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Crack-free concrete for outside industrial floors in the absence of wet curing and contraction joints

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ABSTRACT

Shrinkage-compensating concrete can be manufactured by using an expansive agent provided that an adequate wet curing is carried out after demolding: the surface treatment should be wet cured for at least one week.

In the present work a special superplasticized shrinkage-compensating concrete has been studied which does not need any wet curing, provided that it is protected for 1 day by a polyethylene sheet from rain or sunny weather, when an outside industrial floor is cast. The superplasticizer (PA/SRA) is still based on a polyacrylate superplasticizer (PA), but it also contains a special chemical group acting as shrinkage-reducing admixture (SRA) incorporated in its molecular structure. Due to the increase in the pH of the aqueous phase caused by the cement hydration, the SRA chemical group is liberated from the molecular structure of the superplasticizer and is then capable of reducing the surface tension of the pore. This change in the surface tension of the pore water increases the restrained expansion of the concrete containing a CaO-based expansive agent.

Due to this additional effect, a superplasticized shrinkage-compensating concrete can be successfully placed even in the absence of a wet curing. In this paper a practical application is shown where this crack-free concrete is used for an outside industrial floor of 800 m^2 without contraction joints and in the absence of any wet curing.

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1. Introduction

Shrinkage-compensating concrete can be advantageously used to build reinforced concrete structures without contraction joints, provided that adequate wet curing is immediately carried out. In particular, surface extensions of 600 or 900 m^2 without contraction joints can be achieved for outside or inside industrial floors, respectively [1]. This technique is based on the early restrained expansion that occurs between the expansive agent and water. Due to the restraint produced by metallic reinforcements, the concrete expansion is transformed into a self-stressing action that compensates for stresses induced by the subsequent drying shrinkage starting at the end of the preliminary wet curing.

In the absence of wet curing, this technique is not successful because the restrained expansion does not occur and then the contraction joints are needed to avoid drying cracks. Depending on the type of expansive agent, the preliminary wet curing must be prolonged for 2 or 7 days. For instance, calcium sulfo-aluminate (CSA) reacts with water in the presence of lime and calcium sulfate producing ettringite according to the reaction (1):

$$4CaO \cdot 3Al_2O_3 \cdot SO_3 + 6CaO + 8CaSO_4 + 96H_2O \Rightarrow 3[C_3A \cdot 3(CaSO_4) \cdot 32H_2O] \quad (1)$$

This reaction takes about 7 days to be completed, which implies that continuous wet curing for about one week is needed to achieve all the potential restrained expansion. Concretes with other expansive agents, such as those based on dead burnt lime (CaO), must be kept wet for shorter times (about 1–2 days depending on the porosity and the particle size distribution):

$$CaO + H_2O \Rightarrow Ca(OH)_2 \quad (2)$$

The porosity and the particle size of CaO can affect the time to complete the expansion related to Eq. (2). Burning temperatures in the kiln as high as 1000 °C and relatively big particles with maximum size of about 100 μm are needed to develop a properly slow reaction rate [2]. On the other hand, high porosity and small size particles of CaO accelerate its transformation into $Ca(OH)_2$. When this process is too rapid, with respect to the hardening process of the cement, the expansion occurs without any restraint by metallic reinforcements due to the poor bond strength between steel and the still plastic concrete.

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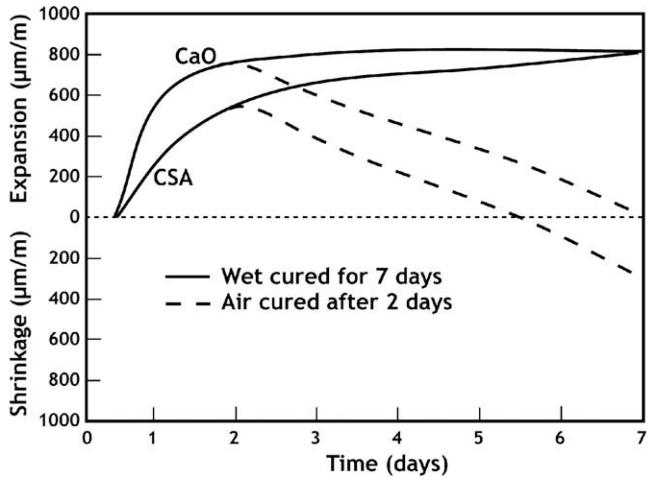

Fig. 1. Length change of reinforced concrete specimens with CaO or CSA as expansive agent: dashed curves refer to air curing (RH = 65%) after wet curing for 2 days.

