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Durability of expanded polystyrene mortars

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HIGHLIGHTS

- The durability of mortars improve with the presence of expanded polystyrene.
- The use of additives allows make mortars with high amount of EPS with a better durability.
- EPS has a positive effect in mortars subjected to heat cycles.
- EPS in mortars improve and/or maintain their durability under freeze–thaw cycles.
- The impedance spectroscopy and mercury intrusion porosimetry are not suitable to study the microstructure of EPS mortars.

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ABSTRACT

The influence of the addition of various types and various concentrations of expanded polystyrene foam (both commercial and recycled) on the durability of Portland cement mortars is studied. In particular, the microstructure is studied utilizing the following methods: capillary absorption of water, mercury intrusion porosimetry, impedance spectroscopy and open porosity. In addition, the effects of heat cycles and freeze–thaw cycles on compressive strength are examined. Scanning electron microscopy is used as a complementary technique. An air-entraining agent, water retainer additive and superplasticizer additive are used to improve the workability of mortars. The results show that the presence of expanded polystyrene in mortar results in a decrease in the capillary absorption coefficient. The mercury intrusion porosimetry technique and the equivalent circuits previously used by researchers to interpret impedance spectra of ordinary cementitious materials were found to be inadequate for interpreting the microstructure of mortars with expanded polystyrene. This is due to the polymeric nature as well as the internal porous structure of expanded polystyrene. A slight increase of compressive strength is observed in mortars with expanded polystyrene subjected to heat cycles. The compressive strength of mortars subjected to freeze–thaw cycles likely improves because expanded polystyrene particles absorb part of the pressure of ice crystallization. It is concluded that the durability of mortars improve with the presence of expanded polystyrene, making them viable for more sustainable usage in masonry, stucco and plaster mortars.

1. Introduction

Expanded polystyrene foam (EPS) is a thermoplastic polymer with a closed cellular structure. It is biologically inert and non-toxic. EPS has interesting properties such as being of low density, thermal insulation, hydrophobicity and chemical resistance when exposed to acids and alkalis. EPS may be granulated into small particles that can be considered as non-absorbent and a lightweight polymeric aggregate (less than 300 kg/m^3 density) [1,2]. These aggregates may be used to produce light building materials.

Research in the field of concrete incorporating EPS as an aggregate is mainly devoted to the characterization of the mechanical properties of the concrete and trying to improve these properties by characterizing them for various EPS grain sizes, additives, and other additions such as fly ash and silica fume [3–5]. Other studies characterize both mechanical and thermal EPS concrete properties using simultaneous optimization of these properties with respect to EPS parameters. These studies proposed modelling methods to predict and optimize these properties [6]. Recent articles show the adequacy of wet concrete of a self-compacting lightweight structural made with nano-SiO_2 and EPS [7].

Other studies have used EPS beads to design thermal insulator composites made with foamed cement pastes as a matrix, using granules of EPS as filler, along with additives to prevent segregation and improve adherence [8]. EPS has also been used for the manufacture of gypsum and plaster plates and panels [9] with the plaster matrix reinforced with polypropylene fibres in the

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manufacture of industrial components [10] and with mixtures of fly ash and metakaolinite to obtain light inorganic polymeric materials (light geopolymers) [11].

Expanded polystyrene foam (EPS) represents 0.1% of total municipal solid waste. The recycling of solid polymeric wastes as components of mortars and concretes requires research that differentiates the characteristics of the polymers that improve their incorporation into cementitious materials and demonstrates the value added through their use. Previous work has identified the influence of the addition of various types and dosages of EPS, both commercial and recycled, on physical and mechanical characteristics of Portland cement mortars. These studies have concluded that it is possible to produce mortars with mechanical properties adequate for use in masonry, rendering and plaster mortars [12] using a high content of EPS waste.

