Smart heat storage building material development with Loess and SSPCM for building energy saving

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Abstract. This experiment aimed at the development of energy efficient and sustainable building materials. The specimens were made using loess, styrene butadiene latex (SBL), shape stable phase change material (SSPCM) made from x-GnP and n-octadecane for mechanical and thermal performance improvement. Compressive strength test, FT-IR (Fourier-transform infrared spectroscopy) and dynamic thermal transfer experiment were performed. From the result of the compressive strength test, it was found that the addition of SBL increases the compressive strength and the addition of SSPCM reduces the compressive strength. FT-IR analysis revealed no chemical reaction between PCM and x-GnP, indicating only physical binding. As a result of the dynamic heat transfer analysis, peak temperature reduction was observed. According to energy analysis, storage capacity energy was improved and PCM 7.5 was the most energy efficient.

1. Introduction
Energy saving and sustainable materials are one of the most important issues [1]. These issues are aimed at reducing carbon emissions and preventing global warming. Especially in the field of architecture, many efforts have been made to reduce building energy [2]. It is important to use materials that are environmentally friendly, sustainable and energy-efficient for building energy and carbon emission reduction. As an energy-efficient and sustainable material, loess has been used as an eco-friendly building material. And many of these studies are proceeding to develop the building materials of the loess [3]. However, it is structurally difficult to construct and maintain loess. Cracks and low strength are the structural disadvantages of the loess, which can be supplemented by structural latex [4]. The advantage of the high sensible heat of the loess is that it can meet the advantages of high latent heat of the phase change material and have more amplified performance. However, most phase change materials cause a decrease in strength when added to the binder. These disadvantages also need to be considered. Therefore, in this study, it was attempted to develop materials using phase change material and loess for the development of building materials with high sensible heat and latent heat and to develop new building materials with latex added to complement their structural weaknesses.

2. Materials and methods
2.1 Materials
Products of Dongbang Mortal Company was used for loess binder, which is produced in Gyeongbuk province, Korea. The composition of the loess binder contains 40% of natural loess, 35% of calcium sulfate and 35% of anhydrous gypsum. SSPCM uses x-GnP, a carbon material, and phase-stable PCM, which is a vacuum-impregnated n-octadecane, a paraffinic organic PCM. The latent heat of SSPCM is 113.5 J/g and the thermal conductivity is 1.363 W/mK. As structural latex, styrene butadiene latex (SBL)
used an emulsion type latex having a solid content of 48.5%, a viscosity of 130 and a pH of 9.7, and SB Latex ksl 362 product of Kumho Petrochemical Co., Ltd. was used.

2.2 Methods of experiments
2.2.1 Mechanical properties analysis. Compressive strength measurements were carried out in accordance with ISO 679 [5]. For the compressive strength measurement, three specimens were measured for each case and the compressive strength of the specimens after 28 days of curing was measured. The specimens were produced in sizes of 50mm × 50mm × 50mm. The measurement equipment was a universal gesturing machine (UTM) and the load-unloading speed was 20kN / min.

2.2.2 Morphological analysis. Microstructures were observed for morphological analysis. The microstructure of the material is related to the thermal properties deeply related to porosity and also to mechanical performance. Therefore, it was conducted for the interpretation of measurement results. Image analysis using Scanning Electron Microscope (SEM) was used for the microstructure analysis. Images were run to determine the microstructure of the specimens of the loess binder produced. Microstructural imaging was performed for H, L, PCM5. The specimens used for SEM were part of the specimens subjected to the compressive strength test and coated with platinum. The microstructure image was enlarged 500 times.

2.2.3 Analysis of binding characteristics. FT-IR analysis was performed to determine the chemical stability and bonding of the loess binder to the synthetic state. The analysis was carried out for H Case, which was made only with loam, L Case with SBL, and PCM_5 Case, which was added with SSPCM. The instrument was a Nicolet 6700 from Thermo Scientific of the United States and the wavelength range was set at 4000-650.