Fig. 1 schematically shows the restrained expansion, determined according to the ASTM C 878 test method, based on the length change measured on reinforced concrete specimens demoulded at the setting time (about 6–8 hours after mixing) and then permanently kept under a lime-saturated water for 7 days. The expansion occurs in less than 2 days in concrete with a properly manufactured CaO as expansive agent, and in about 7 days in concrete with the CSA expansive agent. This measurement appears to be unrealistic if one considers the real wet curing which can be carried out in practice on concrete structures demoulded at 1–2 days or even on concrete industrial floors. A more realistic wet curing, based on a continuous water ponding for 2 days reduces the expansion rate by about 50% in the CSA concrete specimen and the subsequent drying shrinkage completely cancel in about 5 days any previous expansion (Fig. 1). Even for the CaO-expansive concrete there is a complete lost of the expansion in about 1 week if the concrete is exposed to air with relative humidity of 65%. Therefore, a successful application of shrinkage-compensating concrete for crack-free industrial floors without contraction joints is still difficult to achieve in practice.

Recently [3], the combined addition of a shrinkage-reducing admixture (SRA) with a CaO-based expansive agent has been found to be very successful in producing restrained expansion of laboratory specimens even in the absence of any wet curing (Fig. 2). The influence of the SRA on the length change behavior of a shrinkage-compensating concrete includes two different aspects: the β effect in Fig. 2, due to a reduction in shrinkage when the concrete is exposed to drying as expected for the presence of a shrinkage-reducing admixture (SRA); the unexpected α effect, which is an increase in the restrained expansion when the concrete is protected from drying, as would occur in concrete placed in formworks or concrete floors covered with a plastic sheet.

This results has been confirmed by Maltese et al. [4] who have found that the use of a CaO-based expansive agent with a shrinkage reducing admixture allows to obtain mortars less sensitive to drying.

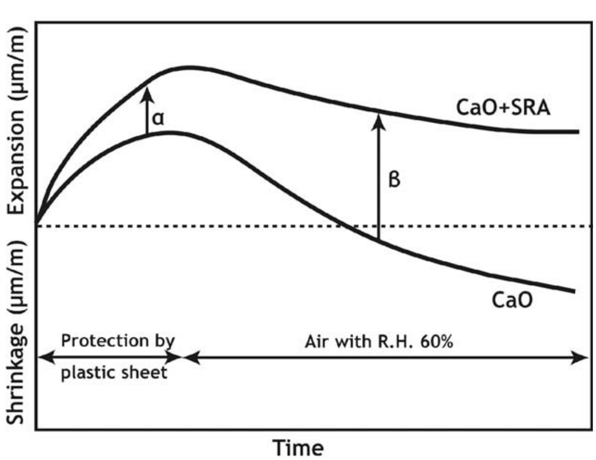

Fig. 2. Schematic view of the influence of SRA on the length change behavior of a shrinkage-compensating concrete.

2. Scope of the work

The research work focused on the combined use of a CaO-based expansive agent and a special polyacrylate superplasticizer (PA/SRA) capable of reducing both the amount of mixing water and drying shrinkage, due to the presence of the SRA group chemically incorporated in the polymer chain (Fig. 3). A practical application of this system was undertaken and it involved casting of a crack-free concrete industrial floor without any contraction joint for 800 m^2 and without any wet curing.

3. Experimental: materials and methods

Table 1 shows the composition of five concrete mixtures all at a superfluid consistency S5 (slump > 210 mm) and at a given water–cement ratio (w/c) of 0.62, to manufacture a concrete with a 28-day cube compressive strength of about 30 MPa. The reference (control) mixture does not contain any chemical admixture. In the concrete mixture SRA, a Shrinkage-Reducing Admixture (SRA) was used to reduce the surface tension of the pore water in order to decrease the drying shrinkage with respect to the control mixture at a given w/c and slump level. The concrete mixture PA contains 0.6% of polyacrylate superplasticizer (PA) in order to reduce both water and cement with respect to the control mixture at a given workability, and then to increase the aggregate–cement ratio (a/c) in order to reduce the drying shrinkage. In the concrete mixture PA/SRA, a special superplasticizer was used which can reduce

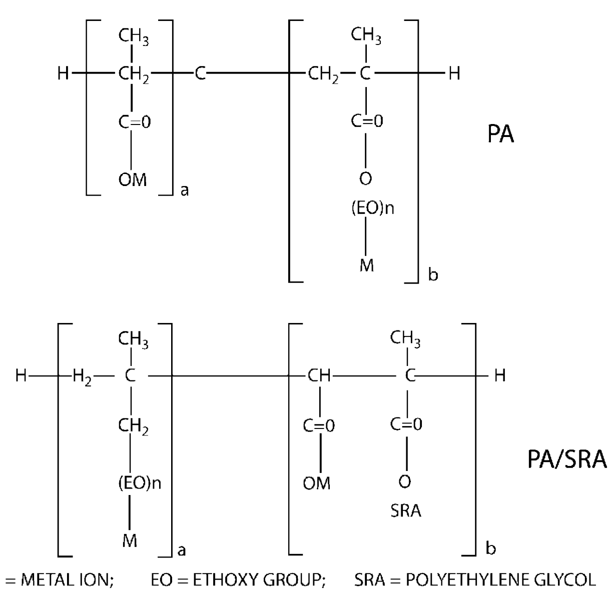

Fig. 3. Chemical composition of the PA and PA/SRA superplasticizers.

