New Admixture Combats Concrete Shrinkage

At last, a liquid admixture that's designed to reduce materials shrinkage due to drying

BY ANNE BALOGH

Ask concrete contractors to name one of the most exasperating problems of building with concrete, and they're likely to say shrinkage cracking. By its nature, concrete tends to shrink and ultimately crack as it dries. But a new liquid admixture, introduced to the North American market last March, is the first of its kind available to ready mix producers and contractors for chemically altering the basic mechanism of shrinkage without adding expansive materials to the concrete. The developers of the product, Grace Construction Products, Cambridge, Mass., and ARCO Chemical Co., Newton Square, Pa., claim that it can reduce 28-day concrete shrinkage by 50% to 80%, with reductions in ultimate shrinkage of 25% to 50%.

The new shrinkage-reducing admixture (SRA) is recommended for use in structures where cracks due to drying shrinkage often occur and the consequences can be serious. Some examples are concrete bridge decks, parking garages, marine structures, primary and secondary containment structures, and industrial floors.

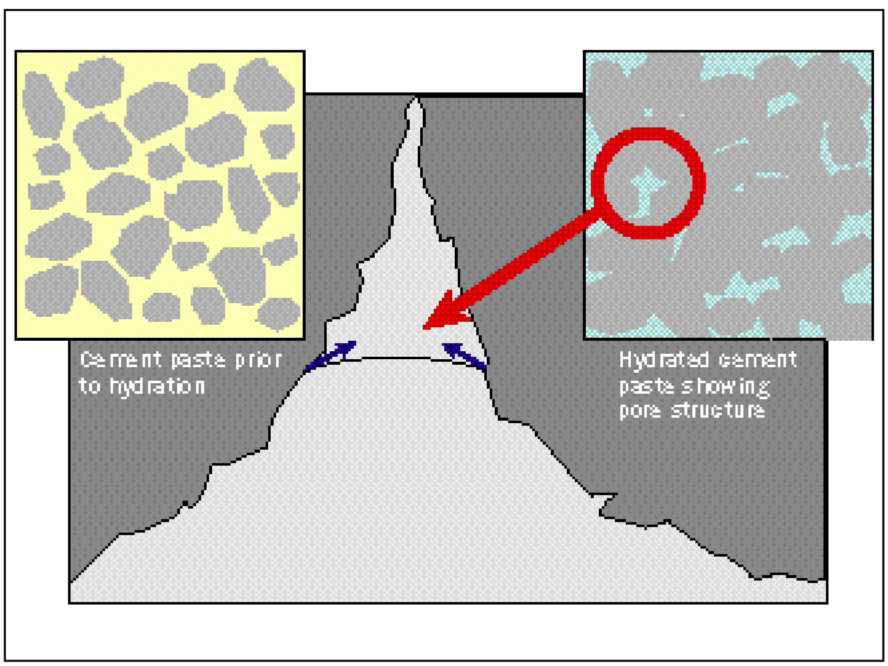

Figure 1. **When capillary pores in concrete dry, a meniscus forms and surface tension in the remaining water pulls pore walls inward.**

How the Admixture Reduces Shrinkage

Concrete drying shrinkage is a complex process that has several causes (see box on next page). One cause is surface tension that develops in small pores within the cement-paste portion of hardened concrete. When these pores lose moisture, a meniscus forms at the air-water interface. Surface tension in this meniscus pulls the pore walls inward, and the concrete responds to these internal forces by shrinking (see Figure 1).

This shrinkage mechanism occurs only in pores within a fixed range of sizes. In pores larger than 50 nanometers (0.00000004 inch), the tensile force in the water is too small to cause appreciable shrinkage. And in pores smaller than 2.5 nanometers (0.000000002 inch), a meniscus can't form.

The amount of cement-paste shrinkage caused by surface tension depends primarily on water-cement ratio. It can also be affected by cement type and fineness and by any other ingredients that alter the pore-size distribution in the hardened paste.

The SRA reduces shrinkage of this kind by reducing the surface tension of water in pores between 2.5 and 50 nanometers in diameter. Like other types of liquid admixtures, the SRA can be dissolved in the concrete mix water or dispersed in the concrete during mixing. After concrete hardens, the admixture remains in the pore system, where it continues to reduce the surface-tension effects that contribute to drying shrinkage.

In both laboratory and field tests of various concretes containing the admixture, the product seemed to be most effective when added at a rate of 1.5% to 2% by weight of cement. But dosages ranging from 1% to 2.5% can be used to obtain the desired level of shrinkage reduction.