2.2.4 Evaluation of thermal performance. The heating and cooling behaviors of the adiabatic chamber were analyzed to compare the thermal behavior of the loess binder containing SSPCM with the loess binder without SSPCM. It is composed of an outer box and inner box to minimize the effect on the surrounding environment. The outer box was 400 mm x 400 mm x 400 mm, the inner box was 160 mm x 160 mm x 200 mm, and the heat insulator was installed to a thickness of 30 mm. After placing the specimen in the inner box, the hot water was flowed to the aluminum pipe at the lower part of the specimen using the constant temperature water tank, and the water passing through all the pipes at the lower part of the specimen was moved to the constant temperature water tank and the constant temperature was supplied. The temperature sensors were mounted on the upper and lower surfaces of the specimen using ThermoCouple (TC) type K and the temperature was measured once per minute using a data logger. In addition, the temperature of the air inside the outer box and the inner box was measured. The hot water supply temperature using the constant temperature water bath was set at 50°C and heated for 4 hours, and the temperature was measured for 6 hours for observing the heat storage effect due to latent heat after peak temperature. The experimental set up for thermal performance evaluation is shown in Figure 1.

Figure 1. Inner box of experimental set up for dynamic heat transfer
2.3 Preparing specimens for each experiment

Table 1 shows the mixing ratio of the loess agent for preparing the test pieces used in the experiment. First, SBL mixed with powdery loess and water is mixed for 1 minute using a stirrer at 1000 rpm. In the case of SSPCM-added specimens, loess and SSPCM were dry mixed at 1000rpm for 1 minute using a stirrer, and then mixed with SBL and water for 1 minute at 1000 rpm. The mixture was cured in a mold of 100 mm x 100 mm x 20 mm at room temperature for 6 hours to prepare a test specimen for a thermal performance test. After 6 hours, the mixture was taken out of the mold and cured at a temperature of 60 DEG C for 48 hours. The specimens for compressive strength were manufactured using the same process with 50 mm × 50 mm × 50 mm mold and cured for 28 days after the fabrication.

| Specimen | Loess (g) | SBL (g) | Water (g) | SSPCM (g) | W/L (g) | SBL/L (g) |
|----------|-----------|---------|-----------|-----------|---------|-----------|
| L        | 400       | 28.8    | 92        | 0         | 23      | -         |
| SBL      | 400       | 28.8    | 64        | 0         | 16      | 7.2       |
| PCM2.5   | 400       | 28.8    | 68        | 10        | 17      | 7.2       |
| PCM5     | 400       | 28.8    | 72        | 20        | 18      | 7.2       |
| PCM7.5   | 400       | 28.8    | 76        | 30        | 19      | 7.2       |
| PCM10    | 400       | 28.8    | 80        | 40        | 20      | 7.2       |

3. Results and discussion

3.1 Mechanical properties analysis

The average compressive strength of Loess was 6 MPa. The average compressive strength of Loess with SBL was 1.84 times higher than that of Loess case. This means that the compressive strength of the loess binder can be improved by adding SBL. It is generally known that adding SBL is known to cause a reduction in compressive strength. However, since the strength of loess is relatively less than 6 MPa compared to concrete, SBL can be considered to have a strength increasing the effect in a range of low strength. Compressive strength of SSPCM specimens is lower than that of SBL. For PCM 2.5 and PCM 5, compressive strength was 110 and 1.08 times higher than for Loess, and PCM 7.5 and PCM 10 were 0.9 and 0.88, respectively. The addition of the binder is determined that SSPCM can be prevented from being known to occur with reduced compressive strength, the strength is greatly decreased as compared to the compressive strength Loess reinforced by the addition of SBL.