Table 1
Composition of concrete mixtures at a superfluid consistence (slump = 230 ± 108 mm)

Composition (kg/m^3)	Control mix	PA mix	SRA mix	PA/SRA mix	PA/SRA + CaO mix
CEM II A–V 42.5N*	348	290	340	280	285
Water	215	180	210	174	176
Sand 0–5 mm	900	972	905	975	960
Gravel 5–25 mm	765	934	870	937	925
PA	–	3.0	–	–	–
SRA	–	–	4.0	–	–
PA-SRA	–	–	–	7.0	7.0
CaO	–	–	–	–	25.0
w/c	0.62	0.62	0.62	0.62	0.62
a/c	5.1	6.6	5.2	6.8	6.6

both the water surface tension and the amount of mixing water, at given w/c and slump level with respect to the control mixture. A fifth concrete mixture was manufactured by using both the PA/SRA superplasticizer and the CaO-based expansive agent: this concrete is identified by the code PA/SRA + CaO.

Length change measurements were carried out according to the ASTM C 878 test method except that wet curing in lime-saturated water was replaced by more realistic curing conditions as follow:

– Procedure A: wrapping of the specimens at 20 °C with a polyethylene sheet for 1 day and then permanent exposure to air with a relative humidity (R.H.) of 55% (this condition is recommended for outside industrial floors in order to protect the surface of the fresh concrete from rain or sunny weather); in this study, this procedure was applied to all concrete mixtures.
– Procedure B: immediate and permanent exposure to open air at 20 °C with R.H. of 55% (this condition is usually adopted for inside industrial floors); this procedure was applied to only the shrinkage-compensating concrete PA/SRA + CaO in this study.

Measurements of compressive strength were carried out on cube specimens (150 mm) kept at 20 °C at a relative humidity of 100%.

4. Results and discussion

The composition of the concrete mixture SRA is similar to that of the control mixture at the same slump level of about 230 mm (Table 1). Fig. 4 shows that the drying shrinkage of the SRA concrete is significantly lower than that of the control mixture: the reduction in the drying shrinkage (about 50% at early ages and 30% at longer ages) is related to the reduction in water surface tension caused by the SRA [5]. However, Wittmann [6] thinks that shrinkage is linked to the decrease in the disjoining pressure and not with the surface tension of the water filling the pores.

In the PA mixture there is a reduction in mixing water by 16% with respect to the control mixture at a given w/c (0.62); then, also the amount of cement is reduced by 16% (290 vs. 348 kg/m^3), whereas the aggregate–cement ratio increases from 5.1 to 6.6 (Table 1). Due to the change in the aggregate–cement ratio, the drying shrinkage of the PA mixture decreases by about 40% with respect to the control concrete (Fig. 4).

The composition of the PA/SRA mixture is very close to that of the PA mixture containing an ordinary polyacrylate superplasticiz-

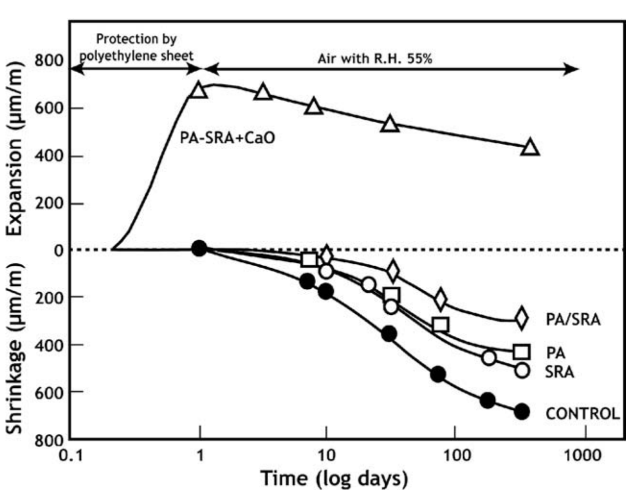

Fig. 4. Restrained length change of reinforced specimens according to the Procedure A for different concrete mixtures shown in Table 1.

