The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

Evaluation of High Absorptive Materials to Improve Internal Curing of Low Permeability Concrete

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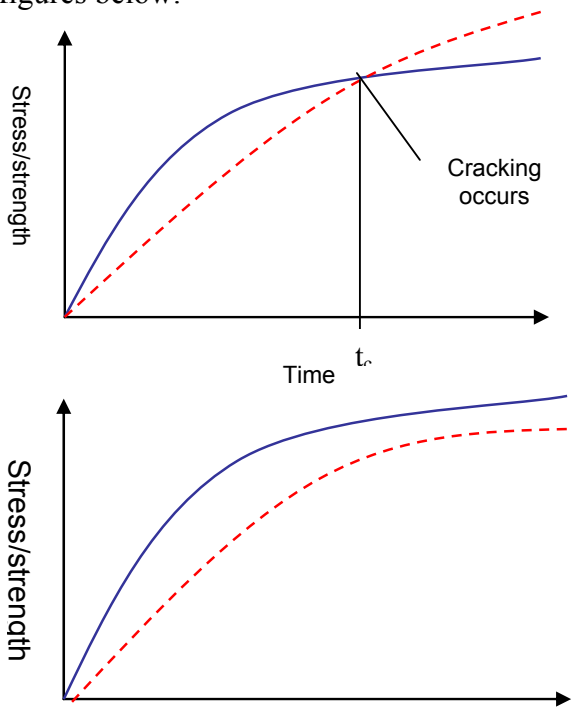
Problem

Early age cracking of bridge decks is a national problem, and may substantially reduce service lives and increase maintenance costs.
Cracking occurs when the tensile stress exceeds the tensile strength of the concrete. This is a time-dependent phenomenon, since both the stress and strength change at early ages. Moisture loss increases stress (with increasing shrinkage) and impairs strength gain. This is illustrated in the figures below.



In the top figure, at time of cracking t_c the tensile stress (dashed line) exceeds the tensile strength of

the concrete (solid line) and a crack develops.
In the second figure, either the tensile stress is reduced, or the tensile strength is increased, or both, and the crack does not form. Internal curing is one method that has been suggested to reduce early age bridge deck cracking, particularly of concretes with low water to cementitious materials (w/cm) ratios.

Objectives

The purpose of this research was to develop methods to economically produce more durable and crack resistant high performance concrete using internal curing. Observations by ODOT District 12 indicated that there is a relationship between the amount of cracking on the bridge decks and the absorption of the coarse aggregate. District 12 developed a specification requirement for HPC concrete that requires aggregates to have 1% or greater absorption.
This research project was carried out to evaluate and validate District 12 findings and, if true, establish other alternate methods of providing internal moisture for curing. One alternative is the use of highly absorptive products in small quantities such as fine lightweight aggregate (LWA).

Description

A literature survey was carried out concerning internal curing and early age cracking, particularly of bridge decks. The research was divided into four phases: concrete mixtures using traditional ODOT materials and mixture designs, concrete mixtures using high absorption fine LWA, concrete mixtures using coarse aggregate with a larger nominal size in a blended mixture, and field testing.
For each concrete mixture, the following tests were performed:

- Fresh concrete properties – slump, air, and unit weight
- Hardened concrete properties – compressive, flexural, and splitting tensile, performed at 7 and 28 days, plus 56 and 90 days for high performance concrete
- Unrestrained shrinkage (bar) tests, sealed and unsealed – measurements taken up to 90 days
- Restrained shrinkage/cracking tendency (ring) tests – measurements taken up to 90 days. The ring test is shown in the figure below.

The ring test is used to determine the time of cracking of a concrete specimen due to drying and autogenous shrinkage against the restraint of the

steel ring. Tests were carried out until cracking or for a maximum of 90 days.
Crushed limestone coarse aggregates with three different absorption levels were tested, along with gravel aggregate at a single absorption level. Concrete mixtures that were very susceptible to early cracking were modified by the inclusion of small amounts of fine lightweight aggregate.

Conclusions & Recommendations

The strongest effect on cracking was due to the replacement of a small maximum size coarse aggregate (#8) with an aggregate blend of #8 and #57. ODOT's current HP mixture uses only #8 aggregate. No matter what the level of absorption, the shrinkage was dramatically reduced with a blended mixture. Only one of eight specimens made with an aggregate blend cracked before 90 days elapsed. Increasing the coarse aggregate absorption level from low to medium had a less dramatic effect, as did the introduction of LWA for internal curing to the low absorption coarse aggregate. Internal curing enhanced the early as well as the ultimate strength of the concrete. Compressive strengths increased by up to twenty percent when fine LWA was used.

Implementation Potential

Based on this research, there are two possible ways to substantially reduce bridge deck cracking. These methods may also be applied to other transportation concrete applications, particularly with low w/cm ratios.
The first way is by replacing small maximum size coarse aggregate (#8) with a larger size aggregate (e.g., # 57) or a blend of sizes. Since most producers have these materials readily available, the added cost should be small. Since larger coarse aggregate allows a reduction in cementitious material content, it would in fact be possible to reduce the cost of the concrete. This would require modifications to the current ODOT high performance (HP) specifications.
The second way is by internal curing, replacing a portion of the fine aggregate with fine LWA. Strength of the concrete is also increased. This method, however, may cost more than the first. Producers do not currently keep fine LWA on hand, and there may be costs associated with handling an additional material. The costs may, however, be outweighed by the performance benefits.
Internal curing may also be used to improve the durability and performance of concrete pavements. Economic benefits of implementation include substantial reduction in maintenance costs for concrete structures and pavements in both the long and short term. ODOT District 12 field observations have documented early cracking of bridge decks that is likely to add up to considerable maintenance expenditures over the projected life of the bridges, starting a few years after construction. Further research of concrete with internal curing would be beneficial to document field performance and to investigate the effect on freeze-thaw durability, wear resistance, and permeability. Use of internal curing may also help reduce differential drying shrinkage of concrete pavements slabs, thus helping to reduce the magnitude of locked in warping (observed during the LTPP program). Internal curing is also likely to be beneficial for improving thin concrete overlays on bridge decks or pavements.