Crack-Reducing Admixture

A new frontier in the battle against drying shrinkage cracking

by Charles K. Nmai, Dan Vojtko, Steve Schaef, Emmanuel K. Attiogbe, and Mark A. Bury

Concrete undergoes volume changes shortly after placement, and a major contributor is drying shrinkage. Restraint of these volume changes leads to the development of tensile stresses within the concrete matrix and, invariably, cracking of the concrete. Cracking is a major concern in concrete construction because cracks compromise aesthetics and, depending on the specific application, may lead to serviceability and durability problems. These durability problems can include leakage in water-retaining structures or chloride-induced corrosion in bridges and parking structures. Consequently, it is important that, in addition to taking measures to control cracking, crack width is minimized as much as possible should cracking occur.

Drying Shrinkage of Concrete

There are several factors that affect the drying shrinkage of concrete. These include the proportions and characteristics of the concrete mixture ingredients, design and construction practices, and environmental influences. However, the constituents of a concrete mixture that have the greatest influence on drying shrinkage are water and coarse aggregate, because both can have a profound effect on minimizing the paste content. For a given set of concreting materials, proper mixture proportioning will help in producing concrete with low drying shrinkage.

Shrinkage-reducing admixtures

The drying shrinkage of concrete can be minimized further through the addition of conventional shrinkage-reducing admixtures (SRAs), which were first introduced in Japan in the early 1980s[1-3] and have been available in the United States since the mid-1990s.[4-6] Depending on dosage, SRAs can reduce drying shrinkage by about 50 to 80% at 28 days and between 30 and 50% in the long-term—their performance attributes are well documented.[1,2,5-9] However, observations from restrained shrinkage evaluations performed in accordance with ASTM C1581/C1581M, "Standard Test Method for Determining Age at Cracking and Induced Tensile Stress Characteristics of Mortar and Concrete under Restrained Shrinkage," or the "ring test" as it is more commonly known, show that SRAs have a minimal, if any, effect on crack width when cracking occurs.

In the ring test, a sample of freshly mixed mortar or concrete is placed and consolidated in the annulus space created by an outer steel ring and an inner ring that is instrumented with strain gauges (Fig. 1). The top surface of the specimen is subsequently sealed using either paraffin wax or adhesive aluminum-foil tape. Therefore, with the test specimen resting on a nonabsorptive base, drying occurs only from the outer circumferential surface when the outer steel ring is removed after a specified curing duration. The drying shrinkage of the mortar or concrete is

Fig. 1: Ring test setup

restrained by the inner ring, leading to compressive strain in the ring that is measured with the strain gauges.

Cracking of the test specimen is indicated by a sudden decrease in the steel ring strain, as shown in Fig. 2. The age at cracking from the time of casting and the rate of tensile stress development in the test specimen are indicators of the material's potential to resist cracking under restrained shrinkage. Concrete mixtures not optimized for low shrinkage typically exhibit cracking within 14 days in the ring test.[10] SRA-treated concrete will delay the time-to-cracking depending on dosage.

However, as shown in Fig. 2, SRAs do not change the mode of failure in the ring test and failure occurs due to a sudden release of all the compressive strain in the inner ring. In addition, as shown in Fig. 3, initial crack width in untreated or SRA-treated concrete specimens is typically about 0.04 in. (1 mm). As stated earlier, SRAs have minimal effect on crack width.

Crack-reducing admixture

BASF Corporation is introducing a new admixture formulated specifically to reduce not only drying shrinkage but also initial crack width, should cracking occur. This innovative crack-reducing admixture (CRA) is based on a specialty alcohol alkoxylate and it is being marketed under the trade name MasterLife CRA 007 admixture.

The recommended dosage range of the CRA is 1 to 3% by mass of cementitious materials or approximately 1.0 to 2.0 gal./yd^3 (5 to 10 L/m^3) of concrete. It can be used in both non-air-entrained concrete and air-entrained concrete. As with conventional SRAs, the CRA should be used with synthetic air-entraining admixtures in air-entrained concrete applications. The effects of the CRA on the properties of concrete, particularly setting time and strength, are similar to the effects of SRAs. Therefore, depending on dosage, as well as on concrete and ambient temperatures, setting time may be slightly delayed. In addition, a slight reduction in strength may occur depending on dosage of the CRA.

