CENTER OF EXCELLENCE FOR AIRPORT TECHNOLOGY

TECHNICAL NOTE

TECH NOTE NO: 4

TITLE: Feasibility of Shrinkage Reducing Admixtures for Concrete Runway Pavements

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DATE/REV: 10/18/04

1. Introduction

Shrinkage reducing admixtures (SRA) are a relatively new class of chemical admixtures designed to lower early-age shrinkage of Portland cement concrete. This technical note compiles recent literature to outline the mechanisms through which SRAs work as well as the benefits and possible side effects. A cost analysis was conducted to check the feasibility of using SRAs in concrete runway pavement.

2. Drying Shrinkage Mechanisms in HPCs

Although numerous measures are implemented in the proportioning, placing, and curing of concrete to prevent early-age cracking, it is practically inevitable. Early-age cracking can be a result of many issues, especially drying shrinkage. Drying shrinkage, caused by moisture loss from hardened concrete[1], is unavoidable unless the concrete is submerged in water or exposed to 100 percent relative humidity[2]. If drying shrinkage can be minimized, then the concrete may remain in a relatively crack-free condition for decades, insuring that the concrete structure will survive its intended design life.[3]

The current trend towards high-performance concretes (HPCs) has possibly exacerbated early-age cracking issues. The low water-to-cement ratio (w/c), increased cement content, addition of superplasticizer, and incorporation of pozzolanic admixtures such as silica fume, characteristic of HPCs, creates a water starved, super dense microstructure within a few days or less.[4] This rapid development of a very fine pore network within the cement paste portion of the HPC creates an impermeable medium and effectively seals the concrete off from its environment. Unable to obtain the externally available curing water, the HPC consumes water from its own capillary pores. This self-desiccating action leads to microstructural stresses in the same fashion as the diffusion of pore water during drying.

To understand the mitigation strategies for drying shrinkage, an understanding of the primary concept used to reduce drying shrinkage is necessary. The fundamental mechanism of drying shrinkage in concrete is partially described by the Gauss-Laplace equation.[5,6] This Gauss-Laplace equation can be used to calculate the tensile stress in the pore fluid:

$$\sigma_{cap} = \frac{2\gamma}{r}$$

where σ_{cap} is tensile stress in the pore fluid, γ is surface tension of the pore solution, and r is the radius of the largest water-filled cylindrical pore.[7] As concrete dries or is self-desiccated, curved menisci form in the pores. This leads to a reduction in pore relative humidity (RH) which in turn increases the internal capillary pressure, drawing the walls together and resulting in drying shrinkage.[6] An examination of the Gauss-Laplace equation shows two free variables which directly effect the tensile stress in the pore fluid. Even at early-age, the pore structure of the cement matrix is well defined, thus making the pore radius unchangeable. We can, however, manipulate the other free variable, surface tension of the pore solution, with chemicals called shrinkage reducing admixtures.

3. Shrinkage Reducing Admixture

Lowering capillary pressure via reducing surface tension is achieved with the addition of a shrinkage-reducing admixture (SRA). These low viscosity, water-soluble liquids were originally developed in Japan in 1982.[2] Some common SRAs are propylene glycol derivatives which are added to both normal and high strength concrete at 1 to 2 percent SRA by weight of concrete.[8] SRAs can also be applied as a topical curing compound (also known as the impregnation method)[2] but this method has proven costly for use in concrete pavement. The use of SRA admixtures has become commonplace as, according to CE News, an average of 36% of different types of engineering firms specified their use.[9]

4. Benefits

It is not uncommon for SRA datasheets to claim that the 28-day concrete shrinkage is reduced by 50-80% and the ultimate shrinkage is reduced by 25-50%.[10,11,12] Polyalkyl ether based SRA admixtures have been shown to lower the measured surface tension of distilled water about 57% by the addition of 6% SRA.[3] The work of Tazawa and Miyazawa showed that the percentage of decrease in the autogenous shrinkage nearly corresponds to the percentage of decrease in the surface tension[13], agreeing with the previous statements. Typical lab results show reduction in drying shrinkage of about 50-60% at 28 days and about 40-50% after 12 weeks.[2,14,15] Studies at the University of Illinois showed about a 30% decrease in shrinkage at only 8 days at the addition of 1.5% SRA, as shown in Figure 1 on the next page.[6] The effects of dosage optimization can also be seen in this figure.

