SHRINKAGE OF CONCRETE
WITH AND WITHOUT FLY ASH

by

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• Cracking of concrete due to autogenous shrinkage and drying shrinkage continues to be a concern, especially for concrete exposed to weather.

• Cracking leads to lower durability, shorter life span, and higher life-cycle costs.

• Use of high-range water-reducing admixtures and fibers has had limited success in the reduction of overall cracking of bridge decks, parking garage slabs, and other structures.
The objective of this research project was to evaluate and compare the effectiveness of different brands of shrinkage-reducing admixtures (SRA-1, SRA-2, and SRA-3) for reducing autogenous shrinkage and drying shrinkage of concrete made with and without fly ash.
The effects of the SRAs on air content, slump, initial setting time, compressive strength, splitting-tensile strength, chloride-ion penetrability, and changes in air content and slump during the first hour after concrete mixing were investigated.
• Concrete mixtures were made based on mixture proportions of WisDOT Grade A, Grade A-FA, and a high-cementitious concrete mixture.

• Grade A concrete did not contain supplementary cementitious materials (fly ash or ground granulated blast furnace slag).

• For Grade A-FA and the high-cementitious concrete, Class C fly ash was used to replace 30% of cement. The high-cementitious concrete contained 30% more cement and fly ash than Grade A-FA concrete.
• Effects of three types of coarse aggregate were evaluated using Grade A-FA mixture proportions:
  • Aggregate 1, crushed quartzite stone;
  • Aggregate 2, semi-crushed river gravel; and
  • Aggregate 3, crushed dolomitic limestone.
Several sources of shrinkage-reducing admixtures (SRAs) were identified. The following three were selected and evaluated:

1. SRA-1: Eucon SRA from Euclid Chemical Company;
2. SRA-2: Eclipse Plus from Grace Construction Products; and
3. SRA-3: Tetraguard AS20 from Degussa (formerly Master Builders).
• Each SRA was used with a mid-range water-reducing admixture (MRWRA) and air-entraining admixture (AEA) supplied by the same manufacturer as the SRA.

• SRA was added last into a concrete mixer after all the other ingredients were intermixed.
Slump test of fresh concrete

Testing for air content of fresh concrete
Wet-sieving of concrete through a 4.75-mm sieve for obtaining a sample for initial setting time test of concrete

Testing for initial setting time of concrete by penetration resistance
Autogenous shrinkage beam mold
Preparing Autogenous Shrinkage Specimens
Sealed Autogenous Shrinkage Beam Immediately After Casting
Test Setup for Autogenous Shrinkage at Early Ages
Storage of Sealed Autogenous Shrinkage Beams
Autogenous Shrinkage Test Setup After Beams Are Sealed With Aluminum Adhesive Tape
Center for By-Products Utilization

Air Storage of Drying Shrinkage Beam Specimens, Following 28 Days of Moist Curing in Lime-saturated Water
Drying Shrinkage Test Setup
Finishing Cylindrical Specimens
Compressive Strength Test of Concrete

Center for By-Products Utilization
Splitting Tensile Strength Test of Concrete
Specimens in Contact With 3% NaCl (−) and 0.3 N NaOH (+) Solutions and Subject to 60 V DC

Center for By-Products Utilization
Setup for Electrical Indication of Chloride-ion Penetrability Test

Center for By-Products Utilization
Shrinkage-Reducing Admixture Dosage

- Three dosage rates of SRA were used: (1) zero (reference); (2) the average dosage rate of 1.8 L/100 kg of cementitious materials (average of the minimum rate [1.0 L/100 kg of Cm] and the maximum rate recommended by the SRA manufacturer); and (3) the maximum recommended dosage rate of 2.5 L/100 kg of cementitious materials.
## Mixture Proportions of Concrete (Chemical 3, Aggregate 1)