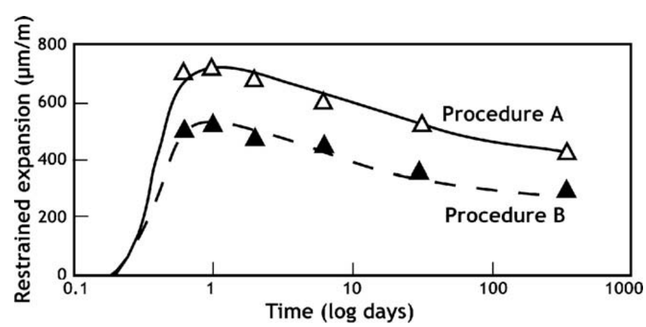

Fig. 5. Restrained expansion of "PA/SRA + CaO" concrete according to the Procedure A or Procedure B.

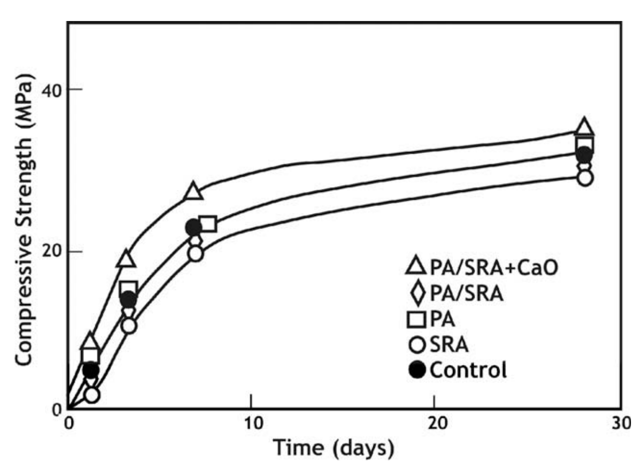

Fig. 6. Compressive strength of different concrete mixtures shown in Table 1.

Fig. 7. Placing of the concrete mixture at a superfluid consistency (slump = 230 mm) for a reinforced industrial floor.

Fig. 10. View of the concrete floor area without contraction joints.

Fig. 8. Finishing operation of the concrete floor.

Fig. 11. Construction joint on the left and insulation joint on the right.

Fig. 9. Protection of the concrete floor after finishing for 1 day from placing.

er: again, with respect to the control concrete there is an increase in the a/c from 5.1 to 6.8 (Table 1).The drying shrinkage is much lower than that of the control concrete: 80% at early ages and 60% at longer ages (Fig. 4).

In the shrinkage-compensating concrete (PA/SRA + CaO), based on the use of CaO as expansive agent and PA/SRA as superplasticizer, the w/c and a/c are very close to the corresponding values of the PA/SRA mixture (Table 1). However, with respect to all the other concretes, there is a significant restrained expansion in the absence of wet curing which remains even at longer ages when measured according the *Procedure A* (Fig. 4) as well as according to the *Procedure B* without the 1-day protection by the polyethylene sheet (Fig. 5).

Fig. 6 shows the strength development of the concretes. With respect to the control mixture there is a slight decrease in the compressive strength of the concretes containing SRA or PA/SRA. On the other hand, this effect is counterbalanced by the presence of CaO in the concrete PA/SRA + CaO probably for the reduction in the actual w/c due to the consumption of a small part of mixing water due to the transformation of CaO into $Ca(OH)_2$.

On the basis of these laboratory results, two concrete mixtures (PA/SRA and PA/SRA + CaO) were selected to make two outside industrial floors on the ground, both in the absence of wet curing. In particular, the PA/SRA + CaO concrete was placed at a superfluid consistency (Fig. 7), protected by a plastic sheet (Fig. 8), finished by troweling (Fig. 9), and then exposed to open air (R.H. = 60%) without wet curing and contraction joints for a surface area of 800 m^2 (Fig. 10). Only construction joints were used at the end of the day (Fig. 11).

On the other hand, the PA/SRA mixture was placed, protected for 1 day by a plastic sheet, sawed for the contraction joints (with an interspace of 6 m), and then exposed to open air (about 60% of R.H.) without wet curing.

No crack has been observed on the surface of these two outside industrial floors after eight months of the placement.

5. Conclusions

With the use of a special polyacrylate-based superplasticizer (PA/SRA), containing in its molecular structure a chemical group acting as shrinkage-reducing agent (SRA), an outside industrial floor on the ground was cast with up to 6 m spacing between contraction joints and without wet curing. No cracking was observed after eight months from the time of casting.

With the combined use of the PA/SRA superplasticizer with a CaO-based expansive agent, a shrinkage-compensating concrete (whose restrained expansion did not need any wet curing) was cast. No contraction joints were made in this 800 m^2 concrete floor, but construction joints were made at the end of the day. No crack has been recorded after four months from placing. The key point of this joint-less floor is the robustness and crack-free performance that can be obtained even in the absence of wet curing.

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