# DEICER SCALING RESISTANCE OF CONCRETE PAVEMENTS, BRIDGE DECKS, AND OTHER STRUCTURES CONTAINING SLAG CEMENT

**Pooled Fund Project**

**Problem Statement**
**February 2004**

## PROJECT TITLE

Deicer Scaling Resistance of Concrete Pavements, Bridge Decks, and Other Structures Containing Slag Cement

## PROBLEM STATEMENT

Concrete containing slag generally exhibits excellent long-term strength and durability. However, several authors have expressed concern about the scaling resistance of concrete containing slag, especially when the dosage of slag exceeds 50% of the total cementitious material in the mixture (*1-6*). Much of the concern appears to be based on the results of laboratory scaling tests (most commonly ASTM C672) (*7*), which tend to be in poor agreement with field observations (*2-6, 8-10*). Others indicate that the test performs adequately for evaluating the relative scaling resistance of concrete specimens (*11*). A systematic study is needed to determine why this anomalous relationship exists between the scaling of field and laboratory concrete specimens containing slag.

## PROJECT GOALS

- Document the field performance of existing concrete pavements, bridge decks, and other structures made with slag cement that have been exposed to cyclical freeze-thaw cycles in the presence of deicing chemicals.
- Determine from the field study and construction/design records which mixtures and construction parameters have produced scale-resistant concrete containing slag.
- Determine the effectiveness of ASTM C672 in predicting the deicer scaling behavior of field concrete. If discrepancies are noted, an attempt will be made to explain why the lab tests do not adequately mimic field performance and alternative procedures will be recommended to improve the correlation between lab tests and field performance.

## BACKGROUND

Ground granulated blast-furnace slag (GGBFS), referred to simply as “slag” in this document, has a long history of use with portland cement in concrete. Generally, slag improves many properties of both plastic and hardened concrete. The Transportation Research Board (TRB) Committee on Chemical Additions and Admixtures for Concrete summarizes the impact of slag on the properties of portland cement concrete (PCC) as listed in the table below (*1*). It is apparent that slag can make a significant contribution to the production of durable concrete products.

### Impact of Slag on Important Concrete Properties

| Concrete Property | Impact of Slag |
|---|---|
| Plastic Concrete Properties | |
| Air entrainment | Slag may require a slightly larger amount of air-entraining admixture (0%-20%) to reach a given air content; however, this depends on the fineness of the slag. |
| Water requirement | Slag has little impact on the water demand of concrete. |
| Workability and finishing | Slag improves the workability and finishing of concrete. |
| Bleeding | Slag generally reduces bleeding of concrete. |
| Time of setting | Slag has little influence on the setting time when ambient temperatures are above 80ºF. Below 60ºF special precautions need to be observed to avoid a delay in construction processes. |
| Hardened Concrete Properties | |
| Strength | Slag may reduce the early (1 to 7 days) strength of concrete. However, the longer-term (ultimate) strength is generally increased. |
| Freeze-thaw resistance | Concrete containing slag cement has good freeze-thaw performance; however, scaling may increase. |
| Permeability | Slag, even at modest replacements (25%), greatly reduces the permeability of concrete and improves its resistance to chloride penetration. |
| Alkali-silica reaction (ASR) resistance | Slag decreases the expansion caused by ASR. |
| Sulfate resistance | Slag increases the resistance of concrete to sulfate attack. |
| Temperature rise | Slag reduces the temperature rise in mass concrete when used in sufficient quantities. |

Recent changes to the Iowa Department of Transportation (Iowa DOT) Standard Specifications have had a major positive impact on the constructability of PCC pavements in Iowa. This improved constructability appears to have played an important role in avoiding premature distress and improving the overall durability (service life) of PCC pavements. Much of the improvement has been attributed to the use of better cementitious materials in the concrete mixtures. Slag has played an important role in this reformulation of cementitious materials because it commonly replaces 20%-35% of the portland cement in the mixtures. Iowa DOT engineers have had great success in the field with binary (slag and portland cement) and ternary (slag, portland cement, and Class C fly ash) mixtures containing slag.

