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*Research article*

## **Mechanical properties of concrete containing beeswax/dammar gum as phase change material for thermal energy storage**

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**Abstract:** This study aims to investigate the mechanical properties of concrete containing phase change materials (PCM). This research begins with the investigation of melting temperature, enthalpy, the thermal conductivity of the phase change materials using the T-history method, followed by preparation of concrete containing PCM, and finally testing of mechanical properties of concrete through compressive strength test. This study used beeswax, tallow, and dammar gum as PCM mixture. From the results of the PCM properties test, shows that the latent heat energy content from beeswax and tallow exhibit an excellent potential to be used as PCM, while dammar gum is benefited in increasing the thermal conductivity of concrete containing PCM. From concrete specimen test containing 10%, 20% and 30% PCM with 7 days and 28 days aged, the results exhibit that the mechanical properties of the concrete decreased along with the increasing of PCM content. The same test also conducted at the PCM melting temperature. Therefore, the concrete compressive strength test conducted at 45 °C. From the test results, the concrete compressive strength decreased about 3–24% of PCM-0% concrete compressive strength. Drastic compressive strength reduction tends to occur in PCM-Tallow concrete mixture. This study concluded that the PCM is potentially useful as a heat energy absorber material in buildings and lightweight concrete rather than construction structures.

**Keywords:** beeswax; phase change material; concrete; building

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## 1. Introduction

Final energy consumption continues to increase in line with the economic growth, population, energy prices, and policies set by the Indonesia Government. Final energy consumption during 2010–2015 increased relatively small which is only about 1.3% per year. By 2015, the most significant share of final energy consumption was household sector (35%) followed by transportation (31%), industry (29%), commercial (4.0%) and others (2.0%). From 2010 to 2015, transportation sector had the tremendous growth of 5.2% per year, followed by household (3.8%), and commercial (2.9%). The growth of industrial and other sectors decreased to only 4.6% and 10% respectively [1]. Energy saving efforts in the building sector are carried out with the issuance building legislation and regulation arranged in Law 28/2002, Government Regulation 36/2005, and Ministry of Public Works & Housing regulation no 02/PRT/M/2005. Green building is a building that meets the requirements of buildings and has significant measurable performance in saving energy, water, and other resources through the application of green building principles by the function and classification in every stage of its operation.

To lower energy consensus in buildings has led to research that focuses on building highly energy-efficient and thermal energy storage systems. The phase change material (PCM) is a set of functional materials that utilize high-energy storage densities in narrow temperature intervals. A considerable number of the literature on PCM applications in buildings has been published. However, almost all of the articles focused only on material studies, performance improvements to the system [2–5], optimization of PCM laying position [6–8]. Several preliminary studies have been to obtain beeswax properties as PCM in the form of nanocomposites [9] and the use of wax-clay as PCM in building [10].

There are three different ways of using PCM on buildings, PCM in the walls of buildings; PCM in building components other than walls, such as floors and ceilings; PCM in heat and cold storage units as it located in building interior instead of an envelope, such as storage heat [11]. Various studies about the utilization of PCM on concrete has been conducted by Vincente, Shi and Cabeza while study about PCM selection, has been performed by Feldman, Xu, Fauzi, Amin and Liu [15–19].

The mechanical properties of concrete materials, i.e., strength, stiffness, and volume stability, are essential parameters for determining the use of concrete as a structural material, has been conducted by Feldman, Xu, Fauzi, Amin, Liu, Yang, and Ye [15–22]. Research related to the testing method of the concrete properties containing PCM was described by Lázaro, Yinping, Peck and Hong.

This study investigates the potential utilization of beeswax, tallow, and dammar gum as PCM on concrete buildings. The research was conducted in three stages, starting with testing the thermal properties of beeswax, tallow, and dammar gum, followed by preparation of concrete cement containing beeswax, tallow, and dammar gum, and finally testing the mechanical properties of concrete containing PCM.

## 2. Materials and methods

### 2.1. Materials

Amin [18] which use beeswax/graphene phase change material as energy storage for building applications, and Fauzi [17] proposed dammar gum as additional material improve the thermal conductivity and thermal performance on the preparation of composite phase change material.

