Influence of chemical admixtures on the drying shrinkage of concrete

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Synopsis: The following four concretes were manufactured all with portland cement at a given slump of 220-240 mm: a) control mixture without any chemical admixture; b) concrete with a policarboxylate-based superplasticizer at the same water-cement ratio as that of the control concrete; c) concrete containing a shrinkage-reducing admixture (SRA) at the same composition as that of the control concrete; d) concrete with both superplasticizer and SRA at the same water-cement ratio as that of the control mixture.

Concretes were exposed to a dry environment with a relative humidity of 50% after a wet curing of 2 days. Measurements of drying shrinkage were carried out as a function of time up to 1 year.

In the superplasticizer mixtures both cement and water were reduced at given water-cement ratio and slump. The drying shrinkage at a given time of the superplasticized concrete decreased by 15-20 % with respect to that of the control concrete due to the higher aggregate-cement ratio.

In the presence of SRA the drying shrinkage was reduced by 20-25 % with respect of that of the control mixture at the same composition of the concrete mixture.

In the presence of both superplasticizer and SRA the drying shrinkage decreased by 30-35 % with respect to the control mixture at given water-cement ratio and slump.

Because of the decrease in the drying shrinkage caused by the chemical admixtures, the cracking in restrained slabs was significantly reduced in terms of number and maximum width of cracks.

Keywords: chemical admixtures, drying shrinkage, superplasticizer, shrinkage-reducing admixture.

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INTRODUCTION

Drying shrinkage is the most important and frequent parameter that negatively affects the cracking of concrete. This can aggravate the vulnerability of the concrete structures by the environmental aggressive agents and in particular increases the risk of corrosion of the metallic reinforcements due to chloride and carbon dioxide penetration.

Figure 1 schematically shows that cracking can occur when the shrinkage-induced tensile stress (σ_t) caused by the restrained shrinkage-induced strain is higher than the concrete tensile strength (f_t):

$$\sigma_t > f_t \qquad [1]$$

Therefore, in order to avoid this cracking the drying shrinkage should be adequately decreased, so that the induced tensile stress (σ_t') becomes lower than the tensile strength:

$$\sigma_t' < f_t \qquad [2]$$

There are two potential ways to reduce the drying shrinkage by using chemical admixtures:

- increase of the aggregate-cement ratio (*a/c*) by using superplasticizers (*SP*) as water reducers at a given water-cement ratio (*w/c*), so that the content of both water and cement is decreased; this change results in a reduction of the volume of cement paste that is responsible for drying shrinkage; the volume decrease of the cement paste is compensated by an equal increase in the volume of aggregate and this mitigates the concrete drying shrinkage (1);

- use of shrinkage-reducing admixtures (*SRA*) at given composition of the concrete mixtures in order to reduce the water surface tension (γ) and consequently the capillary pression (*P*) caused by the formation of water menisci developed in capillary pores which is responsible for the drying shrinkage of the cement paste (2):

$$\mathbf{P = 2\gamma / r \cdot \cos \Theta} \qquad \textbf{[3]}$$

where *r* is the radius of the water meniscus in the capillary pores and Θ is the wetting angle of free water with the cement paste.

The present paper shows the influence of *SP* (at higher aggregate-cement ratio) and of *SRA* (at given composition of the mixture) on the concrete drying shrinkage.

EXPERIMENTAL: MATERIALS AND METHODS

Portland cement (*CEM I 42.5 R* according to the European Norm EN 197) was adopted to produce concrete mixtures.

A 30 % aqueous solution of policarboxylate-based superplasticizer (*SP*) was used to reduce the content of both water and cement at given *w/c*. Shrinkage-reducing admixture (*SRA*), based on pure neopentyl glycol, was used at the same composition of the control mixture without chemical admixtures. This admixture reduces the surface tension of pure water (72.8 mN/m) to 32.4 mN/m in a 2% *SRA* aqueous solution.

Natural sand (0-4 mm) and gravel (4-25 mm) were used as aggregate.