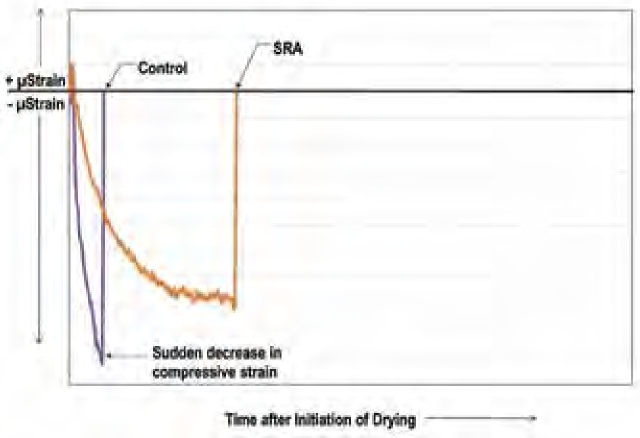

Fig. 2: Sudden decrease in compressive strain at cracking in ring test

Similar to conventional SRAs, the CRA reduces the surface tension of water and it provides similar reductions in drying shrinkage at equal dosages. However, typical results for restrained shrinkage testing of untreated concrete, conventional SRA-treated concrete, and concrete treated with the CRA show that the CRA changes the mode of failure from a sudden release of all the compressive strain to a gradual reduction in strain in the inner steel ring, thereby providing a greater increase in time-to-cracking (Fig. 4). This phenomenon may be attributed to a relaxation of tensile stress (internal stress relief) within the CRA-treated concrete specimens.

As a result of the gradual relief of shrinkage-induced stress in concrete treated with the CRA, it has been observed in ring specimens cast from concrete treated with the CRA that, in the event of cracking, the cracks are hairline in nature with initial crack widths on the order of 0.004 in. (0.1 mm), as shown in Fig. 5. By contrast and as mentioned earlier, untreated concrete or conventional SRA-treated concrete ring specimens typically exhibit a crack width of about 0.04 in. (1 mm) at failure. Therefore, to differentiate the CRA from conventional SRAs, the CRA is defined as "a special class of shrinkage-reducing admixture that produces a maximum initial crack width of 0.007 in. (175 µm [0.175 mm]) in a high-performance, crack-prone (HPCP) concrete mixture when tested in accordance with ASTM C1581/C1581M." The HPCP mixture is proportioned to crack in less than 10 days and it exhibits an initial crack width of approximately 0.04 in. (1 mm).

In practice, the very small hairline cracks observed in the ring specimens cast from concrete treated with the CRA will not transport water easily and have the potential to heal over time.

Field Application of CRA

CRA was used in combination with a macrosynthetic fiber in a jointless slab-on-ground application for a warehouse in Champaign, IL, in July 2013 (Fig. 6). The slab,

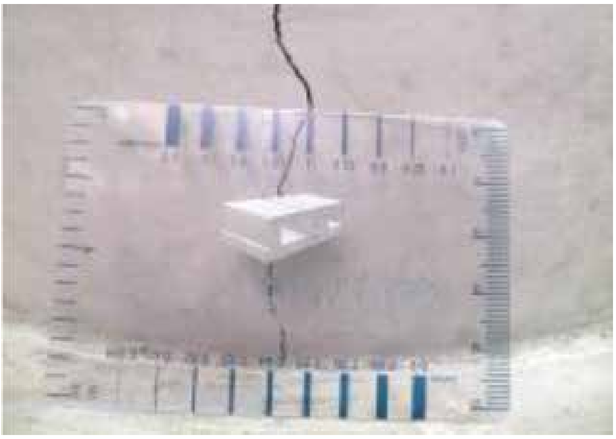

Fig. 3: Typical crack width of 0.04 in. (1 mm) in untreated or SRA-treated concrete specimens

