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EFFECT OF PCMS ON MECHANICAL PROPERTIES OF HEAT CURED MORTAR

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Abstract: Using phase change materials (PCMs) in cement mixtures has become an interesting area of research in the recent decade. PCMs have the abilities to enhance cement mixtures properties like thermal capacity and thermal resistance. In this study, microencapsulated PCMs incorporated in mortar mixtures at a rate of 3%, 6%, and 12% as a replacement of sand at exposed to normal and heat curing. Fresh and mechanical properties including flow table and compressive were evaluated for all mixtures under various curing conditions. Results indicated that the addition of PCMs would affect the development for different tested mixtures. The higher the added dosage, the great the effect.

INTRODUCTION

Several materials used in the construction industry such as wood, steel and cement based. Cement based mixtures are the most used among all other construction materials. Massive construction seasonal projects have placed a big demand on the production of the concrete elements. Precast elements are the most common and needed in the market, following the designs, satisfying the specifications, and for the sake of time saving too. The production of such elements consumes a lot of energy during the curing process, tight production schedules, and the need to reuse of the molds. Raising the heat and maintain a relatively humid environment in order to accelerate the hydration process and advance the strength gaining to a certain level.

Heating up for curing is the costly part of the process. Researchers have investigated the procedure of curing along using different types of mixtures. Its reported that strength development of the steam cured specimens where always higher than that for control specimens that kept under normal conditions. (Ramezanianpour, 2013). On the other hand, excessive temperature effect reported to be negatively affecting the hydration process and the strength development at early ages, and reported to cause delayed ettringite formation at later ages. In addition, one of the methods of the accelerated curing is carbonation, this method consists in the utilization of the exothermic reaction between carbon dioxide (CO_2) and the calcium compounds in the cement.

Curing process is all about the hydration; for heat curing, the typical accelerated heat curing cycle consists of initial set in a controlled environment is needed for the specimens to gain some strength and for the handling. Increasing the temperature of the surrounding environment around specimens to a certain level (Ramping), which will accelerate the hydration process and strength gaining. Then holding period for the product to gain the required strength. Afterwards, cooling period, the temperature again decreased to the normal room temperature (noting that increasing and decreasing the temperature happens gradually). One of the limitations is reaching high curing temperatures, excessive temperature (more than 60Co to 70Co) will result in a non-uniform distribution for the heat among specimens, which will affect the strength gaining and hydration process negatively. (Kosmatka,2011). Other limitation that could affect the production is the sudden drop in environment temperature while moving the precast elements to the site, after curing finished specially in cold temperature regions; which will affect the continues hydration process accordingly (Nassif, 2013)

Enormous amounts of raw materials are consumed along with producing several pollutions increase the ecological and environmental impacts of energy production. Hence, heat curing has relatively high price. Incorporation of phase change materials can be a solution. Phase change materials (PCM) known for its abilities to store and release heat at certain temperatures, which can be utilized in reducing the amount of heat consumed during the curing process. (de Gracia A, 2015). Were PCM will provide the heat back to the medium. Moreover, adding different PCMs protect the precast element even after the curing by incorporation of a low phase transition temperature PCMs in the mixtures, which will start absorbing and storing the heat in at low temperatures. On the other hand, a limitation reported in the literature review for some loss of mechanical properties comes from the inclusion of such materials with cement mixtures should be considered, which was reported to be up to 20% replacement of sand by volume without significant loss in the strength for the structural applications. (Meshgin, 2012)

Hence, in this study the incorporation of the phase change materials in the mixtures to reduce/eliminate heat curing investigated. Microencapsulated phase change material from were used as sand replacement in mortar mixture with the percentages of 3%, 6%, and 12%. PCM The hydration process will be studied and the effect of the selected PCM with several percentages as sand replacement will be investigated under different curing conditions. Temperatures will be monitored and mechanical properties will be tested along with the process.

