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Effect of curing temperature and relative humidity on early age and hardened properties of SCC

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HIGHLIGHTS

- Effect of curing conditions on SCC properties was assessed.
- 10°, 20° and 30 °C and 40 and 80% of RH were considered.
- Temperature sped-up reaction, microstructure and mechanical properties.
- Lower RH increased evaporation, shrinkage and hydration speed.
- Hot-wet and cold-dry conditions increased compressive strength.

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ABSTRACT

The type and particle size of the additions used in SCC influence the setting and early hardening, modifying hydration speed and the development of initial properties. These processes are also altered by the curing temperature and relative humidity (RH) during Early age (EA) and would also affect SCC hardened properties.

An experimental study was carried out to compare the effect of different curing temperatures, 10, 20 and 30 °C, and RH, 40 and 80%, on EA and hardened properties of SCC incorporating limestone filler (LF), microsilica (MS) and nanosilica (NS). It was observed that temperature modified the reaction speed and the evolution of EA properties while relative humidity affected evaporation and shrinkage at early age and hardened porosity and stiffness. SCC microstructure and pore-network formation were found to depend on the combination of curing conditions and the type and particle size of the additions.

1. Introduction

Self-compacting concrete (SCC) can be considered a construction technology rather than a new material due to its huge technological improvement as casting technique regarding to conventional concrete. The combination of SCC casting technology, reducing energy and time consumption, plus the improved properties provided by some supplementary cementitious materials replacing cement can produce sustainable construction materials [1,2].

However, the large amount of paste that characterizes SCC can increase the risk of undesirable effects of curing conditions on fresh state and EA properties [3–5]. Drying shrinkage and cracking have been reported to be larger in SCC than in other types of concrete [6–10].

The large amount of cementitious materials incorporated in SCC mixtures affects the setting process and early hardening of the material, modifying hydration speed [10–13]. The particle type and size of the additions also produce changes in the formation of the rigid microstructure and the pore-network [1,12]. The use of reactive microsilica and nanosilica additions have been reported to improve the hardened properties and durability of SCC [1,14]. Binary and ternary binders, combining fillers and active additions, has been proposed as a design strategy to improve SCC performance complying with sustainability criteria.

As any other cement based material, SCC are characterized by the hydration of cement that produces the change in the material from a fresh state plastic suspension into a pseudo-rigid hardened material. The main transformations occur during a short period of time after the mixing of the dry components with water. This

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period is commonly referred as setting, although a more general term "Early Age (EA)" is preferred when referring to the development of the material mechanical properties [6,13,15–17].

During EA, several processes take place: a chemical process, governed by cement hydration; a physical process, related to solid/porous microstructure formation; and the development of mechanical properties. Their combination produces the change from fresh-plastic to pseudo-rigid hardened material [13,15].

Water plays the main role at EA. On one hand, water reacts with cement and the hydrating products dissolve in the water moving to the solid particles, crystallizing and creating linkages among them. On the other, water creates an interconnected porous network, where menisci get formed, as water gets consumed and does not fill the network, producing EA shrinkage [10,18].

The chemical reaction and water consumption, both by cement hydration and due to evaporation, also depend on curing conditions at EA [2,5,10,13,17,19,20]. Curing comprise a set of protective measurements leading to control reaction speed and water supply to protect CBM form undesirable damage, as EA cracking or lack of mechanical development [1,21–24]. Temperature, relative humidity and air velocity (wind) have been identified to be the most important environmental conditions that affect EA properties [2,13,16,17,19,22,25].

Curing conditions can affect the development of SCC microstructure and consequently modify its hardened performance. Although there is abundant literature about experimental laboratory studies dealing with the effect of supplementary cementitious materials on SCC performance [14,26,27], there are few holistic studies that systematically evaluate the effect of curing conditions on EA parameters and how do they affect SCC hardened properties.

To assess the effect of curing conditions on early age and hardened properties of SCC incorporating limestone filler, microsilica (MS) and Nanosilica (NS), a comparative experimental study was carried out on SCC samples subjected to different combinations of temperature, 10, 20 and 30 °C, and relative humidity (RH), 40 and 80%, simulated in a climatic chamber. This study reports a systematic experimental research on the combined effect of temperature and relative humidity on the EA and hardened properties of SCC with limestone filler and MS or NS. The aim of the study was to analyze the effect of curing temperature and RH on cement hydration, microstructure formation, mechanical properties development and shrinkage at EA and on physical and mechanical hardened properties.

