based macro-encapsulated PCM

Figure 3. The sample of foam concrete based on macro-encapsulated PCM

2.2. Methods of Heat Absorbent Test

Foam concrete wall heater was simulated using four lamps with 200 watts of power, respectively. The distance between the lamps and the test equipment was 12 cm. K-type thermocouple was placed on samples at 2 (two) points, inside (T_1) and on the surface (T_2) which were connected to Agilent Type A 97410. The reading results from Agilent were recorded and stored on a computer device. Data from this computer will be processed into graphics. The complete schematic is shown in Figure 4.

The first test was carried out by sample without using PCM, then the sample with a variation of 1% to 5% addition of macro-encapsulation. The testing process begins by turning on the Agilent 34970A acquisition data that has been connected to the computer. Data acquisition was carried out and read once in each 5 seconds. The incandescent lamps were turned on for 7 hours. Then, the lamps were turned off and left until the temperature reaches a constant.

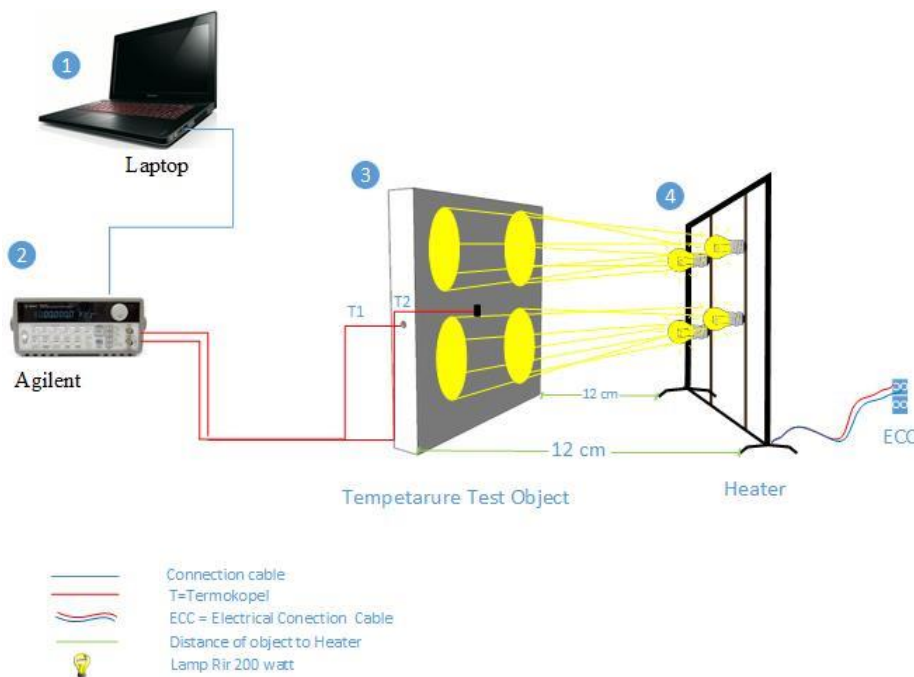


Figure 4. Scheme of research

3. Results and Discussions

3.1. Temperature profiles in foam concrete walls based on macro-encapsulated PCM

Thermal performance testing for foam concrete wall based macro-encapsulated PCM of beef tallow/ damar gum has been successfully carried out. Figure 5a shows the temperature profiles of the foam concrete wall based macro-encapsulated PCM. The temperature in the wall appears to decrease along with the increasing of the PCM quantities, where the temperature without PCM is 51.9 °C, with the addition of PCM 1% the temperature in the wall drops to 50 °C. Likewise, the addition of PCM 3% and 5% cause the temperature in the wall also fall by 48.26 °C and 44.7 °C, respectively. Figure 5b describes the percentage of the effect of adding PCM to a foam concrete mixture. It can be explained that the percentage due to the addition of PCM 1%, 2%, and 3% resulted in a decreasing of temperature in the building walls of 3.66%, 7.01%, and 13.87%, respectively.

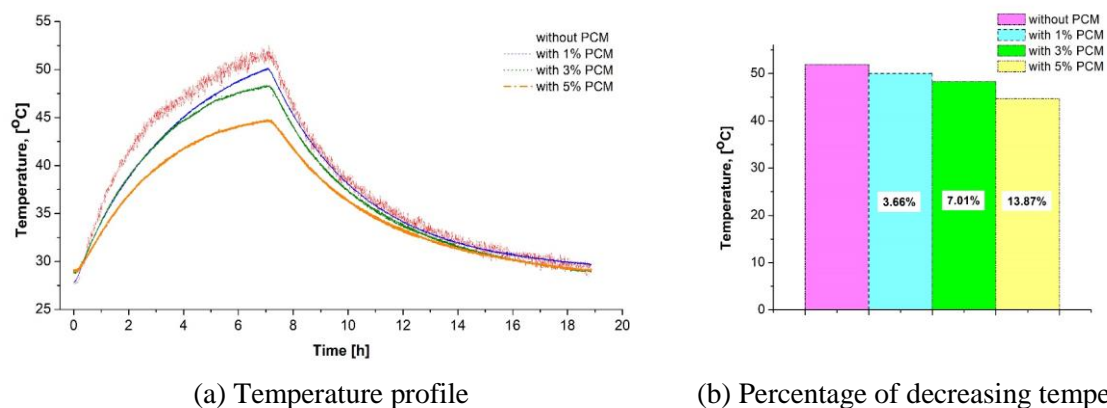


Figure 5. Thermal performance inside of foam concrete wall based on macro-encapsulated PCM

