Thermal performance of heat storage gypsum board with paraffin based mixed SSPCM

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ABSTRACT

In this study, we prepared paraffin based mixed SSPCM (PBMS) and gypsum boards. The prepared PBMS was added to gypsum powder as a fine aggregate. In the experiment, we used n-hexadecane and n-octadecane as the PCM, which have 254.7J/g and 247.6J/g of latent heat capacity, and melting points of 20.84°C and 30.4°C, respectively. The PBMS was prepared by an impregnation method in a vacuum, following the manufacturing process. The physical and thermal properties of the PBMS gypsum board were analyzed by Fourier transform infrared spectrometry, differential scanning calorimetry, enthalpy analysis and thermogravimetric analysis. From the FTIR analysis, PBMS could be maintained in the structure of the gypsum board due to its physical rather than chemical bonding. From the specific heat and enthalpy analysis, the PBMS has high enthalpy and thermal inertia property. In addition, we confirmed that the gypsum board with PBMS has high latent heat capacity and high thermal efficiency.

KEYWORDS
Paraffinic PCMs, Gypsum board, Heat storage, Thermal properties

INTRODUCTION
Latent heat thermal energy storage (LHTES) using phase change materials (PCMs) is considered to be the method with the most potential to solve the energy shortage problem. The PCMs employed in the LHTES system store the heat energy from the heating system during off peak periods and release the stored heat energy during on peak periods. Paraffinic PCMs are considered one of the most promising candidates for energy storage, due to their large latent heat, low vapor pressure in the melt, good chemical stability, self-nucleating behavior, and safety (Jeong et al. 2013, Jeong et al. 2015). However, some drawbacks limit the application of the paraffinic PCMs to a large extent, such as the leakage of melted paraffinic PCMs and low thermal conductivity. In order to solve these problems, PCMs can be shape-stabilized by encapsulating the PCMs in porous supporting materials and then keeping the composites solid in the phase change process. Gypsum board is usually used as a

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cladding element for the walls and ceilings of building interiors. This guarantees the use of most of the thermal inertia that can be provided by integrated PCMs. Such potential has therefore motivated past efforts towards the development of PCM gypsum board. Although significant advances have been made towards the development of PCM gypsum board over the past two decades, problems with the integration and heat transfer associated with the phase change materials still need to be addressed. Therefore, in this study we prepared heat gypsum board which contains paraffin based mixed shape stabilized PCM (PBMS). The prepared PBMS was added to gypsum powder as a fine aggregate. We then prepared the SSPCM gypsum boards by mixing the PBMS and gypsum powder in water, and casting the mixture into a mold.

EXPERIMENTAL

Two types of liquid paraffinic PCMs, with different melting points, were used in this study. In the experiment, we used n-hexadecane and n-octadecane as the PCM, which have 254.7J/g and 247.6J/g of latent heat capacity, and melting points of 20.84°C and 30.4°C, respectively. The n-hexadecane and n-octadecane are made of the alkane series and belong to the paraffinic PCMs. The paraffinic PCMs were obtained from Celsius Korea, South Korea. In addition, the xGnP used is a graphitic carbon-based material. The graphite was obtained from Asbury Graphite Mills, Inc., NJ, USA, by applying a cost- and time-effective exfoliation process initially proposed by Drzal's group (Karaipekli et al. 2007). The PBMS was prepared by an impregnation method in a vacuum, following the manufacturing process. 100g of xGnP was dried in a vacuum oven before the impregnation process. This xGnP was placed inside a filtering flask which was connected to a water tromp apparatus to evacuate air from the porous structure of the xGnP. Then, 100g of liquid state n-hexadecane and n-octadecane was placed into a beaker at a 1:1 ratio. The mixture was constantly stirred at a 500rpm for 5min using a shear stirrer apparatus. A funnel was then prepared with 200g of paraffinic PCMs. Then, the valve between the flask and the funnel was opened, to allow flow into the flask to cover the xGnP nanoparticles. The vacuum process was continued for 90min, and air was then allowed to enter the flask again to force the liquid paraffinic PCMs to penetrate into the porous structure of the xGnP. After the penetrating process, the excess PCM remaining in the flask needed to be removed through a filtering process. The PBMS in a colloidal state was filtered using 1μm filter paper, until a granular sample appeared which was dried in a vacuum drier at 80°C for 48h. To fabricate the heat-storage gypsum board samples, we began with the following proportions: α-type gypsum hemihydrate with 10, 20 and 30wt% of PBMS relative to the gypsum powder weight. Then, with a mixing ratio of gypsum powder to water of 1:0.7, we constantly stirred the mixture of the α-type gypsum hemihydrate and water at a rate of 500 rpm for 8-10 min, with a shearing stirrer at room temperature, after which the viscosity of the gypsum hemihydrate and water mixture was appropriate for blending in the PBMS particles. The prepared PBMS was placed into the gypsum hemihydrate and water mixture and mixed at a rate of 500 rpm for 5 min, with a shearing stirrer at room temperature. Finally, the mixed samples

