The Effect of Adding Shape Stabilized Phase Change Material on The Mechanical Properties of Mortar

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Abstract. This paper is attempted to develop energy storing cement mortar by integrating phase change material (PCM) in the cement mortar. Phase change materials (PCM) are materials with high latent heat. Solid–liquid PCM can store latent heat as it melts and the energy restored as the PCM solidifies. The benefits of thermal energy storage in the building are to reduce indoor temperature variation, and delay maximum indoor air temperature to off-peak electricity demand period which will reduce the energy consumption in buildings interiors. In particular, thermal energy storing shape stabilized phase change materials (SSPCM) integrated cement mortar was developed. Shape stabilized phase change materials is a composite material. SSPCM is made of PCM and supporting material in which the PCM is dispersed in such as (high density polyethylene etc.) to form a stable composite material. A polymeric matrix fixes the PCM in a compact form, even after its melting. The SSPCM can keep its shape as the PCM changes from solid to liquid and suppresses leaching. In this paper paraffin wax was used as phase change material and high-density polyethylene as a supporting material. Cement mortar cubes were prepared with SSPCM to evaluate the compressive strength of the cement mortar with PCM. The results showed that the presence of SSPCM lowered the compressive strength of cement mortars.

1. Introduction

As reported by the International Energy Agency (IEA) statistics, the annual energy demand increases by about 2.3% [1]. Many reasons has led to the energy use increment such as economic growth, industrial developments, and population growth. Moreover, as global temperature rises and the household incomes increase around the world a strong air conditioning growth is expected. Electricity consumption increases on hot days which is drives from using air conditioning, fans and other substitutes. Throughout summer days, peak electricity consumption is from 12 pm to 6 pm. Shifting some of the electricity demand to off beak time brings significant economic benefits. PCM use is advantageous as it allows storage of latent heat in addition to sensible heat, because the PCM material undergoes a phase change during the expected heating cooling cycles, and it provides a larger heat capacity over a small temperature range by storing heat at nearly constant temperature. PCMs store 5-14 times more heat per unit volume than sensible heat storage in water, masonry or rock [2]. PCM use in building materials has gained more attention as is borne out by the following studies. Cabeza et al [3] tested the compressive strength and tensile splitting strength of PCM-concrete after 28 days. They reported that the compressive strength was 25 Mpa and tensile splitting strength was 6 MPa. These
results mean that the prepared PCM-concrete is applicable for some structural application. Xu, Biwan, and Zongjin [4] developed cement based composite with thermal energy storage capability by integrating paraffin-diatomite PCM. The PCM was integrated (10, 150, 20, and 30) %, by weight of cement. It was found that the reduction in compressive strength was 48.7% while the reduction in flexural strength was 47.5% after 28 days. Cui et al [5] produced a graphite-modified MPCM-cement mortar composite with heat storage ability and reasonable mechanical strength. The results indicated that adding the PCM to cement mortar reduced the compressive and flexural strengths of cement mortar but they were still applicable to be used for thermal energy storage in buildings and as functional building materials with 20% PCM by weight of cement. Lecompte et al [6] mixed up 29% in volume micro encapsulated PCM with concretes and mortars. They measured thermal and mechanical properties of the composite and compared with classical civil engineering models. It was found that PCM-mineral matrix composite have an acceptable mechanical strength with a good effect on walls thermal characteristics. Cunha et al [7] characterized fresh and hardened PCM-mortars based in different binders which were aerial lime, hydraulic lime, gypsum and cement. Different contents of PCM were used ranging from 0 to 60 % for each type of binder. It was observed that the integrating PCM in mortars affected mortar properties such as workability, microstructure, compressive strength, flexural strength and adhesion. Ramakrishnan et al [8] partially replaced fine aggregate by composite PCM (paraffin and hydrophobic expanded perlite) ranging from 20-80% in ordinary cement mortar. The results indicated that the developed composite has remarkable thermal characteristics with adequate mechanical properties.

In this paper, the integration of latent heat storage system by using organic phase change materials (PCM) in cement mortar with the intent of reducing the energy consumption in buildings was studied by developing thermal energy storing shape stabilized phase change materials (SSPCM) integrated cement mortar. The main goal of this work is to investigate the effect of adding shape stabilized phase change materials on the compressive strength of cement mortar.

2. Experimental

2.1. Materials

Technical grade wax with a melting point of 60 °C was used as phase change material and a pellet form high density polyethylene (HDPE) with a softening temperature of about 120 °C was used as supporting material. To prepare mortar, a Portland cement, sand and water were used.