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>S3-0.0</th>
<th>S3-1.8</th>
<th>S3-2.5</th>
<th>S3-0.0-FA</th>
<th>S3-1.8-FA</th>
<th>S3-2.5-FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement (kg/m³)</td>
<td>326</td>
<td>330</td>
<td>326</td>
<td>233</td>
<td>230</td>
<td>229</td>
</tr>
<tr>
<td>Class C fly ash (kg/m³)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>100</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Water (kg/m³)</td>
<td>134</td>
<td>132</td>
<td>132</td>
<td>134</td>
<td>119</td>
<td>123</td>
</tr>
<tr>
<td>Fine aggregate, SSD (kg/m³)</td>
<td>822</td>
<td>831</td>
<td>821</td>
<td>828</td>
<td>817</td>
<td>814</td>
</tr>
<tr>
<td>Coarse agg., ≤ 19 mm, SSD (kg/m³)</td>
<td>996</td>
<td>1010</td>
<td>995</td>
<td>1000</td>
<td>990</td>
<td>986</td>
</tr>
<tr>
<td>Mid-range water-reducing admixture (L/m³)</td>
<td>3.16</td>
<td>0.64</td>
<td>1.66</td>
<td>1.61</td>
<td>0.64</td>
<td>0.62</td>
</tr>
<tr>
<td>Air-entraining admixture (L/m³)</td>
<td>0.06</td>
<td>0.10</td>
<td>0.39</td>
<td>0.11</td>
<td>0.14</td>
<td>0.30</td>
</tr>
<tr>
<td>Shrinkage-reducing adm. (L/m³)</td>
<td>0</td>
<td>5.87</td>
<td>8.05</td>
<td>0</td>
<td>5.75</td>
<td>8.09</td>
</tr>
<tr>
<td>W/Cm</td>
<td>0.41</td>
<td>0.40</td>
<td>0.41</td>
<td>0.40</td>
<td>0.36</td>
<td>0.37</td>
</tr>
</tbody>
</table>
## Fresh Properties and Time of Initial Setting of Concrete
*(Chemical 3, Aggregate 1)*

<table>
<thead>
<tr>
<th>Mixture designation</th>
<th>S3-0.0</th>
<th>S3-1.8</th>
<th>S3-2.5</th>
<th>S3-0.0-FA</th>
<th>S3-1.8-FA</th>
<th>S3-2.5-FA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slump (mm)</td>
<td>76</td>
<td>64</td>
<td>51</td>
<td>83</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>Air content (%)</td>
<td>6.2</td>
<td>5.8</td>
<td>6.2</td>
<td>5.7</td>
<td>7.2</td>
<td>6.0</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>2280</td>
<td>2310</td>
<td>2280</td>
<td>2300</td>
<td>2260</td>
<td>2260</td>
</tr>
<tr>
<td>Time of initial setting (hours)</td>
<td>7</td>
<td>8.25</td>
<td>8.5</td>
<td>15</td>
<td>8.5</td>
<td>8</td>
</tr>
</tbody>
</table>
Effects of SRA-3 on W/Cm

• The design W/Cm of concrete was 0.40.

• Use of SRA-3 reduced either the MRWRA-3 demand (Mixtures S3-1.8 and S3-2.5 Vs. S3-0.0) or both the MRWRA-3 and water demand (Mixtures S3-1.8-FA and S3-2.5-FA Vs. S3-0.0-FA) in concrete mixtures, meaning that SRA-3 had a water-reducing effect.

• Use of fly ash also reduced the MRWRA-3 demand (Mixtures S3-0.0-FA Vs. S3-0.0; and Mixtures S3-2.5-FA Vs. S3-2.5).
AEA-3 demand

- The target air content was $6 \pm 1.5\%$.
- When SRA-3 was used at its average dosage rate, the AEA-3 demand was slightly higher than that of the reference (no SRA) concrete mixtures.
- When SRA-3 was used at its maximum dosage rate, the AEA-3 demand increased significantly.
- The AEA-3 dosage itself was small ($\leq 0.39 \text{ L/m}^3$ of concrete, or $0.12 \text{ L/100 kg of Cm}$) regardless of the SRA-3 dosage.
Time of Initial Setting

• The time of initial setting of concrete was determined for starting the measurements for autogenous shrinkage.

• The time of initial setting of the reference (no SRA) Grade A-FA fly ash concrete was exceptionally long (15 hours); the reason for this is not known (test error?).

• The rest of the concrete mixtures made with chemical admixtures from Source 3 showed an initial setting time of 7 to 8.5 hours.
Drying shrinkage of Grade A no-ash concrete vs. SRA dosage rate (Chemical 3, Aggregate 1)
Drying shrinkage of **Grade A-FA fly ash concrete** vs. SRA dosage rate (Chemical 3, Aggregate 1)
Drying shrinkage of no-SRA concrete and SRA concrete influence by fly ash use (Chemical 3, Aggregate 1)
Drying Shrinkage

• For a SRA-3 dosage rate of up to 1.8 L/100 kg of cementitious materials, Grade A-FA fly ash concrete mixtures showed either approximately the same or a somewhat higher drying shrinkage than their Grade A no-ash counterparts.