Table 1 shows the composition of the following concrete mixtures at equal *w/c* of about 0.60 and given slump of 230-240 mm:

- *CONTROL mix*: concrete mixture without chemical admixtures;
- *SP mix*: mixture with superplasticizer (1% by cement weight)
- *SRA mix*: mixture with shrinkage-reducing admixture (1% by cement weight)
- *SP/SRA mix*: mixture with *SP* and *SRA* (both at 1% by cement weight).

Compressive strength of wet cured 150 mm cube concrete specimen at 20 °C was measured at 1, 7, 28 and 90 days.

The drying free shrinkage of prismatic specimens (100x100x500 mm) demolded at 2 days was measured at 20°C in a room with RH of 50 % from 2 weeks to 1 year.

Very severe field tests were carried out to check the appearance of cracks in restrained concrete slabs (8 m long, 400 mm wide and 60 mm thick) kept in the open air. Slabs made of *CONTROL mix*, *SP mix*, *SRA mix*, and *SP/SRA mix* were exposed to the same conditions of temperature, RH and wind speed. The slabs were fixed on the foundation at the two ends, so that the restrained shrinkage caused by drying in the open air could produce cracks on the surface of concrete. The width and the number of cracks were recorded at 4 months to assess the behavior of the concrete restrained slabs.

RESULTS

Table 1 shows that in the presence of the superplasticizer there is a reduction of about 30 % in the content of both water and cement in the *SP mix* and *SP/SRA mix* with respect of the *CONTROL mix*. This reduction of the cement paste in the concrete mixture results in a significant increase of the aggregate volume, and therefore the aggregate/cement ratio increases from 5.2 in the *CONTROL mix* to 8.1 in superplasticized concretes (*SP mix* and *SP/SRA mix*).

Figure 2 shows the compressive strength of concretes all at *w/c* of about 0.60: the 28-day compressive strength is in the range of 30-35 MPa. In particular, the strength of the superplasticized concrete *SP mix* at early and later ages is the same as that of the concrete *CONTROL mix*, whereas in the presence of *SRA* there is a small reduction of the strength probably due to a slight lower degree of cement hydration caused by neopentil glycol.

Figure 3 shows the influence of the superplasticizer on the concrete drying shrinkage at RH of 50 %: since the aggregate-cement ratio of the *SP mix* is significantly higher than that of the *CONTROL mix* (Table 1)), the drying shrinkage of the superplasticized concrete is reduced by 15-20 % with respect to that of the concrete without admixture. This effect is related to both the volume decrease of the cement paste, which is responsible for the drying shrinkage, and the volume increase of the aggregate whose rigid grains oppose the shrinkage strain.

Figure 4 shows the influence of the shrinkage-reducing admixture on the drying shrinkage of the concrete exposed to an environment at RH of 50 %: the reduction of the drying shrinkage caused by the presence of *SRA* is 20-25 % compared to that of the *CONTROL mix* without admixture. This effect, without any change in the *w/c* (0.62) as well as in the *a/c* (5.2), is due to the reduction of the surface tension of the free water in capillary pores caused by the presence of *SRA* and consequently to the decrease of the capillary pression according to equation [3].

Figure 5 shows the influence of the combined addition of *SP* and *SRA* on the drying shrinkage of the concrete: the decrease in the drying shrinkage caused by the presence of these chemical admixtures is 30-35 % by that of the control concrete mixture. This effect is related to both the increase in the aggregate-cement ratio (from 5.2 to 8.1) caused by *SP* and the decrease in the water surface tension caused by the *SRA* addition.

The effect of the chemical admixtures on the number and width of cracks induced by restrained drying shrinkage was studied in concrete slabs exposed to open air for 1 year. The results of these field tests are summarized in Table 2: with respect to the *CONTROL mix*, the number and the width of the cracks have been significantly reduced in the *SP mix* and more effectively in the *SRA mix*. This effect is increased when both these chemical admixtures are used together in the *SP/SRA mix*: only one microcrack 150 μm wide appeared in the 8 m long, 400 mm wide and 60 mm thick restrained slabs.

