

## SELF-COMPACTING / CURING / COMPRESSING CONCRETE

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**ABSTRACT:** The practice of using expansive agents has been recommended to manufacture shrinkage compensating concrete provided that an adequate wet curing is carried out. On the other hand, shrinkage-reducing admixture (SRA), based on the use of poly-glycol products in the concrete mixes, has been more recently suggested to reduce the risk of cracking in concrete structures caused by drying shrinkage. The mechanism of this admixture is based on a physical change (reduction of the surface tension of the mixing water) rather than on a reduction of water evaporation. This technology can reduce the drying shrinkage but it is not able to completely remove it. In the present paper some innovative experimental tests will be described on the combined use of CaO-based expansive agents and SRA. This combination surprisingly allow to manufacture shrinkage-compensating concretes even in the absence of any early water curing. This technology appears to be very interesting in producing self-curing and self-compressing concretes with the reinforcing bars under tensile stress and the cementitious material under compressive stress. This technique has been combined with that of the self-compacting concrete in order to manufacture a very innovative concrete which is "*3 times self*": self-compacting, self-curing and self-compressing concrete. The type of CaO-based expansive agent has been adapted in order to produce an effective expansion mainly after the cement hardening process is started, so that the expansion loss which occurs in concrete in the fresh or plastic state is reduced and the useful expansion in the hardened state is advantageously increased.

**Keywords:** Expansive agents, Superplasticizer, Shrinkage Reducing Admixture, Self-Compacting Concrete, Self-Curing Concrete, Self-Stressing Concrete.

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## INTRODUCTION

The main reasons of discrepancy between the performance of the laboratory concrete specimens and that of the concrete structures depend on the three following parameters:

- Degree of compaction of the fresh concrete.
- Early curing of the demoulded concrete.
- Exposure to drying shrinkage at later ages.

The purpose of this research is to study a new concrete mixture which is simultaneously characterized by the following three properties:

- It does not depend on the degree of compaction of the fresh mixture as for a Self-Compacting Concrete.
- It does not depend on the way of curing.
- It does not depend on the environmental drying exposure.

Such a special concrete should be a very innovative material with negligible or no discrepancy between the properties of laboratory concrete and structure concrete. It should be a self-compacting, self-curing and self-compressing concrete ("*3 times self*").

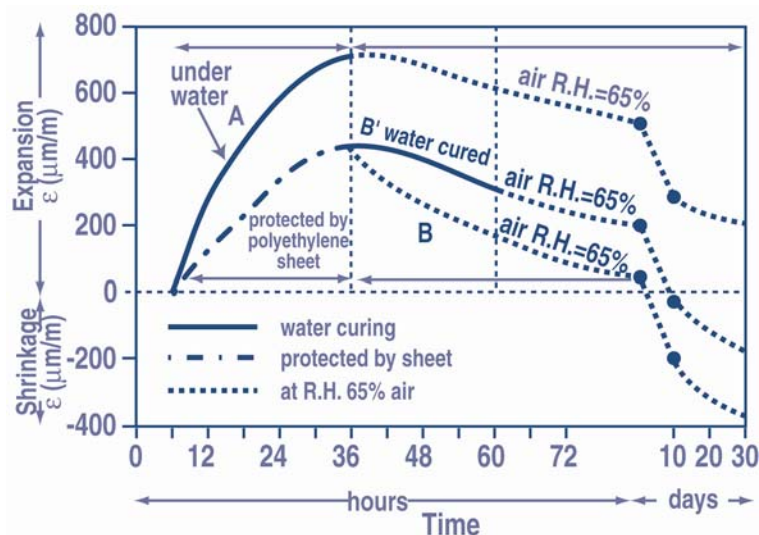
## THE ROLE OF EXPANSIVE AGENTS OR SRA TO PRODUCE A SHRINKAGE-FREE CONCRETE

The technology of shrinkage-compensating concrete is based on the use of special products, such as calcium sulpho-aluminates or calcium oxide, which react with water and produce a restrained expansion in reinforced concrete structures. This technology has been invented many years ago [1], but its use has been very limited in practice due to the difficulty in adopting a continuous water curing absolutely needed in the early ages after setting. From a practical point of view, this technology can be adopted only in some special constructions such as concrete floors or slab foundations.

