



Comparison between the performance of expansive SCC and expansive conventional concretes in different expansion and curing conditions



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HIGHLIGHTS

- Influence of curing and restraining conditions in expansive SCC was evaluated.
- Concrete composition influences the reactivity of the expansive agents.
- Type-K agent reactivity depends greater in curing conditions than type-G agent.
- Restraining conditions affect the morphology and composition of expansive hydrates.
- Limestone filler is advisable instead of fly ashes when designing expansive SCC.

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ABSTRACT

Present paper evaluates the performance of expansive conventional concretes and expansive SCC, their physic-mechanical and microstructural properties, and their uniaxial restraining expansion regime, under different both restraining and curing conditions. The obtained results indicate that restraining conditions influence compressive strength and porosity structure, as well as the morphology and the chemical composition of the resulting expansive hydrates (ettringite formed from type-K agent and portlandite formed from type-G agent). The curing conditions and the concrete composition also influence the reactivity of the expansive agents. The use of limestone filler is advisable instead of fly ashes when designing expansive SCC.

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1. Introduction

Limitation of shrinkage strains is of practical importance for the concrete industry since considering certain structural uses, concrete shrinkage may cause cracking, decreasing its durability [1]. In this sense, the development of expansive concretes by using expansive agents/additives with different chemical compositions has demonstrated to be an effective means of reducing shrinkage thus also reducing the related crack formation; hence, their application to construction projects is gradually becoming popular for both new construction and refurbishment. There are already many cases where expansive concretes are applied, such as pavements without expansion or contraction joints, watertight walls, roofs made of monolithic concrete without roofing or taxiways without

joints, and even structural applications like concrete confined in steel tubes, or concrete filling of steel tubes for columns or bridge beams [2–11]. Confined structural applications usually require larger amount of expansion than shrinkage-compensating concretes.

Three main types of expansive agents are described in literature. They are classified as CaO-based, ettringite-based and MgO-based expansive agent [8,12]. This paper only studies the two first types: type-K (ettringite-based) agent, which is a mix of calcium sulfoaluminate and calcium sulfate that promotes the ettringite formation, and type-G (CaO-based) agent, mainly formed by calcium oxide that promotes the portlandite formation. The crystallization pressure generated by the oversaturation of crystals (ettringite or portlandite) when the agents are added to concrete would result in a significant expansion in the hardened state that would compensate the subsequent shrinkage. However, the involved phenomena are not fully understood yet [9,10,13–16]. Moreover, there are many parameters to consider that influence the efficacy of the expansive agents and the performance of the corresponding expansive concretes. Both curing and restraining

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conditions, and concrete composition are possibly the main parameters affecting the total expansion [2,3,5,6,8–10,17]. In fact, the use of both expansive agents seems to have some limitations. For example, due to the fast hydration of CaO and the relatively high solubility of portlandite, the application of CaO-based expansive agent in normal concrete has been limited [18]. In the case of ettringite-based expansive agents, their effectiveness relies on the water mix content and the free access of outer supplied water. As a large amount of water is needed for the formation of ettringite, the ettringite-based expansive agents depend strongly on wet curing to generate sufficient expansion [8]. Thus, in both cases the expansive performance is influenced by the curing conditions that mainly depend on the specific construction application [19].

Additionally, in some of these applications, the designed concretes must be self-compacting concrete (SCC) in order to make easier the delivery and casting at site (e.g., concrete filling of steel tubes) [16,20–22]. In this sense, the interaction between the chemical and mineral admixtures needed for SCC design and the expansive agents is not fully evaluated yet. Although previous studies have demonstrated the feasibility of developing SCC and the use of expansive agents [16,23,24], some challenges remain. The aim of the present paper is to advance on the knowledge about the performance of expansive self-compacting concretes under different curing and restraining conditions, compared to the performance of a conventional expansive concrete with similar cement content and w/c ratio.

