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Hygro-thermal and durability properties of a lightweight mortar made with foamed plastic waste aggregates

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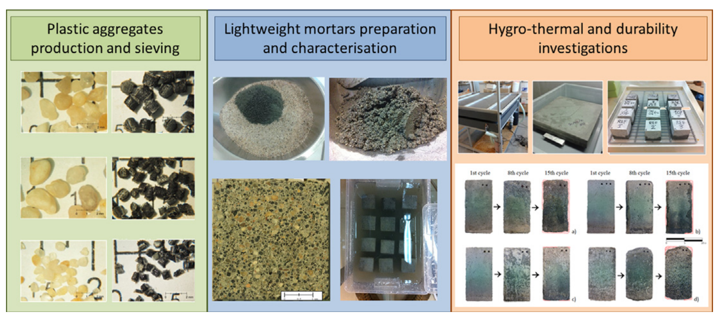
HIGHLIGHTS

- Foamed end-of-waste plastic aggregates were used instead of natural silica sand.
- Increasing artificial aggregates content an increase of macropores was observed.
- Water vapour permeability increased while capillary water absorption decreased.
- Plastic aggregates reduced both mortar density and thermal conductivity.
- Lightweight mortars are suitable as pavement and/or roofing materials.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present study, hygro-thermal and durability related properties of a cementitious mortar containing highly porous foamed aggregates obtained from polymeric end-of-waste materials were investigated. The evaluation of capillary water absorption, thermal conductivity, water vapour permeability and sulfate attack resistance of samples where natural quartz sand was replaced by 10%, 25% and 50% in volume with foamed aggregates was carried out. Experimental investigations showed that the presence of plastic aggregates decreased mortar density (up to 36%, compared to the reference sample, for the maximum investigated natural sand volume replacement) as well as thermal conductivity (10% for the 50% volume replacement). Moreover, water vapour transmission rate increased at increasing natural sand replacement while capillary water absorption decreased. Finally, after fifteen cycles of sulfate attack test, lightweight mortars evidenced a lower mass loss compared to the reference sample. The results were related to morphological modifications in the mortars bulk porosity, demonstrating by mercury intrusion porosimetry investigations, that polymeric foamed aggregates determine a variation of the pores microstructure, resulting in an increased pores dimension.

1. Introduction

Replacement of natural aggregates in mortar and concrete production is one of the main issue to reduce depletion of natural resources in production of construction materials. Crushed asphalt from road rehabilitation [1], cast iron industry by-products [2]

