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THERMALLY ENHANCED GEOPOLYMER CONCRETE TO MITIGATE AIR-CONDITIONING DEMAND IN BUILDINGS

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ABSTRACT

Thermal properties of geopolymer concrete (GPC) are enhanced by adding phase change material (PCM) capsules. The capsules were developed and tested in our previous research. In total, five compositions of GPC cubes were developed for testing, one pure geopolymer as a reference, two compositions by 50% volume substitution of pure geopolymer with the two different PCM capsules and two compositions by 50% substitution of each porous material for comparison. Thermal and structural tests were conducted to investigate the effects of capsules on the properties of produced GPC. The produced thermally enhanced GPC can reduce heat transmission to indoors in the hot climates like the United Arab Emirates and its compressive strength is acceptable for non-loadbearing wall components.

Keywords: phase change materials, geopolymer concrete, U-value, peak temperature damping

NONMENCLATURE

Abbreviations	
EC	Expanded clay
EC-PCM	Capsules of PCM in expanded clay
GPC	Geopolymer concrete
PCM	Phase change material
PU	Polyurethane foam
PU-PCM	PCM capsules in polyurethane foam
U-value	Thermal transmittance

1. INTRODUCTION

Geopolymer concrete is getting attention recently as a replacement to cement as a binder in construction industry. Major advantages of the geopolymer is that it is composed of the industrial wastes like fly ash (e.g. waste of coal power plants) and slag (waste of blast furnace). These silica containing constituents are when activated with strong alkali form long chain polymers. The durability and strength of the resultant polymers is superior to cement [1,5].

Extensive research is conducted to evaluate the development/curing conditions and variation of constituents on the durability and thermal characteristics of the GPC [1-5]. The physical state and size of PCM capsules have impact on mechanical properties of GPC [2]. Overall, thermal conductivity of the GPC is decreased with the addition of PCM, however, the value of thermal conductivity is higher in the liquid state of PCM as compared to the solid state [2]. Experimental studies revealed that 34.8% power consumption is reduced by using PCM in walls [3]. Agglomeration of PCM capsules and their breakage during mixing and settling of GPC can reduce compressive strength of the concrete [4]. To overcome the fragile shell material and dealing with the leakage issues of the PCM, geopolymer as a coating was applied around the matrix materials filled with PCM (Paraffin – RT31) [6,7]. Rigorous testing and several freeze-thaw cycles revealed the efficacy of the geopolymer as an efficient and effective coating material for PCM capsules [6,7]. These developed capsules were further used for detailed structural and thermal testing.

This research evaluates the heat transmission characteristics of geopolymer concrete embedded with

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newly developed PCM capsules. Further, thermal transmittance (U-value) and compressive strength of the samples were measured experimentally.

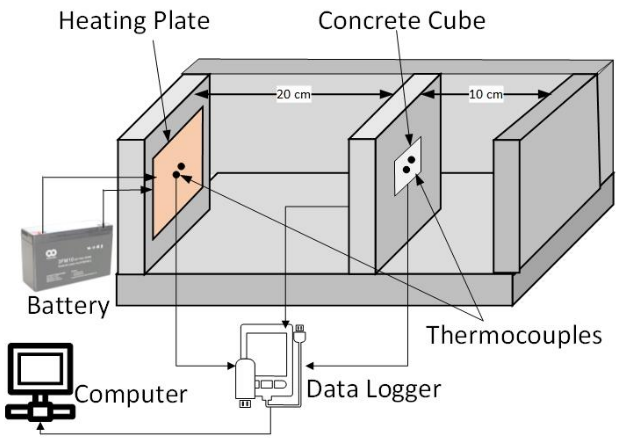

Fig 1 Schematic of the experimental set-up used for thermal testing

2. MATERIALS AND METHODS

2.1 *Materials and Sample Development*

PCM (RT-31) procured form Rubitherm - Germany was encapsulated into expanded clay (EC) and polyurethane (PU). For PU, the process was simple immersion while vacuum impregnation was adopted for EC because immersion could not assist the viscous PCM to penetrate the very narrow pores of EC. Optimized parameter (time, temperature and vacuum duration) and complete procedure are detailed in [6,7]. Later, a layer of geopolymer was coated around these matrix material (EC and PU) containing PCM to protect the PCM from leakage in its liquid phase. Complete method of capsules development and the verification of the robustness of the shell is described in [6,7].

