Wisconsin Highway Research Program

Research Project – Request for Proposals

Problem Title:

Reduction of Minimum Required Weight of Cementitious Materials in WisDOT Concrete Mixes

Background and Problem Statement:

It has been noted that several other upper Midwestern states currently allow concrete pavement mixes with lower cementitious materials content than the minimum of 565 lbs/cy currently required under WisDOT specifications. In most cases the other states lack a rigorous data set which verifies the long term durability of these mixes with lower cementitious materials contents. WisDOT currently has no data based upon local materials to use to identify how far cementitious materials content can be reduced for a pavement mix in a severe freeze/thaw environment without detrimental reduction in long term durability.

Scope:

It is anticipated that there are two tasks in this project. The first is a research and materials collection phase. The second is a laboratory study of representative concrete mixtures with standard and reduced cementitious materials content to determine engineering properties and long term durability.

The first task entails conducting a literature search to determine work done in this area to date in other states and universities and then setting up a testing matrix of representative concrete mixes for the State of Wisconsin. It is anticipated that the following materials and proportioning strategies will be considered as part of the matrix of concrete mixes to be tested:
(It is recognized that a full factorial experiment is probably not possible given the budget available for this project. Researchers should identify any proposed partial factorial design, and provide justification for its selection.)

Materials Sources

Portland Cement Sources: 3 sources with differing chemistry commonly used for PCC Pavement on WisDOT projects (Suggested sources are Lafarge - Alpena, MI; St Mary's - Charlevoix, MI; and Holcim - Clarksville, MO)

Slag Source: 1 source Grade 100 GGBFS

Fly Ash Sources: 2 sources Class C fly ash with differing chemistry
(Suggested: Columbia Plant at Portage & Weston Plant at Wausau)

Air Entraining Admixture: 1 source vinsol resin type for all batches – dosage to be adjusted to achieve 6 +/- 1% air content.

Water Reducer: 1 source low range water reducer for all batches to be used at constant dosage per 100 lbs of cementitious materials in batch

Coarse Aggregate Types: 2 types as follows from WIsDOT approved sources with LA Wear < 35% (AASHTO T96) and Sodium Sulfate soundness < 6% (AASHTO T103).

- 1 Igneous glacial gravel aggregate from northern WI to be matched with fine aggregate from same source
- 1 Crushed dolomite quarried aggregate source from southern WI to be matched with typical southern WI fine aggregate

Mix Proportions

Cementitious Materials Content: Batches with all respective materials combinations with total cementitious materials contents of 565, 517, 470, 423, and 376 lbs/cy

Cementitious materials Combinations: Ordinary Portland cement mixes from each source plus binary mixes with 30% fly ash from each source plus binary mixes with 50% GGBFS.

Aggregate Size and Proportions: Coarse aggregate shall consist of 100% size #1 (AASHTO #67) material. Fine aggregate shall represent 40% of the total aggregate weight in each batch.

Water Content and W/Cm Ratio: Water content shall be adjusted so that the slump for all batches is 3+/- 1 inch. W/Cm ratio shall be reported for each batch.

Testing – Concrete Properties (AASHTO Spec designation)

- Air Content (T152) – 1/batch
- Slump (T119) – 1/batch
- Unit Weight (T121) – 1/batch
- Compressive Strength (T22) – 8/batch (test 2 each at 3, 7, 28, 90 days)
- Splitting Tensile Strength (T198) - 8/batch (test 2 each at 3, 7, 28, 90 days)
- Freeze/Thaw Durability (T161 Method A) – 3 prisms per batch (test 300 cycles in 5% NaCl solution – moist cure 28 days then air cure 28 days)
- Shrinkage (ASTM C157) – 3 prisms per batch (test at 28 days)
- Rapid Chloride Permeability (T277) – 3 specimens per batch (sawed from single cylinder)(moist cure and test at 90 days)

Task 2 of this project will include the mixing of concrete, preparation of test samples, performing the prescribed testing, reporting the results and recommending minimum cementitious material values to be used by the Department for future concrete pavement mixes.

Specific Results, Findings, Tool, etc.

1. Recommended values for revised minimum cementitious materials contents to be used by the Department for future pavement mixes.
2. Recommendations for future work in this area by WisDOT.

Length of ResearchProject and Approximate Cost to Complete

A two year study is proposed with an approximate cost of $115,000.

Urgency and Potential Benefits:

Successful completion of this project will allow for improved economy and efficiency of WisDOT mixes for PCC pavements.

Cementitious materials are the most expensive components of the concrete mixture. If the quantity of these materials in our PCC mixes can be reduced without reducing durability, significant savings will be realized.

Reducing the quantity of cementitious materials in the mix can also result in improved engineering properties in terms of reduced shrinkage and cracking susceptibility. This would reduce the risk of cracking problems for contractors.