were cured in the mold for 3 hours. Fourier transform infrared (FTIR) spectroscopy (300E Jasco) was utilized to monitor the change of chemical groups upon curing. Clear potassium bromide (KBr) discs were molded from powder and used as backgrounds. The thermal properties, such as the melting and freezing temperature and the latent heat capacity of the PBMS and the PBMS with the heat storage gypsum board were measured using DSC (Q 1000). The thermal durability of the PBMS and heat storage gypsum board was carried out using TGA (TA Instruments, TGA Q5000).

RESULTS AND DISCUSSION
**FTIR analysis and chemical stability test of PPES gypsum board**
To confirm the chemical stability of the PBMS gypsum board, we carried out an FTIR analysis. The FTIR absorption spectra of the gypsum boards with PBMS contents are shown in Fig. 1. The PBMS consist of n-hexadecane, n-octadecane, and xGnP, and these materials are physically bonded. Therefore, the PBMS has the chemical properties according to the alkane chain of n-hexadecane and n-octadecane. The alkane is a saturated hydrocarbon. This means that PBMS has $-CH_2$ and $-CH_3$ bonding; we thus confirmed the chemical stability of the heat-storage gypsum board by monitoring the $-CH_2$ and $-CH_3$ peaks in the FTIR spectra of the PBMS. Also in this experiment, we fabricated the PBMS gypsum board by using hemihydrate gypsum. The hemihydrate gypsum used has a molecular formula of $CaSO_4 \cdot 1/2H_2O$. Therefore, the O-H stretching and bending bands, and the SO_4 stretching and bending bands exist in the hemihydrate gypsum. In the experiment, the FTIR absorption spectra of the PBMS gypsum board, with absorption peaks of 2962, 2926, 2872, 2855,
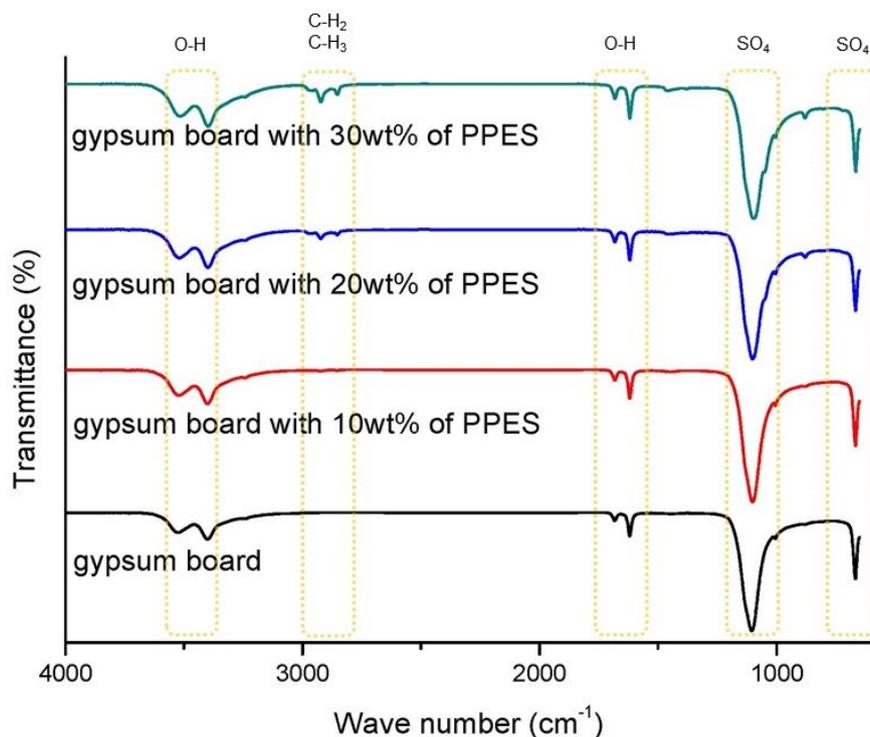
Figure 1. *FTIR spectra of the PPES and PPES gypsum board*
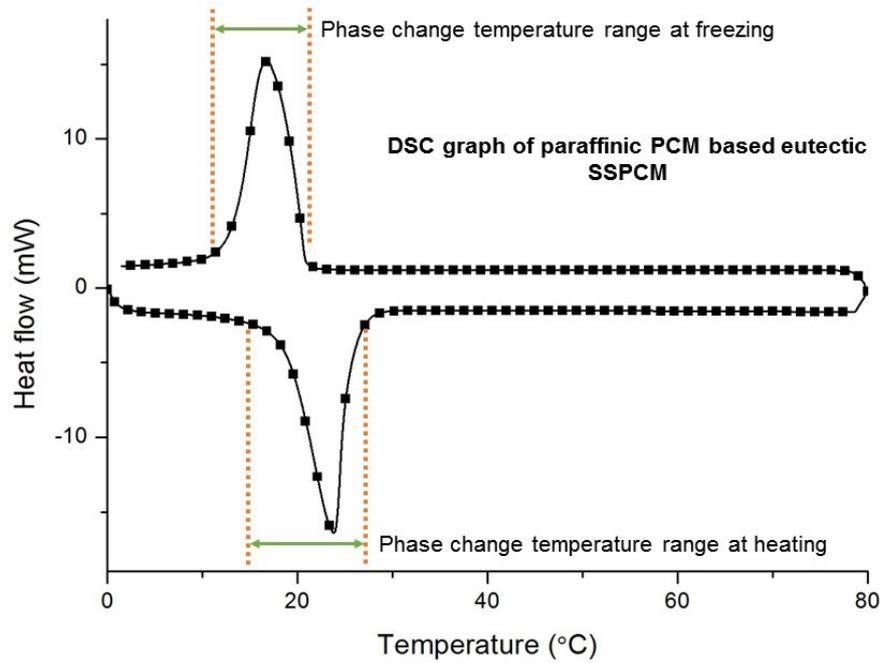
(a) PPES
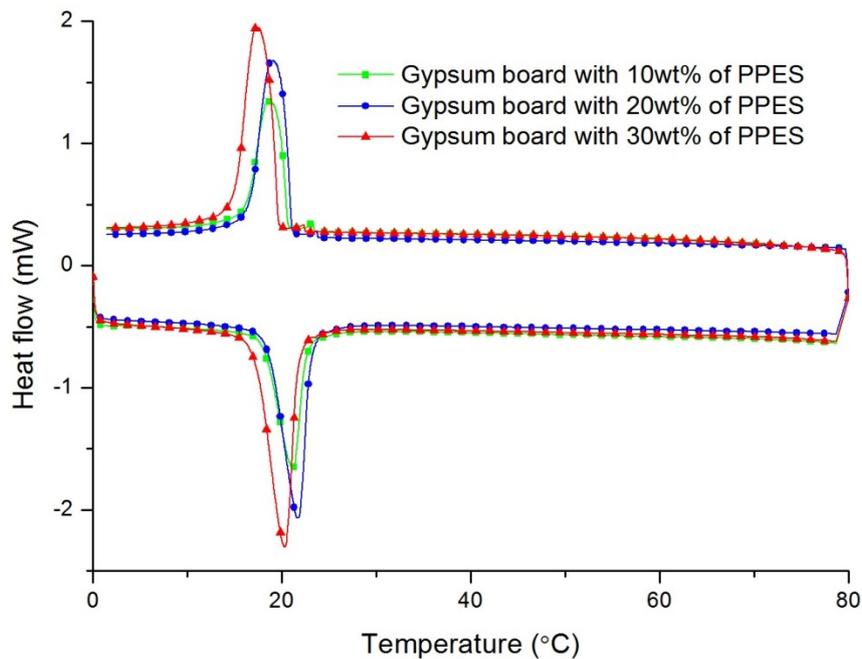
(b) gypsum boards with PPES