Experimental Program

Materials

General use (GU) hydraulic cement according to the CSA-3001-03 was used as the binding material. Table 1 shows the chemical composition for the used cement. The used fine aggregate was a natural riverside sand with a fineness modulus was 2.70 according to ASTM C136 (2014), specific gravity and water absorption of 2.51 and 2.73% determined by ASTM C 128 (2015), respectively. Sieve analysis for fine aggregate meet ASTM C33 (2018) as illustrated in Fig. 1.

Table (1) Chemical and physical properties of cement

		OPC [1]
SiO_2	(%)	19.80
Al_2O_3	(%)	4.90
CaO	(%)	62.30
Fe_2O_3	(%)	2.30
SO_3	(%)	3.70
Na_2O	(%)	0.34
MgO	(%)	2.80
C_3S	(%)	57.00
C_2S	(%)	14.00
C_3A	(%)	9.00
C_4AF	(%)	7.00
Na_2Oeq	(%)	0.87

Loss on ignition	(%)	1.90
Specific gravity	--	3.15

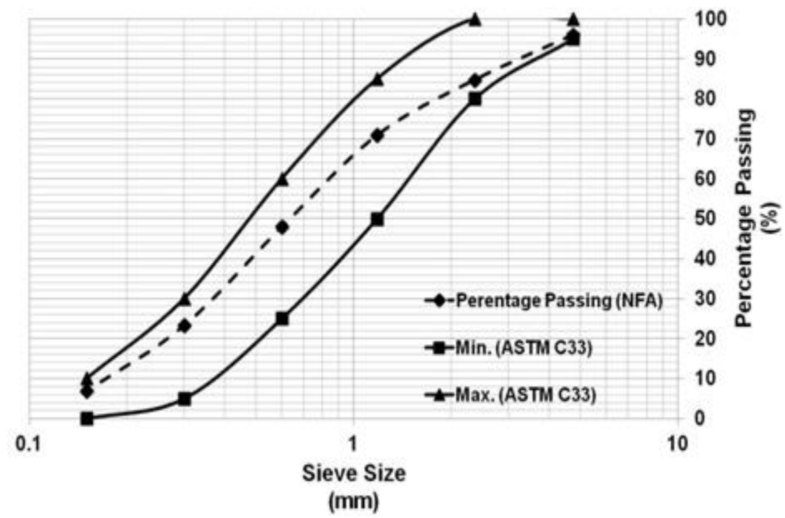

Figure 1: Sieve analysis of fine aggregate

Mixtures proportions

Table 2, shows the composition for all tested mixtures. PCMs were added as partial replacement by volume from the sand at rates 0%, 3%, 6% and 12%. Water to cement ratio kept as 0.4 for all mixtures. Sand was added at a ratio of 2.75 with respect to cement.

Table (2) Mixture compositions for mixtures with PCMs

	Mix Code			
	Control	P3	P6	P12
Cement/cement	1	1	1	1
Sand/cement	2.75	2.65	2.57	2.41
PCMs(%)	0	3	6	12
Water/cement	0.4	0.4	0.4	0.4

Mixing procedure

First, mixing the dry part of the mix together, and let it dry mix for 2 minutes, which is the sand and cement, then, add half of the mixing water and let it continue mixing for one minute. Afterward add the rest of the mixing water and let it continue mixing for one more minute. Lastly, adding the MPCM to the mixture as the last step, and let it continue mixing for one more minute in order to reduce the damage that may occur to the PCM particles during the mixing.

Curing Conditions

After casting under laboratory temperature 23°C, specimens were demolded after 24 hours and stored in plastic containers till the testing dates, which represents condition 1: normal temperature. Condition 2, samples were prepared at lab temperature and kept for 3 hours under lab temperature which is pre-set. Then moved into an environmental chamber with their molds. Molds kept in the chamber for couple of hours and temperature raised gradually by 15°C/Hour till it reached 60°C, the ramping period, and kept on that temperature, which represents the onset period, before lowering the temperature again by the same rate of 15°C/Hour, the second ramping period, till it is back to normal lab temperature. After 24 hours from casting, at that point samples were demolded and stored in plastic container till the testing dates.