## RESEARCH PLAN (PROJECT DESCRIPTION)

The proposed research project will investigate the important variables that impact the scaling resistance of concrete containing slag cement. The project will consist of a field study and a laboratory study. The field study will collect and evaluate concrete samples extracted from pavement slabs. The laboratory study will investigate how specific variables influence the deicer scaling resistance of concrete mixtures.

### Technical Advisory Committee

A technical advisory committee (TAC) will be formed from participating entities (both public section and industry) on the project. The TAC will help formulate specific work plans and will provide guidance and oversight regarding the execution of the research.

It is anticipated at this time that the first TAC meeting will be held on April 13, 2004, in order to facilitate expeditious execution of the research plan. For details, please contact Tom Cackler, PCC Center Director, 515-294-3230, tcackler@iastate.edu.

**Field Study**

The field study will focus on the inspection and testing of selected, well-documented concrete pavements and bridge decks (and possibly one or more vertical structures in splash zones) that contain slag cement. Pavement sites containing ternary mixtures (slag, portland cement, and fly ash) will also be investigated in this study. An attempt will be made to select about 15 field sites that exhibit a wide range of slag replacement levels (about 20%-50%) and have been in service for a wide range of time (about 5-40 years). The scope of the field study will be limited to pavement sites in wet-freeze climates that commonly use deicer chemicals during the winter months.

Appropriate department of transportation (DOT) personnel will be contacted for help in obtaining relevant site information, construction records, traffic control, and extraction of concrete test specimens for the study. It is hoped that full-size field specimens for use in ASTM C672 testing can be extracted from the majority of the field sites. Cooperation between the researchers and personnel from the participating state DOTs is of paramount importance to the success of this project. It is anticipated that the participating DOTs will provide staff and resources for the field inspections and field sampling of concrete.

The objective of the sampling plan will be to obtain an approach that is as statistically valid as is feasible.

Field study tasks:

1. Contact states in wet-freeze regions that have a history of using slag cement in pavement and bridge deck construction. Build a list of potential sites that range in age from 5 to 40 years of age.
2. Select 15 pavement sites that have a good range of scaling performance (i.e., range from those not exhibiting any deterioration characteristics to those that have significant scaling). Conduct a field condition survey on the selected pavement sites. Site selection will require close consultation between the TAC and researchers.
3. Collect mix details, construction details, traffic details, and environmental details.
4. Extract sections and/or cores from pavement and bridge deck sites (two scaling slabs and three to five cores per site, depending on the condition).
5. Perform testing on specimens extracted from good, medium, and poor (if any) performance sites:
    - petrographic analysis, including depth of carbonation and water/cement ratio
    - evaluation of air void parameters and chemistry of near-surface region
    - measure chloride profile of near-surface region of the specimen
    - compressive strength of the cores

- scaling test (ASTM C672) on specific sites (repeating petrographic work *after* testing)

6. Document results of testing and create a database of site information and physical properties that can be correlated to results of the laboratory study. Prepare an interim report that documents pavement/bridge deck surveys and site selection.

**Laboratory Study**

The laboratory study will be conducted to supplement information obtained in the field study. Laboratory mixes will be used to simulate some of the pavements from the youngest service-life category (pavement ages from about 5 to 10 years of age). Pavements in this service-life category would have been made using materials (portland cement, slag, fly ash) that are reasonably similar to those that are available today. Hence, laboratory concrete mixtures can be made and exposed to environmental conditions that produce various levels of scaling (depending on the severity of the test).

Laboratory study tasks (task numbers continue from field study):

7. Review materials used in the field survey and obtain representative samples of the cementitious materials for use in the laboratory study (if such materials are still available).
8. Review options for the scaling tests and decide on method(s) that will be used for this study.
9. Fabricate lab test specimens for scaling. Cure and test as per method(s) selected in task 8. Strength properties (compressive strength and modulus of rupture) versus time will be measured for each mix.
10. Perform scaling tests on the test specimens.
11. Perform testing on cores extracted from selected test specimens:
    - petrographic analysis
    - evaluation of air void parameters and chemistry of near-surface region of the core
    - chloride permeability (ponding test and rapid chloride permeability [RCP])
12. Correlate lab tests to the database generated in task 5 of the field study. Document results of the entire research project in a final report.