CONCLUSIONS

The risk of cracking can be mitigated by reducing the concrete drying shrinkage. This can occur in two ways:

- reduction of the cement paste which is responsible for the drying shrinkage and increase in the volume of the aggregate which opposes the drying-induced strain; this effect can be realized by using a superplasticizer (*SP*) in order to reduce both water and cement at equal *w/c* and slump; in the present work a reduction of 30 % of the weight of both water and cement and an increase in the aggregate-cement ratio from 5.2 to 8.1 have been accomplished by adding a policarboxylate based superplasticizer (1 % by weight of cement); through this change in the composition of the concrete mixture a reduction of 15-20% of drying shrinkage was carried out at ages from 2 weeks to 1 year;
- reduction of the surface tension of the free water filling the capillary pores and consequently decrease of the capillary pression responsible for the drying shrinkage of the cement paste; due to this effect the drying shrinkage of the concrete was reduced by 20-25 % when 1 % of *SRA* by weight of cement was used.

The combined addition of 1 % of both *SP* and of *SRA* is even more effective since the reduction in the drying shrinkage with respect to the control mixture was 30-35 %.

The effect of the reduction in drying shrinkage was confirmed by measuring the number and the maximum width of cracks in restrained 8-m long, 400-mm wide and 60-mm thick concrete slabs exposed to open air for 1 year. In particular, when both *SP* and *SRA* are used only one microcrack 150 μm wide was observed.

REFERENCES

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Table 1 – Composition of concrete mixtures at given w/c (0.62) and slump (230-240 mm)

Composition (kg/m^3)	CONTROL Mix	SP Mix	SRA Mix	SP/SRA Mix
Cement	357	248	356	250
Water	222	153	221	155
Sand 0-4 mm	933	1000	931	1004
Gravel 4-25 mm	926	1015	920	1020
SP	---	2.43	---	2.50
SRA	---	---	3.56	2.50
Slump (mm)	240	230	240	240
w/c	0.62	0.62	0.62	0.62
Aggregate/Cement	5.2	8.1	5.2	8.1

Table 2 – Crack distribution in concrete slabs caused by restrained drying shrinkage

Concrete mixture	Number of cracks	Maximum crack width (mm)
CONTROL mix	7	2.50
SP mix	4	1.52
SRA mix	3	0.42
SP/SRA mix	1	0.15

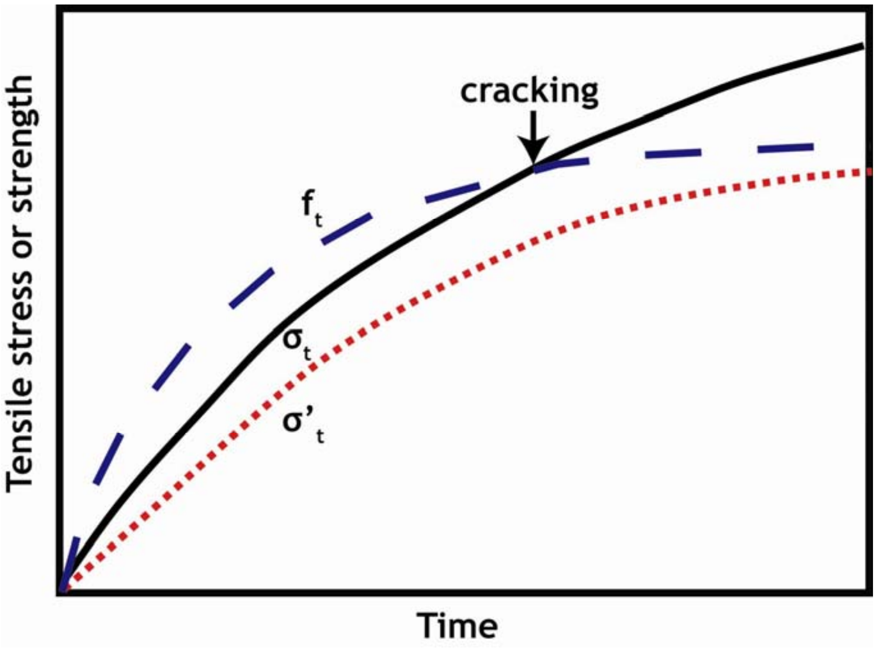

Fig. 1 – Tensile stress (σ_t and σ'_t) or strength (f_t) as a function of time.