Reduced shrinkage is a direct effect of the addition of an SRA. This reduction in early-age drying shrinkage provides the concrete sufficient time to harden before extreme tensile stress is imposed on it. In other words, since the drying shrinkage is delayed a substantial amount of time, if not indefinitely, then the cement matrix has more time to develop and build tensile strength. With this higher tensile strength, cracking due to drying shrinkage is less likely. If cracking does occur at a later age, the crack openings will likely be significantly smaller.[15]

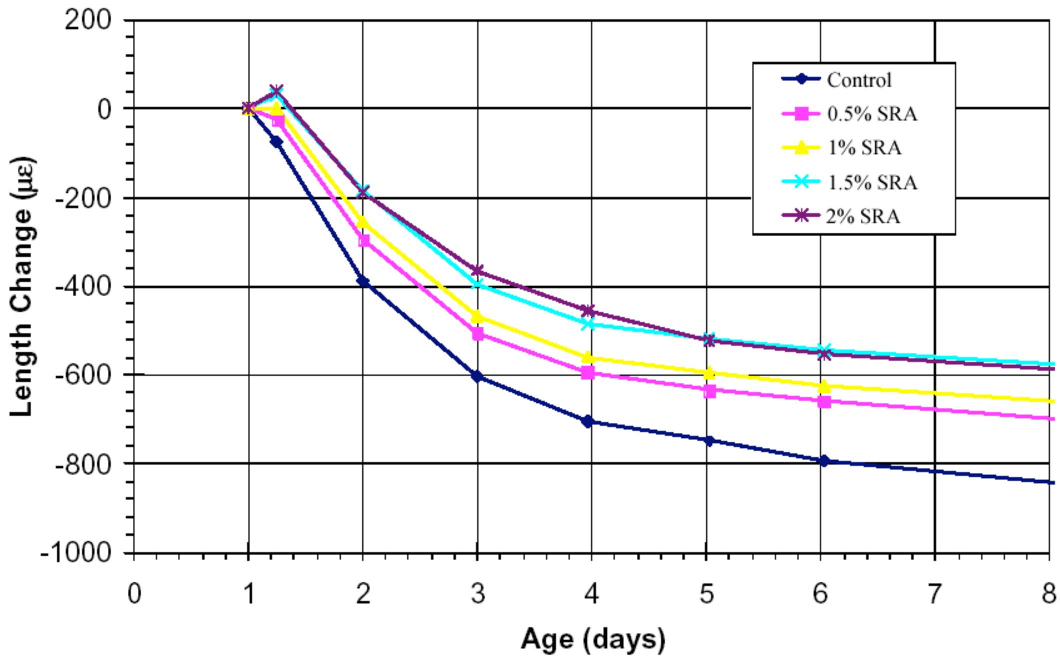

Figure 1.[17] Unrestrained shrinkage of mortar bars, w/c = 0.5

5. Limitations and Potential Side-Effects

SRAs have been shown to reduce surface tension of the pore fluid, reducing shrinkage and the likelihood of cracking which leads to a more durable concrete. These chemical admixtures, as with any admixture, have potential negative side effects. The primary negative side effects include a chance of strength loss early in the concrete's life, a slight delay in set time, potential interaction with other admixtures (air-entraining agent) and the potential for the SRA to wash out over time.