Geopolymer cubes were casted in steel molds of dimensions 50 mm × 50 mm × 50 mm. For reference cube, the composition of GPC is tabulated in Table 1. For other samples, 50% volume of the solid constituents was replaced with EC, EC-PCM capsules, and PU-PCM capsules. In the case of PU, 50% additional foam was consumed within the equal volume constituents of reference samples. All the samples were cured indoor at identical conditions for 7 and 28 days for thermal and structural testing.

Table 1. Composition of the reference geopolymer (mass ratio, Kg/m^3)

Fly ash	Slag	Sand	NaOH	Na_2SiO_3	Total
457	152	914	101	252	187

2.2 Thermal performance testing

All samples were exposed to the known level of heat flux in a customized experimental set-up one at a time until steady state was achieved. The set-up was properly insulated to avoid interference of outer environmental conditions. After steady state, the power supply of the heating element was disconnected to allow the samples to cool under natural convection. One face of the GPC cube facing towards the heating plate is named as front-surface which is like the outer face of the real building exposed to solar irradiance. Opposite side of the front-surface is named as back-surface which mimics the interior face of a wall in real building transferring heat to indoor space. Temperatures were measured on all surfaces of the samples using K-type thermocouples to observe heat propagating, peak temperature damping and delaying of peak temperature. All temperatures were recorded using data acquisition system of National Instruments interfaced with LabVIEW. Schematic diagram of the experimental set-up is shown in Figure 1.

2.3 Thermal Transmittance Testing

Thermal transmittance (U-value) of all the samples was also measured experimentally using a U-Value kit by GreenTEG-Switzerland. Method of measurement is detailed in [7].

2.4 Compressive strength testing

Compressive strength of the samples was tested in accordance with the ASTM C109-16 [8] after 7 days and 28 days of sample curing using a 2000 KN Universal Testing Machine.

3. RESULTS AND DISCUSSION

3.1 Thermal performance

Figure 2 is the temperature profile for front surface exposed towards the heat flux as also shown by block diagram in the inset of graph. A small variation is observed in the front surface temperatures which is due the back-effect of low temperatures within the bulk of the samples due to difference in heat capacity of the samples.

The peak damping and peak delay can be observed in Figure 3 representing the back-surface temperature profiles. Back-surface is also illustrated by a block diagram in the inset of Figure 3. Addition of PU increased the surface temperature which could be due the increase

