



Impact of admixtures on the plastic shrinkage cracking of self-compacting concrete



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ARTICLE INFO

Article history:

Received 31 May 2013

Received in revised form 30 October 2013

Accepted 2 November 2013

Available online 9 November 2013

Keywords:

Self-compacting concrete

Plastic shrinkage

Cracking

Admixtures

ABSTRACT

Cracks accelerate the ingress of harmful fluids, impairing the durability of reinforced concrete structures. Plastic shrinkage cracking poses a problem in particular for concrete components such as slabs, in which a high percentage of the surface area is exposed to drying.

In this study, the impact of different admixtures on the occurrence and on the extent of plastic shrinkage cracking of SCC was investigated. Plastic shrinkage cracking was measured according to ASTM C1579-06 in a climate chamber at a temperature of 30 °C and relative humidity of 60%. Starting directly after casting, the settlement, the capillary pressure and the mass loss were recorded. At the end of the test, the crack-width distribution was analyzed.

A shrinkage reducing admixture and a paraffin-based curing compound were effective in preventing cracking. Based on the observed evaporation, settlement, capillary pressure and cracking behavior, the mechanisms for crack prevention were identified.

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1. Introduction

Cracks impair the durability of concrete structures as they accelerate the ingress of harmful gases and aqueous solutions that might induce corrosion of the reinforcement. The earliest crack formation can already occur right after concrete placement and compaction, i.e., before initial setting, when concrete has lost its fluidity but has not yet achieved any appreciable cohesion [1,2]. The occurrence of such plastic shrinkage cracking poses a problem in particular for slabs, where a high percentage of the surface area is exposed to drying right after casting [3–5].

Immediately after placement, when the concrete is still workable, the evaporation of water from the concrete surface leads to the formation of water menisci and negative capillary pressures in the pore water of the concrete [6–12]. In this phase, the volume loss of the fluid concrete due to water evaporation is completely compensated by settlement [9,13]. However, due to loss of water and consolidation under the capillary pressure, the concrete loses its workability before cement hydration (and with it strength development) starts. In this phase, the concrete can no longer settle and its horizontal deformation, when restrained, may lead to cracking.

As plastic shrinkage cracking is dependent on evaporation rate, settlement and capillary pressure, the concrete mix design, the

duration of the dormant period, and the environmental conditions (concrete and air temperature, relative humidity and wind speed) ultimately determine the risk of cracking [2,4,8,14]. At the construction site, measures to prevent plastic shrinkage cracking include spraying of either water [15] or curing compounds [16] on the concrete surface or minimizing the evaporation of water by applying protective cover sheets [17]. Recently, the use of shrinkage reducing admixtures [11,18–21] was shown to reduce evaporation, settlement, capillary pressures and plastic shrinkage cracking. Lin and Huang [22] observed that stabilizers (cellulose-based) reduced the evaporation rate and the amount of plastic shrinkage cracking. Internal curing, either by means of saturated lightweight aggregates [23] or superabsorbent polymers [24] was also shown to reduce plastic shrinkage cracking. According to Leemann et al. [25], a paraffin dispersion can also be effective in reducing evaporation and cracking when it is used as a concrete admixture, not only as a curing compound. Different types of fibers, especially fibrillated polypropylene fibers, have been employed to reduce the extent of plastic shrinkage cracking (e.g., [26,27]). Kronlof et al. [28] studied the horizontal plastic deformation of mixtures with accelerator and retarder and observed higher shrinkage for accelerated mixtures, followed by the reference mixture and the retarded one. Similarly, Combrinck and Boshoff [29] measured a higher total crack area of plastic shrinkage cracks in samples with accelerator, followed by the reference mixture and by a retarded mixture.

As self-compacting concrete (SCC) generally has a higher paste volume compared to vibrated concrete, it is expected to show

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higher settlement and early shrinkage. Whereas this has been proven for drying shrinkage [30,31], little is known about the plastic shrinkage cracking risk of SCC in general and about the influence of admixtures in particular. Only few papers have been published about plastic shrinkage and plastic shrinkage cracking of SCC (e.g., [20,32–37]). These papers mainly deal with comparisons of ordinary vibrated concrete and SCC or with the influence of the type or fineness of the filler. Gram and Pentti [32] compared the early horizontal shrinkage of SCC and ordinary concrete and found 2–3 times higher shrinkage of SCC. On the contrary, Holt and Schodet [33] measured lower horizontal shrinkage in SCC mixtures made with different fillers (granite, fly ash, limestone) than for ordinary concrete. According to Turkry and Loukili [34], SCC mixtures exhibited the same evaporation rate, but higher horizontal shrinkage than ordinary concrete. In a follow-up study, Turkry and Loukili [35] compared the horizontal plastic shrinkage and the plastic shrinkage cracking of SCC and ordinary concrete mixtures for samples exposed to drying at 20 °C and 50% RH with as well as without wind. Without wind, while no plastic shrinkage cracking was observed, the SCC mixtures had faster horizontal shrinkage and capillary pressure development, with higher final horizontal shrinkage. In the presence of wind (severe drying conditions), horizontal shrinkage and capillary pressure development of SCC became more similar to those of ordinary concrete. However, ordinary concrete exhibited larger maximum crack widths and earlier cracking than the corresponding SCC mixtures. The authors attributed this result to the higher strain capacity of SCC. Löfgren and Esping [20] studied the plastic shrinkage cracking of a number of SCC mixtures with water-to-cement ratio (w/c) from 0.38 to 0.67 and compared them with ordinary concrete. A high cracking tendency was observed with silica fume addition and at the lowest and the highest w/c. The minimum crack tendency was found at w/c 0.55, while a higher percentage of coarse aggregate also reduced cracking. Esping [36] studied the effect of limestone fillers with different specific surface area on the plastic shrinkage cracking of SCC, finding that filler with a large area decreased the evaporation, the capillary pressure and the plastic cracking tendency. With additional water, added to regain the original flowability, the plastic shrinkage cracking tendency instead increased.