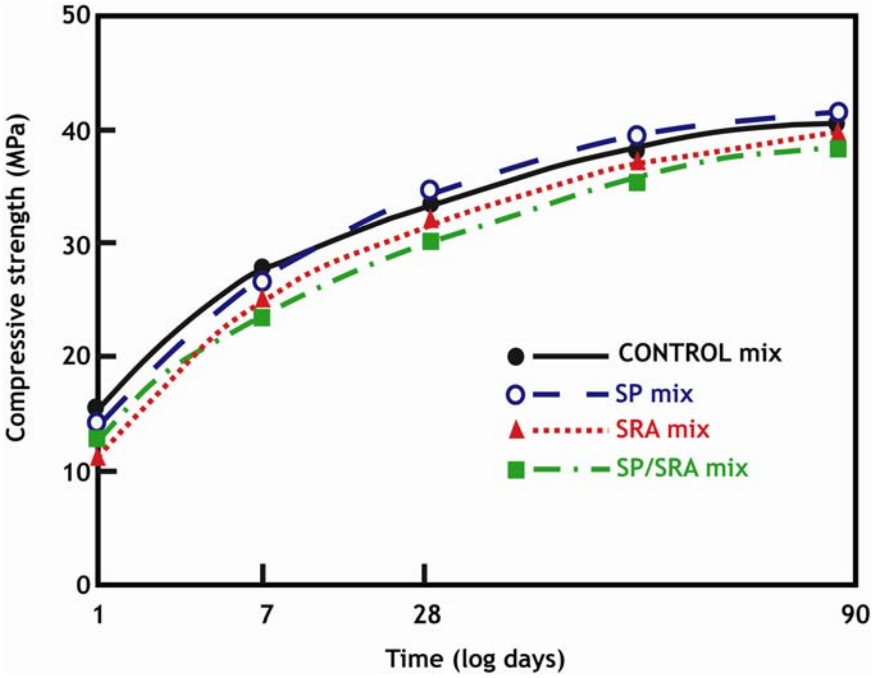

Fig. 2 – Influence of superplasticizer (SP) and/or shrinkage-reducing admixture (SRA) on the compressive strength.

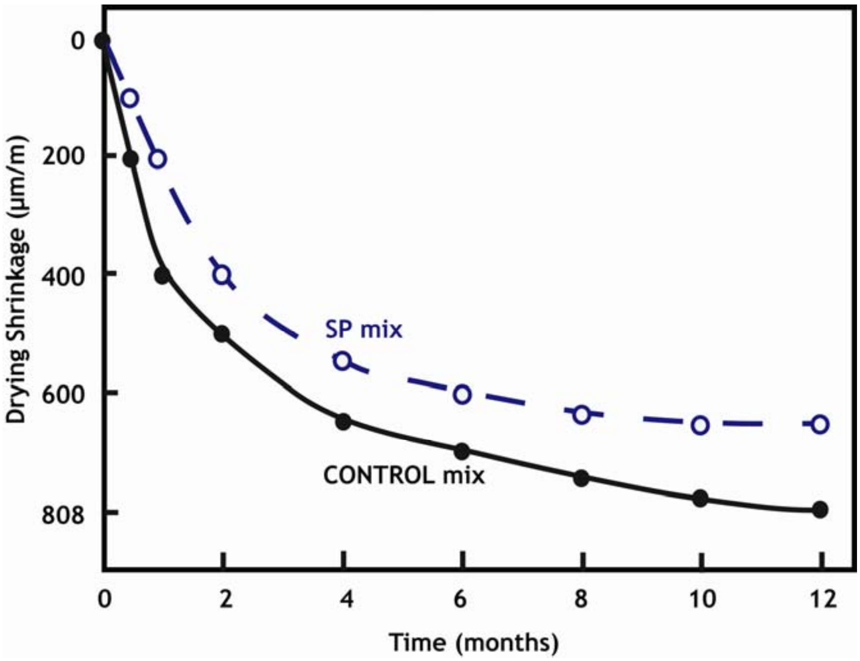

Fig. 3 – Influence of superplasticizer (SP) on concrete drying shrinkage.