The main aim of this study is to evaluate the influence of the addition of EPS on the durability of Portland cement mortars in order to demonstrate their viability and enhanced usage in the fabrication of mortars suitable for use as masonry, stucco and plaster mortars. To do this, the microstructure of mortars containing various types and EPS dosages were studied using water capillary absorption, mercury intrusion porosimetry and impedance spectroscopy. Additionally, the compressive strength was tested after subjecting the mortar to heat cycles and freeze–thaw cycles.

2. Experimental programme

2.1. Material and sample preparation

The following materials were used for this study: Portland cement type CEM I 52.5R, silica sand in compliance with the European standard given in EN 196-1:2005 [13], distilled water, several types of EPS, and three types of additives.

The types of EPS used were: commercial expanded polystyrene (EPSc), pre-expanded polystyrene (EPSpex) and ground expanded polystyrene from clean recycled waste (EPSw). In all cases the EPS used is white, with a 100% material loss on ignition and a softening point temperature between 80 and 100 °C. Other properties of EPS particles are given in Table 1.

The three types of additives used were: an air-entraining agent (A), Basf Rheomix 934; a water retainer additive (R), Hydroxypropyl methyl cellulose; and a superplasticizer additive (F), Basf Rheomix GT 205 MA.

Table 2 shows the EPS dosage as addition percentage of total mortar volume, considering as such the apparent volume of sand (v/v%) and the additive dosage as a percentage of the weight of the cement. The mortars were prepared with a cement/sand/water ratio (by weight) of 1:3:0,5. All mortars studied were prepared with the following amounts of materials: 450 g of CEM I 52,5R, 1350 g of silica sand of 1,67 g/cm^3 density and 225 g of distilled water.

Mortar workability was tested to determine the amounts of EPS and additive necessary to obtain adequate consistency of fresh mortar through the use of a flow table according to EN 1015-3:2007 [14]. These results have been published in a previous study [12]. Using the results of this study, the additive dosages given in Table 2 were chosen and are shown as a percentage of the weight of the cement (w/w%). All mortars were manufactured according to the European standard EN 196-1:2005 [13]. After preparation, the specimens were cured under water at a temperature of 20 ± 2 °C for various curing times depending on the test in which the sample was used.

2.2. Test methods

2.2.1. Capillary absorption

Capillary water absorption of mortars has been determined according to EN 1015-18:2003 [15]. In order to do this, three specimens of 4 × 4 × 16 cm were made for each of the dosages shown in Table 2. The specimens were kept in moulds for 2 days, after which they were removed from their moulds and were cured underwater for 5 days. After the curing period, specimens were cut in half, and dried in an oven at a temperature of 65 ± 2 °C. After drying, the lateral sides of each specimen were sealed with an adhesive plastic film to restrict the water flow along the longitudinal axis. The water flux through the specimen was measured by partial immersion of the samples at a depth of 5 mm. The gain in water mass was measured by weighing the samples 10 and 90 min after submersion. The capillary absorption coefficient, C_{90}, was estimated from the slope following to the equation $W = a + Ct^{1/2}$, where W (kg/m^2) is the capillary absorption, a (kg/m^2) is the initial absorption, C (kg/m^2 min$^{0.5}$) is the capillary absorption coefficient and t (min) is the absorption time, using the equation: $C_{90} = 0{,}1(M_2 - M_1)$, where M_1 is the weight of the specimen after 10 min of testing, and M_2 is the weight of specimen after 90 min of testing according to EN 1015-18:2003 [15].

2.2.2. Impedance spectroscopy (IS)

The microstructure of the mortars was studied using impedance spectroscopy for mortars containing 70% of each of the three types of EPS and additives, as shown in Table 2. For this study a cylindrical specimen of 10 cm diameter and 16 cm in height was manufactured for each of the dosages. After 24 h, the specimens were removed from their moulds and cut into 1 cm thick disks. Each of the disks was then cured underwater for 120 days. After curing, the discs were removed from the water bath, and the surface of each disk was then dried with paper. The impedance spectra were obtained for each disc using an Agilent 4294A impedance analyzer. This model permits capacitance measurements in the range from 10^{-14} to 0.1 F and has a maximum resolution of 10^{-15} F.