At last, it is well known that in some construction applications where a large volume of concrete is needed, excessive thermal gradients between the core and the exposed faces of the element due to the dissipation rate of the accumulated internal heat produced by the hydration of cement, or restraint to bulk thermal contraction, can cause cracking within days, or weeks, of casting [25,26]. In order to decrease the thermal stress in large-volume pours and also to increase the sustainability of the construction process, supplementary cementitious materials (SCM) are usually added, such as ground granulated blast furnace slag (GGBS) and fly ashes (FA) [27–31]. Their inclusion also decreases the amount of generated hydration heat. Regarding the combined use of SCM's and expansive agents, a recent paper has demonstrated that for different contents of mineral admixtures, the expansion rates decreased with the increasing content of GGBS or FA, but this decrease is lower for FA concretes, mainly with FA contents below 30% in cement weight [32]. The smaller influence of the FA in the measured expansion should be related to its lower initial reactivity compared to GGBS [33]. In agreement with these results, two SCC mixtures with the same FA content have been designed and characterized in the present study, and the results have been compared to those measured in a SCC with the same amount of limestone filler (LF). LF has been commonly used in SCC design. Although LF is supposed to be an inert mineral admixture, recent studies have demonstrated a significant influence in the early hydration processes [34–36]. This influence could increase when expansive agents are used.

In order to give a further understanding of the performance of expansive conventional concretes and expansive SCC, their physic-mechanical and microstructural properties have been evaluated under different restraining conditions, and their expansion regime under uniaxial restraining has been assessed under different curing conditions.

2. Experimental

2.1. Materials and mix proportions

Six different concrete mixes have been designed in order to evaluate the influence of the self-compacting characteristic in the

expansive performance developed in different expansive concretes. A CEM I 42.5R according to EN 197-1 was used in all of them. Two crushed siliceous gravels (12/20 mm and 4/12 mm) and one siliceous sand (0/4 mm) were used as aggregates. Table 1 shows the nominal compositions of the evaluated concretes. C mixes refer to conventional concretes and S mixes refer to self-compacting concretes. In the SCC the coarsest aggregate phase was eliminated, a liquid polycarboxylate-based superplasticizer (density = 1.056 g/cm³) was used and the fine content was increased by using class F low CaO fly ashes or limestone filler. The concretes with FA are referred as SF and the concretes with LF are named SL. For each concrete type (C, SF and SL) two expansive agents were also considered: a type-K agent (based on calcium sulfoaluminate) and a type-G agent (based on calcium oxide). Table 2 shows the chemical compositions of both expansive agents. In order to avoid any influence of the cement content and the w/c ratio in the obtained results, both parameters were maintained constant in all the samples.

Expansive agents contents were different depending on the agent type considered: 15% in weight cement for agent type-K and 5% for agent type-G. These different contents were selected according to previous results where lower contents of type-G agent promoted larger longitudinal expansions than type-K agent when no water curing took place [16].

2.2. Test procedures

The fresh state of the fabricated concrete mixes was assessed by measuring the consistency according to EN 13350-2 in C concretes, and by conducting the filling ability tests (slump flow and T_{50cm} spread time according to EN 12350-8 standard) and the passing ability J-ring flow test (EN 12350-12) in S concretes. Density (EN 12350-6) and air content (EN 12350-7) were also determined in all cases. In the hardened state, the physic-mechanical properties and the expansion characteristics were evaluated under different conditions, as well as some microstructural properties. Ø100 × 200 mm sized cylindrical concrete specimens were fabricated to assess the compressive strength evolution at 7, 28 and 90 days according to EN 12390-3. Three samples for each age, concrete type and condition were used. The specimens were cured under water at 20 °C, except three samples for each case that were cured in their own steel moulds at 20 °C. The exposed face was wrapped in retractable film in order to avoid the water loss from concrete. For these last samples the compressive strength was measured at 28 days in order to analyze the influence of the confinement in the development of the concrete strength gain. Smaller cylindrical specimens (Ø75 × 150 mm sized) were fabricated to evaluate the total porosity and the pore size distribution of the fabricated samples, by using a Mercury Intrusion Porosimeter (MIP, Micromeritics porosimeter Model 9320) at 2 and 28 days of curing. A sample of concrete of approximately 1cm³ was used. In this case, two conditions were again considered: samples cured under water and samples cured in their own steel moulds and wrapped in retractable film. The microstructure of these concretes was characterized by BSEM with EDX analyses, by means of a scanning electron microscope Hitachi S-4800 equipped with an energy dispersive analyzer BRUKER 5030. The samples were embedded into an epoxy resin, cut, polished and then coated with carbon.

Eventually, prismatic specimens were fabricated to measure the expansion under uniaxial restraining following the ASTM C878 “Standard Test Method for Restrained Expansion of Shrinkage-Compensating Concrete”. In this test, two square end steel plates connected by a steel bar were placed on each end of the prismatic moulds before specimens of 254 × 76 × 76 mm size were cast (six per concrete mix). For all cases longitudinal expansion along the main axis of the prism was measured by using a digital comparator

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