• But when the SRA-3 dosage rate increased to 2.5 L/100 kg of cementitious materials, the drying shrinkage of the fly ash concrete S3-2.5-FA was about the same as that of its no-ash counterpart, Mixture S3-2.5.
Autogenous shrinkage of Grade A no-ash concrete vs. SRA dosage rate (Chemical 3, Aggregate 1)
Autogenous shrinkage of **Grade A-FA fly ash concrete** vs. SRA dosage rate (Chemical 3, Aggregate 1)
Autogenous shrinkage of no-SRA concrete and SRA concrete influenced by fly ash use (Chemical 3, Aggregate 1)
Autogenous Shrinkage

Compared with Grade A no-ash concrete mixtures, Grade A-FA fly ash concrete mixtures generally showed a lower autogenous shrinkage at ages of up to 14 days, but showed either a similar or higher autogenous shrinkage at 28 and 56 days.
Compressive strength of Grade A no-ash concrete and Grade A-FA fly ash concrete vs. age (Chemical 3, Aggregate 1)
Compressive Strength

- SRA-3 did not affect the compressive strength of Grade A no-ash concrete mixtures.
- Grade A-FA fly ash concrete mixtures containing SRA-3 showed somewhat higher compressive strength than their reference (no SRA) Grade A-FA fly ash concrete mixture. SRA-3 itself does not seem to have affected the compressive strength of concrete considerably.
FINDINGS AND CONCLUSIONS

1. Drying shrinkage and SRA dosage rates: SRA-1, SRA-2, and SRA-3 showed similar performance in reducing the drying shrinkage of concrete. Drying shrinkage normally includes the effect of autogenous shrinkage.
(b) The drying shrinkage reduced in an approximately direct proportion to the amount of SRA used. When SRA is used in excess of the above recommended dosage rates, drying shrinkage may not reduce any further.

(c) SRA was most effective in reducing the drying shrinkage of concrete during early periods (up to about four days) of exposure to dry air when the rate of drying shrinkage is otherwise the highest. In effect, SRAs eliminated much of the initial high drying shrinkage of concrete.
2. Autogenous shrinkage: Overall, SRA-1, SRA-2, and SRA-3 showed similar performance in reducing the autogenous shrinkage of concrete. As for the effect of fly ash on autogenous shrinkage, Grade A-FA fly ash concrete mixtures (with and without SRA) usually exhibited a lower autogenous shrinkage at early ages and then a higher autogenous shrinkage starting from 14 to 56 days.
3. Changes in air content and slump: Fresh concrete mixtures had an initial air content of 6 ± 1.5%.

SRAs did not significantly affect the changes in air content and slump of fresh concrete mixtures during the first hour after the concrete was mixed.

The changes in air content and slump during the first hour were about the same regardless of whether SRAs were used or not.

Thus, there was no adverse effect of the SRAs on the initial air content, air-content stability, and slump retention of fresh concrete.
4. Compressive strength:

(a) Usually, SRA-1 and SRA-3 either increased the compressive strength or did not affect the compressive strength.

(b) Concrete mixtures made with chemical admixtures from Source 2 showed a relatively low compressive strength. An increase in SRA-2 dosage either lowered the compressive strength or did not affect the compressive strength. This could be due to the significant increase in AEA-2 demand with increasing SRA-2 dosage.
5. The material cost of SRA is rather high. By using SRA, however, the life and performance of bridge concrete decks and concrete pavements can be improved.

• Also, use of certain brands of SRA (SRA-1 and SRA-3) either reduces or eliminates the cost of using water-reducing admixtures and/or air-entraining admixtures.
6. Based on the results of this research, SRA-1 appears to be the best product, followed by SRA-3, and lastly SRA-2 (due to its high AEA demand and relatively lowered concrete strength).
Thank you very much for your interest.
Aabhar Tamaro, Afcharisto Poly, Arigatou Gozaimasu, Grazie Molte, Maraming Salamat, Merci Beaucoup, Muchas Gracias, Muito Obrigado, Salamat, Shukriya, Spasibo, Thank you, Toda Raba.