Iowa State University
Institute for Transportation

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RESEARCH PROJECT TITLE
Investigation into Shrinkage of High-Performance Concrete Used for Iowa Bridge Decks and Overlays – Phase II Shrinkage Control and Field Investigation

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Investigation into Shrinkage of High-Performance Concrete Used for Iowa Bridge Decks and Overlays – Phase II Shrinkage Control and Field Investigation

tech transfer summary

While high-performance concrete mixes have the potential to improve concrete properties, measures must be taken to mitigate their high risk of shrinkage cracking.

Problem Statement

High-performance concrete (HPC) is increasingly being used in bridge decks and deck overlays because of its high strength, low permeability, and excellent durability. However, due to its high cementitious content, low water-to-binder (w/b) ratio, and use of various admixtures, HPC is also at high risk for shrinkage cracking.

Objectives

- Investigate different methods for controlling shrinkage cracking in Iowa HPC mixes and identify the most practical and effective applicable methods
- Investigate the field performance of selected Iowa HPC mixes and compare the performance of different mixes with varying shrinkage cracking potentials and the field performance of concrete mixes with and without shrinkage control methods
- Based on the results and observations from the laboratory and field investigations, provide recommendations for effectively controlling HPC shrinkage

Crack survey being conducted on concrete overlays in the field

Background

A Phase I laboratory study conducted from 2011 to 2013 evaluated the shrinkage behavior of 11 HPC mixes commonly used in Iowa bridge decks and overlays. The mixes were characterized based on their shrinkage behavior and mechanical properties as having either high, medium, or low cracking potential. Different shrinkage control technologies were suggested for these mixes.

Three concrete mixes with different shrinkage cracking potentials were selected from the Phase I study for further investigation in the Phase II study:

- Mix 6 (O-4WR), a mix with high shrinkage cracking potential, made with 100% Lafarge I/II cement, with a w/b ratio of 0.33
- Mix 8 (HPC-O-C20-S20), a mix with medium shrinkage cracking potential, made with quartzite as coarse aggregate, 80% Lafarge I/II cement, and 20% ground granulated blast furnace slag (GGBFS), with a w/b ratio of 0.40
- Mix 2 (HPC-O-C20), a mix with low shrinkage cracking potential, made with 80% Ash Grove IP cement and 20% Class C fly ash, with a w/b ratio of 0.40

Research Description

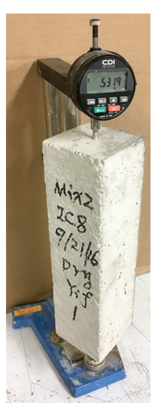
The research involved laboratory and field investigations.

In the laboratory investigation, the three selected HPC mixes from the Phase I study were modified using the following shrinkage control methods:

- For Mix 6, shrinkage-reducing admixtures (SRAs) and shrinkage compensating admixtures (SCAs)
- For Mix 8, cementitious material (CM) reductions
- For Mix 2, internal curing (IC) agents

The selected mixes were modified until optimal shrinkage behavior was achieved in terms of autogenous shrinkage, free drying shrinkage, and restrained shrinkage. For Mix 2 in Phase II, it was found that when different aggregate and water reducing admixtures were used, it displayed much higher shrinkage than that in Phase I. The modifications yielded the following new, optimal concrete mixes:

- Mix 6M or Mix6-1.25SRA, obtained using 1.25 gal/yd^3 of SRAs in Mix 6
- Mix 8M or Mix8-90CM, obtained using 90% CMs (or reducing CM by 10%) in Mix 8
- Mix 2M or Mix2-34%LWFA, obtained using 34% (by volume) lightweight fine aggregate (LWFA) as an IC agent to replace sand in Mix 2



Concrete specimen being tested for free drying shrinkage

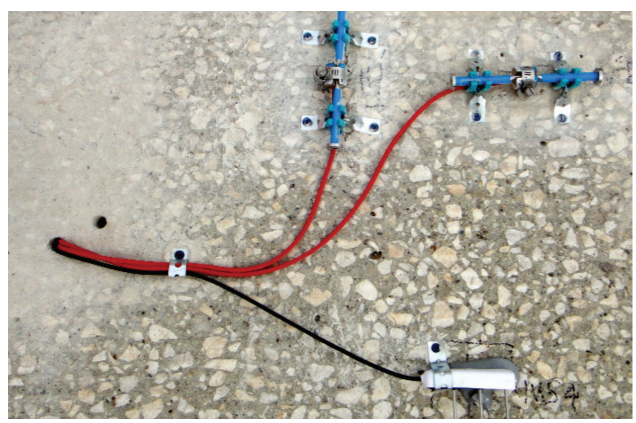
In the field investigation, two of the original mixes and their modified counterparts were evaluated on the US 20 over I-35 dual bridge in central Iowa. Mix 6 and Mix 6-1.0SRA (which used 1.0 instead of 1.25 gal/yd^3 of SRAs) were placed side by side on the westbound bridge overlays. Mix 8 and Mix 8-90CM were placed side by side on the eastbound bridge overlays.

Westbound　Eastbound

Finished overlays before opening to traffic

Strain gages and temperature and moisture sensors were installed in the concrete overlays to monitor the strain, temperature, and moisture of the concretes for approximately one year. The concrete surfaces before, during, and one year after overlay construction were examined visually to record the sizes and patterns of shrinkage cracks.

In addition, cylinders, prisms, and mini slabs for each of the four field-tested concrete mixes were cast in the field. Some were cured in the field under similar conditions to the overlays, and some were cured in the laboratory. The mechanical and freeze-thaw (F-T) durability properties of the field-cast samples were tested and compared to those of laboratory-cast samples.



