



Internal curing with lightweight aggregate produced from biomass-derived waste



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ARTICLE INFO

Article history:

Received 7 November 2013

Accepted 29 January 2014

Available online 16 February 2014

Keywords:

Aggregate (D)

Fly ash (D)

Shrinkage (C)

Image analysis (B)

Pore size distribution (B)

ABSTRACT

Shrinkage of concrete may lead to cracking and ultimately to a reduction of the service life of concrete structures. Among known methods for shrinkage mitigation, internal curing with porous aggregates was successfully utilized in the last couple of decades for decreasing autogenous and drying shrinkage. In this paper, the internal curing performance of pre-saturated lightweight aggregates produced from biomass-derived waste (bio-LWA) was studied.

In the first part of this paper, the microstructure of the bio-LWA is investigated, with special focus on their pore structure and on their water absorption and desorption behavior. The bio-LWA has large porosity and coarse pore structure, which allows them to release the entrained water at early age and counteract self-desiccation and autogenous shrinkage. In the second part, the efficiency of internal curing in mortars incorporating the bio-LWA is examined by neutron tomography, internal relative humidity and autogenous deformation measurements.

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1. Introduction

External curing is a common approach for limiting shrinkage of concrete. In this method, exposed concrete surfaces are kept wet or loss of moisture is limited with physical barriers or curing compounds [1,2]. However, external curing may be difficult due to geometry or accessibility and it is generally labor-intensive and expensive. In high-performance concrete (HPC), curing water is mainly meant to compensate for self-desiccation [3,4]. For these mixtures with low water-to-cement ratio (w/c), low porosity and permeability, external curing may not be efficient because the curing water penetrates only the surface layer of the concrete. An alternative to external curing is internal curing, which consists of introducing internal water reservoirs into the concrete mixture [3–5]. These reservoirs absorb significant amounts of water either before or during mixing and release the water gradually during concrete hardening. The released water restores part of the water which has been lost through internal or external drying. As reservoirs, mainly porous lightweight aggregates (LWA) [6–9] and superabsorbent polymers (SAP) [10,11] have been used.

LWA, the most common internal curing agent, are either natural (e.g. pumice [7]) or artificial products (e.g. expanded shale [9], expanded clay

[6]). To be efficient as internal curing agents, LWA should rapidly absorb water (typically 10–30% by mass [12]) when conditioned before concrete mixing. In addition, the LWA should release a substantial fraction of the absorbed water during maturing of concrete. Whereas the water in a cementitious material has high mobility at early ages [13,14], the water needs first to be rapidly released from the reservoirs when the internal relative humidity (RH) is still high. The desorption behavior of the LWA depends mainly on their pore size distribution. Generally, a coarse pore structure leads to steeper desorption isotherms at high RH, which is beneficial for internal curing [12,15,16]. A recent study [17] confirmed that the internal curing performance of LWA depends critically on their microstructure: expanded-clay LWA, with coarse pore structure and well-interconnected pores performed well, whereas natural zeolite aggregates, in spite of high absorption, did not release the absorbed water due their extremely fine pore structure.

In Thailand, biomass (e.g. agricultural wastes such as rice husk, bagasse, straw, wood chips, and palm oil) is widely used as alternative fuel for energy production. The combustion by-products are mainly fly ash and bottom ash with high loss on ignition (LOI). The high LOI limits the potential use of biomass-derived ashes as a concrete admixture and for any construction applications. In a previous study [18] a novel approach was developed to produce synthetic bio-lightweight aggregate (bio-LWA) from sugar cane bagasse fly ash. With an efficient and economic approach, the waste ash was pelletized, sintered, crushed and sieved into appropriate sizes. The bulk density of the bio-LWA was

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0.6–0.8 g/cm³, the porosity 30–40% and the water adsorption 5–15% [18]. This novel bio-LWA allowed the production of lightweight precast concrete with a bulk density of 1600–1850 kg/m³ and 28-day compressive strength exceeding 40 MPa [18].

In this study, the performance of this novel bio-LWA as an internal curing agent for HPC is investigated. The use of the bio-LWA from sugar cane bagasse fly ash as an internal curing agent would allow converting agricultural wastes into a high-value product. Although the bio-LWA has water absorption and porosity in the range of LWA that have been used for internal curing, so far only limited information on their microstructure and no information on desorption properties are available.

In the first part of this paper, the absorption potential, sorption isotherms and pore structure of the bio-LWA are investigated, to assess their suitability as internal curing agents. In the second part of the paper, the efficiency of internal curing in high-performance mortars containing bio-LWA is investigated by neutron tomography (to measure directly the water release), internal RH and autogenous deformation measurements.

2. Materials

2.1. Bio-lightweight aggregate

The sugar cane bagasse fly ash for the production of the bio-LWA was obtained from a sugar mill located in Central Thailand and had a mean particle size of 55 μm, bulk density 330 kg/m³ and particle density 1700 kg/m³. The sugar cane bagasse fly ash was used directly as-received, with no previous thermal treatment [18]. An inorganic powder binder (sodium bentonite) was prepared separately and mixed with the sugar cane bagasse fly ash to produce a homogenous mixture. During the pelletization process, water was sprayed onto the mixture and depending on the rotating speed and tilt angle of the pan-pelletizer, fresh pellets of different sizes were obtained [18]. Prior to high-temperature sintering, the fresh pellets were pre-heated slowly until a sintering temperature of 1100 °C. The sintering process removed any existing fiber, pith and volatile remnants within the dried pellets and formed a semi-liquid phase on the exterior surface of the dried pellets to seal off any open pores. When the sintering temperature was lowered to ambient conditions, the exterior surface of the bio-LWA is solidified and chemically inert while the interior structure is porous [18]. The chemical composition of the LWA (by mass %) was 92.2 SiO₂, 2.3 Al₂O₃, 1.7 Fe₂O₃, 1.1 CaO, 1.3 K₂O, 0.8 P₂O₅ and 0.5 TiO₂, with almost negligible LOI [18].