Figure 2. *Heat storage analysis of (a) the PPES and (b) the gypsum boards with PPES*

1377, and 720cm^{-1} were caused by stretching vibrations of the functional groups of the –CH2 and –CH3 bonding. In the FTIR spectra of the PBMS gypsum board, we confirmed that the PBMS gypsum board samples with high PBMS loading showed strong FTIR peaks at the aforementioned wavelengths. This means that the PBMS gypsum board with 30 wt% of PBMS has a high heat capacity in comparison with other gypsum boards. We also confirmed that the absorption peaks of 3548, 3492,

3407, 3245, 1684, and 1621cm^{-1} were caused by stretching vibration of the functional groups of the O-H bands. Also, in the FTIR spectrum analysis, an SO$_4$ functional peak also occurred at 1136, 639, and 617cm^{-1}. Consequently, we determined that the heat storage characteristics of PBMS could be maintained in the structure of the gypsum board due to its physical, rather than chemical bonding.

Heat storage capacity analysis of PPES gypsum board
Fig. 2 presents the heating and freezing curves from the DSC measurements of the PBMS and gypsum boards with PBMS. In the graph, the phase transition of PBMS occurred between 18°C and 28°C during heating, and the corresponding heat capacity was 94.80J/g. The solidification temperature range of this composite was reduced to between 15°C and 25°C, compared to the melting temperature. Its corresponding heat capacity was 93.53J/g. We also confirmed that the peak melting temperature and freezing temperature of PBMS is 23.85 and 16.95°C, respectively. The melting temperature of the prepared gypsum boards with PBMS showed 21.20, 21.70, and 20.31°C at loads of 10, 20, and 30wt% of PBMS, respectively. Also, the freezing temperatures of the prepared gypsum boards with PBMS were 18.69, 19.21, and 17.44°C at loads of 10, 20, and 30wt% of PBMS, respectively, similar to melting temperature of the prepared gypsum boards with PBMS. From the DSC analysis, we also confirmed that the latent heat capacity of gypsum boards with PBMS was large due to the high loaded PBMS amounts. The latent heat values of the heat storage gypsum boards were 13.63, 19.56, and 21.07°C during heating and 14.24, 20.21, and 21.56°C during freezing at loads of 10, 20, and 30wt% of PBMS, respectively. As a result, we confirmed that the gypsum board with PBMS has a high latent heat capacity and high thermal efficiency. Therefore, we expect that this high latent heat capacity of gypsum board with PBMS will have important potential for heating and cooling applications in various fields.
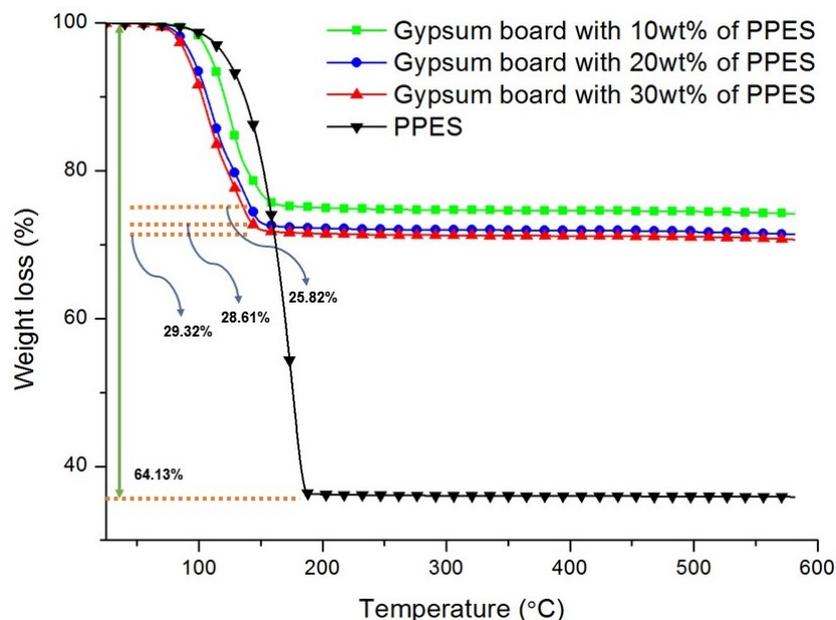
Figure 3. *Thermogravimetric analysis of the PPES and gypsum boards with PPES.*