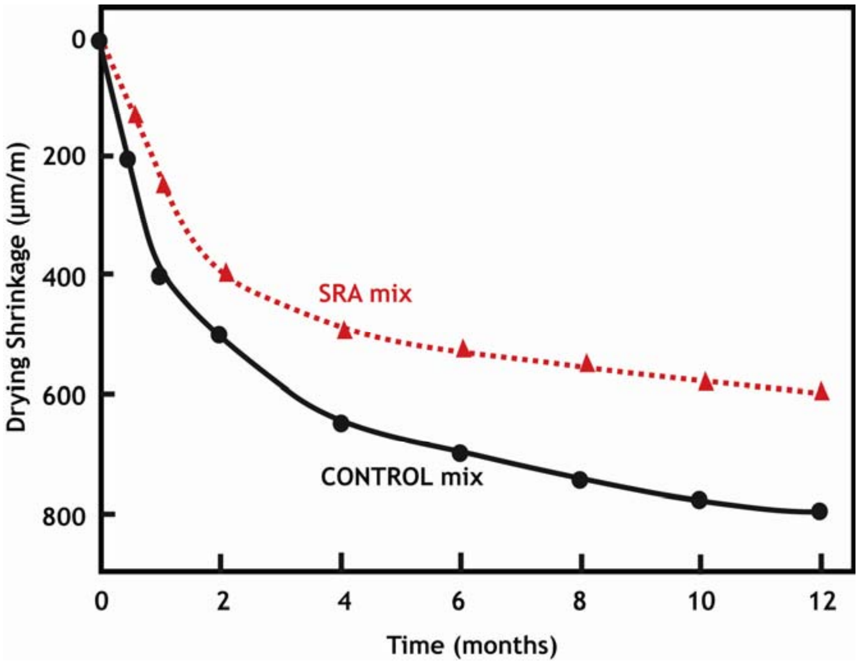

Fig. 4 – Influence of shrinkage-reducing admixture (SRA) on concrete drying shrinkage.

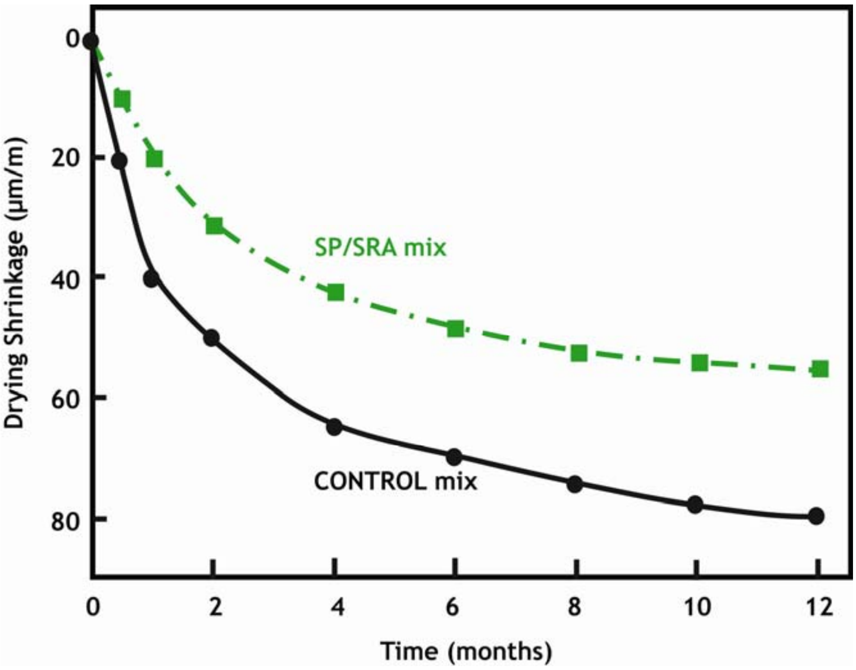

Fig. 5 – Influence of superplasticize (SP) and shrinkage-reducing admixture (SRA) on concrete drying shrinkage.