PUTTING RESEARCH TO WORK

BRIEF

Higher-Grade Slag Helps Wisconsin Concrete Pavements Go Green

For more than a century, ground granulated blast furnace slag—a byproduct of the steel manufacturing process—has been used as a cementitious material in concrete. Federal highway regulations link federal funding levels to the use of recycled materials in highway construction, a requirement that can be met by using slag in portland cement concrete pavements. Since slag is plentiful in Wisconsin, WisDOT began using it in the 1990s to replace portions of the cementitious materials in concrete pavement mixtures.

What's the Problem?

Slag cement concrete takes longer to cure than regular concrete, and it does not always perform well. A concrete patch on Interstate 90 poured in 1999 showed unacceptably low strength soon after it was poured. In addition to potential strength deficiencies, slag cement can be more susceptible to chemical damage from deicing salts than regular concrete.

A 2005 WHRP study (WisDOT Project 0092-02-14a, "Effects of Ground Granulated Blast Furnace Slag in Portland Cement Concrete"; see the project page at http://www.whrp.org/Research/Rigid/rigid_0092-02-14a/) found that grade 100 slag cement performed acceptably in terms of strength and resistance to deicer scaling, but only at a 30 percent replacement level. If the slag cement was poured at air temperatures of approximately 70 degrees F, curing required an average of seven days (compared to three days for cement without slag). But the cement cured too slowly for practical use at temperatures below 40 degrees F. WisDOT wanted to know if its highest-grade slag, grade 120, held more promise for slag cement concrete.

Research Objectives and Methodology

To determine the potential of grade 120 slag to perform effectively in slag cement concrete at 30 percent and 50 percent replacement levels, investigators evaluated:

- **Slag variability.** Over the course of one year, researchers evaluated the chemical composition and strength properties of the slag provided each month by a local ready-mix supplier.
- **Strength and air void development.** Investigators prepared 24 concrete mixture types—eight each with no slag, with 30 percent replacement and with 50 percent replacement—at different temperatures. Samples were moist-cured and tested for strength at the end of multiple curing periods.
- **Deicer performance.** Investigators prepared 12 concrete types—four each with no slag, with 30 percent slag cement replacement and with 50 percent replacement. Researchers began conducting deicer scaling tests on the samples after an initial curing period of 28 days, and then repeated the tests after every fifth freeze-thaw cycle until 60 cycles were completed. The effects of two commercial curing compounds and four other curing methods on scaling loss were evaluated.

Results

Researchers found that grade 120 slag cement concrete compared well to regular Wisconsin PCC mixtures in most respects. Specific findings included:

- There was little variability in the slag supplies tested.
- The cement brand, coarse aggregate type and slag replacement level affected the rate of strength gain and the final strength of the concrete. Depending on the type of aggregate, 30 percent slag cement took an average of four to six days to reach a compressive strength of 3,000 psi, while 50 percent slag cement required six to eight days and regular cement took only three or four days.

Investigator

"Slag works as a partial replacement for cement in concrete pavement mixtures. We recommend using grade 120 slag cement in these applications."

–Irene Battaglia
formerly of the University of Wisconsin–Madison
irene.battaglia@dot.state.wi.us

During the iron-making process (left), slag is skimmed and discarded. To keep slag from entering the waste stream, the byproduct is used in other applications, such as in building "green" concrete pavement with slag cement (right). (Slag cement photo courtesy of the Portland Cement Association.)

- At a curing temperature of 40 degrees F, these averages jumped to 12 days for 30 percent slag cement and 17 days for 50 percent slag cement, but increased more moderately to seven days for no-slag concrete.
- These curing times are an improvement over the curing times of grade 100 slag cement concrete.
- In terms of the tensile-compressive strength ratio, the difference between regular cement and grade 120 slag was negligible.
- Deicer scaling resistance diminished with increases in slag content. Curing methods and cement brands also affected deicer scaling resistance, but the tested samples generally performed well by international standards.

Benefits

Slag can be an effective "green" cement material in Wisconsin concrete pavements. This research demonstrated that grade 120 slag is viable for use at 30 percent and 50 percent replacement levels in concrete pavement, particularly when poured at temperatures above 40 degrees F.

Implementation

Researchers recommend that WisDOT institute a seasonal restriction on the use of slag cement concrete in pavements. They recommend using grade 120 slag for concrete pavement mixtures, and constructing these pavements between April 15 and October 15 to ensure that temperatures will reliably be above 40 degrees F. If possible, exposure to atmospheric carbon dioxide should be limited at curing.

Further Research

Curing compounds performed poorly with slag cements and with some ordinary cement concretes in this study. Further research may identify the impact of curing compounds on deicer scaling resistance for ordinary and slag cement concretes in various curing conditions as well as the role of compounds in protecting concrete from carbon dioxide exposure.

This brief summarizes Project 0092-05-01, "Effects of Ground Granulated Blast Furnace Slag in Portland Cement Concrete—Expanded Study," produced through the Wisconsin Highway Research Program for the Wisconsin Department of Transportation Research Program, 4802 Sheboygan Ave., Madison, WI 53707.

Nikki Hatch, WisDOT Research and Communication Services

Rigid Pavements TOC Chair

"In warm weather, grade 120 slag cement concrete can be effective and durable for Wisconsin pavements."

–James Parry
WisDOT Bureau of Technical Services
james.parry@dot.state.wi.us

Co-investigators:
Ryan Foley and Steven Cramer, UW–Madison

Brief prepared by CTC & Associates LLC
ctcandassociates.com