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Hardened properties and microstructure of SCC with mineral additions

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HIGHLIGHTS

- The effects of three active mineral additions (AMA) on hardened SCC were investigated.
- The use of AMA increased compressive strength but did not significantly modify stiffness.
- AMA also reduced porosity and Water Vapor Permeability (WVP), improving durability.
- WVP was directly related to porosity, rather than to pore size or tortuosity.
- Larger evaporation at Early Age reduced porosity, tortuosity and WVP, although increased pore size.

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ABSTRACT

The paper investigates the effects of three active mineral additions (AMA): microsilica (MS), nanosilica (NS) and metakaolin (MC), on the hardened properties, microstructure and mechanical performance of self compacting concretes (SCC) with limestone filler (LF). Compressive strength, P- and S-waves Ultrasonic Pulse Velocity (P- S-UPV) of hardened SCC were jointly studied with porosity and water vapor permeability (WVP) of paste samples covered and uncovered with plastic film during setting time, simulating two environmental conditions during early ages (EA). The interfacial transition zone (ITZ) was also examined using scanning electron microscopy (SEM). Substitution of 50% of cement by LF significantly reduced density, stiffness and compressive strength while slightly increased paste porosity and WVP in comparison with reference SCC. The use of AMA significantly increased compressive strength and reduced the presence and size of large Portlandite crystals in the ITZ of concrete, but that did not significantly improve the stiffness (ultrasonic modulus of elasticity). AMA also moderately reduced porosity and WVP of the paste phase, which would expect to improve durability of concrete. It was deduced that WVP was correlated to porosity rather than pore size or pore tortuosity. Compressive strength of pastes followed a different pattern regarding porosity. Depending on the presence of LF, the strength increased with porosity on pastes without filler while it decreased in its absence, depending on AMA's pozzolanic activity. The curing conditions at EA also affected hardened properties and paste's microstructure as larger evaporation for uncovered samples significantly reduced porosity, tortuosity and WVP, although increased average pore diameter.

1. Introduction

Self Compacting Concrete (SCC) typically contains a larger amount of cement paste than Conventional Concrete (CC). This is mainly in order to achieve the flowability requirements in the fresh state [1,2]. The paste of SCC can be obtained combining cement with other reactive and non-reactive materials having equal or smaller particle size, as mineral additions (MA), with the aid of a high range water reducing admixture (HRWRA) [2–6]. As the paste composition and amount vary in SCC, several changes can also be expected to occur on the composite performance both on the fresh and hardened states. The MA change the workability and rheology [7,8], the setting process [4,9] and the hardened microstructure [10,11]. However, SCC has been reported to exhibit similar hardened properties in comparison with CC by several investigations i.e. [11,12].

Two groups of MA can be used in producing SCC: fillers or non-active additions [5,6,9,13–15] and active mineral additions (AMA), which show potential hydraulicity or pozzolanic activity [7,16–22]. A combination of filler and an AMA is an innovative

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approach to obtain a moderate strength SCC [4,22–24]. The composition and the particle size of MA can be highlighted among the most important variables that can affect the cement hydration process and the packing ability of the binder [4,9,22,25]. Therefore the Early Age (EA) features and hardened performance of SCC can be improved [3,5–7,9,11,13–15,21–24].

The effect of MA on EA microstructure formation has been related to two different mechanisms: a physical effect which can facilitate the nucleation of hydrated cement crystals in addition to the filling effect and the chemical reactivity, particularly in the case of AMA [16,17,20,21,25]. Accordingly, the smaller particle size of AMA has been described to improve both nucleation and reactivity during the hydration process [4,7,16,18–24,26]. Nevertheless, the presence of MA has been described to limit some of the adverse effects of environmental conditions on the microstructure of cement based pastes (strength reduction or porosity increase) [4,8].

MA can affect both physical and mechanical performance of hardened SCC due to the expected change in the microstructure including the change in the pores' network features [13,15,27,28], which is mainly occurred during the EA [23–25]. MA can also change both the pore size and the total accessible pores (porosity) [14,27,29], which might lead to an increase of permeability [3,10,18,30,31] and may also compromise the durability [32,33]. Therefore, the hardened microstructure is a key factor to be considered in evaluating the concrete performance because of its impact on both hardened properties in short term and long term performance [7,18,30,31,34].