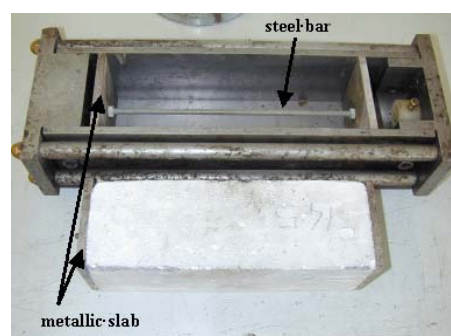
Figure 1 shows the length change of a shrinkage compensating concrete (based on CaO as expansive agent) as a function of the early curing of the concrete after 6 hours when the hardened concrete specimens can be demoulded (Figure 2).

The length-change of the steel bar is then recorded as a function of the curing time. Figure 1 (curve A) shows the behaviour of a concrete specimen (with the composition A shown in Table 1) demoulded at 6 hr, immersed under water up to 36 hr and then exposed to air with R.H. of 65%. At 30 days there is still a certain level of tensile stress in the metallic bar (and of compressive stress in the concrete) corresponding to the remaining expansion of about 200  $\mu\text{m/m}$ .

From a practical point of view the special curing adopted for the reinforced concrete specimen according to the above test method (curve A in Figure 1) is definitely unrealistic for any reinforced concrete structure except, perhaps, for an industrial concrete floor which could be soaked by water after the setting time. Therefore, this test does not reflect the real curing of reinforced concrete structures which cannot be water-soaked in the period of time (1-2 days) corresponding to the expansion process when the concrete is still protected by the formwork.



**Figure 1** Length change of reinforced concretes demoulded at 6 hours, cured under water up to 36 hours (A) or protected by polyethylene sheet up to 36 hours (B) or protected by polyethylene sheet (36 hours) and then water cured up to 60 hours (B'). Composition of the concrete mix (A/B) is shown in Table 1.



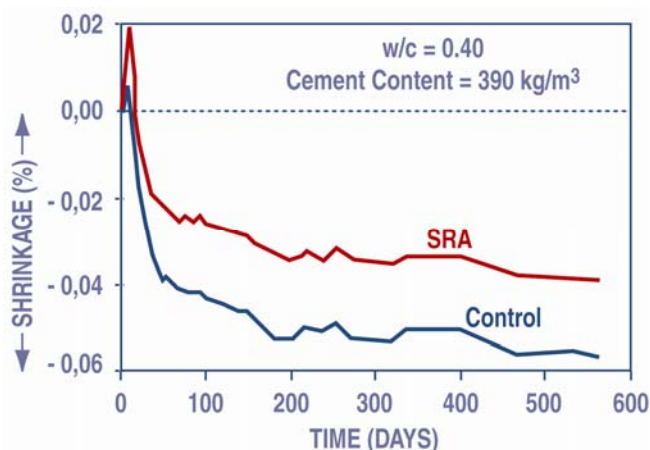
**Figure 2** Formwork for measurement of restrained expansion according to ASTM 845-90.

A more realistic expansion process has been carried out with the same concrete mixture by protecting from drying the reinforced concrete specimens by a polyethylene sheet (from 6 to 36 hours) in order to simulate the expansive behaviour of a concrete structure protected from drying by the formwork (curve *B* in Figure 1). After removing the polyethylene sheet at 36 hours, the reinforced concrete was exposed to unsaturated air (R.H. of 65%) immediately (curve *B*) or after a water fogging time for 1 day (curve *B'*). Although the 1-day water fogging treatment improved the behaviour of the shrinkage-compensating concrete, with respect to the same concrete immediately exposed to air, the remaining expansion was completely lost at about 10 days.

Therefore, the performance of shrinkage-compensating concrete based on expansive agents does not appear to be successful in practice even with a fogging treatment of the concrete surface just after demoulding at 1-2 days.

On the other hand, more recently the use of Shrinkage Reducing Admixture (*SRA*) has been suggested [2,3] to improve concrete performance in terms of lower risk of cracking related to autogeneous [4] or drying shrinkage.