In this study used beeswax, tallow, and dammar gum as a PCM. Beeswax is obtained from a honeycomb that has been taken by honey, while tallow obtained by heating the fat cow. Dammar gum is a natural resin produced by the family tree *Dipterocarpaceae* and *Burseraceae*, the most generated dammar gum in Indonesia is *Shorea Javanica*. Dammar gum has a density of 1,040 kg/m<sup>3</sup> to 1,120 kg/m<sup>3</sup> and a melting point of up to 120 °C. The dammar gum used in this study that has undergone a purification process that is carried out using toluene solvent. Purification was conducted by grinding 200 grams of dammar gum and collected them in a glass cup, then mixed with 1600 grams of toluene and stirred using a stirrer for 15 minutes at 200 rpm. After the dammar wholly dissolved, then activated charcoal was added and stirred them for another 15 minutes at 200 rpm with a temperature maintained at 45 °C. The mixed solution then was cooled at room temperature for two hours, then filtered, the unscented part of the filter was separated, while the filtrate was evaporated using a rotary evaporator for two hours at 80 °C. The purified dammar gum was placed in an oven for eight hours at 85 °C to remove any remaining toluene. The dammar gum powder was ground in a rotary ball mill and screened in a sieve shaker to obtain 100 µm sized particles [17].

### 2.2. Methods

Testing of PCM characteristics was performed using T-history method [24,25,27], which is a suitable method for determining the freezing point, specific heat, latent heat, thermal conductivity, and thermal diffusion coefficient of PCM. The advantage of the T-history method is to use only conventional tubes as PCM sample containers so that the measurement becomes convenient and the process of phase-phase change can be observed. In this method, a glass tube filled with a phase change material and the second one with reference material (generally pure water). Both materials had the same mass and heated to a temperature above the melting temperature of PCM. Then the test tube was suddenly exposed to room temperature and allowed to cool. Temperature changes during the cooling process were recorded, and a PCM cooling curve and water cooling curve was obtained. The physical properties of thermal were derived from the thermodynamic equations which describe the two cooling curves [28].

The next step was the preparation of concrete containing PCM. The preparation of the concrete was conducted based on the Indonesian National Standard (SNI), for the analysis of fine and coarse aggregate abrasives based on (SNI 03-1968-1990) or ASTM C.127-1993, Specific gravity and fine aggregate absorption (SNI 03-1970-1990) or ASTM C.127-93, and concrete mix design based on SNI T-15-1990-03. The cement used was the best quality Portland cement available in the market, and the excellent quality of the coarse and fine aggregate was selected. The excellent quality of concrete samples prepared through a series of step including the quality analysis of the fine and coarse aggregate. The analysis was useful in determining gradation/distribution of sand and gravel

grains in the concrete. The proportion of concrete materials in this study revealed in Table 1. Also, the proportion of the mixture in this test is fixed according to the following equations:

$$\text{Water}/(\text{cement} + \text{PCM}) = 0.32 \quad (1)$$

$$\text{Cement}/(\text{Fine aggregate} + \text{coarse aggregate}) = 0.43 \quad (2)$$

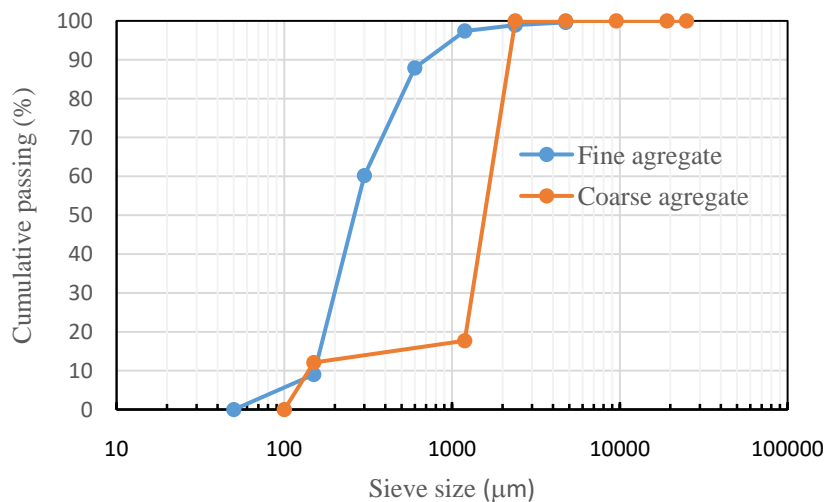
$$\text{Fine aggregate}/(\text{fine agregate} + \text{coarse aggregate}) = 0.35 \quad (3)$$

