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Effects of nano-components on early age cracking of self-compacting concretes

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HIGHLIGHTS

- Nano-components in a self-compacting concrete can improve mechanical performance.
- Nano-components produced side effects, increasing early age drying cracking risk.
- Monitoring several parameters allowed identifying key points of early age cracking.
- Early age cracking was controlled by low amounts of polypropylene micro-fibers.

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ABSTRACT

The influence of nano-components (nanosilica and carbon nano-fibers) on self-compacting concrete (SCC) hardened properties and at early age, when SCC evolves from a fresh state into a rigid structure, was assessed.

The methodology combined fresh and hardened characterization and several early age parameters were monitored, as temperature, ultrasonic pulse velocity (UPV), free shrinkage and early cracking, to identify the key points of the process.

In the hardened state, nanosilica improved compressive strength and carbon nano-fibers increased flexural strength of pastes. However, early age cracking risk was increased, which can compromise SCC durability. The addition of low amounts of polypropylene micro-fibers mitigated early age cracking.

1. Introduction

Self-compacting concrete (SCC) is nowadays one of the most efficient solutions in the world of concrete [1]. The design of SCC is based on the use of a large amount of fine particles and a high range water reducing admixture (HRWRA), also called superplasticizer [2]. Among the fine particles which can be used for SCC manufacturing, some nano-components are being considered. The inclusion of nano-additions and nano-fibers has been reported to improve the SCC properties in the hardened state [3,4].

Due to their size, the use of additions and fibers at this nano-scale can modify the properties form the beginning of setting, as these components take part in the formation of concrete nano-structure [5]. As a consequence, the material properties are improved and the effectiveness of the added components is also increased regarding to other micro-additions [6,7]. Carbon nano-fibers (CNF) are one of the components to be considered whose mechanical properties, as Young's modulus and tensile strength, make them suitable for cracking control at nano-scale size and to improve the hardened performance of SCC [6–8].

However, the effect of nano-components at early age is not studied enough for SCC. Their behavior might be different in SCC than in an Ordinary Portland Concrete (OPC) and they can produce related side effects that influence concrete durability.

In the hardened state, SCC performs similar to an Ordinary Portland Concrete (OPC) [9]. However, the behavior in the fresh state is rather different, mainly related to rheological aspects of mixtures. Consequently, the characterization tests are also different to those used for OPC. As it could be expected, SCC behavior at early age (EA), when the setting process takes place and the hardened structure is formed, is also going to be different, because of its different composition [10].

The increase of fines in SCC affects shrinkage at EA, as it has been previously described in other studies [11,12]. It have been demonstrated that increasing the paste volume, raises cracking risk due to shrinkage [11,13]. Previous studies had shown that

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the trend to surface cracking is higher in some types of SCC than in OPC [14].

The main factors involved in EA shrinkage can be sorted in two groups [15,16]. The first group corresponds to the physical changes and chemical reactions that occur during setting, which are related to cement hydration. A second group is related to external factors, closely linked to water evaporation, the use of dry constitutive materials and/or subtraction of water by the formwork.

The main undesirable effect of shrinkage at early age is cracking, which can produce permanent damage to the material, compromising its durability [17]. However, the relationship between shrinkage and cracking is not entirely clear, since larger shrinkage is not always associated to larger cracking risk [18].

EA shrinkage is the result of a combination of several factors: the hydration process, the effects of the environment plus the stiffening of young concrete and the evolution of the mechanical capacity. Depending on the environmental conditions, the stress developed in the material produces shrinkage during setting and early hardening. If the material does not have the capacity to absorb the stresses generated, it would crack [18,19].

EA shrinkage is also related to the water of the material. Water reacts with cement, fills the space among the solid particles, creating a pore net, and the lack of water inside the pores is behind drying shrinkage. Water exchange with the environment depends on the loss of water by surface drying [20,21] just after the solid microstructure is interconnected [22]. When the evaporation rate is larger than the exudation rate, a migration of water from the interior of the capillary pore net to the surface occurs, producing drying shrinkage. This yields to the volumetric variation that can trigger on very small internal cracks if concrete has not developed the capacity to absorb the stresses yet. Cracking may increase due to subsequent shrinkage in the hardened state and mechanical strain in loaded structural members.