Additional Requirements for Implementation:

Review and acceptance by the Department and incorporation into construction specifications and guidelines Phase 2 of this project will include the mixing of concrete, preparation of test samples, performing the prescribed testing, reporting the results and recommending minimum cementitious material values to be used by the Department for future concrete pavement mixes.

Submitted by:

Rigid Pavement TOC
Jim Parry, Chairman

Transportation Literature Search

Research and Library Services
Wisconsin Department of Transportation
wisdotresearch@dot.state.wi.us
library@dot.state.wi.us

Lowering Cementitious Levels in Rigid Pavement Mixtures

Prepared for
Wisconsin Highway Research Program
Rigid Pavements Technical Oversight Committee

January 29, 2007

Transportation Literature Searches are prepared for WisDOT staff and principal investigators to heighten awareness of completed research in areas of current interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) and other academic, engineering and scientific databases as appropriate. Links to online copies of cited literature are noted when available. Hard copies may be obtained through the WisDOT Library at library@dot.state.wi.us or 608-264-8142.

SUMMARY

We found three studies, and two more in progress, that relate to issues of reducing total cementitious materials content in rigid pavement designs. One completed study focuses on water-cementitious materials content, a mixture characteristic related to cementitious materials content levels. The second study deals with the related performance issue of reducing shrinkage cracking, and the third focuses on design methods for reducing these materials in self-consolidating concrete.

The **Research in Progress** studies are of more direct interest. The first focuses on reduction of total cementitious materials content, the second on performance prediction of low cementitious materials mixes.

KEYWORDS

Cementitious, material, content, quantity, low, lower, reduce, reduction, durability, design, vary, variation.

CITATIONS

Title: Effect of *w/cm* and High-Range Water-Reducing Admixture on Formwork Pressure and Thoxotropy of Self-Consolidating Concrete
Author(s): Kamal H. Khayat, Joseph Assaad
Date: May/June 2006
Doc ID/URL: *ACI Materials Journal*, Vol. 103 (3), May/June 2006: 186-193.
http://www.concrete.org/MEMBERS/103-m21.pdf
Description: 8 pp.
Contents: An experimental program was undertaken to evaluate the effect of water-cementitious material ratio (w/cm) and type of high-range water-reducing admixture (HRWRA) on the development of formwork pressure that can be exerted when using self-consolidating concrete (SCC). Pressure variation was monitored using an experimental column measuring 2800 mm in height. The tested mixtures were proportioned with a similar initial slump flow consistency of 650 ± 15 mm. Three w/cm of 0.36, 0.40, and 0.46 and three types of HRWRA (polycarboxylate, polynaphthalene sulphonate, and polymelamine sulphonate) were investigated. Variations in lateral pressure were related to the thixotropy of the concrete. Test results show that the variations in lateral pressure and thixotropy of SCC are significantly affected by the w/cm. Irrespective of the HRWRA type, mixtures proportioned with 0.46 w/cm exhibited greater initial pressure and lower thixotropy compared with mixtures made with a w/cm of 0.40 and 0.36. This is related to the higher water content and lower coarse aggregate volume in concrete proportioned with the higher w/cm, which can lead to a reduction in shear strength properties of the plastic concrete. The rate of pressure drop and increase in thixotropy with time, however, were greater in mixtures made with a higher w/cm. This is attributed to the lower HRWRA demand that can lead to sharper fluidity loss with time. For any given w/cm, the type of HRWRA appears to have a limited effect on initial lateral pressure. Compared with

naphthalene- and melamine-based HRWRA, the use of polycarboxylate-based HRWRA in SCC resulted in lower rate of pressure drop with time. This is reflected by the greater fluidity retention of the mixtures containing the polycarboxylate-based HRWRA. The incorporation of a water-reducing agent in mixtures made with polynaphthalene sulphonate-based HRWRA is shown to increase lateral pressure development of the plastic concrete over time.

Title: Improving Concrete Mixture Designs for Reduced Shrinkage in High Performance Concrete
Author(s): Savita Goel, Paul J. Tikalsky, Andrea J. Schokker
Date: March 2003
Doc ID/URL: FHWA-PA-2002-040-97-04 (81-2); PTI 2003-27. Final Report.
Description: 126 pp.
Contents: High -Performance concrete (HPC) is the concrete designed to produce a durable structure for the specific environmental and structural conditions. In the Commonwealth of Pennsylvania, concrete durability of bridge decks is primarily influenced by deterioration mechanisms such as shrinkage, freeze-thaw, scaling, corrosion of embedded reinforcement bars, compressive strength, and alkali-silica reactivity. This study characterizes HPC mixtures to minimize shrinkage in the bridge decks. A shrinkage prediction model is an important tool for a design engineer, particularly when designing special structures such as very tall buildings, very long-span bridges, cooling towers, etc. This study evaluates shrinkage as per the prediction models Bazant and Baweja, 2000 (B3); Gardner, 2000 (GZ); ACI 209, 1997 (ACI) and Branson to assess their validity for high-performance concrete mixtures containing supplementary cementitious materials, chemical admixtures and low water-to-cementitious materials ratio. The results show that HPC can be economically designed to minimize shrinkage strains for concrete bridge decks. The necessary changes to current practice include the **reduction in total cementitious content**, increased use of ternary cementitious mixtures, rapid initial curing procedures, curing concrete a minimum of 7 days, and maintaining a modest w/cm ratio.

