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September 2013

RESEARCH PROJECT TITLE
Investigation into Shrinkage of High-Performance Concrete Used for Iowa Bridge Decks and Overlays

SPONSOR
Iowa Department of Transportation (InTrans Project 11-403)
Iowa Highway Research Board (IHRB Project TR-633)

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Investigation into Shrinkage of High-Performance Concrete Used for Iowa Bridge Decks and Overlays

tech transfer summary

This study investigated the shrinkage behavior and cracking potential of the HPC overlay mixes commonly used in Iowa.

Background

High-performance concrete (HPC) is used increasingly in buildings and bridge structures due to its rapid strength development, superior workability, and excellent durability. However, with high cementitious material content, low water-to-cementitious material ratio, and various admixtures, HPC often possesses a high risk of shrinkage cracking.

Problem Statement

Many states have reported cracking on HPC bridge decks at early ages, and this problem is a great concern in Iowa.

Objectives

This research project was aimed at evaluating various shrinkage components (such as chemical, autogenous, and drying shrinkage) in the HPC mixes used for bridge decks and overlays in Iowa, assessing the cracking potential of the HPC mixes, and providing recommendations for reducing the concrete shrinkage cracking potential.

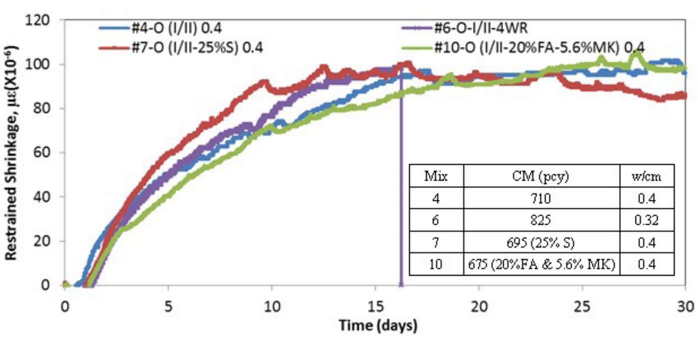
Research Methodology

In this project, 11 mixes were composed of three types of cement (Type I, I/II, and IP), various supplementary cementitious materials (SCMs) (Class C fly ash, slag, and metakaolin at the cement replacement levels of 20, 25, and 5.6 percent, respectively), and different chemical admixtures (normal water reducer, mid-range water reducer, retarder, and air-entraining agent). Limestone, with two different gradations, was used as coarse aggregate in 10 mixes and quartzite was used in one mix.

Chemical shrinkage tests were performed for pastes. Autogenous and free drying shrinkage tests were performed for mortar and concrete. In addition, restrained (ring) shrinkage tests were performed for concrete on all 11 mixes. Mechanical properties (such as elastic modulus and compressive and splitting tensile strength) of these concrete mixes were also evaluated at different ages. Creep coefficients of these concrete mixes were estimated using International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM) B3 and National Cooperative Highway Research Program (NCHRP) Report 496 models. Cracking potential of the concrete mixes was assessed based on the simple stress-to-strength ratio method as well as the ASTM C 1581 stress rate method.

Key Findings and Conclusions

- Among the 11 mixes studied (see table), three of them (Mixes 4, 5, and 6) cracked during the restraint ring tests.
- Autogenous shrinkage of the HPC mixes ranged from 150 to 250 microstrain and free dying shrinkage of the HPC mixes ranged from 700 to 1200 microstrain at 56 days.
- Predictions based on the simple peak shrinkage stress-to-splitting tensile strength ratio with the consideration of concrete creep indicates the following:
  - o Mixes 4, 5, and 6 have high cracking potential, which is consistent with the results of ring tests and only the concrete rings made with these three mixes cracked.
  - o Mixes 1, 7, 8, 9, and 10 have medium cracking potential.
  - o Mixes 2, 3, and 11 have low cracking potential.
- Not all mixes having high shrinkage cracked. Cracking is associated mainly with restrained shrinkage strain, modulus of elasticity, and creep coefficient.
- 20% Class C fly ash replacement for cement reduced all types of shrinkage in paste, mortar, and concrete.
- 25% ground granulated blast-furnace slag (GGBFS) replacement for cement reduced chemical shrinkage of paste and autogenous shrinkage of mortar noticeably, but it increased free drying shrinkage and restrained shrinkage of concrete significantly.
- Replacing cement by 20% fly ash and 5.6% metakaolin increased chemical shrinkage of paste and autogenous shrinkage of concrete. However, it had little effect on restrained shrinkage of concrete.
- Mixes with cement content greater than 700 lb/yd^3 (Mixes 4 and 6) showed high potential for cracking.
- Mixes made with Type I cement yielded greater shrinkage than those made with Type I/II cement, which in turn yielded greater shrinkage than those made with Type IP cement.
- Mixes with high cementitious material content generally displayed high total (autogenous + free drying) shrinkage.



Group 2 restrained shrinkage: While showing lower shrinkage values than Mix 7, all three Mix 6 ring specimens cracked, at 16, 16.5, and 18 days, and two of three Mix 4 specimens cracked, at 13 and 18 days

HPC mixes used for this study

Mix	Type	Cement	Fly Ash	GGBFS	Metakaolin
1	HPC-O	IP	0	-	-
2	HPC-O	IP	20%	-	-
3	HPC-S	IP	20%	-	-
4	HPC-O	I/II	0	-	-
5	HPC-S	I/II	0	-	-
6	O-4WR	I/II	0	-	-
7	HPC-O	I/II	0	25%	-
8*	HPC-O	I/II	20%	25%	-
9	HPC-S	I/II	20%	25%	-
10	HPC-O	I/II	20%	-	5.6%
11	HPC-S	I	20%	25%	-

*Quartzite is used in Mix 8 as coarse aggregate; otherwise limestone is used

Research Implementation

- It is recommended to continue the requirement for use of fly ash in combination with metakaolin and/or GGBFS in the concrete used for bridge decks and overlays in Iowa. Given that fly ash is not permitted in the current O-mix, it is suggested to use Type IP cement, instead of Type I or I/II cement, in future Iowa bridge deck and overlay projects.
- For the HPC mixes with high shrinkage cracking potential (such as Mixes 4, 5, and 6), further study shall be conducted to incorporate a shrinkage reducing agent (SRA) and internal current (IC) technique into the concrete to reduce the concrete shrinkage and cracking potential. The effects of SRA and IC on the mechanical property and durability of the concrete shall also be studied. For the HPC mixes with medium/moderate-high shrinkage cracking potential (such as Mixes 1, 7, 8, 10, and 11), further study can be conducted to modify the concrete mix proportions and balance water-to-cementitious ratio, cementitious content, shrinkage, and tensile strength of the concrete, thus further lowering the cracking potential of the concrete mixes.
- A field study shall be conducted to compare the performance of the high- and low-risk HPC mixes side-by-side. The high-risk mix may be the currently-used, high shrinkage cracking potential mix as identified in the present study (such as Mix 6), while the low-risk mix may be the one selected after mix proportion adjustment, with (or without) SRA or IC agents, and approved in the laboratory as a low shrinkage cracking potential mix. Quality control tests (including workability, air content, and compressive/tensile strength) of the field concrete may be conducted. Shrinkage and cracking behavior of the field concrete will be monitored over 3 to 5 years to verify the present and future research findings.