The bio-LWA were then crushed and sieved into different sizes, of which the size fractions #30 and #50 were examined in the present study. Size fraction #30 had particles between 0.5 and 1.4 mm (for 95% of mass) with a mode at 0.71–1 mm, and fraction #50 had particles between 0.25 and 0.71 mm with a mode at 0.25–0.5 mm. Fig. 1 shows

SEM images of the bio-LWA particles at different magnifications. The typical pore size of the bio-LWA appears to be in the range of several μm, with some occasional larger voids (Fig. 1a).

2.2. Mortars

All mortars in this study contained a standard CEM I 42.5 N Portland cement, with modified Bogue composition [19] (by mass %): C₃S 60.8, C₂S 12.5, C₃A 4.76, C₄AF 9.8, free CaO 0.5, Na₂O eq. 0.81 and a Blaine fineness of 277 m²/kg. The workability of the mixtures was adjusted by replacing part of the mixing water (deionized water) with a liquid polycarboxylate-based superplasticizer (0.6% by mass of cement).

In the reference mortar with w/c 0.300, normal weight aggregates were added in an amount corresponding to 40% of the mortar volume. The aggregate was alluvial sand from Switzerland composed of (by mass %): dense sandstone 37%, limestone 37%, dolomite 18% and metamorphic rocks 8%, with well-rounded particles of size 0.25–1.0 mm. The water absorption of the normal weight aggregates, determined according to EN 1097–6, was 0.6% and the dry density was 2659 kg/m³.

In the mixtures with bio-LWA, either 48% (LWA-low mixture) or 72% (LWA-high mixture) of the volume of normal weight aggregates were substituted by the saturated bio-LWA. This corresponds to a volume occupied by the LWA in the mortars of 19% and 29%, respectively. Two size classes of bio-LWA were employed, #30 and #50. The bio-LWA were first dried and then saturated under vacuum according to the procedure specified in Section 3.1. The required mass of dry bio-LWA according to the mixture composition was saturated. Next, the saturated bio-LWA were added, together with mixing water and superplasticizer, to the dry cement and normal weight aggregates. The mixture composition of the mortars used in the internal RH and autogenous deformation measurements is shown in Table 1. The same mixture composition was used for both fractions of bio-LWA, #30 and #50. It was assumed that the bio-LWA had an adsorption of 15% by mass (see Section 3) and a particle density of 1700 kg/m³ (measured by mercury intrusion porosimetry, see Section 3.3). The total w/c can then be seen as the sum of the basic w/c 0.300 and the entrained w/c of either 0.050 or 0.075. The lower amount of bio-LWA (19% by volume of the mortar), assuming that all absorbed water can be released from the bio-LWA to the cement paste, would be sufficient for compensating chemical shrinkage and thus avoiding self-desiccation and self-desiccation shrinkage (based on Powers' model for the phase composition of Portland cement pastes, see e.g. [4]).

The mortars were mixed in a 0.5 l vacuum mixer (Twister Evolution) at 450 rpm for 2 min. Approximately 250 ml of mortar was mixed each time. For the neutron tomography investigations with the two bio-LWA size fractions, two mortars similar to the mortar with 19% vol. bio-LWA were mixed, with the only difference being the absence of the normal weight aggregates (while keeping the same basic w/c and entrained w/c). Theoretically, this should correspond to an increase of the LWA

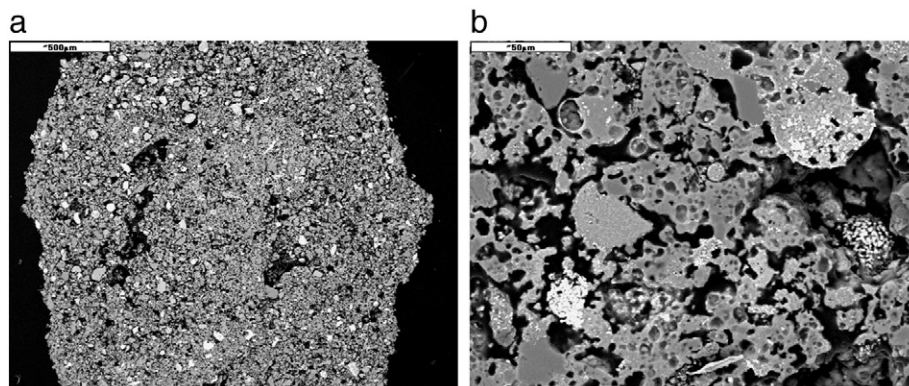


Fig. 1. SEM images of bio-LWA particles: (a) bar length is 500 μm and magnification 50× and (b) bar length is 50 μm and magnification 500×.

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