Figure 3 shows the influence of *SRA* on the shrinkage of a concrete wet cured during the first week in comparison with the control mix [3]. Due to the presence of *SRA* there is reduction in the shrinkage. However the risk of cracking related to drying shrinkage can be mitigated but not completely eliminated.



**Figure 3 Length change as a function of time for concretes with and without *SRA*, wet cured during the first week [3].**

Therefore, neither expansive agent nor *SRA*, when used separately, can definitely and safely avoid the risk of cracking caused by drying shrinkage in real concrete structures under the practical conditions existing on many job-sites.

### **COMBINED USE OF *SRA* AND CaO-BASED EXPANSIVE AGENT**

The combined use of *SRA* and a CaO-based expansive agent has been studied [5] in order to check the potential success in producing shrinkage-compensating concrete with a length-change behaviour similar to that of the water cured concrete (curve *A* in Figure 1) even in the absence of any type of curing.

The concrete mixture (*C*) was the same as that shown in Table 1 for mixes *A* and *B* except for the presence of propylen-glycol (1.15% by cement weight) acting as *SRA*. The amount of mixing water was reduced by a volume corresponding to that of *SRA*. A reference mix (*D*), without expansive agent and with *SRA* (1.15%) was also studied (Table 1).

The expansion of the mix *C* (with *SRA* + CaO) and that of the mix *D* (with *SRA*) is shown in Figure 4 in comparison with those of mixes *A* and *B* (both with CaO). All the concretes (except mix *A*) were demoulded at 6 hr, protected by a polyethylene sheet up to 36 hours and then exposed to air with R.H. of 65%; the concrete *A* was cured under water from 6 to 36 hours according to the test method ASTM 845-90, and then exposed to air at R.H. of 65%.

The behaviour of the concrete *C* (with *SRA* + CaO) performs much better than that with CaO only (concrete *B*) or with *SRA* only (concrete *D*).

Surprisingly the expansion caused by the CaO hydration in the presence of *SRA* (concrete *C*) is very close to that of the concrete *A* even though no water curing was adopted as that for the concrete *A*. Moreover, when the polyethylene sheet was removed, concrete *C* exposed to air (R.H. of 65%) behaves, in terms of length-reduction, much better than concretes with CaO only (*A* and *B*). The final result indicates that there is a remaining expansion of about 400 µm/m after about 1 month of exposure to air with R.H. of 65%.

**Table 1 – Mix composition and properties of concretes.**

| INGREDIENT                                    |         | ORDINARY MIXES |      |      | SCC  |      |
|---|---------|----------------|------|------|------|------|
|   |         | A/B            | C    | D    | E    | F    |
| Cement (II B-L 42.5N) (kg/m <sup>3</sup> )    |         | 350            | 350  | 350  | 365  | —    |
| Cement (II A-L 42.5R) (kg/m <sup>3</sup> )    |         | —              | —    | —    | —    | 365  |
| CaO (kg/m <sup>3</sup> )                      |         | 35             | 35   | —    | 35   | 35   |
| Ground Limestone (>100µm)                     |         | —              | —    | —    | 160  | 160  |
| Sand (0-5 mm) (kg/m <sup>3</sup> )            |         | 980            | 980  | 1015 | 880  | 880  |
| Gravel (5-20 mm) (kg/m <sup>3</sup> )         |         | 860            | 860  | 860  | 720  | 720  |
| Water (kg/m <sup>3</sup> )                    |         | 160            | 156  | 156  | 170  | 170  |
| w/c   |         | 0.46           | 0.44 | 0.45 | 0.47 | 0.47 |
| Acrylic superplasticizer (kg/m <sup>3</sup> ) |         | 3              | 3    | 3    | 7    | 7    |
| Propylen-glycol (kg/m <sup>3</sup> )          |         | —              | 4    | 4    | 4    | 4    |
| Slump (mm)                                    |         | 180            | 190  | 200  | —    | —    |
| Slump flow (mm)                               |         | —              | —    | —    | 705  | 700  |
| Compressive strength (MPa) at                 | 1 day   | 16             | 13   | 11   | 16   | 22   |
|   | 3 days  | 37             | 36   | 36   | 43   | 47   |
|   | 28 days | 45             | 44   | 43   | 55   | 58   |

