Light-weight Self-compacting Concrete

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ABSTRACT: Self-compacting lightweight concrete was developed to attain good workability, high compressive strength (R_{ck} about 40 Mpa), minimum cracks, effective durability even in very aggressive exposures, and low specific weight (about 2000 kg/m^3), as well as low elastic modulus (about 30 GPa). Concrete was evaluted in the fresh state as well as in the hardened state by measuring compressive strength, restrained expansion, carbonation and chloride penetration, and dynamic elastic modulus. This concrete should be particularly suitable in meeting the specific requirements of concrete used in seismic areas. The present paper shows the results of the preliminary trial tests to attain these objectives by using high-quality raw materials available during the last decade: polycarboxylate admixture (PCA) as superplasticizer, shrinkage-reducing admixture (SRA), CaO-based expansive agent, PVA (What is PVA? Please provide full name the first time it is used.) fibres, expanded clay to reduce the specific weight under 2000 kg/m^3, and ground limestone filler to manufacture uniform self-compacting concrete without bleeding and segregation. Many of these objectives for properties were attained by using about 400 kg /m^3 of portland cement, about 100 kg/m^3 of limestone filler, 900 kg/m^3 of coarse sand (0-8 mm), 400 kg/m^3 of expanded clay (0-15 mm), 12 kg/m^3 of PCA, 4 kg/m^3 of SRA, 30 kg/m^3 of the expansive agent, and 4 kg/m^3 of PVA fibres.

1 INTRODUCTION

Lightweight self-compacting concretes were manufactured with special performances in terms of low water/cement ratio, low drying shrinkage even in dry environments, low specific weight and elastic modulus. The latter two performances are particularly suitable for concrete to be used in reinforced structures exposed to the risk of seismic actions.

1.1 Materials and experimental

A combination of about 400 kg/m^3 of portland cement (CEM I 52.5 R according to the European norm EN 197-1) and about 95 kg/m^3 of ground calcite filler (with a Blaine fineness of 450 m^2/kg) were used to manufacture cohesive self-compacting concretes (SCCs) with a slump-flow of at least 700 mm without bleeding and segregation.
A shrinkage-reducing admixture (SRA) was used at a dosage of 1% by cement weight to keep as low as possible the drying shrinkage.
In one of these SCCs part of the filler (30 kg/m^3) was replaced by a CaO-based expansive agent to manufacture a shrinkage-compensating concrete (Collepardi et al. 2005).
In one of the examined SCCs 15-mm long and 0.5-mm thick PVA organic macro-fibers were used in order to study whether or not they can reduce the number and/or the thickness of cracks if any.
A poly-carboxylate admixture (PCA) at a dosage of 3% by cement weight was used as superplasticizer to keep the w/c ratio as low as 0.42 in all the concrete mixtures.

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Table 1 shows the composition of the *control mix* (SCC without SRA, CaO, and fibers) and that of the other three SCCs containing SRA with or without the CaO-based expansive agent or the PVA fibers which will be respectively called: *SRA mix*; *SRA/Ca0 mix*; *SRA/PVA mix*:

- free shrinkage according the UNI 6555 norm of the unreinforced specimens demoulded at 1 day and then kept at a RH of 55%;
- restrained expansion of reinforced specimens demoulded at 6 hours, protected by plastic coating for 2 days and then exposed to air with RH of 55% according to the norm UNI 8147- B method;
- dynamic modulus of elasticity determined longer ages (180 days) by measuring the velocity of ultrasonic waves;
- visual measurements at 180 days of cracks and their size opening by optical microscope in field tests on SCCs slabs (8 m-long, 400 mm-wide and 60 mm-thick) exposed to open air and restrained to the end in order to induce tensile stresses caused by drying shrinkage (Figure 1).

Table 1 – Composition of the SCC mixtures.