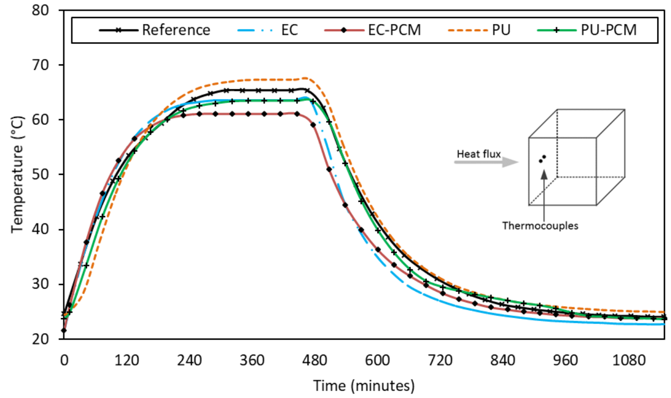

Fig 2 Temperature profile for front surface

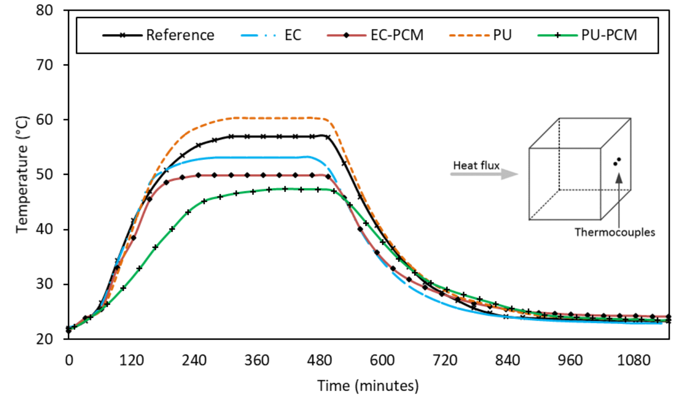

Fig 3 Tempareture profile for back surafce

in density of the material. The results are validated in compressive strength of the samples. However, further research is needed to establish the fact. For all other additions, (EC, EC-PCM and PU-PCM), the back-surface temperature was significantly lower than the reference. The magnitude of the reduction in the temperature for these three additions was 3.8°C, 7.1°C and 9.6°C respectively. The different in case of both PCM capsules is that PCM absorption is relatively higher in PU as compared to EC because PU is extremely high porous. In real buildings, this back surface is equivalent to the inner wall which transmits heat from the surface to the indoor air by radiating and through natural convection. It is anticipated that the developed geopolymer can reduce the indoor energy demand significantly to maintain indoor thermal comfort.

3.2 Thermal Transmittance (U-value) results

U-value of the GPC increased from 2.04 to 2.06 W/m^{2}K with the addition of PU as compared to the reference sample. Addition of EC, EC-PCM and PU-PCM decreased the U-value from 2.04 to 1.71, 1.16 and 1.32 W/m^{2}K for the samples respectively as shown in Figure 4. It is worth mentioning that as the magnitude of U-value decreases, insulation properties of the building material increase, hence, the geopolymer with the addition of EC-PCM is the best among all compositions.

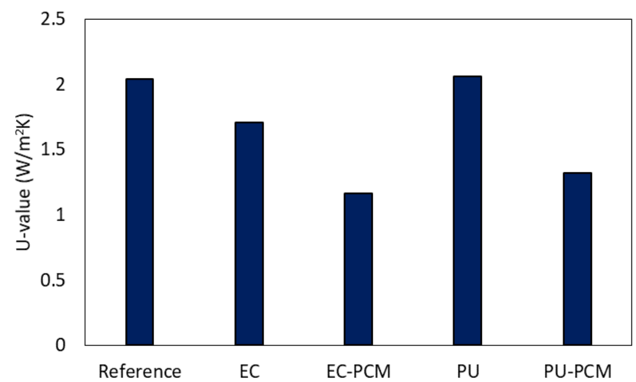

Fig 4 U-value of all samples

3.3 Compressive strength

Compressive strength of the sample increased with time curing for 7 to 28 days in all cases. Addition of PU marginally increased the compressive strength as compared to the reference. In the cases of EC, EC-PCM and PU-PCM, compressive strength was dropped from 65.7 MPa to 11.4, 12.3 and 13.01 MPa respectively at the age of 28 days as represented in Figure 5. This strength is complying with the international standard ASTM C129-17 which requires the compressive strength of 4.14 MPa for non-loadbearing components [9].

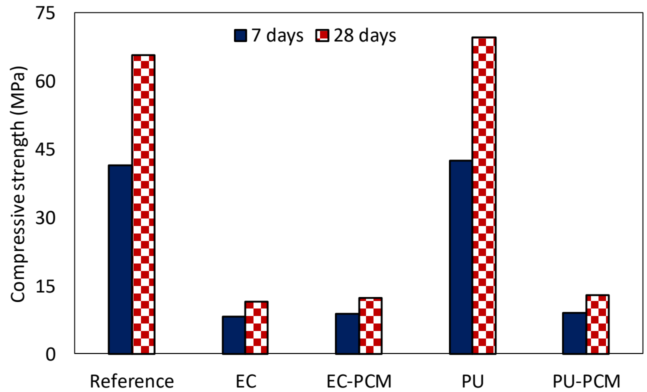

Fig 5 Compressive strength of the smaples after 7 and 28 days

4. CONCLUSIONS

The Addition of polyurethane foam (PU) increased the peak temperature at the back-surface and increased the U-values of the sample as compared to the reference. However, addition of expanded clay (EC), PCM capsules in EC (EC-PCM) and PCM capsules in PU (PU-PCM) decreased the back-surface temperature (9.6°C at the maximum in the case of PU-PCM capsules). In the case of EC, the reduction in temperature and corresponding lower in U-value is due to the air entrapped in the pores of EC. The same gains were the consequences of latent heat effect in the cases of PCM capsules. Addition of EC and PCM capsules lowered the compressive strength from 65 MPa to approximately 13.01 MPa which is still acceptable for non-loadbearing wall components.

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