Testing

In this study, fresh performance was evaluated based on the flow table, while mechanical performance was evaluated based on compressive strength at different ages. For each mixture, three 50 × 50 × 50 (mm) cube samples were prepared for testing at ages 1,3,7, 14 and 28 days.

RESULTS AND DISCUSSION

Followability

The flowability test were conducted directly after mixing, which gives a clear indication about the flowability and the applicability of the prepared mortars. According to Fig. 2, increasing flow table readings were observed by the increment of the MPCM replacement from the sand in the mixture by volume. Which is justified based on, a constant w/c ratio were kept for all the mixtures. And that decreased amount of sand, as part of the solid content of the mixture lead to higher flow table readings. Knowing that other studies showed that micro-capsulated PCM inclusion will increase the amount of the water absorbed by the polymeric walls of the micro-capsules, and increase the porosity of the mixture, which will lead to low flowability.

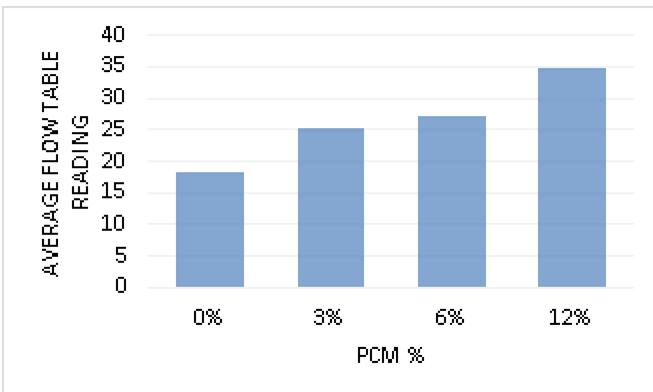

Figure 2: Flowability for mixtures incorporating different percentages of PCMs

Density

The hardened density was evaluated for all mixtures at age 28 days. As shown in Fig. 3, at low PCMs addition rate (i.e. 3%), there was a slight change in the total density. However, increasing the PCMs contents had induced higher reductions in the unit weight. The higher the PCMs content, the lower the achieved density. For instance, mixtures incorporating 12% PCMs exhibited a reduction in the density with about compared to that of the control mixtures without PCMs. This can be attributed to the lower unit weight of PCMs compared to that of the sand. Hence, as sand was replaced by lighter materials, the final density will reduce.

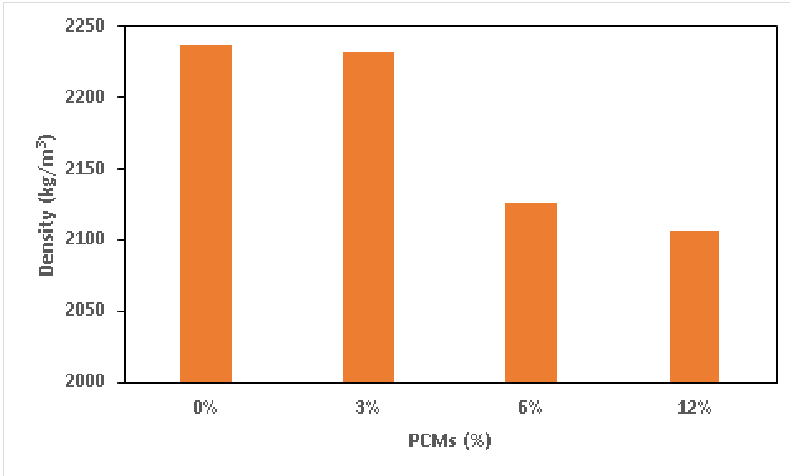

Figure 3: Hardened density for all mixtures with and without PCMs

Compressive strength

Adding MPCM to cement mixture is reported to decrease the strength, and that is experienced by the brittle polymeric microcapsules wall shells. Figure 4, shows that adding 3% MPCM as sand replacement did not induce considerable change at age 28 days. On the other hand, increasing the amount of MPCM in the mixture from 0% (reference mortar) to 12%, will lead to a decrease superior to 30% in the compressive strength.