5a. Potential Early-Age Strength Loss

The affect of SRA on concrete strength is not clear. Research by Nmoi stated that the addition of an SRA had minimal effect on compressive strength[2] whereas SRA datasheets admit that a reduction in compressive strength on the order of 0 to 10% should be expected at 28 days.[10] Folliard observed a reduction of compressive strength, especially at the age of one day. He attributed such reductions to the effects SRA has on early cement hydration.[14] Weiss found that in one experiment with normal strength concrete the compressive strength increased with the addition of SRA. In another experiment, this time with HPC, the addition of 1% SRA had no effect whereas the addition of 2% displayed slight losses in strength.[16] This early-age strength loss has also been seen by Grace researchers[10] as well as Folliard.[14]

5b. Delay in Set Time

As SRA reduces the surface force of attraction in the pore water, it could also reduce the forces of attraction of the flocculated binder phase, resulting in a retarded set time.[17] This effect is more pronounced with larger dosages and even more significant when combined with superplasticizer, which is typically used in HPC. Brooks showed that the initial and final setting times could be retarded as much as 25% and 24%, respectively, with a dosage of 1.25% SRA.[17]

5c. Interaction with Air-Entraining Agent

The phenomenon of the interaction of shrinkage reducing admixtures and air-entraining agents (AEA) is not fully understood. SRAs displayed air-entraining capabilities as early at 1983[18], a trend noted into the 1990's.[19] When combined with an AEA, however, the air-entraining abilities of SRA have been said to both decrease and increase the effective air-entrainment. Research shows that excellent freeze-thaw resistance can be obtained as long as compatible admixtures are chosen.[20] Certain SRAs have been designed to be compatible with conventional air-entraining agents and their respective datasheet will support the claim with freeze-thaw data.[11]

5d. Potential of Washout

Although there is also no published data available on the likelihood of a SRA to washout, the possibility causes concern in terms of durability. SRA is a chemical which simply lowers surface tension in the pore fluid but does not combine chemically with hydration products. It is thus potentially available to washout with migrating water. Its application, however, is primarily to reduce early-age shrinkage so the loss of the chemical late in the service life may be of little concern as the shrinkage stresses will have been delayed until the material has gained sufficient strength.

6. Cost Analysis

A cost analysis was performed which considered the addition of a common SRA to a standard concrete mix with a cost of \$70/yd^3 at normal dosages, 0.5gal/yd^3 to 1.5gal/yd^3.[11] This analysis was normalized to square feet by using a 15 inch slab depth.

Material Cost Analysis

Material:	Plain Concrete	SRA (1.0gal/yd^3)	SRA (1.5gal/yd^3)	
Cost of just concrete:	70.00	70.00	70.00	\$/yd^3
Cost of SRA:		20.00	30.00	\$/yd^3
Total Cost per cy:	70.00	90.00	100.00	\$/yd^3
Total Cost per cf:	2.59	3.33	3.70	\$/ft^2
Depth of concrete is 15inches				
Material Cost per ft^2	3.24	4.17	4.63	\$/ft^2
Cost Percent Increase:		28.7	42.9	%

Construction Cost Analysis

Finishing cost	Length (ft)	Width (ft)	Cost (\$/ft)	Plain (\$/ft^2)	1.0 gal/yd^3 (\$/ft^2)
Trans Sawct. - SRA slabs (ft)	25	25	1.8		0.072
Trans Sawct. – Plain slabs (ft)	20	18.75	1.8	0.09	
Long Sawct. – SRA slabs (ft)	25	25	1		0.04
Long Sawct. – Plain slabs (ft)	20	18.75	1	0.05	
Dowels – SRA concrete slabs	25	25	9		0.72
Dowels – Plain concrete slabs	20	18.75	9	0.93	
Construction Costs per ft^2				1.07	0.83

TOTAL COST	**4.31**	**5.00**
Percent Increase		15.9%

This cost analysis shows that only a 15.9% increase in cost was realized with the addition of a typical dosage of SRA (1.0gal/yd^3) because the concrete slabs dimensions were able to be increased from 20'x 18.75' to 25'x 25'.

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