Even fewer papers have been dedicated to studying the effect of admixtures on the plastic shrinkage cracking of SCC. Turkry and Loukili [34] showed that by spraying a curing agent (a copolymer diluted in a solvent) on the surface of the SCC, the evaporation rate and the horizontal shrinkage in the first hours after casting could be reduced. According to Löfgren and Esping [20], the addition of SRA (polymeric glycol, 1% and 2% by cement mass) was able to reduce both the rate of evaporation and the total area of plastic shrinkage cracks. Adding an accelerator (sodium-based) reduced the crack area, while adding a retarder (polyalkyl ether) increased the crack area. This effect was comparable to the effect of changing the dosage of superplasticizer in the SCC. A paraffin-based curing compound applied on the SCC surface was effective in reducing the cracked area. Ghoddousi and Shirzadi Javid [37] measured settlement, horizontal shrinkage and plastic shrinkage cracking of SCC with water-to-powder ratio 0.45 and limestone filler, with addition of silica fume and latex modifier. While the addition of silica fume increased the horizontal shrinkage and the plastic shrinkage crack-

ing, further addition of latex decreased settlement, horizontal shrinkage and cracking.

From this literature review, it appears that, with the partial exception of Löfgren and Esping [20], no systematic studies about the influence of admixtures on the plastic shrinkage cracking of SCC have been published so far. In the present study, different admixtures were added to a reference SCC in order to assess their impact on the occurrence of plastic shrinkage cracks. Plastic shrinkage was measured according to ASTM C1579-06 on two specimens. The experimental set-up included a wind channel in a climate chamber with a temperature of 30 °C and relative humidity of 60%. Starting directly after casting, the capillary pressure, the settlement and the mass loss were recorded. At the end of the test, the crack width distribution was analyzed. In addition, the bleeding was measured on separate concrete samples and the extent of hydration was monitored by isothermal conduction calorimetry on cement pastes with the same w/c and admixtures.

2. Materials and methods

2.1. Materials

Cement composition and concrete mix design are given in Tables 1 and 2. The concrete was produced with 460 kg/m³ of a blended cement containing approximately 15% by mass of limestone powder and 15% by mass of fly ash (CEM II/B-M (V-LL) 32.5 R according to EN 197-1) and had a water content of 202 l/m³ (w/c of 0.44). The alluvial sand and gravel used as aggregates were added as separate fractions (0–1 mm: 35% by mass, 1–4 mm, 21% by mass, 4/8 mm: 19% by mass, 8–16 mm: 25% by mass). A polycarboxylate-based superplasticizer (SP) was used. The used accelerator was based on seed crystals added as dispersion [38], the retarder on sodium pyrophosphate, the stabilizer on modified starch, the curing compound on a paraffin-dispersion and the shrinkage reducing agent (SRA) on organic hydroxyl-compounds. In contrast to sprayed curing compounds, the one used in this study was added to the mixing water [25].

The effect of the SRA and of the stabilizer on the surface tension was measured with the pendant drop method [39] on solutions consisting only of the admixture and deionized water in proportions equal to those employed in the concrete mixtures (Table 2). The surface tension of the SRA solution was 0.0432 ± 0.001 N/m (average and standard deviation of 4 independent measurements), while the surface tension of the stabilizer solution was 0.0593 ± 0.005 N/m (average and standard deviation of 4 independent measurements).

Prior to concrete mixing, the components were stored at 20 ± 1.5 °C, the same temperature at which concrete production took place. After premixing cement and dry aggregates, 90% of the mixing water was added. The rest of the mixing water was poured into the mixer together with the admixtures. The concrete was mixed for 90 s in a pan-type Eirich mixer. The reference concrete SCC Ref was produced and measured three times to assess reproducibility.

For the isothermal conduction calorimetry measurements, cement pastes with identical w/c and admixture addition as the corresponding SCC were measured.

Table 1
Composition of the cement (LOI = loss on ignition).

Type	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO (mass%)	Na ₂ O	K ₂ O	SO ₃	LOI	Blaine (cm ² /g)	Density (kg/m ³)
CEM II/B-M (V-LL) 32.5 R	52.3	23.6	6.9	3.8	1.7	0.3	1.2	2.5	6.9	4140	2900

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