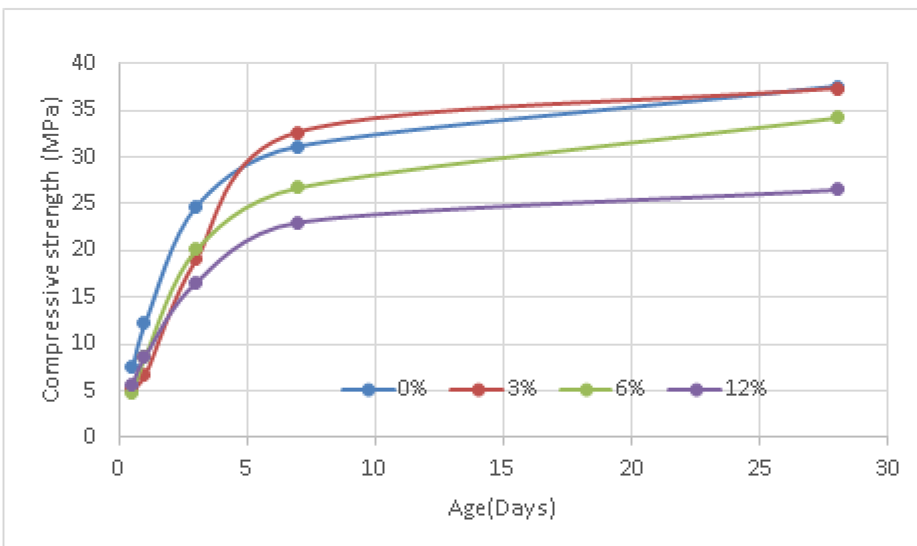

Figure 4: Compressive strength for all mixtures with and without PCMs Condition 1

Figure 5, shows compressive strength differences for specimens undergoes the heat-curing regime, condition 2 and ambient temperature curing, condition 1, at 28 days. For instance, 0% specimens have gained approximately the same strength after 28 days. For 3% specimens, the one that cured in the ambient temperature gained more strength by 4.5%. However, for the 6% and 12% specimens, the specimens that undergoes heat-curing regime compared to the ambient curing, gained more strength at the 28 days superior to 12.5% and 35%, respectively. This result demonstrates that increasing the percentage of the PCM replacement for the ambient condition will affect the strength negatively. However, PCM for the 6% specimens that undergoes heat curing have gained approximately the same strength at 28 days for the 0% specimens, knowing that 6% specimens ambient temperature cured, gained strength approximately 10% less than the 0% specimens. Which leads to say that heat curing for the specimens with PCM will increase the strength by a certain extent, and will affect the strength gain for specimens that undergoes heat curing. Which is caused by the PCM ability to store the heat at the phase transition temperature, give the heat back to the medium after the temperature drops again, and pass the phase transition temperature, which will delay the hydration peak, but will give heat to the ongoing hydration process.

