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Mechanical properties and microscale changes of geopolymer concrete and Portland cement concrete containing micro-encapsulated phase change materials

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ABSTRACT

The effect of micro-encapsulated phase change materials (MPCM) in solid and liquid states on the mechanical properties and microstructure of geopolymer and Portland cement concretes is investigated. Geopolymer concrete (GPC) and Portland cement concrete (PCC) containing different amounts of MPCM were prepared and cured at both 20 °C and 40 °C. The results revealed that the compressive strength of both GPC and PCC decreases with the addition of MPCM. Whether the PCM is in solid (20 °C) or liquid (40 °C) state did not significantly affect the mechanical properties of GPC, while melting the PCM was found to reduce the strength of PCC. X-ray tomography imaging was utilized to examine the effect of MPCM on the porosity of the samples. SEM imaging reveals that air gaps are formed between the microcapsules and the surrounding concrete matrix.

1. Introduction

Phase change materials (PCM) have attracted the interest of the scientific community due to the possibilities of increasing of the thermal energy storage in buildings. Utilization of PCM will reduce the energy demand, and thereby contribute to a better environment. During the daytime, PCM absorbs excess heat by melting. The heat is released when the temperature decreases at night, causing the PCM to solidify [1]. Due to the high latent heat capacity of PCM, a considerable amount of heat energy can be stored during the phase change [1,2]. However, utilizing bulk quantities of PCMs is subject to problems. A low thermal conductivity causes bulk amounts of PCM to solidify only around the edges preventing a good heat transfer process [2,3]. These problems can be avoided by encapsulating the PCM into microcapsules. These microcapsules can then be incorporated into building materials, such as concrete, in order to create a smart material suitable for passive house construction. Incorporating micro-encapsulated PCM (MPCM) in structural materials significantly improves thermal energy storage. However, MPCM has been found to reduce the mechanical properties of building materials [4].

In recent years, the effect of PCMs and MPCMs on the mechanical properties of structural materials especially cementitious materials such as mortar and concrete has been studied at various curing conditions. Unfortunately, the presence of MPCM decreases the mechanical strength of concrete [5–9]. Several factors have been suggested to contribute to this strength reduction. When MPCMs replaces a certain percentage of sand, the mechanical strength decreases due to lower stiffness and strength of MPCM compared to sand [6]. In addition, rupture of the capsules during the mixing process and compression may cause leakage of PCM into the cementitious materials thereby reducing the strength [7]. PCM might induce voids and air bubbles, which also reduces the concrete strength [8]. In addition, weak bonds between the MPCM and the binder matrix can lead to interfacial gaps between MPCM and the concrete matrix [9].

Geopolymer is an attractive alternative to ordinary Portland cement. The negative environmental impact and high cost of Portland cement production can be significantly improved by replacing it with geopolymers [10,11]. Several studies have been conducted on the mechanical properties of geopolymer compositions [12–15] and a few studies have focused on cementitious materials with incorporated

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Table 1
Chemical composition of fly ash (FA) and ground granulated blast furnace slag (GGBFS).

Chemical	FA (wt%)	GGBFS (wt%)
Al_2O_3	25.71	10.65
SiO_2	52.65	34.3
CaO	6.236	43.97
Fe_2O_3	5.307	0.359
MgO	1.402	5.026
K_2O	1.981	0.569
TiO_2	1.2	1.19
Na_2O	1.1	0.28
P_2O_5	1.01	–
SO_3	0.935	3.01
SrO	0.19	–
CO_2	1.74	0.13

MPCM [4,6–8,16]. However, very few studies have examined the mechanical properties of geopolymer compositions with incorporated MPCM [17]. Rasoul et al. [17] observed that the compressive strength of geopolymer mortar decreased after adding PCM, mainly due to the reduced unit weight, and the low strength and stiffness of the PCM. Nevertheless, the compressive strength of geopolymer mortar containing up to 20% PCM was still sufficiently high for applications in buildings.

The main purpose of this study is to examine how incorporation of MPCM influences the mechanical properties of both GPC and PCC at different curing times. Since the state (liquid or solid) of the PCM might influence the compressive strength, the systems have been studied both below and above the melting point of the PCM. The PCM utilized in this study has a melting temperature of about 28 °C, which is suitable for warm climates such as southern Europe [18,19]. In order to gain more information regarding the cause of the reduced compressive strength, we have also investigated how the MPCM alters the microstructures of GPC and PCC.