Effect of shrinkage on cracking. Concrete may or may not crack as a result of shrinkage. If concrete isn't restrained, it can shrink freely and change volume without cracking. But since most concrete is restrained—by subgrades, foundations, reinforcement, or connecting members—it often develops tensile stresses high enough to cause cracking. However, several additional factors affect cracking. These include the rate of shrinkage, creep properties, modulus of elasticity, and tensile strength of the concrete. Because so many factors affect cracking tendency, knowing the ultimate level of shrinkage is seldom sufficient for predicting cracking performance.

Test Results

In lab and field tests conducted by researchers at Grace and Northwestern University's Center for Advanced Cement-Based Materials, Evanston, Ill., three primary factors affected the amount of shrinkage reduction achieved with the SRA: the concrete's water-cementitious materials ratio, type of cement, and level of curing. All shrinkage tests were performed in accordance with ASTM C 157-93, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete," which calls for 28-day moist curing. However, since most field concrete isn't moist-cured for 28 days, the tests were based on curing periods ranging from one to 14 days.

What Causes Drying Shrinkage?

When cement in concrete reacts with mixing water, calcium silicate hydrate (CSH) begins to form in water-filled spaces. In most concretes, the spaces aren't completely filled with CSH, so the remnants of mixing water form a network of capillary voids in hardened cement paste. Although the voids are initially interconnected, they become discontinuous during curing if the water-cement ratio is less than 0.70.

Other, much smaller, voids are present within the CSH. Part of the space within these voids is filled with water that's adsorbed on the surface of the CSH. This adsorbed water and the water in capillary pores are both believed to play a role in concrete shrinkage.

It's been suggested that the adsorbed water causes a disjoining pressure between the CSH surfaces (Ref. 1). When this water leaves the concrete as a result of drying, the disjoining pressure decreases and the cement paste shrinks.

It has also been suggested that when capillary pores dry, the hydrostatic tension in the meniscus that's formed exerts a stress within the rigid skeleton of CSH, causing the cement paste to shrink (Ref. 2). Since capillary water is held less tightly than adsorbed water, moisture is lost from capillary pores when drying begins. Thus, early shrinkage is attributable primarily to surface tension in the water left in capillary pores.

Because shrinkage originates in the hardened cement paste of most concretes, the amount of concrete shrinkage depends on:

- Shrinkage properties of the paste
- Paste-to-aggregate ratio
- Aggregate stiffness
- Strength of the bond between paste and aggregate

Although paste content and properties have a major effect on drying shrinkage, don't overlook the restraining properties of the aggregate. Changing the type of aggregate can sometimes have a twofold effect on the amount of shrinkage.

References

1. P. Kumar Mehta, "Volume Change," *Significance of Tests and Properties of Concrete and Concrete-Making Materials,* STP 169C, ASTM, West Conshohocken, Pa., 1994, p. 222.

2. Sidney Mindess and J. Francis Young, *Concrete*, Prentice-Hall Inc., Englewood Cliffs, N.J., 1981, p. 488.

Water-cementitious materials ratio. Test results varied from mix design to mix design, due primarily to differences in the water-cementitious materials ratio (w/cm). Generally, the lower the ratio, the greater the percent of shrinkage reduction that could be achieved. For mixes with a w/cm less than 0.60, reductions in 28-day shrinkage of 80% or greater and reductions in 56-day shrinkage of 70% were achieved at an admixture dosage rate of 1.5% by weight of cement. In mixes with a w/cm of 0.68, the level of shrinkage reduction at 28 days and 56 days was 37% and 36% respectively.

Type of cement. Because different cements often affect an admixture's performance, the SRA was tested in mortars containing a variety of cementitious materials, including seven different cements, one cement combined with fly ash, and the same cement combined with ground granulated blast-furnace slag (GGBFS). Long-term shrinkage reductions, with no curing applied, ranged from 25% to 38%, depending on the cement combination used. These tests indicate that it's important for contractors and ready mix producers to determine the admixture's shrinkage-reduction levels in concretes made with local materials.

Level of curing. As Figure 2 shows, longer wet curing increases the effectiveness of the admixture, especially in early-age concrete. Ultimate levels of shrinkage are also reduced by longer wet curing. Tests contrasted the performance of concrete mixes containing 1% SRA, 2% SRA, and no SRA, with and without curing. At 28 and 56 days since fabrication, the percent of shrinkage reduction achieved with the SRA was higher in the concretes cured for 14 days. Beyond 90 days, the shrinkage-reduction differences were less dramatic, but drying shrinkage was still less in the wet-cured SRA concretes.

The admixture was also tested in accordance with ASTM C 494-92, "Chemical Admixtures for Concrete." Although no ASTM designation yet exists for the product, the tests helped to confirm some properties of concretes containing the SRA, including shrinkage at 28, 56, and 120 days (see table).