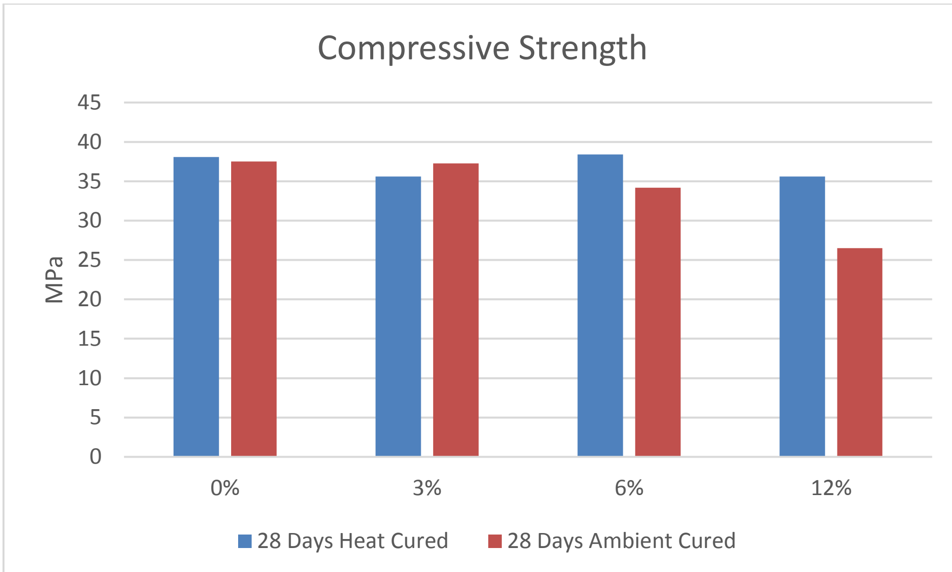

Figure 5: Compressive strength for all mixtures with PCMs Condition 1 and 2 at 28 Days old

Heat of Hydration

Isothermal calorimetry 2000-H machine where used to study the hydration behavior of MPCM and reference mortars. The heat of hydration curves in figure 6, shows the differences in the heat profile development for both, the MPCM 3% mortar and the 0% (reference mortar). The profile shown is an indication about the heat curing cycle for the samples exposed to heat curing, condition 2. Its indicated that while raising up the heat, the MPCM in the 3% mortar started to store the heat. Moreover, at the curve peak, the 3% mortar showed a delayed peak. In addition, while lowering the temperature, MPCM in the 3% mortar expelled the heat stored back to the mortar medium.

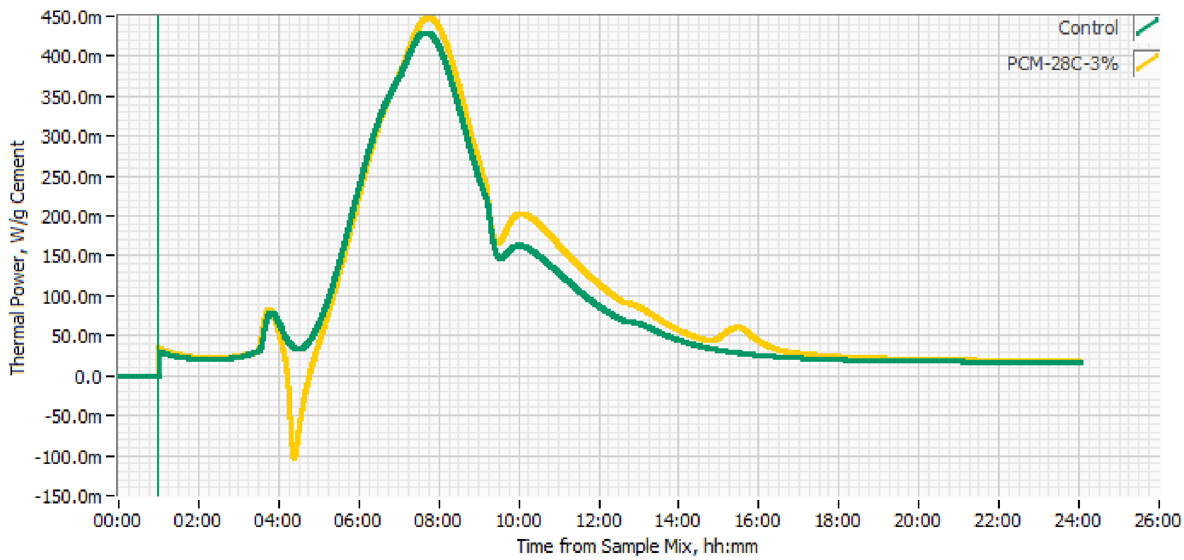

Figure 6: Heat of Hydration Curve – MPCM 28C and Control Mortar

Conclusions

Based on the results it can be concluded that some changes happen to the mortar properties with PCM. It's also well known that adding the PCM to mortar mixtures will reduce the mechanical strength. On the other hand, PCM inclusion will delay the hydration peak. And by maintaining water to cement ration the flowability of mortar mixtures will increase, based on the reduction of solid content of the mixture.

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