To analyze the hardened microstructure of a composite material such as concrete, some parameters related to the paste, the aggregates and the ITZ between them have to be considered on a SCC. Regarding the paste phase, both the bulk paste microstructure and the interfacial transition zone (ITZ) next to the aggregates, in particular, their porosity parameters (pores volume, pores amount and the interconnectivity between them), should be taken into account [35–37]. The physical properties related to SCC porosity are: density, water absorption and permeability [10,28,30], while mechanical stiffness and compressive strength can be related to the solid microstructure including bulk paste and ITZ [12,35].

This paper aims to evaluate the effect of three active mineral additions (AMA), microsilica (MS), nanosilica (NS) and Metakaolin (MC), on the hardened properties, microstructure and performance of self compacting concretes (SCC) with limestone filler (LF). The microstructure, the physical properties and mechanical performance of SCC pastes were investigated. The ITZ of the SCC was also examined to describe the effect of MA on the microstructure of this region. The results obtained, based on SCC pastes, were related to the hardened properties of SCC with the same paste composition in order to propose possible parametrical correlations. These correlations would improve the understanding of the effect of paste composition and microstructure parameters on SCC hardened properties and mechanical performance. They will also assess the sensitiveness of SCC to curing conditions at EA depending on the SCC paste composition.

2. Experimental program

2.1. Materials and mix design

2.1.1. Materials

A cement type CEM I 42,5 R, designated according to UNE-EN 197-1:2000 and supplied by Cementos Portland Valderrivas was used. The admixture used was a high range water reducing admixture (HRWRA), Glenium® ACE 425 manufactured by BASF. The limestone filler (LF), Betocarb® P1-DA, was supplied by Omya Clariana SL. Three active mineral additions (AMA) were used: a densified microsilica (MS), Meyco MS 610, and an amorphous nanosilica suspension (NS), Meyco MS 685, both supplied by BASF Construction Chemicals España S.L., and a metakaolin (MC), Optipozz™, manufactured by Burgess Pigment Company and supplied by Omya Clariana S.L. The nominal chemical compositions and physical properties of the cement, the filler (LF) and the AMA have been previously described [4,24].

2.1.2. Pastes and SCC mix design

Table 1 summarizes the six concrete compositions considered in the study. A reference mixture (HREF) only with cement and a water to cement ratio (w/c) of 0.36 was manufactured. The reference mixture was modified with a HRWRA, to achieve self-compacting ability (HREFG). Next, 50% of the cement was replaced by LF, producing a powder-type SCC (HCA). The three AMA were included to the mixture, substituting 5–10% of the filler. In all the mixtures, except the reference composition without HRWRA, the spread diameter measured using the J-ring slump test was over 650 mm [24]. Table 2 shows the paste compositions which simulate the concrete compositions but aggregates (fine/coarse). To validate the comparison between mixes and hence identify the effect of each component, only one component changed in each composition relative to the previous one.

The water incorporated in the mixtures by the components, such as sand (natural humidity 6.25%), HRWRA and nanosilica suspension, was discounted from the liquid water added to the mixture. Therefore, the water to fines content ratio (w/f) remained 0.36 in all mixtures (Tables 1 and 2).

2.2. Specimen preparation and Experimental Methods

Porosity and water vapor permeability (WVP) were tested on paste samples while apparent density, open porosity, ultrasonic

Table 1
Compositions of the concrete mixtures (components in kg/m^3).

	HREF	HREF G	HCA	HCAMS	HCANS	HCAMC
Cement CEM I 42,5 R	700	700	350	350	350	350
Siliceous gravel (4–20 mm)	790	790	790	790	790	790
Sand (0–4 mm) humidity 6.25%	691	691	691	691	691	691
Limestone filler (Betocarb P1-DA)	–	–	350	315	332.50	332.50
Micro-silica (MEYCO MS 610)	–	–	–	35	–	–
Nano-silica (MEYCO MS 685)	–	–	–	–	79.45	–
Metakaolin (Burgess Optipozz)	–	–	–	–	–	17.50
Water*	209.25	198.75	204	204	142	204
HRWRA (Glenium ACE425)	–	10.50	5.25	5.25	5.25	5.25
w/c**	000	000	0.71	0.71	0.71	0.71
w/binder**	000	000	000	000	000	000

[*] Liquid water added.

[**] Includes the amount of water included in the components (sand, HRWRA and nano-silica suspension).