Cement & Concrete Composites 49 (2014) 1–8

Contents lists available at ScienceDirect

Cement & Concrete Composites

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

Lightweight screed containing cork granules: Mechanical and hygrothermal characterization

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ARTICLE INFO

Article history:
Received 12 February 2013
Received in revised form 9 January 2014
Accepted 31 January 2014
Available online 7 February 2014

Keywords:
Lightweight screed
Expanded cork aggregates
Mechanical properties
Hygrothermal properties

ABSTRACT

This paper presents the results of an experimental study on the use of expanded cork granule waste with cement-based mixtures to produce lightweight screeds as an overlay of a structural concrete slab. Lightweight screeds (LWSs) were made with Portland cement, sand, expanded cork granules (ECG) and water. These cork particles are industrial waste and are still a completely natural material even after industrial processing. The experiments were carried out on 3 cement dosages of 150 kg/m^3, 250 kg/m^3 and 400 kg/m^3, incorporating expanded cork granules as replacement of part of the sand. Three additional mixtures without cork were prepared and used as reference. They had the same cement content as the lightweight ones. Hardened density, compressive strength, thermal conductivity, water vapor permeability, adsorption isotherms and water absorption by partial immersion of the mixtures were determined. Results show that the addition of expanded cork granules affects the screeds by decreasing their density, compressive strength and thermal conductivity while increasing their water vapor permeability.

1. Introduction

An ordinary screed mixture is usually made of cement, water and aggregate. Since thermal and acoustic insulation regulations have become more stringent, extra attention has been paid to the development of new products that can compete with conventional ones in terms of performance [1]. Furthermore, nowadays the sustainability agenda simultaneously demands energy conservation alongside the use of low impact materials to reduce the consumption of raw materials, prevent greenhouse gas emissions and, consequently, global warming. Indeed, in recent years much effort has been invested in making use of industrial waste products: for instance, studies on their potential as alternatives to the usual materials are extremely useful for the construction materials industry, for the above-mentioned reasons. Additionally, their physical and mechanical characterization is essential to understand their behavior and to build suitable mathematical models.

Lightweight aggregates are used in concretes, mortars and screeds to replace conventional mineral aggregates, to reduce their weight and to improve thermal and acoustic performance [2–5]. Moreover, and according to Cui et al. [6], the use of lightweight aggregate in cementitious composites makes construction easier, reduces building costs and exploits green building materials. Although lightweight aggregates have been used in buildings for many years, significant research on them has been carried out only since 1970 [7]. In fact several research studies have been undertaken in recent years on cementitious composites with natural and artificial (or synthetic) lightweight aggregates, in various countries. For instance, aggregates of pumice, shale, wood or cork are derived from natural resources [6,8–13], while expanded clay, shale and perlite are produced by the action of high temperature on natural materials [6,14,15]. Industrial by-products and wastes may also be incorporated in cementitious composites as lightweight aggregates, e.g., construction debris, recycled glass, cenospheres, volcanic slag, plastic waste, fruit husks, municipal solid waste incinerator fly ash and reservoir sediment [16–22].

The use of native materials and the exploitation of industrial waste are interesting solutions which may solve both energy and environment concerns. A literature review found a number of research works centered on sustainable purposes: Khedari et al. [21] investigated the thermal conductivity, compressive strength and bulk density of a cementitious material composed of cement, sand and coconut and durian waste, these last two in fiber form. In this study, the authors concluded that the addition of the fruit husk fibers reduces the thermal conductivity of the composite specimen and yields a lightweight one. Yasar et al. [9], Uysal et al. [10], Gündüz [12] and Hossain et al. [13] reported studies on the use of volcanic pumice, which can be found in the many

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http://dx.doi.org/10.1016/j.cemconcomp.2014.01.012
0958-9465/

once-active volcanic regions around the world, as aggregate. Strength properties, such as tensile and compressive strength, were investigated by Yasar et al. [9] in structural lightweight concrete made with basaltic pumice as aggregate and fly ash as mineral admixture. These authors concluded that the lightweight aggregate can be utilized in its locality to reduce the reactive mass under earthquake loading by using it in the production of structural lightweight concrete. Uysal et al. [10] measured the thermal conductivity coefficients of concretes made of mixtures of pumice and normal aggregates and different cement dosage. They concluded that the addition of pumice aggregate decreases the density and the thermal conductivity of concretes and, if the cement dosage is increased, both the density and thermal conductivity of the concrete increase. Gündüz [12] evaluated the compressive strength, elasticity modulus, bulk density, wetting expansion, drying shrinkage, water absorption and thermal conductivity of lightweight concretes with pumice aggregate. Hossain et al. [13] showed the viability of using pumice in lightweight concrete production and they also highlighted that pumice aggregates can be used in low-cost construction, especially in volcanic areas.