**Table 1.** The mix proportions of the PCM-concrete.

	Cement (kg/m <sup>3</sup> )	Water (kg/m <sup>3</sup> )	Fine aggregate (kg/m <sup>3</sup> )	Coarse aggregate (kg/m <sup>3</sup> )	PCM (kg/m <sup>3</sup> )	Damar-gum (kg/m <sup>3</sup> )
PCM-BW-0%	679	214	554	1036	0	0
PCM-BW-10%	590	214	482	901	87	10.8
PCM-WB-20%	502	214	410	766	160	18.8
PCM-BW-30%	417	214	340	636	258	37.6
PCM-CF-10%	590	214	482	900	80	16
PCM-CF-20%	443	214	433	573	230	26.8
PCM-CF-30%	376	214	368	487	300	38.8

PCM-BW = phase change material beeswax; PCM-CF = phase change material tallow.

The result of size distribution analysis of the fine and coarse aggregate used in the preparation of the concrete displayed in Figure 1.



**Figure 1.** Particle size distributions of fine and coarse aggregates.

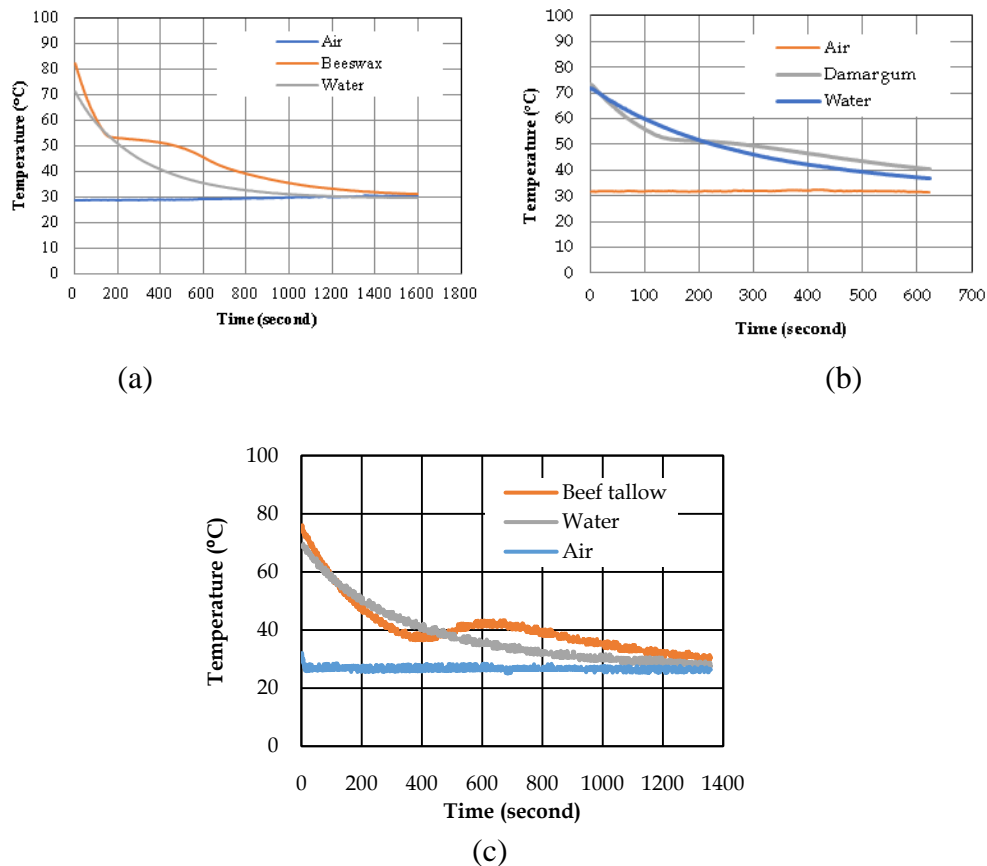
To gain a better understanding of the PCM effect on the mechanical properties of concrete containing PCM, a compressive strength test was performed according to ASTM C 39. Sixty cube specimens with a dimension of 150 mm × 150 mm × 150 mm were molded for each concrete-PCM mixture design, and the compressive strength test was carried out on every three concrete specimens