As far as the authors knowledge reaches, further than the separated effect of temperature [4,5,19,20,22] and the effect of RH [21,25] on SCC properties, there is a lack of experimental studies reporting the combined effect of curing temperature and RH on SCC performance. These new results would help to evaluate the robustness of these SCC mixtures under different on-site curing conditions.

2. Experimental procedure

2.1. Materials and SCC composition

SCC were manufactured using the components listed below:

- A cement type CEM I 42.5 R, designated according to UNE-EN 197-1:2000, supplied by Cementos Portland Valderrivas.
- A high range water reducing admixture (HRWRA) Viscocrete® 5920 manufactured by SIKA.
- Lime-stone filler (LF) Betocarb® P1-DA, supplied by Omya Clariana SL.
- Densified microsilica (MS) Meyco MS 610 supplied by BASF Construction Chemicals España SL.
- A nanosilica suspension (NS) Meyco MS 685 supplied by BASF Construction Chemicals España SL.

Table 1 describes the three different compositions used in this study: a reference SCC with limestone filler (HCA); a SCC where 10% of limestone filler was replaced by MS (HCAMS) and a third SCC with 5% of limestone replaced by NS (HCANS). The water to cementitious materials (cement plus SCMs) ratio remained constant at 0.30 for all the formulations and the amount of paste was constant in all cases. The nominal chemical compositions of the cement, limestone filler, MS and NS have been previously reported [13].

2.2. Curing conditions

Fig. 1 presents the experimental program carried out by placing the fresh SCC samples inside a climatic chamber FDM-C140SX (0–70 °C temperature and 10–98% of relative humidity ranges). Three different temperatures (T), 10, 20 and 30 °C, and two different relative humidity (RH), 40 and 80%, were tested. Therefore, a total of six different curing conditions were used for each of the three mixtures of SCC, making a total of 18 sets of results. Although it has been described that the temperature and the RH on the surface of the samples could be slightly different than the environment, the monitored curing conditions would be enough to reproduce the experimental results.

2.3. Experimental methods

A set of samples were tested simultaneously in the climatic chamber. Fig. 2 shows the experimental setup inside the chamber. Capillary pressure, Evaporation (Ev), free shrinkage (Shr), temperature and ultrasonic pulse P- and S- wave velocities (UPV) were monitored during 24 h at each fixed curing condition. Evaporation and shrinkage were monitored with a shrinkage apparatus with internal dimensions of 250 × 100 × 50 mm placed on a scale to measure the loss of mass. Temperature, Capillary pressure and P-wave UPV (54 kHz) were monitored on a 150 × 100 × 70 mm sample. P- and S-wave were measured on 100 × 60 × 40 mm samples with 250 kHz UPV transducers in direct contact with the concrete sample in order to calculate the Poisson's Coefficient (υ), Ultrasonic Bulk Modulus (K) and Dynamic Young Modulus (E_{dyn}), according to (Eqs. 1–4) respectively [1,15]:

$$\upsilon = (0.5 v_p^2 - v_s^2)/(v_p^2 - v_s^2) \quad (1)$$

$$G_s = \rho \cdot V_s^2 / 1000000 \quad (2)$$

$$E_{dyn} = 2G_s(1 + \upsilon) \quad (3)$$

Table 1
SCC Compositions (components in kg/m^3).

	HCA	HCAMS	HCANS
Cement	350.00	350.00	350.00
Limestone Filler	350.00	315.00	332.50
Gravel (4–20)	790.00	790.00	790.00
Sand (0–4)	679.00	679.00	679.00
Micro-silica	–	35.00	–
Nano-silica	–	–	79.50
Water (*)	179.00	179.00	117.00
HRWRA	3.50	3.50	3.50
w/c (**)	0.60	0.60	0.60
w/powders (**)	0.30	0.30	0.30

* Liquid water added.
** The amount of water included in the components (sand humidity (4.3%), HRWRA and NS) was also considered.