WISCONSIN DEPARTMENT OF TRANSPORTATION

PUTTING RESEARCH TO WORK

BRIEF

Reducing Cement Content in Concrete Mixtures

Concrete mixtures contain crushed rock or gravel, and sand, bound together by Portland cement in combination with supplemental cementitious materials (SCMs), which harden through a chemical reaction with water. Portland cement is the most costly component of concrete mixtures, and its production creates significant amounts of green house gases. To reduce costs and environmental impacts, current WisDOT practice allows a for replacement of a portion of Portland cement supplemental cementitious materials (SCMs) such as coal fly ash or slag cement, both industrial by-products of coal and iron production, respectively.

WisDOT has set a maximum limit on Portland cement replacement through use of SCMs to ensure its performance on concrete pavements. Therefore, the only opportunity to reduce the usage of Portland cement is to lower the required cementitious materials content for WisDOT approved mix designs. The potential benefits in terms of economic costs and environmental impacts are significant, however decreasing the cementitious materials content of a mixture too drastically can reduce pavement strength and durability. It can also reduce workability, or the ease with which a mixture can be compacted and placed during construction.

What's the Problem?

Research was needed to help determine the minimum amount of cementitious material that WisDOT can use in its concrete mixtures and still preserve pavement performance. Several other upper Midwestern states allow the use of concrete mixtures with a lower minimum cementitious material content than currently required by WisDOT specifications, but there is a lack of data on the long-term performance of pavements built with these mixtures.

Research Objective

The goal of this project was to evaluate the effects of reducing the cementitious material content in concrete mixtures, or CMC, measured in pounds per cubic yard of concrete, or lbs/yd^3. Specifically, researchers set out to compare the strength and durability of mixtures with the standard CMC content of 564 lbs/yd^3, required by current WisDOT specifications, to mixtures with 470, 423 and 376 lbs/yd^3 of CMC, respectively. They also explored the use of optimizing aggregate gradation—producing blends of coarse and fine aggregates without major gaps between particle sizes—as a way to reduce CMC without compromising workability.

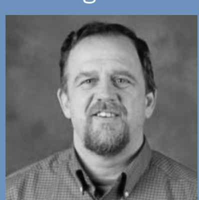
Methodology

Researchers conducted laboratory testing on fresh and hardened properties of 37 mixtures with varying CMC and ratios of coarse to fine aggregates. Properties tested included strength, workability, air content and others.

The research was conducted in two phases: the first, on mixtures using coarse and fine aggregates blended to meet current WisDOT specifications and the second, on mixtures using an optimized grading approach. Phase I mixtures used two coarse/fine aggregate pairs from sources in northern and southern Wisconsin, and Phase II mixtures used only the southern coarse/fine aggregate pair.

Some mixtures included only Portland cement, some replaced 30 percent of the Portland cement with coal fly ash, and some replaced 50 percent of the Portland cement with slag cement. Each mixture also included chemicals commonly used in paving concrete such as a water reducer to improve workability and an air entraining admixture to provide freeze-thaw durability.

Investigator



"This study provides needed data on concrete mixtures having a reduced cementitious material content. This data is based on mixtures using local materials and for concrete intended for use in Wisconsin's winter climate."

–Larry Sutter
Michigan Technological University
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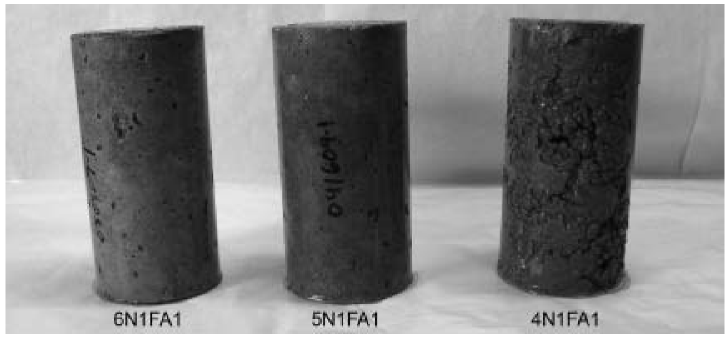

Specimens with a lower cementitious materials content of 376 lbs/yd³ (far right) usually consolidated more poorly than those with a higher CMC of 564 and 470 lbs/yd³ (left and middle, respectively), reducing strength and making them difficult to test for air content. However, all mixtures performed well in freeze-thaw testing.

Results

Many of the concrete mixtures with reduced CMC had problems with workability and consolidation. Poor consolidation involves a failure of cement and fine aggregate to fill the spaces between coarse aggregate particles, creating larger air voids in the concrete. In this case, poor consolidation led to a reduction in compressive and tensile strengths, an increased tendency to absorb water and difficulty in testing air content.

Nevertheless, all mixtures performed adequately in terms of freeze-thaw durability. Some mixtures with reduced CMC consolidated well and had greater compressive and tensile strengths compared with a typical mixture containing 564 lbs/yd³ CMC, including:

- Mixtures containing 470 lbs/yd³ CMC and fly ash. Northern aggregate mixtures in both phases of the project had a 10 to 40 percent increase in compressive strength and a 5 to 30 percent increase in tensile strength. Southern aggregate mixtures also showed increases, although these were less pronounced in Phase I than Phase II mixtures. All 470 lbs/yd³ mixtures were within WisDOT's current recommended range for fine aggregates of 30 to 40 percent of the total aggregate weight.
- One Phase I mixture with southern aggregate, fly ash and 376 lbs/yd³ CMC.
- One Phase II mixture with southern aggregate, fly ash and 423 lbs/yd³ CMC.

Efforts to optimize coarse aggregate grading beyond the prescribed WisDOT limits did not improve the overall performance of the mixtures.

Implementation and Further Research

Based on these results, researchers recommend that WisDOT Grade A concrete specifications be expanded to include mixtures with a CMC of 470 lbs/yd³, and that additional categories be created for 470 lbs/yd³ mixtures containing coal fly ash and slag cement (the current lower limit is 517 lbs/yd³). Based on aggregate optimization results, researchers do not recommend changes to WisDOT's current coarse and fine aggregate grading limits. They also do not recommend that CMC be reduced below 470 lbs/yd³, given the potential for poor workability and lower durability.

WisDOT issued a request for proposal in December 2011 seeking the development of guidelines for optimized concrete mix design. Researchers will evaluate a range of concrete mixture proportions on the basis of both workability and in-place performance and recommend aggregate gradation thresholds and superplasticizer concentrations that will accommodate the use of reduced cementitious materials. Research results are expected in late 2014.

Project Manager

"Greenhouse emissions for Portland cement production are high, so anything we can do to reduce the amount of this cement in concrete mixtures will reduce the carbon footprint of the transportation industry."

–Jim Parry
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This brief summarizes Project 0092-08-08, "Reduction of Minimum Required Weight of Cementitious Materials in WisDOT Concrete Mixtures," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research Program, 4802 Sheboygan Ave., Madison, WI 53707.

Daniel Yeh, WisDOT Research and Communication Services

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