SCC Type	Control Mix	SRA Mix	SRA/CaO Mix	SRA/PVA Mix
CEM I 52.5 R (kg/m^3)	399	399	398	395
Filler (kg/m^3)	93	93	64	92
Expansive Agent (kg/m^3)	-	-	29	-
Expanded Clay (0-15 mm) (kg/m^3)	399	398	398	395
Sand (0-4 mm) (kg/m^3)	907	905	905	899
Water (kg/m^3)	166	166	166	164
PCA (kg/m^3)	12	12	12	12
SRA (kg/m^3)	-	4	4	4
PVA Fibers (kg/m^3)	-	-	-	4
w/c	0.42	0.42	0.42	0.42
Volumic mass (kg/m^3)	1976	1976	1976	1965
Slump-Flow (mm)	720	720	720	720

Figure 1 – Field tests on restrained drying shrinkage of concrete slabs (8 m long, 400 mm wide and 60 mm thick).

2 RESULTS

The results shown in Table 1 indicate that lightweight SCCs with a volumic mass of about 1975 kg/m^3 were manufactured with a slump flow of 720 mm in absence of bleeding water.

Figure 2 shows the compressive strength as a function of the curing time. With respect to the superplasticized *control mix*, there is small reduction in the 28-day compressive strength of the *SRA mix* and *SRA/PVA mix*, whereas in the presence of both SRA and expansive agent (*SRA/CaO mix*) there is small strength increase no reduction at all in the compressive strength (44.5 MPa). At longer ages, such as 180 days, the compressive strength is about 50 MPa in all the lightweight SCCs except the *SRA mix* with 42 MPa.

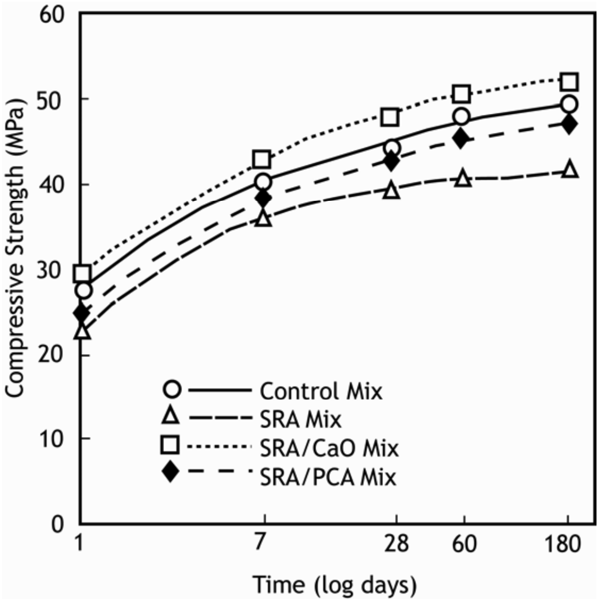

Figure 2 – Compressive strength of the lightweight SCCs as a function of time.

The dynamic elastic modulus at 180 days is about 30 GPa in all the concrete mixtures. These values fit the ACI equation (ACI 363R-92, 1994) between elastic modulus (E) and the compressive strength (f_c = 50 MPa):

$$\mathbf{E = 40{,}000\ (f_c)^{0{,}5} + 6{,}900 = 40{,}000\ (50) + 6{,}900 \approx 30\ GPa}$$

Figure 3 shows the free length-change of the unreinforced concrete specimens (except those containing the expansive agent) due to drying shrinkage measured according to the UNI 6555 norm. There is a significantly lower drying shrinkage (about 15-25%) in the two SCCs containing SRA with respect the *control mix*. The addition of PVA to the *SRA mix* does not reduces the drying shrinkage.

Figure 4 shows the length change of the restrained reinforced specimens of the *SRA/CaO mix*. There is an expansion during the first day, when the specimen was protected from drying by an envelopment made by a thin plastic coating, and then there is a slow expansion-loss up to 2 months of permanent exposure to a dry environment with RH of 55%.

Table 2 shows the number and the crack-width opening determined on the restrained concrete slabs exposed to open air shown in Fig.1: no crack occurred in the *SRA/CaO mix* as well as in the *SRA/PVA mix* although in the latter mixture the drying shrinkage was a little higher than in the *SRA mix* (Fig. 2). This behaviour indicates the influence of the PVA macro-fibers in removing the crack appearance provided that the drying shrinkage is lower than the *control mix* because of the presence of the SRA (Fig.3).

