Int. J. Nanoelectronics and Materials **9** (2016) 133-142

The effect of phase change material on thermal energy storage in cement layers

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Received 28 Jan. 2015; Revised 24 March 2015; Accepted 18 Oct. 2015

Abstract

Due to the increase in weather temperatures during the last decade, the demand for refrigeration and air conditioning have been increased. The building and house wall-covering material can be used as heat storage material for economic advantage over conventional cooling devices. The phase change material PCM can be implemented in wall-covering material as a thermal storage and to become a part of the building structure. PCM is one of the latent heat material having low temperature range and high energy density of melting-solidification compared to the sensible heat storage. Two laboratory experimental cement samples are tested by using thermocouple junctions at the same external thermal load and outer ambient temperatures. The comparison of transient measured temperatures between treated and non-treated cement samples with PCM have been investigated. The study indicates that the transient measured temperatures in treated sample are lower than in non-treated sample about (7.93% to 9.67%) at the same junction position for the two samples. The results have shown that the use of PCM in covering building has significant advantages for thermal storage component in wall structure.

Keywords: Phase Change Material; Latent Heat Storage; Cement Layers; Temperature Measurements; Energy Storage.
PACS: 91.60Hg, 05.70Ce, 07.20Dt, 84.60Ve

1. Introduction

As the demand for air conditioning increased greatly during the last decade, large demands of electrical power led to a surge of efficient energy application. Electrical energy consumption varies significantly during the day and night according to the demand by industrial, commercial and residential activities. The hot climate countries as in Arab gulf especially in Iraq country, the major part of the load variation is due to air conditioning. Better power generation, distribution magnitude and significant economic benefit can be achieved if some of the peak load could be shifted to the off-peak load period. All that can be achieved by thermal energy storage for cooling in residential and commercial building establishments. The wall covering material is capable of capturing a large portion of the solar radiation incident on the walls or roof of a building. The solar energy radiation that reaches the wall is absorbed by the PCM which is buried in the wall envelope. In the literature, development and testing were conducted for prototypes of PCM wallboard and PCM concrete systems to enhance the thermal energy storage (TES) capacity of standard gypsum wallboard and concrete blocks, with particular interest in peak load shifting and solar energy utilization. Stritih and Novak [1] designed an experimental wall which contained black paraffin wax as the PCM heat storage agent. In his work the stored heat was used for heating and ventilation of a house. The results of this work, according to the authors, were very promising. Mehling et al [2] it was shown that (PCMs) can be combined with wood-lightweight-concert and that the mechanical properties do not seem to change significantly. The authors reported many advantages on thermal properties and reaches to calculation when incorporation of PCM which increase the thermal storage capacity, to get lighter and thinner wall elements with improved thermal performance. R. Velraj, A. Pasupathy [3] presented a detail study on PCM incorporation in building material. PCMs integration with building architecture for space heating and cooling. Its results showed that the thermal improvements in a building due to the inclusion of PCM, depend on the melting temperature of the PCM, the type of PCM, the percentage of PCM mixed with conventional material, design and orientation of the construction of the building. The optimization of these parameters is fundamental to demonstrate the possibilities of the success of the PCM in building materials. Christopher K. and Nicholas W.[4] explained the use of PCM impregnated in plasterboard (lightweight construction) for various fusion temperature of the PCM during night, day, and weeklong test durations in hot weather conditions. Also mentioned that the peak temperature can be reduced by (3-4^{o}C),and hours over 24^{o}C can be reduced by (80%) in commercial buildings with moderate heat load, the peaking cooling load can be reduced by (20-25%) cooling to 22^{o}C or by (50-80%) if cooling to 24^{o}C.J. Rose et al [5] described the comparisons between laboratory measurements on a specific building component containing PCM and the results obtained with the developed simulation model. Also, it presented some simple calculations and a detailed case study. In used method, it is implemented a simple validation based on comparisons to laboratory measurements. The manufacturing techniques, thermal performance, applications of gypsum wallboard and concrete block, which have been impregnated with PCMs, have been presented and discussed by Khudhair and Farid, [6]; Zalba et al., [7]; Hauer et al. [8]. The present paper describes an experimental procedure for temperature measurements in two samples, one of them treated by (25%) volume PCM (Paraffin wax). The obtained results of comparison temperature between two samples satisfying that treated sample can be used as thermal storage component in wall building structure.