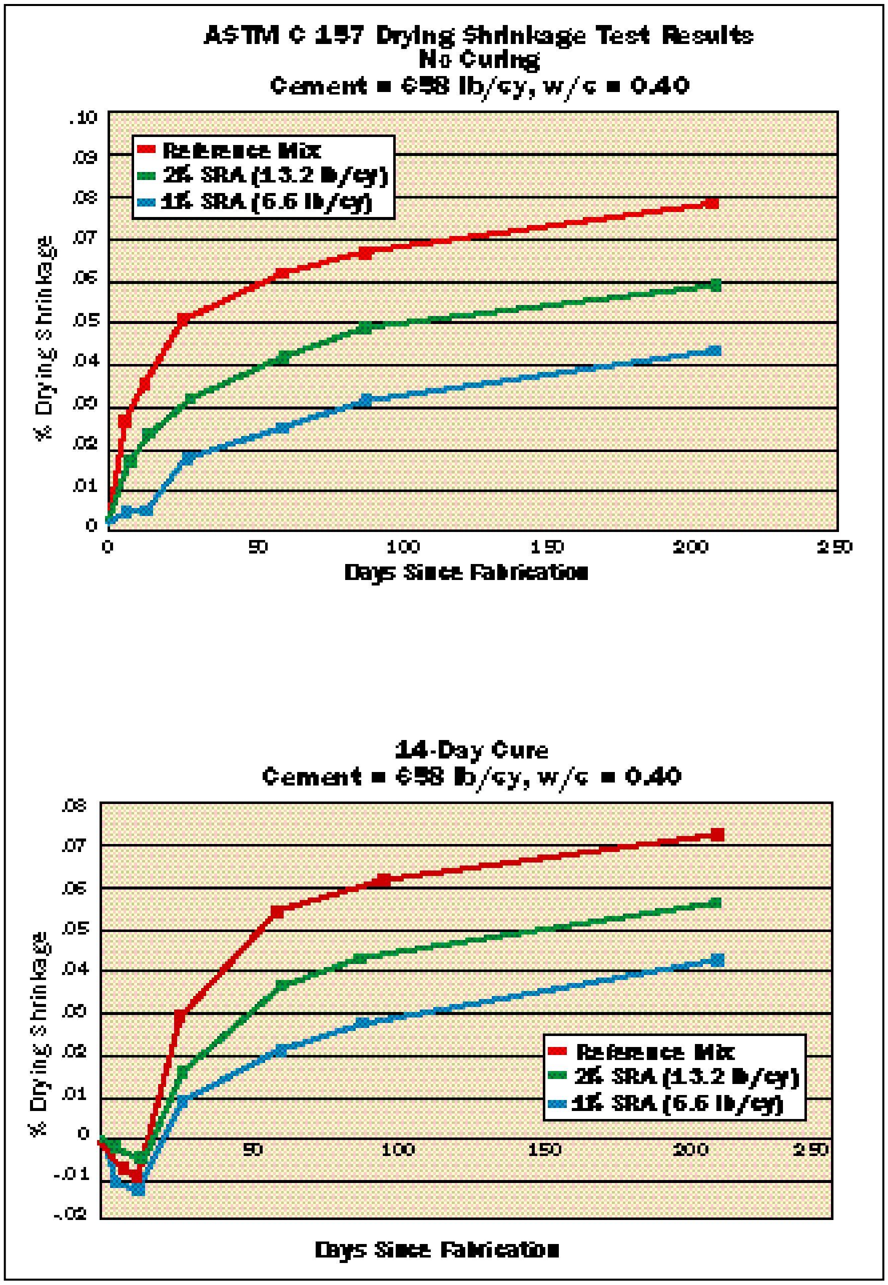

Figure 2. **In ASTM C 157 drying-shrinkage tests, the percent of shrinkage reduction achieved by using the shrinkage-reducing admixture (SRA) was higher in concretes wet-cured for 14 days. At 28 and 56 days since fabrication, cured concrete containing 2% SRA exhibited about 0.015% and 0.035% drying shrinkage, respectively. In the uncured concrete sample containing 2% SRA, drying shrinkage at 28 and 56 days exceeded 0.03% and 0.04%, respectively.**

Other Effects on Hardened-Concrete Properties

Although the primary impact of the SRA is reduced drying shrinkage, the admixture can also affect hardened concrete in other ways.

Shrinkage cracking. Since the admixture has not yet been widely used in the field, it's still too early to say for sure whether the reduction in drying shrinkage reduces shrinkage cracking in large-scale concrete structures. However, Grace has evaluated the product's performance in large-scale concrete test slabs (39 feet long, 3 feet wide, and 4 inches thick). Although the slabs were fully restrained and exposed to relative humidities of less than 50% for 20 months, no cracking occurred. A control slab without the SRA cracked within two months.

