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Editors
Pawan R. Gupta
Prabha Gupta

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Supplementary Papers

SELF-COMPACTING, HIGH-PERFORMANCE AND LIGHT WEIGHT CONCRETES

Mario Collepardi, Emanuela N. Croce, J. Jacob Ogoumah Olagot and Francesca Simonelli

SYNOPSIS

Self-compacting lightweight concrete was proportioned in an attempt to produce good workability, high compressive strength, low incidence of cracking on durability in very aggressive exposure conditions, with low specific weight as well as low elastic modulus.

Concretes were studied in the fresh state as well as in the hardened one by measuring compressive strength, restrained expansion and dynamic elastic modulus. Due to lower specific weight and elastic modulus, these SCCs should be particularly suitable in meeting the specific requirements of reinforced structures in seismic areas.

The present paper shows the results of the preliminary trial tests to attain this object by using the most advanced raw materials available during the last decade: polycarboxylate superplasticizer (PCS), shrinkage-reducing admixture (SRA), CaO-based expansive agent, poly-vinyl-alcohol (PVA) synthetic macrofibres, expanded clay to reduce the specific weight under 2000 kg/m^3, and ground limestone filler to manufacture a uniform self-compacting concrete without bleeding and segregation.

Keywords: Drying shrinkage. Elastic modulus. Expanded clay. Expansive agent. Light weight concrete. Self-compacting concrete. Superplasticizer. Shrinkage-reducing admixture.

Mario Collepardi is Honorary Member of the American Concrete Institute. He is the author or co-author of numerous papers on concrete technology and cement chemistry. He is also the recipient of several awards for his contribution to the fundamental knowledge of superplasticizers and their use in concrete.

Emanuela N. Croce is a doctor in Geology and she is co-author of several papers on the aggregate for concrete. She works as researcher at Enco, Ponzano Veneto (TV), Italy.

Jean Jacob Ogoumah Olagot is a Civil Engineer and he is co-author of several papers on concrete technology. He works as researcher in the field of the concrete at Enco, Ponzano Veneto (TV), Italy.

Francesca Simonelli is a research Civil Engineer of Enco, Engineering Concrete, Ponzano Veneto, Italy. She is co-author of several papers on concrete durability and the repair of damaged concrete structures.

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 re-inforced structures exposed to seismic actions.

MATERIALS AND EXPERIMENTAL

A combination of about 400 kg/m^3 (676 lb/yd^3) of portland cement (CEM I 52.5 R according to the European Standard EN 197-1) and about 95 kg/m^3 (160 lb/yd^3) of ground limestone filler (with a Blaine fineness of 450 m^2/kg or 245.5 lb/yd^2)) were used to manufacture cohesive self-compacting concretes (SCCs) with a slump-flow of at least 700 mm (27 in) without bleeding and segregation. About 900 kg/m^3 (1521 lb/yd^3) of natural sand (0-4 mm or 0-0.16 in) and about 400 kg/m^3 (676 lb/yd) of expanded clay were used as aggregates.

Four kg/m^3 (6.76 lb/yd^3) of a shrinkage-reducing admixture (SRA) were used to keep as low as possible the drying shrinkage. In one of these SCCs part of the filler (30 kg/m^3 or 50 lb/yd^3) was replaced by a CaO-based expansive agent to manufacture a shrinkage-compensating concrete[1].

In one of the SCCs 4 kg/m^3 (6.76 lb/yd^3) of 15-mm long and 0.5-mm thick (0.6 in long and 0.02 thick) poly-vinyl-alcohol (PVA) synthetic macrofibers were used in order to study whether or not they can reduce the number and/or the thickness of cracks, if any. Twelve kg/m^3 of a polycarboxylate superplasticizer (PCS) were used as superplasticizer to keep the w/c ratio as low as 0.42 in all the concrete mixtures. 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*.

The following measurements were carried out to characterize the SCCs:

- slump-flow, bleeding and specific weight of fresh mixtures after 5 min of mixing;
- compressive strength (1-180 days) at room temperature (20 C°) and RH of 95%;
- free shrinkage according to the Italian Standard 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 1 day and then exposed to air with a RH of 50% according to the Italian Standard UNI 8147 norm - B method;
- dynamic modulus of elasticity determined at longer ages (180 days) by measuring the velocity of ultrasonic waves;
- visual measurements at 180 days of cracks and their size width opening by using a hand-held equipment with magnifying lens in field tests on SCCs slabs (8 m-long, 400 mm-wide and 60 mm-thick or 8.75-yd long, 16-in wide and 2.3-in thick) exposed to open air and restrained to the ends in order to induce tensile stresses caused by drying shrinkage (Fig. 1).