2. Experimental setup

The description of experimental setup is shown in Fig. 1. The experimental works of this study investigate the inclusion of PCM in concrete and its effects on temperature measurements. Two models sample of cement material has been manufactured and tested. The experimental models with same thickness, as in the actual, envelope the Iraqi wall parts of the building or house components. Each sample insulated by wood frame around its external thickness. The wood frame has a thickness of (1 cm). The gap between the sample and the wood frame is filled by wool. The cement composite will be cast in wood mold.

2.1 Experimental Models

The first sample is a non-treated cement layer (NCL) as shown in Figure 1.a, and consists of a traditional cement layer of the real Iraq wall which covering the outer cement surface without PCM. The dimension of the sample is (30cm×30cm) with (3cm) thickness. In a middle point of the sample (and along its thickness) seven thermocouples K-type were fixed to measure the temperatures distribution along the sample thickness in x-direction. Table 1 details the distances of thermocouples location from thermal load surface. Figure1.a, shows all dimensions and thermocouples distribution of a sample (NCL). Fig. 2, displays the pictures of the experimental layout. The contents of the sample-1 are illustrated in Table 2. The second sample is the treated cement layer (TCL) has the same dimensions of sample-1 except that the cement layer is divided into three sub-layers which are forming this model. The first sub-layer is the external layer, its thickness (5mm), which is covering the second sub-layer (treated layer) and exposed to the external thermal load. The second sub-layer is the treated layer. Its thickness (20mm) and (25%) of its volume were PCM (represented by paraffin wax) with grain size (2mm ~3mm). The properties of the used paraffin wax are given by Table 3 [7].

Table 1: Thermocouple locations in samples

Symbols of Thermocouple location	Distance from load surface (mm)
TC1	0
TC2	5
TC3	10
TC4	15
TC5	20
TC6	25
TC7	30