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electric arc furnace slag [3,4] and limestone filler recycled from marble industry [5] have been proposed to manufacture environmentally friendly mortars and concretes. More recently, the use of polymeric waste based materials as natural aggregates replacement in concrete is a relatively recent idea driven mainly by the energy and environmental concerns which are becoming remarkably relevant in the construction industry. On the other hand, the use of polymeric lightweight aggregates represent a promising solution in reducing the specific mass of concrete and mortars. From the environmental point of view, as plastic waste management is one of the most critical drawbacks of such versatile materials, the use of lightweight aggregates produced from end-of-waste or post-consumer materials is particularly interesting and the perspective of their use for new applications represent a challenge for researchers. To this extent, in the last ten years, several studies demonstrated the outcomes deriving from the use of recycled plastic wastes as natural aggregates replacement in cementitious materials [6,7]. The incorporation of lightweight aggregates provides several advantages: reduced specific mass, improved thermal properties, impact resistance, sound insulation properties, fire resistance and durability enhancement [8–28]. However, one of the main disadvantages of using polymeric and lightweight aggregates is the reduction of mechanical properties. Thus, authors generally focus the attention on such aspects which are related to the chemical and physical incompatibility between the polymeric phase and the cementitious matrix but also to the lower mechanical properties of plastic aggregates compared to natural aggregates. In the literature, plastic aggregates of different polymeric nature and shape have been investigated but only few studies dealt with hygro-thermal properties of lightweight mortars containing plastic aggregates. Moreover, even less authors investigated durability related problems of such mortars or concretes [8–10]. Hygro-thermal properties are very important parameters that should be taken into account in order to provide favorable living conditions in terms of temperature and relative humidity. Among all plastic waste materials, better results in terms of interfacial transition zone (ITZ) and insulating properties were reported when expanded polymeric aggregates were used, thanks to their porous structure [11–17,22–24]. Recently, Ramírez-Arreola et al. investigated also the possibility to produce foamed HDPE nanocomposite aggregates with different porosity varying nanoclay content [27]. Nanofillers have also been investigated as consolidating and protective agents to improve durability of different construction materials [29,30]. Durability related issues negatively affect structures service life, influencing maintenance costs and structural safety. Thus, it is very important to investigate durability also of lightweight cementitious materials. Dulsang et al. [10] reported an increased resistance to sulfuric acid of ethyl vinyl acetate (EVA) waste lightweight concrete. Turatsinze et al. [19,20] investigated the effects of rubber aggregates, obtained from shredded non-reusable tyres, on the concrete resistance to cracking and toughness increase. Authors demonstrated that cement-based mortars containing rubber aggregates are less prone to crack. Moreover, the use of waste plastic materials as mortar or concrete aggregates instead of virgin polymers, to obtain insulating materials, has not only environmental but also economic benefits [23]. Finally, as widely reported in the literature, one of the main drawbacks in the use of plastic aggregates or fibers in cementitious materials is the weak adhesion among polymeric materials, especially polyolefin, and the cementitious matrix [24,31]. In a previous work [24], Coppola et al. investigated the possibility to use polymeric aggregates with a rough surface, produced from end-of-waste materials by a foam extrusion process. The investigations reported an improved bond between plastic aggregates and the cement paste but also a good dispersion in the specimens cross-section. Moreover, a sharp decrease of density was achieved but also consistency decreased at increasing natural sand replacement. In this study, hygro-thermal and durability properties of lightweight mortars containing such foamed end-of-waste aggregates were studied with the aim of correlating the results to composite morphology which resulted to be strongly influenced by the presence of lightweight aggregates.

2. Experimental procedures

2.1. Materials

Mortar samples were produced using an ordinary Portland cement (CEM I 42.5 N), quartz sand (CEN standard sand according to EN 196-1 [32], density of 2610 kg/m^3) and lightweight aggregates (LWAs). LWAs were produced starting from an end-of-waste material represented by a polyolefinic blend (polypropylene and polyethylene coming from the recycling of flexible packaging materials), supplied in densified pellets. A chemical foaming agent (Hydrocerol CF) was used to produce by extrusion foamed strands that were subsequently grinded to obtain aggregates of four different particle size (2–1.4 mm, 1.4–1.0 mm, 1.0–0.50 mm and 0.50–0.18 mm), according to the procedure described in a previous article [24]. Finally, aggregates were sieved and proportioned to partially reproduce EN 196-1 [32] quartz sand particle size distribution.

2.2. Mixtures preparation

Mortar samples were prepared using dry LWAs to avoid an increase of porosity due to the presence of free water released from LWAs [24], using a *w/c* ratio of 0.50 and a cement/sand ratio of 0.33. Nomenclature of the studied mixtures is reported in Table 1. All the mortar samples were prepared according to EN 196-1 [32]; natural and LWAs were dry mixed in advance to better disperse the aggregates in the mixture. Three natural quartz sand volume replacements (10%, 25% and 50%) were investigated comparing lightweight mortars (LWMs) samples to control specimens, i.e. without LWAs. All the samples were wet cured for 28 days in a humid chamber at 90% RH and 20 °C.

2.3. Density measurement

The oven-dry density, ρ_d, of hardened mortars was determined on specimens dried at 105 °C until constant mass, according to EN 12390-7 [33]. Three specimens for each composition were tested (experimental data are reported in Ref. [34]).

2.4. Capillary water absorption

Lightweight mortars water absorption coefficient due to capillary action, C_w, was determined according to EN 1015-18 [35]:

$$C_w = 0.1(M_2 - M_1) \quad (1)$$

Table 1
Investigated mixtures containing three natural sand volume replacement by lightweight aggregates (LWAs).

Mortar	LWA (%)
Reference	–
LWM10	10
LWM25	25
LWM50	50