RESULTS

The results shown in Table 1 indicate that lightweight SCCs with a specific weight of about 1975 kg/m^3 (3338 lb/yd^3) were manufactured with a slump flow of 720 mm (28.1 in) in absence of any bleed water coming to the surface.

Compressive strength as a function of the curing time is shown in Fig. 2. With respect to the superplasticized *Control Mix*, there is a 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 a small strength increase in the compressive strength up to about 45 MPa (653 psi) at 28 days. At longer ages, such as 180 days, the compressive strength was about 45-50 MPa (6525-7350 psi) in all the lightweight SCCs except in the *SRA Mix* with 40 MPa (5800 psi).

The dynamic elastic modulus was about 25 GPa (362.5•10^4 psi) at 28 days and 30 GPa (435•10^4 psi) at 180 days in all the concrete mixtures. These relatively low values combined with the low specific weight of about 1975 kg/m^3 (3338 lb/yd^3) are particularly suitable for concrete structures in seismic areas exposed to the risk of earthquake.

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 Italian Standard UNI 6555 norm. There is a significantly lower drying shrinkage (about 15-25%) in the two SCCs containing SRA with respect to the *Control mix*. The addition of PVA to the *SRA mix* renders the SRA somewhat less effective.

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. After 24 hours the plastic coating was removed and then there was a slow expansion-loss up to 6 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).

CONCLUSIONS

Some special lightweight SCCs were studied with a *w/c* ratio of 0.42 and a 28-day compressive strength of 40-45 MPa (6525-7350 psi).

The combined use of a shrinkage-reducing admixture (SRA) with PVA macrofibers (15 mm long and 0.5 mm thick or 0.6 in long and 0.02 in thick) or with a CaO-based expansive agent in superplasticized SCCs produces crack-free concretes even in the absence of wet curing.

Therefore durable and reliable structures for the low *w/c* ratio and the absence of cracks can be carried out by using this technique in self-compacting concretes. Moreover these SCCs, with respect to ordinary concrete mixtures, are more reliable and less dependent on the quality of the workmanship on the job site for both placing and curing.

Due to a low specific weight of 1975 kg/m^3 (3338 lb/yd^3) and a relatively small elastic modulus (30 GPa or $435 \cdot 10^4$ psi at 180 days) these SCCs are particularly suitable in seismic areas.

REFERENCES

1. Collepardi, M., Borsoi, A., Collepardi, S., Ogoumah Olagot, J.J., Troli, R., "*Effects of shrinkage-reducing admixture in shrinkage-compensating concrete under non-wet curing conditions*", Cement and Concrete Composites, 6, pp. 704-708, 2005.

Table 1 – Composition of the SCC mixtures in kg/m³ or lb/yd³ with a *w/c* ratio of 0.42, a slump-flow of 720 mm (28.1 in) and a specific weight of 1975 kg/m³ (3338 lb/yd³)

SCC Type	CEM I 52.5 R kg/m³ (lb/yd³)	Filler kg/m³ (lb/yd³)	Expansive Agent kg/m³ (lb/yd³)	Expanded Clay 0-15 mm (0-0.585 in) kg/m³ (lb/yd³)	Sand 0-4 mm (0-0.156 in) kg/m³ (lb/yd³)	Water kg/m³ (lb/yd³)	PCS kg/m³ (lb/yd³)	SRA kg/m³ (lb/yd³)	PVA Fibers kg/m³ (lb/yd³)
Control Mix	399 (674.31)	93 (157.17)	----	399 (674.31)	907 (1532.83)	166 (280.54)	12 (20.28)	----	----
SRA Mix	399 (674.31)	93 (157.17)	----	398 (672.62)	905 (1529.45)	166 (280.54)	12 (20.28)	4 (6.76)	----
SRA/CaO Mix	398 (674.31)	64 (108.16)	29 (49.01)	398 (672.62)	905 (1529.45)	166 (280.54)	12 (20.28)	4 (6.76)	----
SRA/PVA Mix	395 (674.31)	92 (155.48)	----	395 (667.55)	899 (1519.31)	164 (277.16)	12 (20.28)	4 (6.76)	4 (6.76)

Table 2 – Number of visible cracks and their width in the restrained slabs shown in Fig.1

SCC Type	Number of cracks	Crack Width
Control Mix	4	1,4 mm (0.055 in)
SRA Mix	2	0,2 (0.008 in)
SRA/CaO Mix	0	----
SRA/PVA mix	0	----