having ages of 7 days and 28 days respectively according to the mixture design. Another variation of treatment subjected to the specimen of the compressive strength test was also carried out at a specimen temperature around the PCM melting temperature of 45 °C. From the test results, it is expected to obtain concrete compressive strength information at the solid phase and melting temperature of PCM.

### 3. Results and discussion

#### 3.1. Thermal properties of PCM

Figure 2a shows the temperature versus time curves of PCM beeswax testing using the T-history method, where distilled water acted as referenced material. The data collected during the cooling of the samples were then processed using the method which has been described by Yinping [24] and Avignon [29]. From the curve, it is noticeable that the beeswax's melting-temperature places in the range (50–52 °C). The 2b curve shows the results of PCM damar-gum testing obtained by melting temperature ranges (46–49 °C), while Figure 2c shows the melting temperature of PCM tallow in the temperature range (38–41 °C). Figure 2c also depicted sub-cooling condition, which is indicated by the temperature rise after PCM reaches a solidification temperature.



**Figure 2.** (a) Resulting temperature versus time curves for beeswax; (b) resulting temperature versus time curves dammar-gum; and (c) resulting temperature versus time curves for beef tallow.

Table 2 shows the results based on the temperature versus time curves for specific heat, thermal conductivity, and latent heat for PCM. Dammar gum has a smaller latent heat compared to beeswax and tallow, but has a considerable thermal conductivity. The use of Damar gum in concrete is expected to increase the thermal conductivity of PCM-concrete mixtures, which will make PCM concrete easier to absorb and release heat.

**Table 2.** The test result of PCM properties the using T-history method.

	Melting temperature (°C)	Specific Heat (kJ/kg.K)	Thermal conductivity (W/m K)	Latent Heat (kJ/kg)
Beeswax	50–52	2.65–3.45	0.234	171
Tallow	38–41	3.19–4.16	0.181	112
Dammar-gum	46–49	2.54–3.57	0.256	86

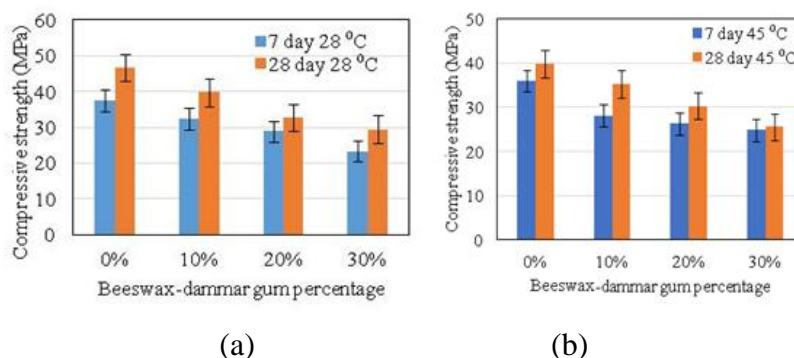
The compressive strength test was performed for PCM concrete specimens aged 7 days and 28 days under ambient temperature conditions (28 °C) and at PCM melting temperature (45 °C) to investigate the mechanical behavior of their property for six proportions of the mixture. Table 3, shows the results of compressive strength testing of various proportions of mixtures under different conditions and percentage decrease in compressive strength values, compared with concrete without PCM (PCM-0%). Figure 3 and Figure 4 shows the compression strength ratio for two different mix design methods under different temperature conditions.