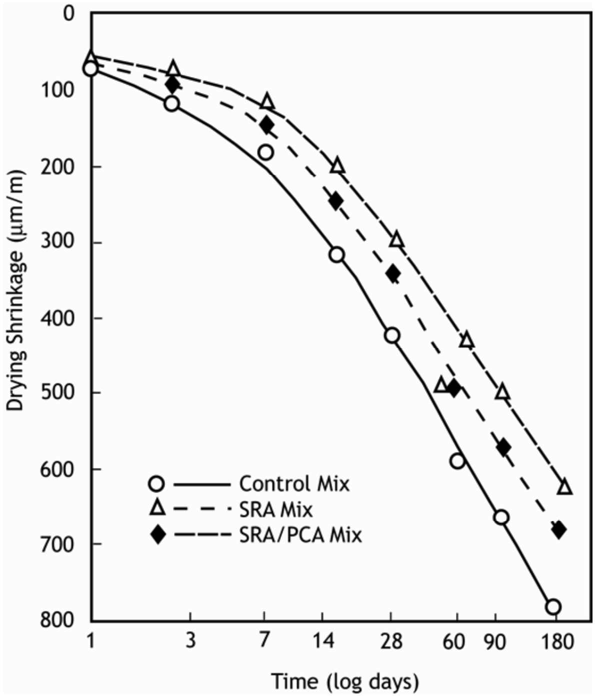

Figure 3 – Free drying shrinkage at RH of 55% of lightweight SCCs.

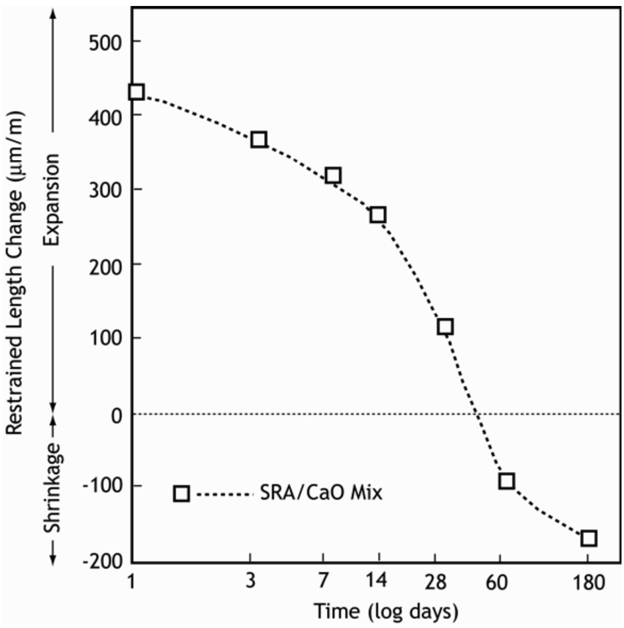

Figure 4 – Restrained expansion of the SRA/CaO mix.

Table 2 – Number of visible cracks and their width determined by an optical microscope.

SCC Type	Number of cracks	Width (mm)
Control Mix	4	1,4
SRA Mix	2	0,2
SRA/CaO Mix	0	----
SRA/PVA mix	0	----

3 CONCLUSIONS

A new type of lightweight SCC was studied. The combined use of a shrinkage-reducing admixture (SRA) with PVA macro-fibers (15 mm long and 0.5 mm thick) or with a CaO-based expansive agent in superplasticized SCC produces crack-free concretes even in the absence of wet curing. Therefore, durable and reliable structures with the absence of cracks can be built by using this technique in self-compacting concretes. These SCC are more reliable and less dependent on the quality of the workmanship on the job site for both placing and curing with respect to ordinary concrete mixtures.

Due to a low specific weight (1975 kg/m^3) and a relatively small elastic modulus (30 GPa) these new types of SCC are particularly suitable in seismic areas.

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