In order to reduce cracking in concrete, several mechanisms of control have been described, acting on the three factors that cause cracking: control of water, control of the environmental conditions and design of mixture composition [23]. Considering the last group, an effective method for cracking control at EA is to incorporate small amounts of short fibers [24,25]. The incorporation of fibers control micro-cracks in concrete at EA. The constitutive material, size, amount and orientation of fibers affects the dispersion ability and the effectiveness of fiber to absorb and transmit stresses during EA [26]. The combination of different kind and sizes of fibers can also enhance concrete performance [27].

To identify the influence of nano-fibers and nano-additions on SCC early age behavior, a study on the changes of behavior at early age (24 h) and in the hardened state of SCC and fluid cement pastes incorporating nanosilica and carbon nano-fibers was carried out. The main goal was to determine the changes related to the nano-scale of the components.

2. Experimental program

The experimental program was designed to monitor the changes of SCC behavior during early age, due to the incorporation of carbon nano-fibers and other additions of different sizes that can improve the properties in hardened state. The aim was to identify the side effects and control them at EA, maintaining the improvements achieved in the hardened state. To assess the behavior from the plastic state to the rigid concrete, several parameters were simultaneously monitored: temperature, ultrasonic pulse velocity propagation (UPV), drying shrinkage and EA cracking risk. The experimental setup was designed to maximize the potential cracking of the samples, applying a continuous air flow of 3 m/s, while other environmental conditions, as temperature and relative humidity remained constant (25–26 °C and 50–55% RH). As a consequence, the effects of each component on the mixture could be identified. Afterwards, the experimental results were analyzed in order to define the evolution pattern of each composition. In a previous study, the evolution at EA and the relationships among the different parameters under study were identified [22], defining the role of some parameters within the hydration process, the microstructure evolution, early age shrinkage and their effect on EA cracking.

3. Materials and methods

3.1. Materials

Table 1 presents the composition of the fluid cement pastes and Table 2 summarizes the SCC compositions. A reference SCC mixture with limestone filler (CA) and five compositions with other components were manufactured. Water to fines ratio (w/f) remained constant at 0.36 in all the fluid cement pastes and SCC samples. The components used in the study were:

Table 1
Compositions of the fluid cement pastes (components in g).

	pCA	pCAm	pCAn	pCAu	pCAu + C
Cement CEM I 42, 5 R	850	850	850	850	850
Limestone filler (Betocarb P1-DA)	850	850	850	850	850
Water[a]	594	594	443[b]	601	459[b]
HRWRA (Glenium ACE425)	5.25	5.25	5.25	–	–
Micro-silica (Meyco MS 610)		85			
Nano-silica (Meyco MS 685)			193		
HRWRA + nano-silica (Ulmix NS SCC)	–	–	–	8.5	8.5
CNF (carbon-nano-fibers)	–	–	–	–	142
W/c[b]	0.71	0.71	0.71	0.71	0.71
W/fines (cement + additions)[b]	0.36	0.36	0.36	0.36	0.36

[a] Liquid water added.

[b] The amount of water included in the minor components (HRWRA, NS and CNF) was also taken into account.

Table 2
SCC compositions (components in kg/m^3).

	CA	CAm	CAn	CAu	CAu + C	CAu + CP
Cement CEM I 42, 5 R	350	350	350	350	350	350
Limestone filler (Betocarb P1-DA)	350	315	332	350	350	350
Water[a]	204	204	142[b]	206	160[b]	160[b]
HRWRA (Glenium ACE425)	5.25	5.25	5.25	–	–	–
Micro-silica (Meyco MS 610)		35				
Nano-silica (Meyco MS 685)			79.5			
HRWRA + nano-silica (Ulmix NS SCC)	–	–	–	3.5	3.5	3.5
CNF (carbon-nano-fibers)	–	–	–	–	58.3	58.3
PPF (polypropylene fibers)	–	–	–	–	–	0.9
Coarse aggregate (4–20 mm)	790	790	790	790	790	790
Sand (0–4 mm)	693	691	691	691	691	683
W/c[b]	0.71	0.71	0.71	0.71	0.71	0.71
W/fines (cement + additions)[b]	0.36	0.36	0.36	0.36	0.36	0.36
djf[c] (mm)	815	750	795	825	765	725
CbE[c] (%)	28	36	79	62	94	85

[a] Liquid water added.

[b] The amount of water included in the sand and minor components (HRWRA and CNF) was also taken into account.

[c] UNE 83362: 2007 – SCC characterization of flowability through rebars. Slump-flow test with J-ring.