Strain gage installed on a new deck overlay

Mini slabs at the field site

Key Findings

Effects of Shrinkage Control Methods on Concrete Properties

Adding 1.0 or 1.25 gal/cu[3] of SRA Mix 6 yielded the following:

- Reduced 28-day autogenous shrinkage by approximately 30%, 28-day free drying shrinkage over 50%, and the stress rate of restrained ring shrinkage by 60%
- Increased 28-day compressive strength by approximately 5%, splitting tensile strength about 9%, compressive elastic modulus by around 22%, and creep rate by almost 22%
- Increased concrete surface resistivity by approximately 24% but decreased the F-T durability factor by almost 8%

Reducing CM by 10% in Mix 8 yielded the following:

- Decreased 28-day autogenous shrinkage and free drying shrinkage by approximately 40% and the stress rate of restrained ring shrinkage by 13%
- Decreased 28-day compressive strength by approximately 12% and splitting tensile strength about 19% but increased compressive elastic modulus by around 15% and creep rate by almost 18%
- Decreased concrete surface resistivity by approximately 11% but had little effect on the F-T durability factor

Using 34% (by volume) LWFA as an IC agent to replace sand in Mix 2 yielded the following:

- Reduced 28-day autogenous shrinkage by 47.5%, 28-day free drying shrinkage by only 11%, and the stress rate of restrained ring shrinkage by only 1.3%
- Increased 28-day compressive strength by approximately 15% and splitting tensile strength about 12% but decreased compressive elastic modulus by around 8% and creep rate by almost 21%
- Increased concrete surface resistivity by about 5% and the F-T durability factor by nearly 4%

Field Performance of Concrete Overlays with and without Shrinkage Control

- Cracks were observed on the overlays made with both original HPC mixes (Mix 6 and Mix 8) after about one year, but no cracks were found on the overlays made with the modified mixes (Mix 6-1.0SR and Mix 8-CM90) in the same period.
- Some differences in compressive strength were observed between the laboratory-cast, laboratory-cured samples and the field-cast, laboratory-cured samples for a given mix, suggesting that environmental conditions on the casting day and the first few days of curing play an important role in the development of concrete properties.

Field Sensor Monitoring Results

MOISTURE CONTENT

- Concrete moisture content decreased rapidly at an early age (before 14 days) and then gradually stabilized.
- The moisture profiles varied noticeably among different concrete mixes that were placed at different dates.
- For a given mix, concrete near the abutment/joint had higher moisture content and took a little longer to stabilize than the concrete farther away from the abutment.

STRAIN

- The overall shapes of all the strain curves of the concrete overlays were opposite to the overall shape of the ambient temperature curve. This implies that thermal strain dominated the total strain in the concrete, while autogenous and drying shrinkage strains were superimposed on the total strain.
- The strains monitored in the concrete overlays in the transverse direction appeared not to vary significantly among the concrete mixes.
- The strains monitored in the longitudinal direction in the concrete overlays made with Mixes 6 and 6-1.0SR were similar, and they were much higher than the strains monitored in the concrete overlays made with Mixes 8 and 8-CM90, which were also similar to each other.
- The strains monitored in the concrete overlays resulted from the combined effects of cementitious hydration (autogenous deformation), the exposed conditions (drying/wetting and thermal expansion/contraction), mechanical loading (structural and traffic loads), and creep behavior. Comprehensive combinations of these effects might have made the strain readings more complex.
- In the mini slabs, maximum strain was the highest and second highest in the samples made with Mix 6 and Mix 8, respectively. This result may help explain the cracks observed in the corresponding overlays one year after construction.

Recommendations for Future Research

- Because the modified Mix 2 was only studied in the laboratory, it is proposed that a field investigation be conducted to verify the effectiveness of LWFA as an IC agent in various HPC mixes (e.g., HPC-O, O-S20-C20, and O-C20).
- Further study is necessary to determine how the addition of SRA influences cement hydration and pore structure. The results would help researchers further understand the moisture sensor readings obtained from this present study.
- Because the strains observed in the field concrete overlays showed the combined effects of several factors, it is proposed that a comprehensive stress analysis be conducted to fully examine these effects for various HPC overlay mixes.
- Sensor monitoring was conducted for only one year, and an extended monitoring time (up to three to five years) may be beneficial. Additionally, sensor data could be transmitted via the internet and downloaded remotely instead of manually on site.

Implementation Readiness and Benefits

Adding 1.0/1.25 gal/yd^3 of SRAs to Mix 6 demonstrated many positive effects on concrete shrinkage control and improved mechanical properties, except for the slight reduction in F-T durability. This shrinkage control method is recommended for shrinkage reduction and the prevention of premature concrete distress in Iowa bridge decks and overlays.

Reducing CM by 10% in Mix 8 decreased autogenous and free drying shrinkage significantly but did not significantly reduce ring shrinkage stress. This modification also noticeably reduced strength, elastic modulus, creep rate, and surface resistivity, which might impair serviceability. Therefore, it is recommended that this shrinkage control method be employed very cautiously.

Using LWFA as an IC material in Mix 2 effectively reduced autogenous shrinkage but only slightly reduced free drying shrinkage and yielded little reduction in ring shrinkage stress. This modification also helped improve concrete strength, surface resistivity, and F-T durability slightly but reduced elastic modulus and creep rate. This shrinkage control method can be considered for use in concrete mixes with moderate free drying shrinkage potential and/or mixes with a high autogenous shrinkage potential (i.e., concrete with a low w/b ratio).