**Table 3.** Compressive strength of the PCM-concrete.

Group	7 day 28 °C		7 day 45 °C		28 day 28 °C		28 day 45 °C	
	Average stress (MPa)	Decrease (%)	Average stress (MPa)	Decrease (%)	Average stress (MPa)	Decrease (%)	Average stress (MPa)	Decrease (%)
PCM 0%	37.60	-	36.00	-	46.60	-	39.78	-
PCM-BD 10%	32.38	13.90	28.17	21.76	39.78	14.64	35.28	11.31
PCM-BD 20%	28.89	10.76	26.28	6.70	32.81	17.52	30.34	13.99
PCM-BD 30%	23.37	19.10	24.83	5.52	29.48	10.15	25.55	15.79
PCM-TD 10%	28.70	23.68	32.81	8.86	35.11	24.66	38.3	3.72
PCM-TD 20%	26.81	6.59	30.96	5.64	31.55	10.14	33.03	13.76
PCM-TD 30%	25.33	5.52	26.07	15.79	28.00	11.25	29.4	10.99

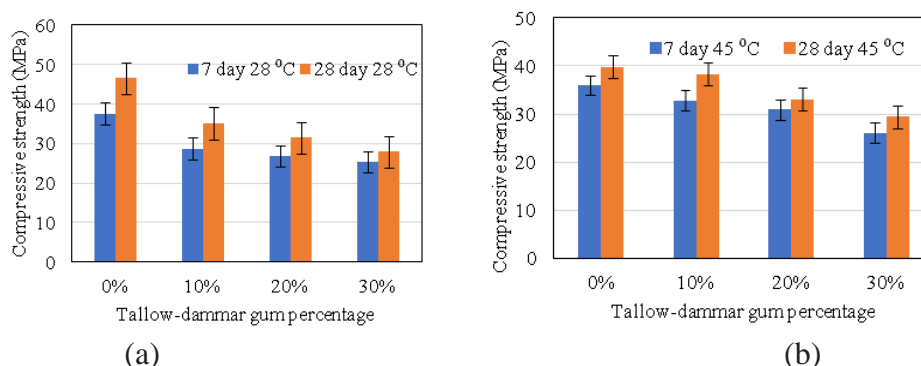
PCM-BD = phase change material beeswax-dammar gum; PCM-TD = phase change material tallow-dammar gum.

From Figure 3a, b it is represented that the addition of PCM beeswax in the concrete resulted in the decrease of the compressive strength value of concrete. The reduction was due to the PCM used was not meant to affect increasing the strength of concrete. The decrease in compressive strength continues to occur with the increasing mixtures of PCM in concrete, as well as in the review of PCM-concrete age. On the other hand, the effect of age and temperature of the sample on the decrease of compressive strength was apparent, where the compressive strength decreased around 21.76% compared to concrete without PCM for the 7-day age specimen.



**Figure 3.** Compressive strength comparison of concrete containing PCM-BD (a) temperature at 28 °C; (b) temperature at 45 °C.

Figure 4a, b shows the results of a compressive strength test for concrete containing PCM-TD. From the graph, it depicts the compressive strength of the concrete tends to decrease rapidly with the increase of tallow mixture in the concrete. This phenomenon exists due to the absence of bonds between cement and tallow and tends to inhibit the occurrence of cement bonds with an aggregate. The similar observable fact also took place with specimen tested at the melting temperature of tallow. Therefore, it can be deduced that tallow is not suitably used as PCM on concrete.



**Figure 4.** Assessment of compressive strength of concrete containing PCM-TD (a) temperature at 28 °C; (b) temperature at 45 °C.

#### 4. Conclusions

Wrapping up the whole discussion of this research, it can be deduced that the T-history method is suitable for determining enthalpy, specific heat and thermal conductivity of phase change materials, the advantage of using this method is that the phase change of the material during the cooling process can be clearly observed. From the test results obtained, it proves that resin gum has a higher thermal conductivity compared to beeswax and tallow. Therefore, they were suitable for increasing the conductivity of PCM mixture. The use of beeswax, tallow, and dammar gum as PCM in the concrete has not been able to increase the strength of concrete, even worse; their existence decreased the

compressive strength of PCM mixture concrete. It can be resolved that the PCM proposed in this study show great potential to be applied as a phase change material in lightweight concrete, nevertheless, not suitably used in building main structures.

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## Conflicts of interest

The authors declare that they have no conflicts of interest.

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