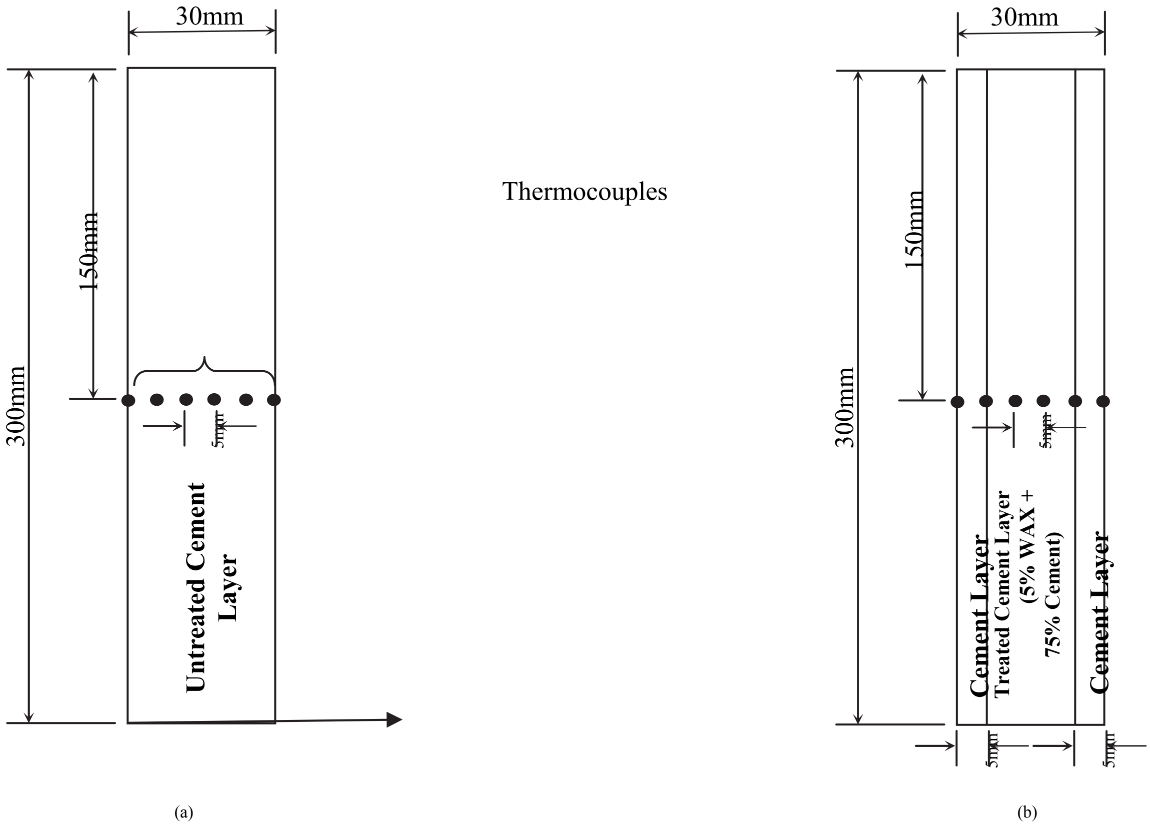

Fig. 1: The dimensions of two samples

The third sub-layer is (5mm) thickness of cement without PCM covering the treated layer from internal side. The dimensions and thermocouples junction nodes distribution of sample-2 (TCL) shown in Fig. 1.b, with same distances between the thermocouples junction as in Table 1.The contents of sample-2 are explained in Table 4. A lamp of 1000W lit on one side of the sample for (170 min.) through the test of heating phase.

Table 2: Mass and volume for sample-1(NCL)

Volume $_{Total}$ (m^3)	Cement (kg)	Sand (kg)	Water (l)
0.0027	1.62	4.86	0.324

Table 3: The material Properties of technical grade paraffin [7]

Paraffin	
Density solid/liquid 15/70 °C (ρ) kg m^{-3}	789 /750
Heat conductivity solid/liquid (k) Wm^1K^{-1}	0.18 /0.19
Heat capacity solid/liquid (cp) $KJkg^{-1}K^{-1}$	1.8 / 2.4
Volume expansion at ΔT=20 °C, %	4.9
Heat storage capacity melting ΔT=30 °C,Jkg^{-1}	175066
Heat storage capacity solidification ΔT=30 °C, Jkg^{-1}	187698

Table 4: Sample-2 (TCL) dimensions and masses contents

Layers No.	Volume (m^3)	Thickness (mm)	Paraffin mass (kg)	Cement mass (kg)	Sand mass (kg)	Water (L)
1	0.00045	5	0	0.27	0.81	0.054
2	0.0018	20	0.355	0.81	2.43	0.162
3	0.00045	5	0	0.27	0.81	0.054
Total volume (m^3)	0.0027					

2.2 Measurement Devices

The K-type thermocouples were used with corresponding K-type selector switch has been connected, K-type microprocessor digital thermometer made by (P.A. Hilton ltd.) to measure the temperature directly. The thermocouples were calibrated against two reference temperatures, with standard thermometer reader at freezing and boiling of pure water temperature. An error of less than (0.5%) was observed. The junctions were fixed and embedded into the cement layer guarantee good stability of readings. A period of (375 min.) was used as a time testing for each sample, the time step is 10 min. for each reading, i.e., therefore we need (35) reading for all nodes in heating and cooling phase.

(a) **(b)**

Fig. 2: The pictures of experimental setup

3. Results and Discussions

In this section the experimental results will be presented and discussed, focusing on temperature data of the heating and cooling phases. The transient temperature reading of all thermocouple junctions have been obtained as results of measurements. The measurements are recorded in two phases. The first one is the load phase (heating phase), when a 1000W lamp lit on one side of the sample for (170min.) period of time. The second type of measurements started after (170min.), when a lamp is turned off the cooling phase is started. Figure 3 and 4 show the nodes temperatures for seven thermocouple junctions as a function of time in two phases. The curves give the behavior of temperatures with time for each sample. TC1, represents the thermocouple junction at load surface, which is reading a higher temperature, but TC7 is the thermocouple junction at other side surface which gives a lower temperature through the test.