3.2 Morphological analysis

Figure 2 shows SEM images of Loess, SBL, and PCM5. (a) shows the microstructure of the Loess, and it can be confirmed that hexagonal crystals are contained. It is judged that the amorphous material and CH crystals formed by the hydration process of anhydrite contained in the loess binder. This is the basis for judging that the hardening of the loess was caused by the hydration reaction. (b) shows the microstructure of the loess-SBL binder. (a) is larger than (b) and much can be seen. This means that SBL can be added to the loess binder to form cohesive forces between particles and reduce large voids. It also means that SBL can increase intermolecular connectivity in the microstructure to form more improved strength. (c) shows the microstructure of the loess-SBL-SSPCM binder. In (c), the amorphous structure includes SSPCM impregnated with PCM, and it can be seen that space is generated in the process including SSPCM. Therefore, it is considered that the incorporation of SSPCM into the binder degrades the cohesive force between the particles to lower the compressive strength.
3.3 Analysis of binding characteristics

Figure 3 shows the FT-IR measurement results of Loess, SBL, and PCM5. In the case of Loess and SBL, the peak of Loess remained intact and no specific peak change due to the addition of SBL was observed. This shows that the chemical bonding of the Loess binder due to SBL addition did not occur. PCM showed peaks at wavelengths 2910 and 1470 as compared to L and SBL, indicating that the added peaks of PCM5 reacted at the typical peaks of n-octadecane, C-H2, and C-H3, which maintained the n-octadecane peak it means. Other peaks of n-octadecane were not observed closely because of the strong peak of the loess binder, but the other intrinsic peaks of n-octadecane remained intact and could be judged to represent only physical fusion in all cases.

3.4 Evaluation of thermal performance

Figure 4 is a graph of the temperature of each specimen varied by the heat supplied by the constant-temperature bath at the positions of TC (1), TC (2) and TC (3). In case of TC (1), a peak delay due to the heat storage action of SSPCM is observed from the operation of the thermostatic tank for the initial 30 minutes. In addition, we can see that the peak temperature of the specimen decreases due to SSPCM incorporation. The temperature rising of the SSPCM-added test specimens at the initial stage of the experiment was gradual, and the temperature increase was delayed due to the phase change. The maximum temperature difference is about 10.5%, which is determined by the influence of SSPCM. For TC (2), which is directly adjacent to the heating temperature, the peak temperature for PCM10 decreased by 6.9% to 45.98 °C of Loess. In the case of TC (3), which is the room temperature of the internal insulation box, the peak temperature ofPCM10 decreased by 10% from 39.83 °C to 35.87 °C.
From the point of view of peak temperature reduction, it can be concluded that PCM10 is the most effective peak temperature reduction.

Figure 4. Dynamic heat transfer change of each TC position, (a) TC1, (b) TC2, (c) TC3

Figure 5 is the heat flux calculated by the heat flow measured by the thermal flowmeter and the thermal change measured by the temperature sensor. The heat flux is calculated by the following equation (1).

\[ \varphi(t) = U_{\text{specimen}} \times \Delta T \]

\( \Delta T \) is the value of the temperature and the temperature difference between the top and bottom of the specimen. It can be seen that the rise and fall of the heat flux of SSPCM at the beginning of the experiment is higher than that of Loess and SBL due to the temperature change and the phase change period. In addition, the decrease in slope in the section indicated by the heat absorption in Fig. 5, is confirmed to be due to the heat storage and phase change due to the SSPCM. PCM 2.5 was 1.8 minutes, PCM 5 was 7.2 minutes, PCM 7.5 was 11.4 minutes, PCM 10 was 7.2 minutes, and PCM 7.5 was the longest. Case SBL exhibits a lower heat flux than Loess and exhibits similar heat flux values after the temperature stabilizes. This means that the heat capacity of the loess binder containing SBL is reduced. Unlike Figure 4, after 6 hours, the points of all the specimens converged to almost zero. Therefore, the heat flux trends up to 6 hours were analyzed, and energy accumulated up to 6 hours was compared.

Figure 5. Heat flux for each specimen

The amount of energy can be calculated using the heat flux and unit time that travels in unit area. Energy can be calculated using the following equation (2).

\[ E(t) = \int_0^t (\varphi_0 - \varphi_t) \, dt \]  

[35]  

Figure 6 shows the energy analysis results. The total amount of energy during storage was the highest at 71.42 in PCM 7.5 and lowest at 57.48 in SBL. This means that the incorporation of SBL can degrade the thermal performance of the loess binder. However, H showed energy of 57.48 when stored, which is significantly lower than that of PCM7.5, which means that the energy performance can be improved by adding SSPCM and SBL simultaneously.
Figure 6. Stored energy of each specimen

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