Construction and Building Materials 84 (2015) 95–102

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental study of geopolymer mortar with incorporated PCM

Rasoul Shadnia [a], Lianyang Zhang [a,*], Peiwen Li [b]

[a] Department of Civil Engineering and Engineering Mechanics, University of Arizona, Tucson, AZ, USA
[b] Department of Aerospace and Mechanical Engineering, University of Arizona, Tucson, AZ, USA

HIGHLIGHTS

- Studied geopolymer mortar with incorporated PCM experimentally.
- Incorporation of PCM leads to slight decrease of compressive strength of geopolymer mortar.
- Compressive strength of geopolymer mortar with up to 20% PCM is still sufficiently high for applications in buildings.
- Incorporated PCM can effectively reduce the transport of heat through geopolymer mortar.

ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 5 March 2015
Accepted 8 March 2015
Available online 19 March 2015

Keywords:
Phase change material (PCM)
Geopolymer mortar
Mechanical properties
Thermal properties

ABSTRACT

Incorporation of phase change material (PCM) in building materials has been an important research topic in recent years. The use of PCM intends to increase the thermal inertia of buildings and reduce the consumption of energy for cooling and heating. This paper studies experimentally the mechanical and thermal properties of geopolymer mortar synthesized with low calcium fly ash and different amount of PCM. First the effect of incorporated PCM on the unit weight and compressive strength of geopolymer mortar was evaluated. Then scanning electron microscopy (SEM) imaging was performed to identify the change of micro structure of the geopolymer mortar after incorporation of PCM. The thermal properties of the geopolymer mortar containing different amount of PCM were also characterized using differential scanning calorimetry (DSC) analysis. Finally model tests were performed using small cubicles built with geopolymer mortar slabs containing different amount of PCM to evaluate the effectiveness of geopolymer mortar wall with incorporated PCM in controlling the heat flow and internal temperature. The results indicate that both the unit weight and compressive strength of the geopolymer mortar decrease slightly after PCM is incorporated, mainly due to the small unit weight and low strength and stiffness of the PCM. However, the compressive strength of geopolymer mortar containing up to 20% PCM is still sufficiently high for applications in buildings. The results also show that the incorporation of PCM leads to substantial increase of heat capacity and decrease of thermal conductivity of the geopolymer mortar and is very effective in decreasing the temperature inside the cubicles. Therefore, the geopolymer mortar with incorporated PCM can be used as building walls to effectively increase the thermal inertia of buildings and reduce the consumption of energy for cooling and heating.

1. Introduction

Different techniques have been studied for improving the energy efficiency related to space cooling and heating in buildings [1–5]. One of the most effective techniques is to use phase change material (PCM) as an additive in the building wall. PCM has high latent heat capacity and can absorb or release heat when changing from solid to liquid state or vice versa [6,7]. By incorporating PCM with a suitable phase transition temperature and enthalpy in the exterior wall of a building, on daytime the PCM will prevent too much outside heat from entering the building by changing phase to store the extra solar heat as latent heat and at night the PCM will release the stored heat into the building if the inside temperature is too low. The results are a more comfortable inside environment with fewer temperature peaks and valleys, and a reduction in energy demand for cooling and heating.

Much research has been conducted on utilization of PCM to improve the energy efficiency related to cooling and heating in buildings [8,9]. The PCM has been implemented in plaster, gypsum board, concrete and other wall covering materials. Zamalloa et al. [10] studied a new plaster with incorporated microencapsulated

* Corresponding author. Tel.: +1 520 6260532; fax: +1 520 6212550.
E-mail address: lyzhang@email.arizona.edu (L. Zhang).

http://dx.doi.org/10.1016/j.conbuildmat.2015.03.066
0950-0618/

PCM for indoor application. They characterized the mechanical, thermal and fire-resistance properties of the plaster and conducted thermal simulations to study the optimal distribution of the plaster inside a building. Then the simulations were validated by constructing two real size concrete cubicles (one of them uses the PCM containing material) and monitoring their temperature and energy consumption. The results show that the new plaster is effective to minimize the thermal fluctuations inside the buildings and reduce the energy needs up to 10–15% in heating and 30% in cooling. To increase the thermal inertia of expanded perlite frequently used in modern buildings, Li and Li [11] produced granular phase change composites by incorporating PCM into the granular porous material. The measurements of temperatures through panels containing the phase change composite indicated that incorporation of phase change composites enhanced the thermal insulation of the panels. Chen et al. [12], using a one-dimensional non-linear mathematical model, analyzed the heat transfer of a PCM energy-storing wallboard and found that applying proper PCM to the inner surface of an ordinary room can not only enhance the indoor thermal-comfort dramatically, but also save the energy required for heating.

Shapiro [13,14] studied the incorporation of several types of PCMs into gypsum wallboard for application in the Florida climate. The results indicate that although the PCMs have relatively high latent heat capacity, they are not sufficiently applicable in the Florida climate because the temperature ranges required for achieving the thermal storage are incompatible with the range of comfort temperature for buildings. Since gypsum wallboards have much lower heat capacity than concrete, many researchers have selected concrete to incorporate PCM so that the total thermal storage capacity can be improved [15–21]. Cabeza et al. [19] constructed two cubicles, one with concrete containing PCM with a melting point of 26 °C and the other with conventional concrete containing no PCM, and then monitored the wall and indoor temperatures. The results indicated that the incorporated PCM improved the thermal inertia and lowered the inner temperatures, demonstrating a real opportunity for energy savings in buildings.

