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Thesis abstract

Development of form-stable phase change material cementitious composite using recycled expanded glass and conductive fillers for thermal energy storage application

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Energy consumption for achieving thermal comfort in buildings is one of the most critical issues in the construction industry. Indeed, space conditioning is one of the dominant sources of energy consumption in Australia and worldwide. Moreover, there is an increasing demand for energy consumption for heating and cooling, accompanied by more greenhouse gas emissions. Hence, the efficient use of energy in buildings using passive technology is increasingly seen as a prospective solution to energy-saving and environmental concerns. In this sense, thermal energy storage (TES) systems in buildings would be a significant aid. The efficiency of TES systems through applying materials with high latent heat (LH) capacity, such as phase change materials (PCMs), has been investigated, proved and implemented within the last decades. Incorporating PCMs into the buildings decreases the fluctuation of interior temperature and shifts the power load from peak time to off-peak time, reducing the heating and cooling system load and energy usage.

Among different incorporation methods, form-stable PCM is increasingly being considered for applying and integrating PCM in buildings due to its feasibility and lower fabrication cost. In this method, PCM is impregnated into fine porous aggregates as supporting materials. Hence, a large fraction of PCM can be integrated into the building, which increases the thermal performance of the TES system. However, some problems and challenges need to be addressed before its practical application in the building industry. Low thermal conductivity of form stable PCM composite, as well as the selection of supporting material with high absorption capacity and compatible with the cement matrix and PCM, are still challenging issues. In addition, there is limited knowledge of the microstructure and physical and mechanical properties of form-stable PCM cement composite.

The ultimate objective of this research is to develop a form-stable PCM composite for incorporation into cement-based materials. For this purpose, an organic PCM is used to fabricate form-stable PCM cement composites due to advantages such as high heat capacity, inertness, stability, and non-toxicity. In this study, PCM is integrated into recycled expanded glass aggregates (EGAs) as a novel carrier using a vacuum impregnation process. In addition, two

types of thermal conductive fillers (TCFs), namely graphite and titanium dioxide, are dispersed in the PCM using the sonication technique to enhance the heat transfer rate of the PCM composite. The thermal properties of the developed form-stable PCM composite, including phase transition temperature and LH capacity, are measured using a differential scanning calorimetry (DSC) test. The thermal and chemical structure stability of the PCM composite is characterised using thermogravimetric analysis (TGA) and Fourier transform infrared spectroscopy (FTIR). The heat transfer rate of the form-stable PCM cement composite and the thermal storage performance of the TES material is assessed by an infrared thermography test and prototype test room experiment, respectively. Moreover, the physical, mechanical, durability and time-dependent properties of the form-stable PCM cement composite are investigated using various tests such as the flow table test and compressive and flexural test. The microstructure and morphology of the PCM composite and the form-stable PCM cement composite are studied using scanning electron microscopy (SEM) observation. Moreover, the fundamental and physical properties of the form-stable PCM cement composite obtained from the experimental results are used for modelling and thermal simulation of a building. To evaluate the thermal performance and efficiency of developed form-stable PCM cement mortar, a room model integrated with PCM was simulated in different climate zones using DesignBuilder. The results revealed a high absorption ratio for the EGA as PCM carrier, and the diffusion-oozing circle test confirmed the stability of the EGA-PCM composite.

Moreover, the microstructure studies demonstrated well dispersion of TCF in the PCM and successful impregnation of PCM into the EGA.

The DSC analysis showed that the phase transition properties of the EGA-PCM composite were slightly shifted, and its enthalpy decreased compared to the pure PCM. Moreover, it was observed that the latent heat capacity of the EGA-PCM composite enhanced by TCF remained reasonable with a maximum deduction of 9.6% and supercooling temperature enhancement up to 3.4°C. The results of TGA and FT-IR demonstrated that there was no chemical reaction between the EGA-PCM composite, including EGA, PCM and TCFs, and the composite was thermally stable in the operating temperature ranges.

The thermal behaviour analysis obtained from infrared thermography (IRT) imaging showed a 50% improvement in the heat transfer rate of the PCM composite. This is evidenced by a reduction in peak indoor temperature of up to 2.5°C compared to the control sample. Moreover, a room model experiment revealed that integrating TCFs into PCM significantly enhanced the performance of EGA-PCM cement mortar.

The results demonstrated that the melting point of PCM should be optimised for each climate zone. The PCM melting point should be higher than the typical summer thermostat setpoint temperature. Moreover, the results revealed that the energy saving rate changes throughout the year as energy utilisation changes with respect to the season. A cost-benefit analysis of a case study building showed that although the costs of production and initial installation of EGA PCM composite are relatively high,

it is more beneficial in terms of economic and environmental considerations in the long run. The results revealed the feasibility of utilising EGA as a novel PCM carrier and the promising thermal performance of EGA-PCM cement mortar.

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