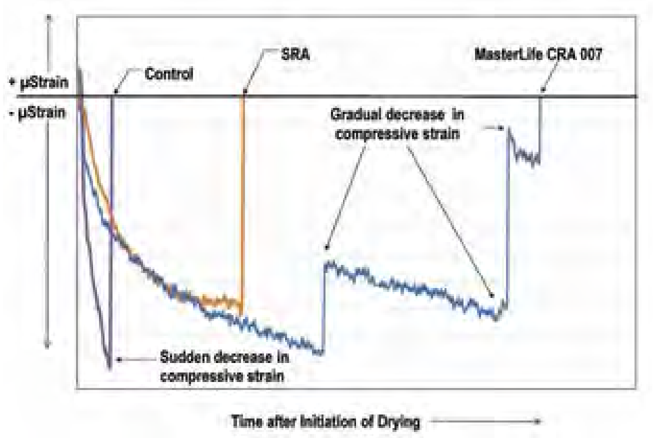

Fig. 4: Typical performance of CRA-treated concrete specimens showing gradual decrease in ring compressive strain compared to sudden decrease in non-CRA-treated specimens

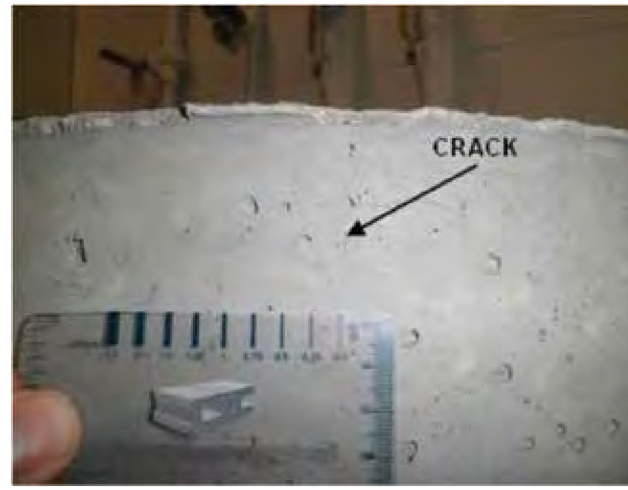

Fig. 5: Typical crack width of 0.004 in. (0.1 mm) in CRA-treated concrete specimens

which was placed on 2 in. (50 mm) of foam plastic insulation, was 7.5 to 8 in. (190 to 200 mm) thick and measured approximately 90 x 60 ft (27.4 x 18.3 m). The CRA was used at a dosage of 1.5 gal./yd^3 (7.5 L/m^3) and the CRA-treated fiber-reinforced concrete was placed at a slump of about 8 in. (200 mm). Concrete slump was maintained over a 20 mile (32 km), 45-minute haul to the job site through the use of a workability-retaining admixture. Concrete placement took place from 7:30 a.m. to about 11:00 a.m. and finishing was performed between 11:30 a.m.

Fig. 6: CRA-treated, fiber-reinforced concrete in a jointless slab-on-ground application

and 2:30 p.m. (because the CRA had very little effect on the setting time of the concrete). No drying shrinkage-related cracks have been observed in the slab, and monitoring is ongoing.

Concluding Remarks

BASF Corporation is introducing MasterLife CRA 007 admixture, an innovative CRA that reduces concrete drying shrinkage and, in the event of cracking, reduces initial crack width. Compared with conventional SRAs, the CRA has been shown to provide internal stress relief in the ASTM C1581/C1581M ring test and, as a result, it changes the mode of failure in the ring test from a sudden release of all the compressive strain in the inner ring to a gradual release of the compressive strain.

The net benefit of the internal stress relief provided by the CRA is a greater delay in the time-to-cracking in the ring test and an initial crack width of about 0.004 in. (0.1 mm) compared to 0.04 in. (1 mm) in untreated concrete and SRA-treated concrete specimens. As a result of this enhanced performance, the CRA is expected to provide significantly better behavior in liquid-containment structures, bridge decks, and other applications requiring liquid-tightness or where superior performance with respect to crack reduction, crack width, and overall durability is desired.

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Selected for reader interest by the editors.

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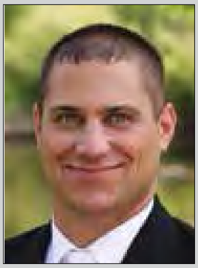

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