2. Experimental

2.1. Materials

Geopolymer concrete was prepared by mixing class F fly ash (FA), ground granulated blast furnace slag (GGBFS), sand, gravel, and an alkaline activator solution. The FA (Blaine fineness = 2954 ± 50 cm^2/g, specific gravity = 2.26 ± 0.02 g/cm^3) and GGBFS (Blaine fineness = 3312 ± 50 cm^2/g, specific gravity = 2.85 ± 0.02 g/cm^3) were purchased from Norcem and Cemex, Germany, respectively. Table 1 shows the chemical compositions of class F fly ash and GGBFS which are determined by X-ray Fluorescence (XRF). The alkaline solution was prepared by adding sodium hydroxide powder (density 2.1 g/cm^3) to water (14 M), before mixing with sodium silicate solution (50 wt%, density of 1.9 g/cm^3). A sodium silicate solution to sodium hydroxide solution weight ratio of 2.5 was used for all GPC mixtures.

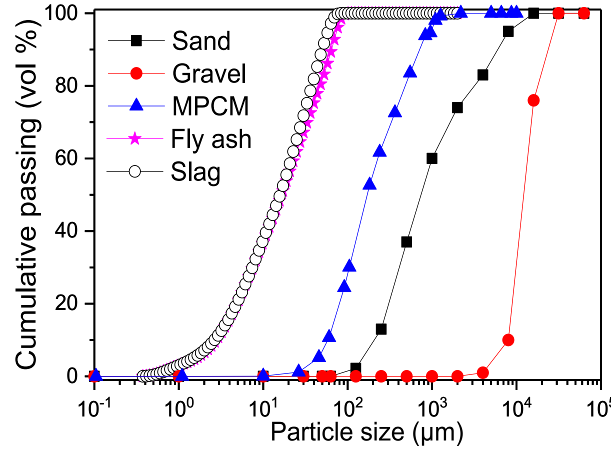

Fig. 2. Particle size distributions of sand, gravel, MPCM, fly ash, and ground granulated blast furnace slag.

Portland cement concrete consists of Portland cement II mixed with FA (Blaine fineness of 4500 cm^2/g, density of 3.0 g/cm^3), was purchased from Norcem, Norway. Dynamon SR-N (density of 1.1 g/cm^3) from MAPEI, Norway, was used as a superplasticizing admixture to improve the workability of PCC and decrease the amount of water. The same sand (density of 2.7 g/cm^3) and gravel (density of 2.6 g/cm^3) were used for both GPC and PCC, and purchased from Gunnar Holth and Skolt Pukkverk AS, originating from Mysen and Råde, Norway, respectively.

MPCMs (density of 0.9 g/cm^3) was synthesized by spray drying [20]. The MPCM has a copolymer shell consisting of low density polyethylene (LDPE) and ethylvinylacetate (EVA) (EVA/LDPE = 0.5), and contain paraffin wax (Rubitherm®RT27) as the core material (RT27/Polymer = 2). The melting point of MPCMs is 28.4 ± 0.9 °C. The melting point of MPCM should be approximately three degrees higher than the room temperature [18], and near the average temperature of the hottest summer month [19]. The mean particle size of the microcapsules was around 5 μm (Fig. 1a). However, as can be seen from the SEM image in Fig. 1b, the microcapsules have a strong tendency to form agglomerated structures with larger sizes (D60 = 240 μm) [21].

The particle size distribution analysis of sand and gravel was carried out by mechanical sieving according to EN 933-1. The FA and GGBFS

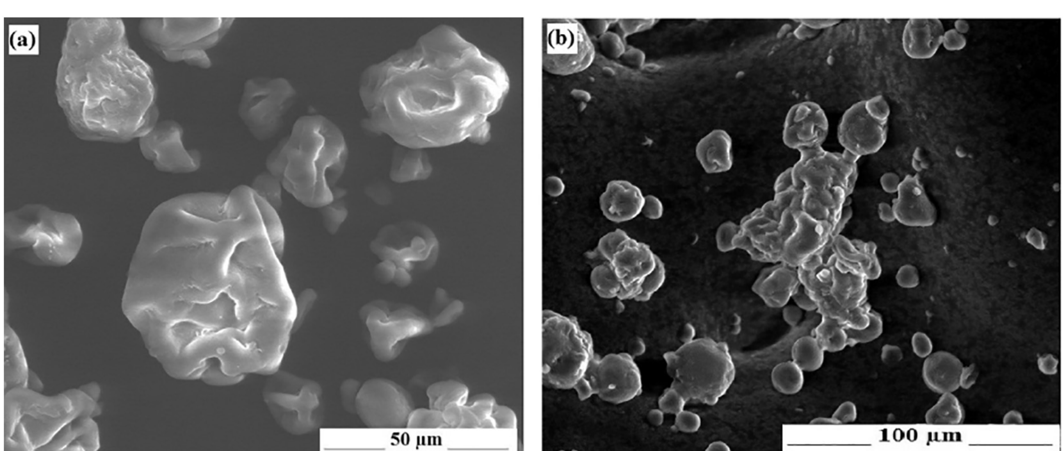

Fig. 1. SEM images of (a) individual MPCM (LDPE.EVA-RT27), (b) agglomeration of MPCM.