Cork particles, a by-product of the cork industry, have also been used as an aggregate in the fabrication of cement composites. Cork is a raw material obtained from the bark of the oak tree, *Quercus suber*, which mainly grows in the Mediterranean basin, particularly in the southern regions of the Iberian Peninsula. Portugal is still the world's main cork producer. Cork is a low density material and provides excellent thermal and acoustic insulation. It is a renewable raw material whose harvesting preserves the tree and also helps to improve its health and extend its life. Cork exhibits low stiffness, low strength and large compressive strains – Silva et al. [23]. Its industrial processing consumes energy which is generated by burning its industrial waste. The waste, in granular form, can be used as aggregates in lightweight concrete mixes [5,8,11,24]. Thus, the integration of cork waste in composite materials, such as screeds, is an appealing alternative to their disposal since it improves thermal and acoustic insulation, substantially reduces the weight of the building (which is particularly relevant in dwellings) and also cuts costs. The expanded cork granules used as aggregates in our work are industrial waste. These lightweight aggregates are a completely natural material, because the industrial processing consists of heat treatment at 350 °C and 300 kPa, and does not add any chemical substance. Recently, Panesar and Shindman [24] investigated the feasibility of combining waste cork with mortar and concrete mixes in the context of their plastic and hardened material properties. The authors evaluated the slump, density compressive strength, static elastic modulus, rapid chloride permeability and thermal resistance of ten mortar mixtures and nine concrete mixtures. The mortar mixtures were prepared as 1:2 mortars with a water-to-binder ratio, w/b, of 0.40, while the concrete mixtures were designed based on a cement content of 400 kg/m^3, w/b = 0.40 and coarse aggregates of 35% of volume. These concrete mix designs combine both a water reducing agent and a superplasticizer. It should be noted that the cork used in Panesar and Shindman's work is industrial waste from cork stoppers, which means that the cork was exposed to boiling water during the manufacturing process. In this work, they replaced 0%, 10% and 20% of sand with cork in mortar mixes and the same percentages of sand and stone with cork in concrete mixes. Carvalho et al. [5] presented an experimental analysis of the cyclic uniaxial and diagonal compression of a traditional mortar with the incorporation of granulated cork waste in order to prove the advantages of this composite in structural elements under cyclic loading. They determined and quantified the improvement in behavior with respect to energy dissipation capacity and concluded that the inclusion of controlled volume fractions of cork granules in mortars is definitely beneficial to the seismic protection of buildings.

The main purpose of our study was to characterize mechanical and hygrothermal properties of lightweight screeds with *Portland* cement, natural river sand, water and expanded cork granules (3-5 mm and 5-10 mm particles). The screeds can be laid over structural concrete slabs, with thicknesses that can typically vary from 0.05 to 0.12 m, to produce a horizontal surface and improve the thermal and acoustic behavior of the floor system. Floor coverings, such as parquet, ceramic tiles and vinyl carpet, can be laid afterwards.

Experiments were carried out on 3 cement dosages of 150 kg/m^3, 250 kg/m^3 and 400 kg/m^3, incorporating expanded cork granules that replaces part of the sand. Three additional mixtures without cork were prepared and used as reference. They had the same cement content as the lightweight ones. Hardened density, compressive strength, thermal conductivity, water vapor permeability, adsorption isotherms and water absorption by partial immersion of the mixtures were determined.

This paper is organized as follows: the next section presents the materials and mix proportions studied and the test procedures adopted; Section 3 presents and analyzes the experimental results, and the main conclusions of this work are summarized in Section 4.

2. Experimental program

The tests were carried out at *ITeCons* – Institute for Research and Technological Development in Construction Sciences, a laboratory that can perform a large number of experimental tests accredited by IPAC – *Instituto Português de Acreditação* (member of EA – European Cooperation for Accreditation and ILAC – International Laboratory Accreditation Cooperation).

2.1. Materials and mix proportions

Lightweight screeds (LWSs) were made with Portland cement (CEM II/B-L 32.5 N), natural river sand, expanded cork granules (ECG) and water. Cork particle sizes used in the mixtures were 3–5 mm (ECG 3/5) and 5–10 mm (ECG 5/10) in equal volume proportion. The particle densities and water absorption of the natural river sand and expanded cork granules were determined with a pycnometer in accordance with NP EN 1097-6:2003 [25], while their bulk density and percentage of voids were obtained according to NP EN 1097-3:2002 [26], (Tables 1 and 2). Granulometric analyses of aggregates were performed in accordance with NP EN 933-1:2012 [27] for natural river sand and with NP ISO 2030:2011 [28] for expanded cork granules (Fig. 1).

The experiments were carried out with 3 different cement dosages: 150 kg/m^3 (M150), 250 kg/m^3 (M250) and 400 kg/m^3 (M400), which means that M150 has a 62.5% lower cement content than M400, while M250 has 37.5% less than M400. Screed mixtures containing Portland cement (CEM II/B-L 32.5 N), natural river sand and water without any cork content were prepared for the same cement dosage (R150, R250 and R400) to be used as reference. In LWSs, 80% of natural river sand was replaced by ECG 3/5 and ECG 5/10, in volume. The volume proportion of the lightweight granules is 50% for ECG 3/5 and 50% for ECG 5/10. The mixture proportions of the screeds are summarized in Table 3. Although some authors argue that mix design codes should be used to define the ingredients composition of cementitious composites (e.g. concrete, mortar, screed), the specificities of the expanded cork aggregates meant that such codes would not be appropriate. Thus, preliminary tests were carried out to determine the best proportions of aggregate/cement weight needed for a suitable workability and to meet the detailed demands of the construction industry. Based on the pre-set quantities of Portland cement, the quantities of solid