



Chloride ingress into structural lightweight aggregate concrete in real marine environment

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ABSTRACT

This study aims to characterize the chloride ingress into structural lightweight aggregate concrete (SLWAC) in real marine environment. For this, common normal weight concrete (NWC) and SLWAC produced with different water/binder ratios, types of aggregate and types and contents of binder were exposed to submerged, tidal and atmospheric conditions. Chloride profiles were obtained at 1 and 3 years of exposure and their chloride diffusion coefficients, D_{cl} , and surface chloride contents, C_s , were analysed. At least for water/cement ratios up to 0.55, D_{cl} was little affected by the type of aggregate, regardless of the exposure conditions. However, C_s and hence the chloride penetration at a given depth were higher in SLWAC with lightweight aggregates (LWA) of higher porosity or without a protective denser outer shell. SLWAC with dense LWA were able to achieve equivalent chloride penetration resistance to NWC with the same composition.

1. Introduction

Chloride-induced corrosion is one of the most frequent and serious causes of concrete deterioration [1], being most likely the dominant mechanism when determining concrete's service life [2].

Although reinforced structural lightweight aggregate concrete (SLWAC) has been used since the beginning of the 20th century, there is still a lack of knowledge on its durability, especially on its performance in real environmental exposure conditions. However, its potential durability has been demonstrated by its good performance in existing structures. Some investigations have been performed in marine structures [3–8] and in specimens exposed to long-term real environmental conditions [9–11].

Various authors [3,4,7,11–13] found that the chloride penetration resistance of SLWAC could be as high as that of normal weight concrete (NWC), which corroborates some laboratory results reported in literature [10,14–20].

After about 18 years of exposure, Polder et al. [7] reported lower chloride ingress in SLWAC than in NWC of equivalent compressive strength. However, SLWAC was produced with higher binder content and lower water/binder (w/b) ratio than NWC.

In SLWAC with expanded slate lightweight aggregates (LWA) exposed to marine environment for 25 years, Thomas and Bremner [11] reported equivalent chloride resistance to similar NWC of the same age. However, the authors found that near the surface the chloride content could be greater in SLWAC than in NWC. Other authors also reported higher surface chloride content in SLWAC than in NWC [21,22].

However, after 15 years of exposure to tidal zone, Osborne [23] observed slightly higher chloride penetration in SLWAC produced with scoria or fly ash LWA than in NWC of the same composition. Greater chloride penetration in total lightweight concrete than in NWC of equal compressive strength was also found by Al-Khaiat and Haque [24], after 3 years of exposure to the seaside.

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Most studies focus on particular types of aggregate, types of binder or environmental exposure classes, being only valid for the specific cases studied. However, SLWAC's behaviour can vary considerably depending on several factors, such as the type of lightweight aggregate, the curing conditions, the paste quality, the water content and penetration mechanism [25]. This may justify the apparent contradictory results reported in literature. As such, more comprehensive studies involving different types of SLWAC are necessary.

In addition, the main normative documents were essentially designed for NWC and do not refer to SLWAC's durability [26–28]. Thus, studies of SLWAC exposed to real environmental conditions are necessary to calibrate the models' parameters used to estimate the SLWAC's service life.

Bearing this in mind, this study aims to characterize the chloride ingress into the most common SLWAC under different real environmental exposure conditions. To this end, SLWAC produced with different types of aggregate, types and amounts of binder and water/binder ratios were subjected to the most representative environmental exposure conditions, according to the sea water chloride induced corrosion exposure classes defined in the European standard EN206 [29]. Chloride profiles were obtained at 1 and 3 years of exposure and their respective chloride diffusion coefficients and surface chloride contents were analysed.

2. Experimental programme

2.1. Materials

Four types of coarse LWA with very distinct porosities were selected for the production of SLWAC slabs: two expanded clay aggregates from Portugal (commercial names Leca and Argex, which was supplied in two different grain size classes, namely Argex 2–4 and Argex 3–8F); one sintered fly ash aggregate from the UK (commercial name Lytag); one expanded slate aggregate from the USA (commercial name Stalite). The main difference between expanded aggregates (Leca, Argex and Stalite) and sintered fly ash aggregates (Lytag) is their outer shell, as a result of their different manufacturing process. Expanded aggregates have a denser outer shell, while sintered fly ash aggregates have a uniform porous structure throughout their thickness. For the production of NWC reference slabs, two crushed limestone aggregates of different grain sizes were used, namely fine and coarse gravel. In order to obtain the same grading curve as Leca, for comparison purposes, a proportion was established between the two fractions of crushed limestone (34% fine and 66% coarse gravel) and the two fractions of Argex (70% Argex 2–4 and 30% Argex 3–8F). Fine aggregates consisted of 70% coarse and 30% fine normal weight sand for both SLWAC and NWC slabs. The main properties of these aggregates are listed in Table 1.

Lime filler (LF) with 38.6% residue on the 45 μm sieve, class F fly ash (FA) with 13.8% residue on the 45 μm sieve and a reactivity index of 84.4%, silica fume (SF) with 94.3% of SiO_2 , cement type I 42.5 R (CEM I) and a polycarboxylate based superplasticizer (SP) were also used.

2.2. Mixture composition and production

SLWAC with normal weight sand and four types of coarse LWA, as well as reference concretes with fine and coarse normal weight aggregates (NA) were analysed. The concretes were produced with different w/b ratios (0.35–0.55) and distinct types of binder, according to EN197-1 [30]. The mixture compositions are indicated in Table 2. These mixtures are representative of common SLWAC used in the construction industry.

The concretes were produced in a vertical shaft mixer with bottom discharge. The LWA were previously soaked for 24 h to ensure a better control of the workability and the effective water content of concrete. The aggregates were then surface dried with absorbent towels and placed in the mixer with sand and 50% of the total water. After mixing for 2 min, the mixture was left to rest for 1 min before adding the binder and the rest of the water. When used, the SP was slowly added with 10% of water, after 1 more minute. The total mixing time was 7 min. For SLWAC with Argex, the aggregates were initially dry before mixing. In this case, the absorption of LWA in the mix was estimated beforehand to take into account the correction of the total mix water, based on the method suggested by Bogas et al. [31].

Table 1
Aggregate properties.

Property	Lightweight aggregates					Normal weight aggregates			
	Leca	Argex 2-4	Argex 3-8F	Lytag	Stalite	Fine Gravel	Coarse Gravel	Fine Sand	Coarse Sand
Dry density (kg/m^3)	1076	669	597	1338	1483	2646	2683	2605	2617
Dry bulk density (kg/m^3)	624	377	330	750	760	1309	1346	1569	1708
Absorption at 24 h (%)	15.8	21.4	19.3	17.9	3.6	0.7	0.4	0.2	0.3
Granulometric fraction (di/Di)	4/11.2	4/8	4/11.2	4/11.2	8/16	0/8	4/11.2	0/1	0/4
Open porosity (%)	40.7	55.5	58.0	39.8	14.9	–	–	–	–

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