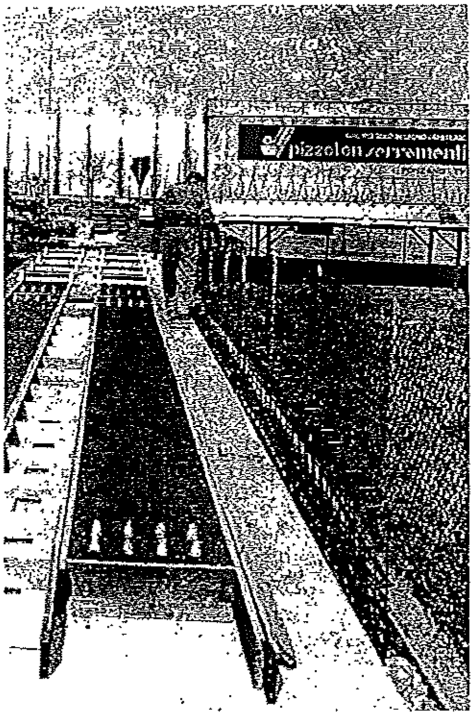

Fig. 1 – Field tests on restrained drying shrinkage of concrete slabs fixed at the ends.

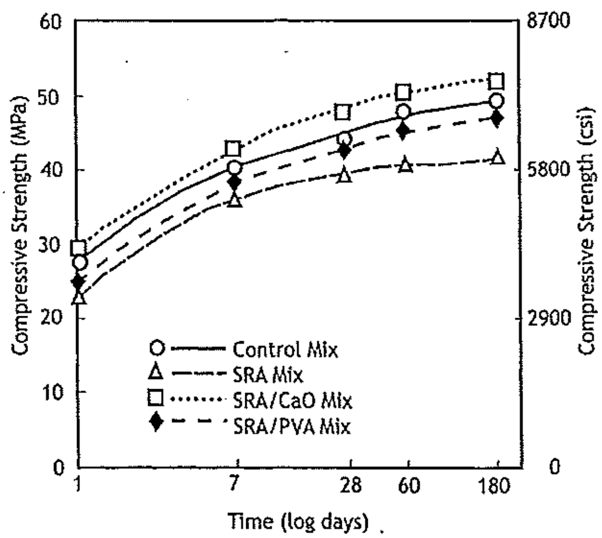

Fig. 2 – Compressive strength of the lightweight SCCs as a function of time.

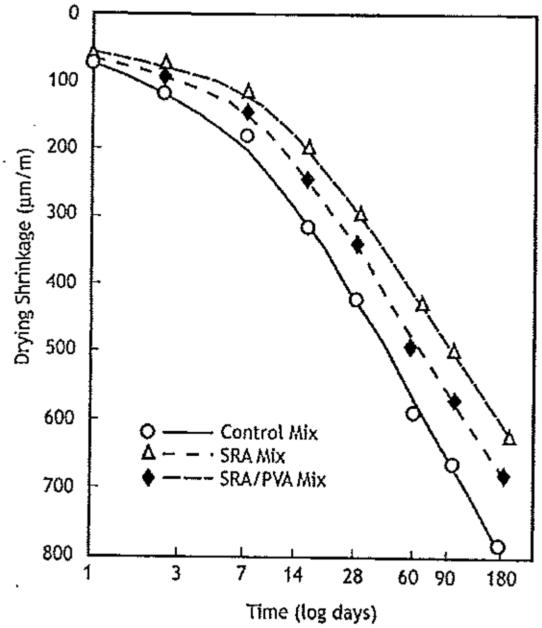

Fig. 3 – Free drying shrinkage at RH of 55% of lightweight SCCs

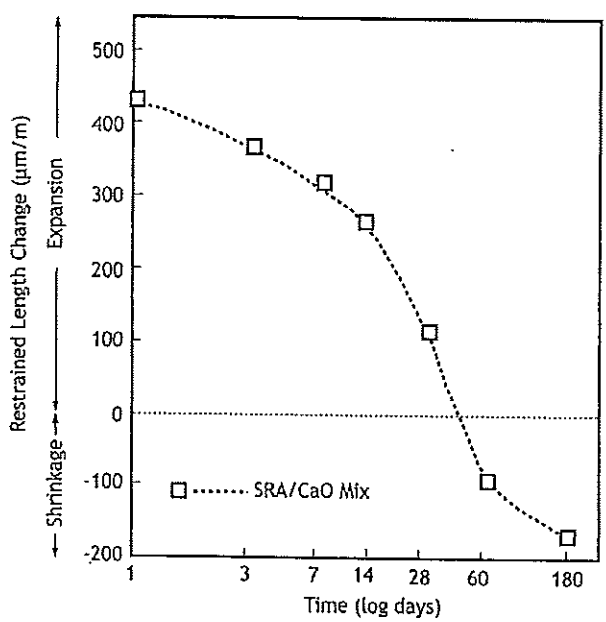

Fig. 4 – Restrained expansion of the SRA/CaO mix