3.2. Foam concrete wall surface temperature profile based on macro-encapsulated PCM

Figure 6a shows the surface temperature profile of foam concrete based macro-encapsulated PCM. The temperature of the wall surface appears to decrease along with the increasing of PCM quantities, where the temperature without PCM is 75.64 °C, with the addition of PCM 1% the wall surface temperature drops to 65.1 °C. Likewise, the addition of PCM 3% and 5% cause the wall surface temperature also decrease by 62.67 °C and 59.7 °C, respectively. This decreasing occurs because the heat inside the wall is absorbed by PCM. Figure 6b explains the percentage of the effect of adding PCM to the foam concrete mixture. It can be explained that the percentage due to the addition of PCM 1%, 2%, and 3% resulted in a decreasing temperature on the surface of the building wall by 13.93%, 17.14%, and 21.87%, respectively.

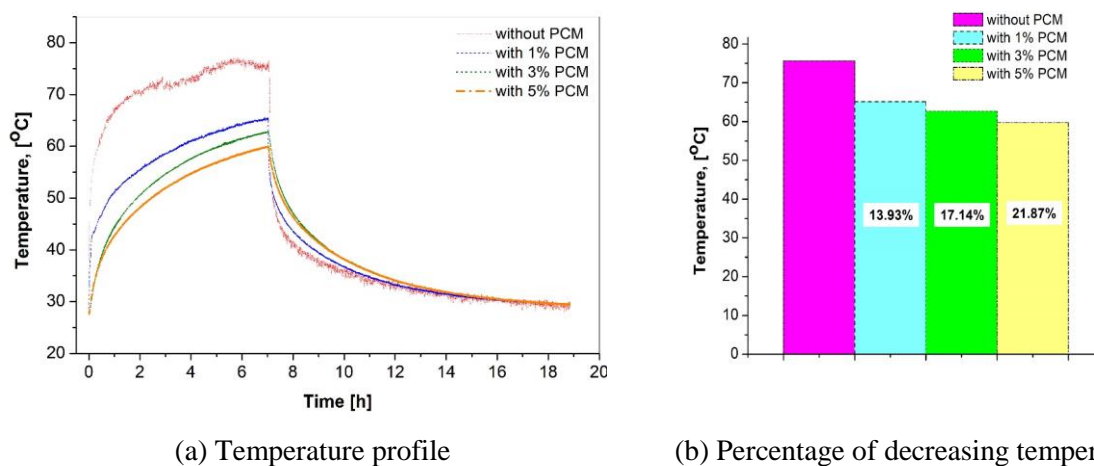


Figure 6. Thermal performance on the surface of foam concrete wall based on macro-encapsulated PCM

The temperature profile due to the heat load is given on the surface wall looks higher than the inside wall. It happens because the surface wall is closer to the heat source. Overall the temperature both inside and on the surface of the wall decrease. This decreasing temperature is caused by the heat inside and on the surface of the wall being absorbed by PCM, which the PCM has a latent heat storage capacity of 112 kJ/kg. Similar results were also obtained from Memon et al. [17]. Table 4 is a summary obtained from the results of foam concrete wall performance testing based on macro-encapsulated PCM of beef tallow/damar gum.

Table 4. The Result of thermal performance of foam concrete wall based macro-encapsulated PCM of beef tallow/damar gum

	Thermal performinside of thefoam concrete wall based macro-encapsulated PCM			
	Without PCM	With PCM 1%	With PCM 3%	With PCM 5%
T ₁ max [°C]	51.9	50	48.26	44.7
Decrease [%]	-	3.66	7.01	13.87
	Thermal performon the surface of thefoam concrete wall based macro-encapsulated PCM			
	Without PCM	With PCM 1%	With PCM 3%	With PCM 5%
T ₁ max [°C]	75.64	65.1	62.67	51.9
Decrease [%]	-	13.93	17.14	21.87

4. Conclusions

Based on the purpose of the study, the method, and the result of the tests that have been carried out, it concluded that with the addition of PCM into the foam concrete, there was a decreasing temperature inside and on the surface of the foam concrete walls. The amount of temperature decreasing both inside and on the surface of the wall is proportional to the increasing of PCM percentages added. In this study, the amount of temperature reduction inside the wall for the addition of PCM 1%, 3%, and 5% is 3.66, 7.01 and 13.87%, respectively. Furthermore, the magnitude of the temperature reduction on the wall surface for the addition of PCM of 1%, 3%, and 5% is 13.93, 17.14 and 21.87%, respectively. This result showed much better than without using PCM.

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