Compressive strength. Adding the SRA to concrete can reduce compressive strength as much as 15% at 28 days (based on a 2% admixture dosage rate). In general, the strength reduction is less in concretes with lower water-cement ratios. If this strength reduction is not acceptable, it's possible to counteract the effect by using a superplasticizer and slightly reducing the SRA dosage. The manufacturer recommends adding enough superplasticizer to reduce mixing water by 7% to 10% while keeping cement content constant.

Thermal cracking. Not all cracks in concrete can be attributed to drying shrinkage; a large percentage is due to thermal effects. There are two basic causes of thermal cracks: temperature differences within massive sections of concrete and overall volume change of thinner sections of concrete caused by cooling.

Although the SRA does not alter the thermal coefficient of concrete, it does lower the rate at which hydration generates heat. This reduces peak temperatures within the concrete, so there's less thermal contraction upon cooling. This reduced heat of hydration at early ages is also the reason for the lower concrete compressive strengths observed when using the admixture. If cement is added to prevent a loss in strength, however, the heat-reduction effect is counteracted.

Curling. Because curling of concrete slabs is caused by the top surface drying and shrinking faster than the concrete below, adding the SRA to slab concrete may reduce the tendency for curling. So far, this effect has only been verified in small lab specimens, but additional testing on larger slabs is being conducted.

Projects that can benefit from the new shrinkage-reducing admixture (SRA) include concrete bridge decks and industrial floors. In April, SRA concrete was used to construct joint-free foundation slabs for a business complex in Minnesota (above). The slab concrete contains 1.25 gallons of SRA per cubic yard and is reinforced with steel fibers instead of conventional rebar. SRA concrete was also used this spring by the Virginia DOT in a test overlay for the Lesner Bridge (right). The overlay concrete contains 1.5 gallons of SRA per cubic yard.

Effects on Fresh-Concrete Properties

When added at a 2% dosage by weight of cement to a concrete mixture with 600 pounds per cubic yard of cement, the volume of the admixture is 1.5 gallons per cubic yard. This liquid volume will increase the concrete's slump and overall porosity just as an additional 1.5 gallons of water will. When substituted for an equivalent volume of water, however, the SRA has little or no effect on concrete slump. It does have a slight retarding effect and may extend setting time, typically by less than an hour.

The admixture also affects the air content of fresh concrete. When the admixture is used in air-entrained concrete, the air-entraining admixture dosage must be increased to achieve a specified air content.

Recent Projects

Though the SRA has not yet been widely used in the field, it has proven to be effective on some recent projects. One example is the construction of slab foundations for the Bass Lake Business Center, a new office-manufacturing complex in Plymouth, Minn. Owner Caliber Development Corp. required crack- and joint-free foundation pads for precision tooling machinery. The project included three 12x25-foot foundation slabs, each 24 inches

Mix	Reference	SRA (1.5%)	SRA (1.25%) HRWR (0.25%)
Water-cement ratio	0.52	0.48	0.45
Water reduction (%)	–	8	14
Slump (inches)	4	3.5	3
Entrained air (%)	5.4	5.7	5.4
Initial setting time (minutes)	210	244	262
Final setting time (minutes)	462	485	574
3-day compressive strength (psi)	2795	3010	3520
7-day compressive strength (psi)	4095	4020	4615
28-day compressive strength (psi)	5755	5940	6365
28-day shrinkage (%)	0.028	0.013 (46% of ref.)	0.008 (29% of ref.)
56-day shrinkage (%)	0.056	0.038 (68% of ref.)	0.032 (57% of ref.)
120-day shrinkage (%)	0.063	0.047 (74% of ref.)	0.039 (62% of ref.)

ASTM C 494 Test Results

thick, and about 10,000 square feet of 10-inch-thick slab to support smaller pieces of equipment.

Engineer Van Doren Hazard Stalling Inc., Minneapolis, and concrete producer Cemstone Products Co., Mendota Heights, Minn., designed a concrete mix containing SRA at a dosage of 1.25 gallons per cubic yard (1.8% by weight of total cementitious materials content). The 4000-psi mix also contained fly ash (50 pounds per cubic yard) and steel-fiber reinforcement (40 pounds per cubic yard). The w/cm was 0.48. The slabs were placed in mid-April, and no early-age shrinkage cracking was observed.

Concrete containing the SRA was also recently used by the Virginia Department of Transportation (DOT) in a test overlay for the Lesner Bridge, Norfolk. Each span of the bridge used a different type of concrete mix. The SRA concrete contained 1.5 gallons of the admixture per cubic yard and 5% silica fume. The w/cm was 0.40. The concrete was supplied by Tarmac Mid-Atlantic Inc., Norfolk.

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