Hunger et al. [20] presented a set of experiments on self-compacting concrete containing different amount of microencapsulated PCM. The PCM was incorporated into the concrete based on direct mixing. The results indicate that the incorporation of PCM leads to decrease of thermal conductivity and increase of heat capacity, which both significantly improve the thermal performance of the concrete and therefore save energy. The results also show a significant decrease in strength of the concrete due to the incorporation of PCM. Meshgin and Xi [21] conducted a more detailed study on the effect of PCM on the mechanical and thermal properties of concrete. The results show that the incorporation of PCM leads to significant increase of heat capacity and reduction of thermal conductivity of the concrete and thus improves the thermal performance of the concrete. In the meantime, however, the incorporated PCM also leads to significant loss of compressive strength of the concrete. Eddhahak-Ouni et al. [22] conducted a similar study and reported almost the same findings except that their study indicated that the small amount of incorporated PCM (up to 5% by total volume of concrete) seems to have no effect on the thermal conductivity of the PCM-concrete.

Although much research has been conducted on concrete with incorporated PCM, it has not been applied in practice yet mainly due to the unfavorable characteristics after incorporation of PCM, such as loss of strength and uncertain long-term stability [15]. The study by Hawes et al. [17,18] indicated that addition of pozzolans such as silica fume and fly ash can improve the stability of concrete containing PCM. The issues related to incorporation of PCM might also be addressed by using geopolymer concrete which has special advantages over the conventional concrete as stated below.

Geopolymer is a relatively new material that has the potential for replacing the ordinary Portland cement (OPC). Geopolymer is an inorganic material synthesized via alkali activation of amorphous aluminosilicates at ambient or slightly increased temperatures, having an amorphous to semi-crystalline polymeric structure. Various raw materials that contain reactive or amorphous silica and alumina, such as metakaolin, fly ash, mine waste, red mud, and blast furnace slag, can be used to produce geopolymer. It is noted that most of these raw materials are industrial wastes or byproducts, and significant environmental and economic benefits can be achieved if the waste-based geopolymer is produced and used in practice. Although geopolymer concrete has some limitations such as the difficulty and sensitivity in its making outside of the laboratory and the suitable supply of source materials [23–25], it provides not only performance comparable to conventional Portland cement concrete, but also additional advantages including rapid development of mechanical strength, small drying shrinkage, high fire resistance, superior acid resistance, effective immobilization of toxic and hazardous materials, and significantly reduced energy usage and greenhouse emissions [26–30].

Considering the unique characteristics of geopolymer concrete, as a first step, this paper studies fly ash-based geopolymer mortar with incorporated PCM. Specifically, geopolymer mortar specimens containing different amount of PCM were produced and systematic experiments were performed to evaluate the effect of incorporated PCM on the physical, mechanical and thermal properties of the geopolymer mortar. Small cubicles were also built with geopolymer mortar slabs containing different amount of PCM to evaluate the effectiveness of geopolymer mortar wall with incorporated PCM in controlling the heat flow and internal temperature.

2. Experimental study

2.1. Materials

Class F fly ash, fine aggregate (sand) and sodium hydroxide solution were used to produce the geopolymer mortar. The fly ash was provided by Salt River Materials Group in Phoenix, Arizona. The fly ash is originated from the San Juan Generating Station in New Mexico. Table 1 shows the chemical composition of the fly ash. The sand is natural river quartz sand and was provided by Arizona Concrete Aggregate in Tucson, Arizona. Grain size distribution analysis was performed for both the fly ash and the sand by mechanical sieving and hydrometer analysis following ASTM D6913 and ASTM D422. Fig. 1 shows the particle size distribution

Table 1
Chemical composition of fly ash based on XRF analysis.

Oxides	SiO_2	Al_2O_3	CaO	Fe_2O_3	Na_2O	MgO
Wt.%	57.5	29.3	6.0	2.95	2.6	1.36

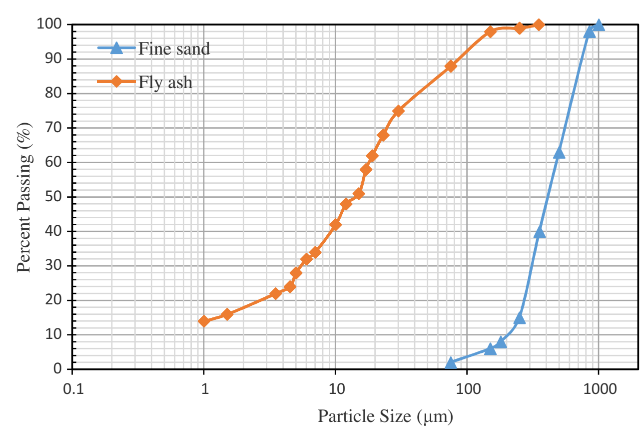

Fig. 1. Particle size distribution curve of fine sand and fly ash used in this study.