**RESEARCH TEAM**

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Dr. Schlorholtz is a scientist at the Material Analysis and Research Laboratory (MARL) at Iowa State University. He will direct this project and manage the day-to-day activities of the research team. His major research interests are in the area of portland cement, PCC materials, fly ash and coal combustion byproducts, and the characterization of inorganic cement binders. He has actively investigated the physical and chemical properties of supplementary cementitious materials and their influence on the fundamental properties of portland cement pastes, mortars, and concretes. He has also attempted to broaden the use of modern analytical techniques, such as x-ray methods, thermal analysis, and scanning electron microanalytical techniques, for the routine characterization of construction materials.

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Dr. Hooton will direct the laboratory portion of the study. He will also be involved in the field investigations. Dr. Hooton's research background includes previous work on the use of slag in hydraulic cement concrete. Before joining the University of Toronto in 1986, he was a research Engineer at Ontario Hydro's Research Division in Toronto, where he did research on freezing and thawing resistance of concrete. His interests are on the durability of concrete to various aggressive environments, such as chlorides, sulfates, deicer chemical scaling, freezing, and alkali-aggregate attack, and on fluid penetration resistance as well as on the properties and performance of cements and supplementary cementing materials such as slag. He is the author or co-author of over 120 publications, several of which address deicing and freeze-thaw resistance or slag cement.

Dr. Hooton is a fellow of the American Concrete Institute (ACI), American Ceramic Society (ACerS), and American Society for Testing and Materials (ASTM). He is, or has recently been, chair of several standards committees including ASTM C09 on Concrete and Concrete Aggregates, ASTM C09.66 on Resistance to Fluid Penetration, ASTM C01.31 on Volume Change of Cements, and CSA Committee A3000 on Hydraulic Cements. He is a member of ASTM C09.69, which has jurisdiction over ASTM test methods on deicer chemical scaling resistance and freezing and thawing resistance. Dr. Hooton is the editor-in-chief of *Cement, Concrete, and Aggregates* and is on the editorial board of *Cement and Concrete Research*.

## RESEARCH FACILITIES

### PCC Research Lab, Iowa State University

The Portland Cement Concrete Pavement and Materials Research Laboratory (PCC Research Lab) at Iowa State University is supported by the Center for Portland Cement Concrete

Pavement Technology (PCC Center) and the Iowa State University Department of Civil, Construction and Environmental Engineering (CCEE). Housed at the CCEE Department, Room 138 of the Town Engineering Building, the PCC Research Lab has a total working space of approximately 2,300 square feet. The laboratory contains all the equipment needed to batch and cure concrete mixtures.

**MARL, Iowa State University**

The Materials Analysis and Research Laboratory (MARL) is also housed in the CCEE Department at Iowa State University. The lab is equipped with state-of-the-art equipment for low-vacuum scanning microscopy; energy dispersive x-ray spectrometry; image acquisition, processing, and analysis; light microscopy; x-ray diffraction; x-ray fluorescence; and thermal analysis. MARL is conducting several projects regarding the durability of concrete, including research into the characterization of concrete microstructure, the factors that determine it, and the influence of that structure on concrete durability. For the last few years, the Iowa DOT has supported research at MARL examining the pore structure of concrete as it affects its durability. Sample preparation, image acquisition, and image analysis techniques continue to undergo development in order to obtain quick and accurate information about the air-void structure. MARL also contains a pozzolan testing lab that routinely conducts performance tests on supplementary cementitious materials. MARL participates in the Cement and Concrete Reference Laboratory (CCRL) pozzolan proficiency sample testing program and the CCRL laboratory inspection program.