### COMBINED USE OF SRA AND CaO-BASED IN A SELF-COMPACTED CONCRETE

The change from an ordinary concrete such as mix *C* to a self-compacting concrete like mix *E*, both shown in Table 1, produces a significant reduction in the early restrained expansion (Figure 5). This is due to the fact that there is a strong increase in the early hardening time (from 6 to 16 hours) due to the higher initial flowing behaviour of mix *E* just after mixing (slump flow = 705 mm) with respect to mix *C* (slump = 190 mm). The increase in the hardening time reduces the useful restrained expansion since the expansion of the concrete in the plastic state (0-16 hours) cannot extend the length of the reinforcing metallic bar in the absence of any steel-concrete bond.

The reduction in the early expansive behaviour (16-36 hours) in mix *E* causes a lower expansion at later ages (36-90 hours) and then a final shrinkage of about 100  $\mu\text{m/m}$  only at 1 month (Figure 5).

In order to reduce this drawback, related to the prolonged time of the plastic state of SCC (much as mix *E*) with respect to an ordinary concrete (such as mix *C*), a more rapid cement 42.5 R instead of 42.5 N was used for the self-compacting concrete. This change (from mix *E* to mix *F*, both SCC as shown in Table 1) increases the restrained expansion at early and later ages, due to the better steel-concrete bond after 6 hours (Figure 6). Therefore, even a self-compacting concrete such as mix *F* can become self-stressing and self-curing concrete, provided that a proper reduction in the final setting time (from 12 to 6 hours) occurs due to the change in the cement strength class (from 42.5 N to 42.5 R).