Thermogravimetric analysis of PPES gypsum board

Fig. 3 shows the thermogravimetric analysis of the PBMS and gypsum boards with PBMS. From the thermogravimetric analysis, we found that PBMS has one curve of thermal oxidation degradation. We also found that the thermal oxidation degradation peak of the PBMS occurred at 175.80°C. Also, the gypsum boards with 10, 20, and 30wt% of PBMS showed peak temperatures of derivative weight of 125.58°C, 110.75, and 105.50°C, respectively. From the graph in Fig. 3, we observed that the mixing of PBMS and gypsum induced a reduction in the oxidation peak temperature of gypsum board with PBMS. However, the difference between each heat storage gypsum board is not problematic because the oxidation temperature ranges of each heat storage gypsum board are similar. Also, we determined that the thermal oxidation degradation of PBMS is 64.13% and the gypsum boards with 10, 20, and 30wt% of PBMS showed thermal oxidation degradation rates of 25.82, 28.61, and 29.32, respectively. As a result, the oxidation rate of gypsum board with high amounts of PBMS is greater than the gypsum boards with low amounts of PBMS because PBMS has relatively low thermal durability compared to the gypsum. From the analysis, the actual oxidation increase ratio of heat storage gypsum board is not as high as the loaded PBMS to gypsum. This means that the xGnP in the PBMS has high thermal durability property.

CONCLUSIONS

In this experiment, we prepared paraffin based mixed SSPCM and PBMS gypsum boards. The prepared PBMS was added to gypsum powder as a fine aggregate. We then prepared the SSPCM gypsum boards by mixing the PBMS and gypsum powder in water, and casting the mixture into a mold. The FTIR analysis showed that the properties of PBMS and hemihydrate gypsum had not changed after the preparation process; we thus determined that the heat storage characteristics of PBMS could be maintained in the structure of the gypsum board due to its physical rather than chemical bonding. In addition, we confirmed that the actual heat storage effect starts to occur after the 20wt% of loading amount of PBMS, and that the gypsum board with PBMS has high latent heat capacity and high thermal efficiency. From the TGA analysis, the oxidation rate of gypsum board with high amounts of PBMS is greater than the gypsum boards with low amounts of PBMS because PBMS has relatively low thermal durability compared to the gypsum. Consequently, we expect the PBMS based gypsum board to be useful in applications in various fields, due to its high thermal properties.

ACKNOWLEDGEMENTS

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