The impedance was measured through both direct contacting and through the non-contacting method, as shown in Fig. 1. The direct contact measurements in Fig. 1a were taken by application of an electrical perturbation through 7 cm diameter flexible graphite electrodes. These electrodes were placed in direct contact with each side of the sample disc. For the non-contacting measurements, shown in Fig. 1b, the sample-electrode interface is isolated by a 100 μm thick layer of acetate. The impedance of the sample is obtained by subtracting the previously-obtained impedance of the acetate layer from the total measured impedance.

To interpret and study the impedance spectra, two previously proposed equivalent circuits were used [16] as shown in Fig. 2. These circuits have been utilized extensively for Portland cement pastes, mortars and concrete [16–21]. In this work the parameter R_1 was analyzed using the contacting method (shown in Fig. 2a). The parameters C_1, C_2 and R_2 were obtained using non-contacting measurements, as shown in Fig. 2b, given that it can be obtained a biggest measurement sensitivity calculating these parameters using the method that avoid the contact between sample and electrode.

In terms of the physical significance of these equivalent circuits, the resistance R_1 depends on the electrolyte in the pores and is associated with the volume of interconnected pores [16] that traverse the length of the specimen. The resistance R_2 is associated with the electrolyte in the occluded pores, or the pores that do not contribute to the electrical conductivity across the sample [18]. The capacitance C_1 is associated to the dielectric response of the solid fraction of the sample, and could be used as a parameter to estimate the solid and pore fractions of the material [16]. Its value decreases as the thickness and porosity of the sample increases. The capacitance C_2 has been shown to be associated to the surface of pore walls in contact with the electrolyte filling the pores [19,21]. Its value increases with electrolytic occupancy of the pores and with increasing thickness of the sample. The analysis of the equivalent parameters using experimental measurements was made with the software program Zfit, developed by the Department of Construction Engineering, Public Works and Urban Organization at the University of Alicante.

2.2.3. Mercury intrusion porosimetry (MIP)

In order to complete the microstructural characterization of the mortars, the Mercury Intrusion Porosimetry technique was employed. This technique was employed in mortars made with 70% of EPS (see Table 2). The porosimeter employed was a Micromeritics Autopore IV 9500 which permits pore analysis in the pressure range of 14000–225 MPa and pore diameter determination over the pore diameter range of 0.9–5 nm. The porosity and the pore size distribution of each sample were tested twice using two different pieces of the same sample. The pore size distributions of the mortars were calculated from the applied pressure via the Washburn equation [22] assuming a contact angle of 130°. The pore size distribution of samples was computed using the following diameter intervals: <10 nm, 10–100 nm, 100 nm–1 μm, 1–10 μm, 10 μm–0.1 mm and y>0.1 mm. The samples were oven dried at a temperature of 65 ± 2 °C before be tested.

2.2.4. Open porosity

The open porosity of the specimens was determined from portions of the samples manufactured for the microstructure studies. For this measurement, a dry sample was weighed (m_{dry}) and immersed in water until it reached total saturation. The saturated sample was again weighed (m_{sat}), and finally the weight of the sample immersed in water (m_i) was obtained using a hydrostatic scale (saturated and submerged). The open porosity was then calculated according to the expression: open porosity (%) = $((m_{sat}-m_{dry})/(m_{sat}-m_i)) \times 100$.

Table 1
Properties of the various types of EPS used in mortar preparation.

EPS type	Waste	Particle diameter (mm)	Particle geometry	Density (g/cm^3)
EPSc	No	>3	Spherical	0.008
EPSpex	No	<3	Spherical	0.052
EPSw	Yes	<1	Irregular	0.013