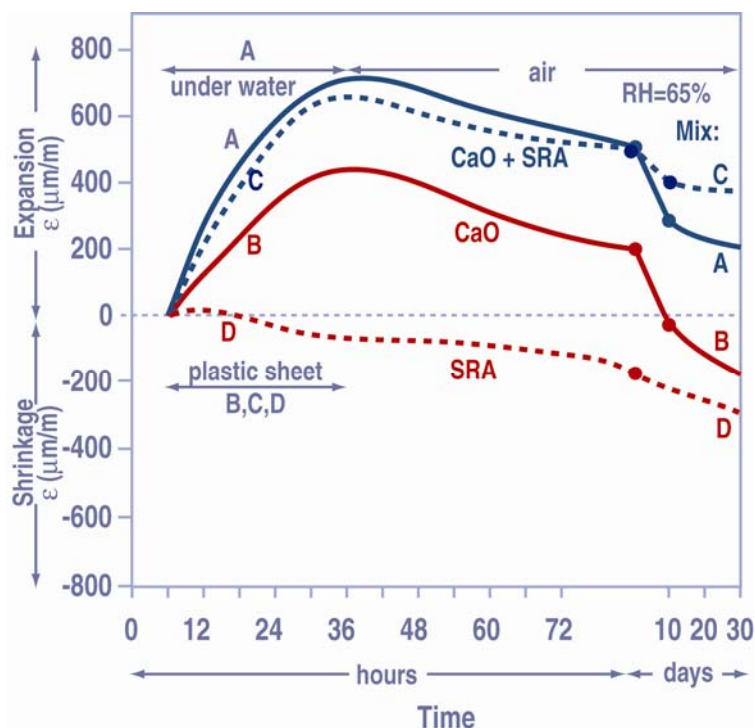
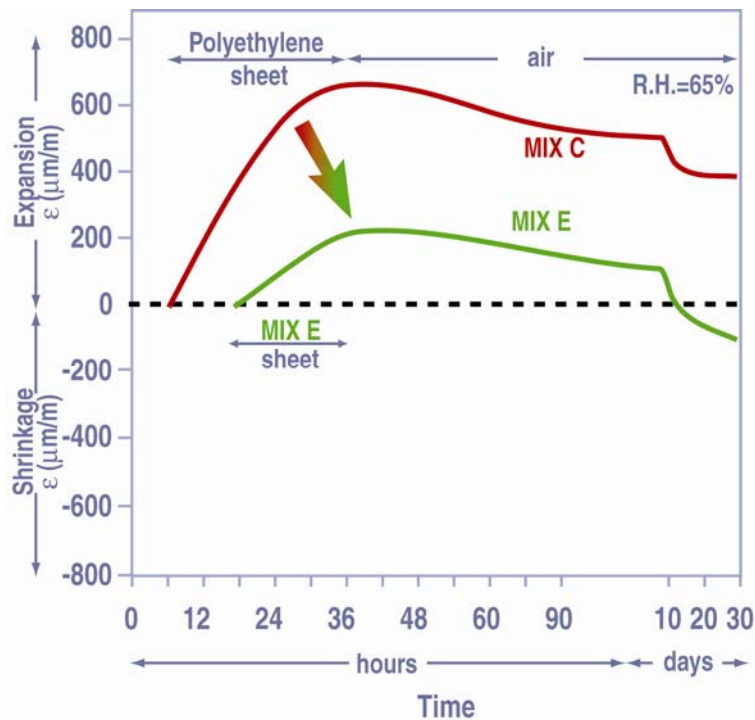
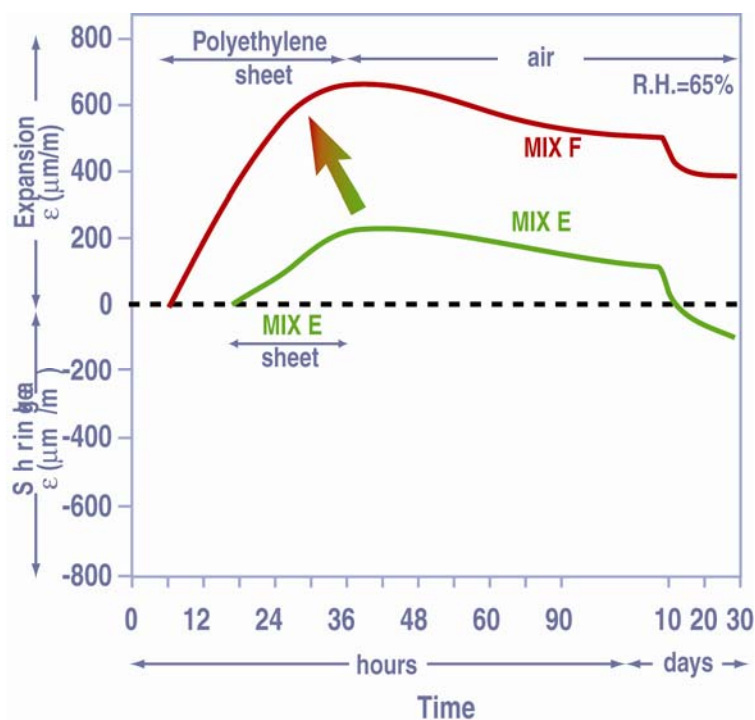


Figure 4 Length change of concretes (Table 1) cured under water (A) or protected by polyethylene sheet B, C and D. See Table for mix composition.



**Figure 5 Influence of the change from an ordinary mix C to a self-compacting concrete E protected by polyethylene sheet for 20 hrs. after the demoulding time at 16 hrs. Table 1 shows the mix composition.**



**Figure 6 Change of the cement strength to increase the early expansive behaviour of mix E to that of mix F, both SCC (Table 1).**

## CONCLUSIONS

There is a synergistic effect in the combined use of SRA and a CaO-based expansive agent in terms of more effective expansion in the absence of wet curing. Moreover, there is a lower shrinkage after removing the polyethylene sheet used to simulate the protection from drying before demoulding the concrete structure on the job site.

However, these effects are significantly reduced when a self-compacting concrete is used because of the prolonged fluid and plastic state of this mixture. This is also due to the higher dosage of superplasticizer in the self-compacting concrete with respect to that used in ordinary superplasticized concrete.

However, a change in the cement with a higher strength at very early ages such as from CEM II B/L 42.5 N to CEM A-L 42.5 R, can reduce the setting time and then increase the restrained expansion which occurs only when a steel-concrete bond exists.

Alternative ways can be adopted to produce Self-Compacting Concrete which is also a Self-Compressing and Self-Curing concrete ("*3-time self*"): to use a superplasticizer with a reduced retarding effect or to use an expansive agent based on CaO produced at higher temperature (>1100°C) so that the restrained expansion occurs later and then in a hardened concrete.

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