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# Development, mechanical properties and numerical simulation of macro encapsulated thermal energy storage concrete

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ABSTRACT

Macro encapsulated lauryl alcohol–lightweight aggregate (LA–LWA) was prepared for subsequent development of thermal energy storage concrete (TESC). The macro encapsulated LA–LWA was obtained by encapsulating the surface of LWA with epoxy and modified cement paste. From sealing performance test, it was found that after 150 thermal cycles the mass loss of PCM in LWA with epoxy coating was less than 1%. The thermal conductivity of TESC was lower than control LWAC while the compressive strength of TESC macro encapsulated with epoxy was around 30 MPa. Therefore, TESC can be used for structural applications.

Based on the better performance of epoxy coated LWA, further investigations were carried out. The macro encapsulated LA–LWA was found to be thermally stable and reliable. From outdoor thermal performance test, it was found that TESC room model was efficient in reducing indoor room temperature. Computer simulations for the room model were then performed. It was found that PCM integrated walls showed best thermal and energy performance. Among different cities, the thermal performance in Changsha city was the best. Finally, it was shown that the application of PCM in a typical public housing flat in Hong Kong is economically feasible with a payback period of 14 years.



## 1. Introduction

With development of economy and society, people are paying more attention to environmental protection and energy saving. As a result, researchers are focusing more on the development of green building materials having energy saving qualities. Moreover, it has been pointed out that the combination of building materials and PCM is an efficient way to increase the thermal energy storage capacity of building components for the purpose of direct thermal energy storage in buildings [1]. Phase change energy storage concrete is a PCM enhanced concrete having structural and thermostatic properties [2].

The PCM can be incorporated in concrete by direct incorporation and immersion [3–5], form-stable composite PCM [6,7] and encapsulation [8–13]. Among these techniques, encapsulation (micro and macro) is the preferred choice. Some researchers [7,10] experimentally investigated the incorporation of different percentages of micro encapsulated PCM on the mechanical properties of concrete and found that it significantly reduces the compressive strength of concrete. In addition, high investment cost renders its feasibility to reach commercial state [14]. Due to these reasons, macro encapsulation is preferred and widely used [15].

In study of Zhang et al. [8], porous lightweight aggregates (LWA) were successfully impregnated with a butyl stearate PCM that melts at around 18 °C. However, the research did not evaluate the effect of surface encapsulation of LWA on the mechanical properties of TESC. Moreover, the outdoor tests were not performed to evaluate the thermal performance of TESC. Bentz and Turpin [16] also using LWA as carrier for PCM showed that it can reduce the number or intensity of freeze/thaw cycles experienced by a bridge deck or other concrete exposed to a winter environment. However, after obtaining the thermal properties of PCM–LWA, only simulation of freeze/thaw cycling was done.

In this research, we prepared macro encapsulated lauryl alcohol–lightweight aggregate (LA–LWA) for subsequent development of TESC. The macro encapsulated LA–LWA was obtained by encapsulating the surface of LWA with epoxy and modified cement paste. The sealing performance of macro encapsulated LA–LWA

*Abbreviations:* LA, lauryl alcohol; LWA, lightweight aggregate; PCM, phase change material; PCMC, PCM concrete; TES, thermal energy storage; TESC, TES concrete.

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**Fig. 1.** Dedecanol in liquid state.

after 150 thermal cycles was determined. Thereafter, the thermal conductivity and compressive strength of concrete made with macro encapsulated LA–LWA was evaluated. Moreover, the compressive strength of TESC subjected to different thermal cycles (50, 100 and 150 cycles) was evaluated. Based on the better performance of epoxy coated LWA, further investigations were carried out to determine the thermal properties and thermal reliability of macro encapsulated LA–LWA by DSC and thermal stability by TGA. Outdoor test was carried out to evaluate the thermal performance of concrete containing epoxy coated LWA. Computer simulations were performed to determine the best position of PCM in the room model. The energy efficiency rate, $CO_2$ emissions to the atmosphere and the thermal performance of room model in different climates/cities was also evaluated. Finally, economic feasibility of PCM integrated walls was evaluated.

## 2. Experimental investigation

### 2.1. Materials and preparation of macro encapsulated LA–LWA

Lauryl alcohol, procured from Tianjin Kemiou Chemical Reagent Co. Ltd, was used as PCM (Fig. 1) while LWA (Fig. 2), manufactured from expanded clay, was used as container for PCM. The microscopic images of porous LWA are shown in Fig. 3. In these images, the dark colored area represents the pore while the light colored area is the pore skeleton. It can be seen that the LWA is highly porous and pore structure is well interconnected. However, under simple immersion of LWA in PCM it is difficult to absorb large quantity of PCM. This is due to the reason that the pore spaces

**Fig. 2.** Lightweight expanded aggregate used in this research.

in LWA are blocked up with air. Therefore, it was necessary to remove the air from the LWA so that it can absorb large quantity of liquid. This was done by using vacuum impregnation technique (Fig. 4). Here, at first, the LWAs along with melted PCM were put in the beaker placed inside the vacuum chamber. After that, the sample was vacuumed till all the air bubbles were removed. This process took 30–40 min. Finally, the sample was taken out and put in the refrigerator at 4 °C so as to make sure that the PCM becomes solid. The percentage of LA retained by LWA was found to be 49.1 wt%.

After vacuum impregnation process, LA–LWAs were coated with epoxy complying with JC 887-2001 (China) or modified cement paste. For epoxy, LA–LWAs were coated with two layers while for the coating with modified cement paste; the cement paste contained 30% epoxy by weight of cement paste. It is worth mentioning here that both the coatings (epoxy and modified cement paste) were well distributed on the surface of every LA–LWA.

### 2.2. Preparation of thermal energy storage concrete

The mix proportion of thermal energy storage concrete was designed and calculated according to the absolute volume method in Standard JGJ51-2002 (China). Table 1 shows mix proportion of different kinds of TESC. LWAC denotes lightweight aggregate

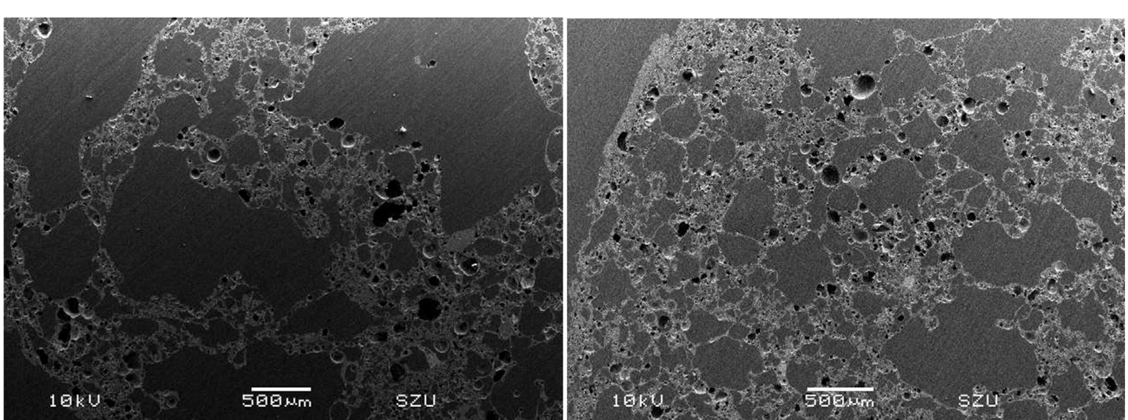


**Fig. 3.** SEM showing LWA is highly porous.