2.2. Preparation of Shape Stabilized Phase Change Materials (SSPCM)

In this study the following steps were used in shape stabilized phase change material (SSPCM) preparation process: SSPCM mixture materials were weighted according to their percentage in the mixture which was 60% PCM, 40% HDPE. The SSPCM mixture percentages were chosen as 60% PCM, 40% HDPE according to Biswas and Abhari, [9]; Tajul, [10] results. They found that high density polyethylene can trap up to 70% wax without leakage. More HDPE was added in order to prevent leakage of the wax during phase change. The high density polyethylene was melted in a pan using Oster single burner. After whole HDPE has been melted, the wax was added gradually and mixed manually with the melted HDPE. Small amount of wax was added each time. During this process the burner temperature should be reduced during the addition of wax because of the high flammability of the wax. Manual mixing was continued until the mixture was pure and uniform. The mixture was casted into thin sheet using two flat plates by pouring the mixture between two sheets of parchment paper and left to cool down and solidify.

2.3. Preparation of mortar with shape stabilized phase change material

The mortar- shape stabilized phase change material was prepared as follows: The shape stabilized phase change material (SSCM), prepared as described previously, was grinded into fine powder. Portland cement, sand, water, and SSPCM powder were weighted according to their percentages in the mixture.
The shape stabilized phase change material were mixed properly. The mixture was casted in 50 mm x 50 mm x 50 mm cubical mold, Figure 1, and it was kept in the mold for 24 hours. After 24 hours, mortar cubes were removed from the mold, Figure 2. The mortar cubes were immerse in water for 2, 7 and 28 days. Table 1 illustrated the weights of mortar SSPCM mixture. Water was added by 0.4% of cement weight.

Table 1: Weights of mortar SSPCM mixture.

| Sample code | Cement (g) | Sand (g) | SSPCM (60% PCM-40% HDPE) (g) | Sample content ratios |
|-------------|------------|----------|----------------------------|-----------------------|
| M1          | 250        | 750      | 0                          | 1C, 3S, 0 SSPCM       |
| M2          | 250        | 700      | 50                         | 1C, 2.8S, 0.2 SSPCM   |
| M3          | 250        | 675      | 75                         | 1C, 2.7S, 0.3 SSPCM   |
| M4          | 250        | 600      | 150                        | 1C, 2.4S, 0.6 SSPCM   |

2.4. Melting temperature using Differential Scanning Calorimetry
This test method involves heating (or cooling) a test specimen at a controlled rate in a controlled environment through the temperature region of fusion or crystallization. 60±5 mg of wax was weighed into a clean, dry specimen capsule. The specimen capsule was sealed with a lid under ambient conditions. The specimen was loaded into the instrument chamber. Required calibrations was first performed. Measurements were performed at a 1 °C/min heating rate and temperature ranges of 0 °C to 90 °C.

2.5. Mechanical characterization
To evaluate the effect of shape stabilized phase change material on mechanical strength, compressive strength values of the 50 mm x 50 mm x50 mm samples were measured after 2, 7, 28 days of
maturation. The compressive strength was done according to ASTM C109-02 [11]. For each mix, three samples were tested. The average compressive strength value of the three samples was calculated.

3. Results and discussion

Differential scanning calorimetry (DSC) was used to measure the phase change temperature. The differential scanning calorimetry (DSC) curve of paraffin wax is presented in Figure (3). It can be seen from Figure (3) that paraffin wax has main phase change peak. The sharp or main peak near 60 °C represents the solid–liquid phase change of paraffin wax. The phase change peak of the wax will still exist after mixing wax with HDPE because there is no chemical reaction between HDPE and wax [12, 13].

![DSC curve of paraffin wax](image)

The mechanical properties of cement mortar with shape stabilized phase change material was obtained by testing the compressive strength. Figures 4, 5, and 6 show the compressive strength of cement mortars with SSPCM after 2, 7, 28 days of maturation.

![Compressive strength graph](image)
As shown from Figures 4, 5, and 6, the presence of SSPCM lowered the compressive strength of cement mortars. This result agreed with Lecompte et al [6] and Hunger et al [14]. The compressive strength loss can be due to many reasons. The presence of SSPCM increases the water required to assure the same strength at fresh state because of the higher absorption of water by PCM as compared to sand. Which was estimated by Lecompte et al [6] around 10% in mass increment. The SSPCM can act as lubricant or it can behave more like voids which reduces the compressive strength of mortar. In addition the reduction may be due to poor interface compatibility. The presence of SSPCM as partial replacement of sand reduces the weight as shown in Figure 7.
4. Conclusions

This project deals with the study of compressive strength of cement mortar with shape stabilized phase change material as partial replacement of sand. Based on the experimental investigation, the following conclusions can be drawn:

Modified method was used to prepare shape stabilized phase change material which can be used for research purposes because the traditional method to prepare SSPCM needs special type of extruder which may not be available in research labs. According to DSC curve the paraffin wax has main phase change peak. The sharp or main peak near 60 °C represents the solid–liquid phase change of paraffin wax. The presence of SSPCM lowered the compressive strength of cement mortars, which may be due to many reasons such as poor interface compatibility.

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