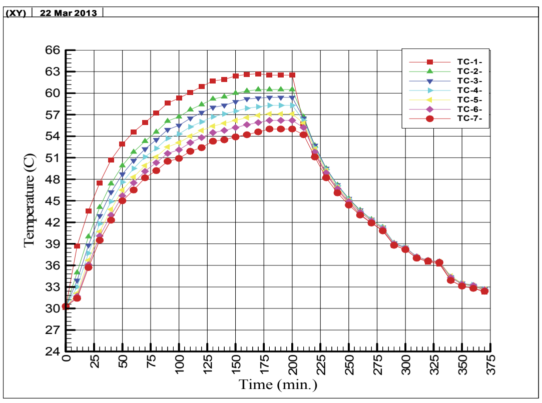

Fig. 3: Temperature distribution of heating and cooling phases for sample-1-.

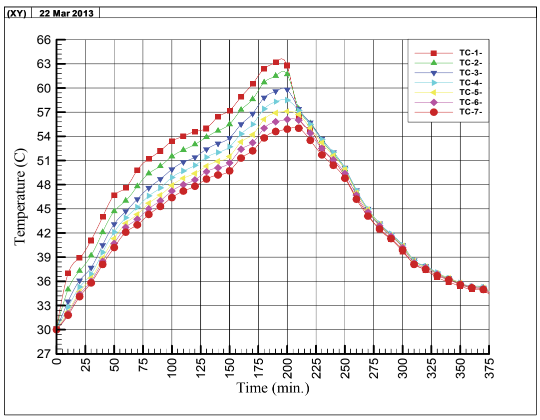

Fig. 4: Temperature distribution of heating and cooling phases for sample2-.

Figure 5 to 10 show the comparison of measured temperatures between the two samples in heating phase. In all above figures the curves of measured temperatures in sample-2 are lower than the curves of measured temperatures of sample-1. This behavior indicates that the PCM in treated sample (sample-2) starts for melting after 30^{o}C, therefore, the heat is charged in this sample with constant temperature at points where the paraffin wax was existed. Because the thermocouple location is not in pure PCM but in the mixture of cement with PCM, then the reading temperatures in sample-2 gives a gradually increase which was not at constant rate and less than as in sample-1. The reason of these phenomena is mainly due to the phase change processes of the PCM in (TCL). Comparing the thermal load period with the weather data for Baghdad city during July as given in [10] indicated that, the maximum period of solar load was in limit of time between (12:30 to 15:30) hrs, i.e., three hours' time period. Certainly, after this period the solar load will be decreased in actual weather conditions. But the samples under test were exposed to continuous thermal load from the lamp about (3hrs). The figures indicate that, in sample-1(NCL) the measured temperatures between (55 ~62^{o}C) at the time (140 min.) and between (55~63^{o}C) at the time (160 min.), but in sample-2 (TCL) the measured temperatures between (50~ 56^{o}C) at the time (140 min.) and between (52.5~58^{o}C) at the time (160 min.), this results of differences in temperatures between the two samples shows that, the (TCL) can be reduced the temperature value from (7.93% to 9.6%) of the original temperature in (NCL). The reduction in temperatures is due to the latent heat of PCM in (TCL) when changing from solid state to liquid state. So the (TCL) sample can be used as thermal storage layer of heat when compared with (NCL) sample. The reason that results compared just for (160 min.) in the present study was due to that curves of TCL were starting to increase gradually at (150 min.). The increase in temperature at (150 min.) is due to that PCM was not saving in small capsules or container to protect them, then the liquid was spreading or diffusing in concrete material at this time. This diffusion was causing the increase in temperature after (150 min.) in sample-2- especially at TC3, TC4 and TC5 in the treated layer.

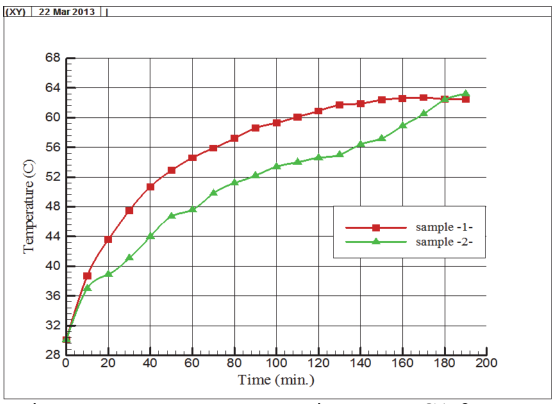

Fig. 5: Temperature comparisons at TC1 for two samples in heating phase.