**Concrete Materials Research Laboratories, University of Toronto**

The Concrete Materials Research Laboratories at the University of Toronto are extensive and are equipped to perform a wide range of tests on concrete and concrete materials. Specialized research equipment includes numerous devices for characterization of the pore structure, permeability, and ion diffusion of concrete. There are six water permeameters, including two high-pressure triaxial cells, which are automated, data-logged, and computer interfaced. One cell is available for gas permeability testing. Several types of chloride ion diffusion migration cells are in use as well as AASHTO T277 Rapid Chloride, TP64 Rapid Migration, and various resistivity devices. There are various devices for measuring rates of surface absorption, evaporative transport, and rates of corrosion. A computer-interfaced Mercury intrusion porosimeter and a Quantasorb BET device are used to measure pore size distributions.

Other materials science equipment at the lab includes a computer-interfaced differential thermal, thermal gravimetric, and differential scanning calorimetry unit, an Hitachi S267ON environmental scanning electron microscope with backscatter detector and light-element energy dispersive x-ray analysis, a stereo optical microscope with X-Y stage, pore fluid extraction equipment, flame photometer, and an autotitrator for chloride and hydroxyl ion analysis. Other equipment includes a glove box, 10 drying ovens, two vacuum ovens and pumps, programmable environmental chamber, static freezers, a cycling freeze-thaw cabinet, autogenous, plastic, drying, and restrained shrinkage devices, five data-loggers, resonant frequency and ultrasonic pulse equipment and numerous minor items of equipment. The basement laboratories include 6, 3, and 0.5 cf. (0.20, 0.020, and 0.10 $m^3$) concrete mixers, a cylinder end-grinder, a 800 sf. (25

$m^2$) moist room, ovens, concrete saws, coring equipment and aggregate jaw and disk crushers, precision milling machine for chloride profiling as well as large 100°F (38°C) rooms for storage of accelerated test specimens, and a 50% humidity cabinet. Strength testing is performed using 600, 450, and 100 kip (4000 kN, 2000 kN, and 500 kN) machines. In addition, other concrete materials characterization equipment can be accessed from other departments in the University. This includes x-ray diffraction equipment, scanning-transmission and field-emission electron microscopes, an electron microprobe, and other instrumental techniques for chemical analysis.

The Concrete Materials Laboratories are supported with funding from the Ontario Ministry of Transportation, various government agencies, and industrial companies and organizations such as LaFarge Cement, St. Lawrence Cement, St. Mary's Cement, Lehigh Cement, RMC Materials, Canada Building Materials, Dufferin Concrete, the Slag Cement Association (SCA), the Portland Cement Association (PCA), and the Cement Association of Canada, as well as local consulting and testing companies.

## ESTIMATED PROJECT DURATION

The total project is expected to take 36 months to complete.

## BUDGET AND SPONSORSHIP

### Proposed Project Funding

The total project budget is estimated at $450,000. A partnership for funding this research is proposed between state DOTs, industry, and the FHWA.

### Sponsorship Goals

| | |
|---|---|
| State DOTs* (10 @ $25,000) | $250,000 |
| Slag Cement Association* | $100,000 |
| Federal Highway Administration | $100,000 |
| **Total Budget** | **$450,000** |

*Can be paid in three (3) annual increments.

### Summary of Requirements for Project Sponsors

- Financial support
- TAC participation
- State DOTs are also asked to work with principal investigators and provide pavement specimens for testing.

## DELIVERABLES

The following products will be submitted as indicated:

1. Interim report that summarizes information about the site investigations and the selection process for the field sites (December 2004)
2. Progress reports at the end of each calendar year to inform TAC of project status
3. Final report that documents the results of the entire study (July 2007)

Note: Actual dates for reports will be a function of the start time of the project.

## IMPLEMENTATION

Implementation of the project results will be conducted through presentations at technical meetings (e.g., TRB, ACI, and Midwest Concrete Consortium [$MC^2$] meetings) and/or symposia and in journal papers.

## PROJECT ADMINISTRATION

The Iowa DOT, through the PCC Center at Iowa State University, will serve as the lead state and handle administrative duties for the project. Each participating entity may provide an individual to serve on the technical advisory committee that will provide direction to the project. The TAC will organize the specifics of the cooperative work tasks and oversee the accomplishment of these tasks. The PCC Center, under direction of the TAC, will provide administrative management and be the lead research institution on the project.

## CONTACT FOR FURTHER INFORMATION

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