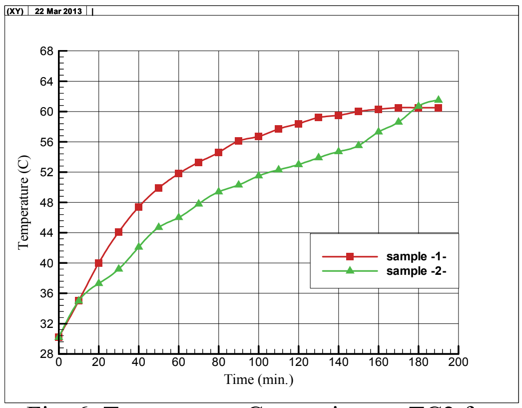

Fig. 6: Temperature Comparison at TC2 for two samples in heating phase.

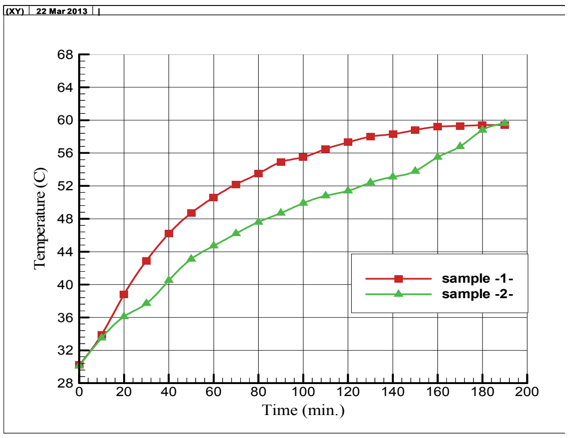

Fig. 7: Temperature Comparison at TC3 for two samples in heating phase.

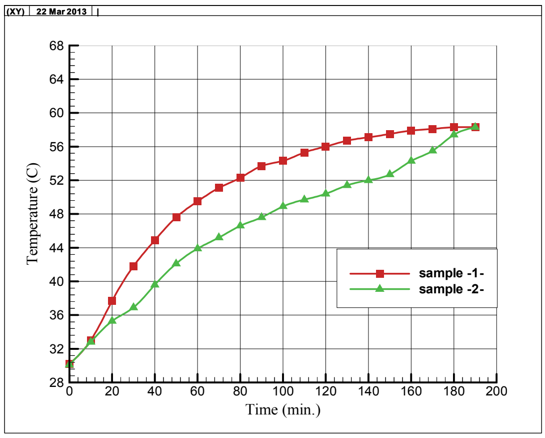

Fig. 8: Temperature Comparison at TC4 for two samples in heating phase.

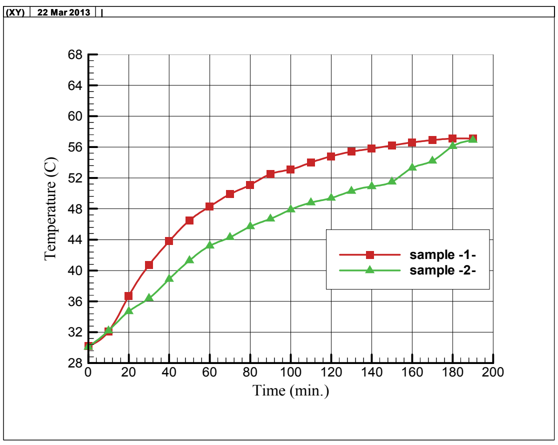

Fig. 9: Temperature comparison for TC5 for two samples in heating phase.

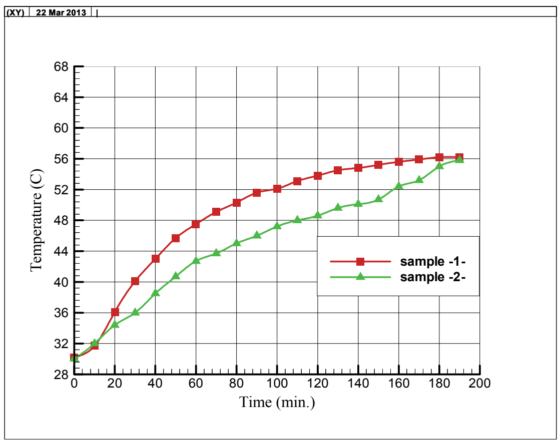

Fig. 10: Temperature comparison for TC6 for two samples in heating phase.

Figure 11 shows the surface temperature (TC7) on the other cold side of the two samples. This figure shows (3.4^{o}C) differences in temperature between NCL and TCL, with is in excellent agreement when compared with the theoretical and experimental results for the two models with [10] and [11]. Figure 12 and 13 show the temperature comparison of TC3 and TC4 in two samples for cooling phase after the lamp is shutoff at (190 min.). The temperature decreases to (32.6^{o}C) in NCL and to (34^{o}C) in TCL sample just when stopping the reading of temperature since the total time = 375 min.

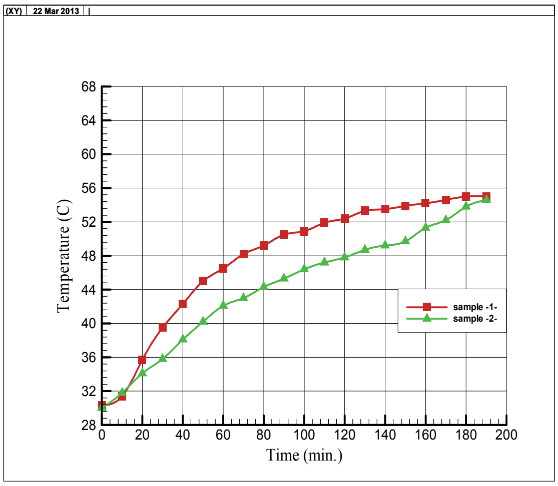

Fig. 11: Temperature comparison at TC7 for two samples in heating phase.

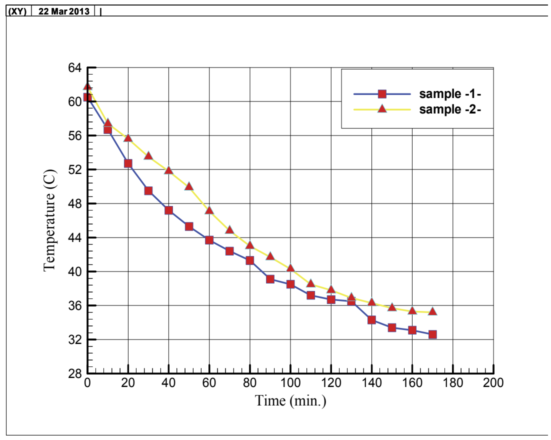

Fig. 12: Temperature comparison at TC3 for two samples in cooling phase.

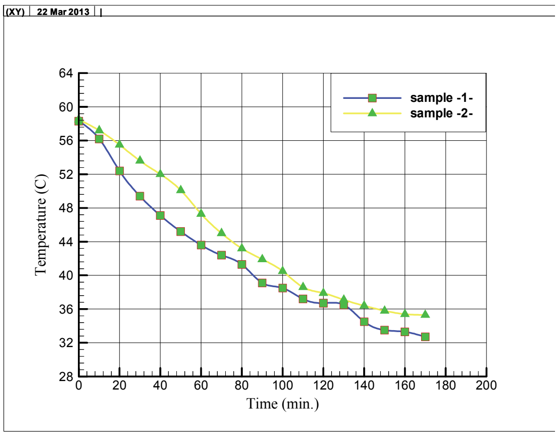

Fig. 13: Temperature comparison at TC4 for two samples in cooling phase.

This fact testify that the TCL was charging in heat more than the NCL sample and finally gets higher in temperature for discharge period. Finally, all the above results confirm that the TCL store the heat more than NCL when the two samples are at the same dimensions and are exposed to the same external thermal load.

4. Conclusion

This paper describes experimental results concerning the effect of PCM included in cement layers. The variation in measured temperatures with two different samples is studied. The measured temperature in treated sample with PCM was compared with non-treated sample in heating and cooling phases. The TCL is charging through the period of heating phase with temperature less than that in NCL. The obtained results confirm that, the heat storage in TCL is much more than in NCL; the measured temperature in TCL was found higher than the measured temperature in NCL at the end of cooling phase. Due to difficulties of setting the PCM in the envelope of the building material, the concept of encapsulation of PCM in a thin membrane of thermoplastic polymer will be used to allow a practical mixing with concrete for the outer layer of the building.

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