Title: Optimizing self-consilidating concrete with limestone filler by using statistical factorial design methods
Author(s): A. Ghezal, K. H. Khayat
Date: May 2002
Doc ID/URL: *ACI Materials Journal*, Vol. 99 (3), May 2002: 264-272.
Description: 9 pp.
Contents: Self-consolidating concrete (SCC) is typically proportioned with relatively high contents of cementitious materials and chemical admixtures, leading to relatively high material costs. Such costs can be tolerated in high-value-added applications, especially if cost savings can be realized from using SCC. However, efforts are still needed to reduce material costs for SCC to gain wider acceptance in a variety of applications. In addition to proper material selection and sound mixture proportioning, incorporation of readily available fillers can enable **reduction in cement and admixture contents**, leading to savings in costs. This paper presents results from an experimental program in which response surface methods were employed to optimize a 4-component concrete containing limestone filler subject to 8 performance criteria.

RESEARCH IN PROGRESS

Title: Economical Concrete Mix Designs Utilizing Blended Cements, Performance Based Specifications, and Rational Pay Factors
Principal Investigator(s): n/a; Christ G. Dimitroplos, Project Manager, 602.712.7850, cdimitroplos@azdot.gov
Start Date: 10/1/2006
RIP URL: http://rip.trb.org/browse/dproject.asp?n=12494
Sponsor Organization: Arizona Department of Transportation
Contents: There is a need to contain the escalating costs of construction projects through the use of economical concrete materials and rational acceptance criteria. This is a proposal to increase competitiveness among project bidders by improving the procedures for materials selection, specifications, and also pay factors for contract administration. A preliminary study conducted for joint ADOT/ARPA committee has indicated that there are significant potential cost savings through the **reduction of minimum specified cement content** in various grades of concrete. Such reductions however must be accomplished so that the performance of final product is not jeopardized. This project will utilize and evaluate recent advances in performance enhancing mineral admixtures and supplementary cementitious materials, in addition to QC parameters used for specification and acceptance criteria in order to develop economical concrete mixtures. This project will promote better quality and economics of using concrete materials by focusing on the: (1) mix design formulation based on economy, superior performance, quality control, and durability; (2) better utilization of mineral admixtures such as fly ash through reducing the minimum cement requirements for 2500 psi and 3000 psi concrete mixtures; and (3) evaluation of the acceptance criteria and

pay factor adjustment methods based on a bonus/penalty factors in improving quality control and specification procedures.

Title: Using Cement Paste Rheology to Predict Concrete Mix Design Problems
Principal Investigator(s): Anol Mukhopadhyay, Texas Transportation Institute, 979-845-1713
Start Date: 9/1/2006
RIP URL: http://rip.trb.org/browse/dproject.asp?n=12161
Sponsor Organization: Texas Department of Transportation
Contents: The current Texas Department of Transportation (TxDOT) specification Item 421 recommends using low water-to-cementitious material ratio, **low total cementitious material content** and encourages judicious use of supplementary cementitious materials (SCMs), chemical admixtures and cements with low C3A and soluble alkali for better workable and durable paving concrete. However, complex interaction between C3A contents, sulfate contents in pore solution, SCMs and chemical admixtures sometimes creates poor cement-admixture compatibility and can give rise to inadequate early workability or premature loss of workability along with setting time and heat evolution abnormalities. Therefore, it is necessary to identify those incompatibilities before the actual placement in order to avoid the problems in the placing and curing process. It is anticipated that cement paste (cement + SCMs + chemical admixtures) rheology measurements could be a good indicator to identify those incompatibilities. Therefore, the purpose of this research project is to develop an easy to use, relatively inexpensive field laboratory test and equipment to predict potential concrete mixture incompatibilities between the sulfate system, mineral and chemical admixtures through the direct measurement of cement paste rheology. The research team proposes the dynamic shear rheometer (DSR) and Brookfield type rotational viscometer as a potential candidate test methods to measure cement paste rheology. A preliminary investigation on measuring viscosity of cement grout using rotational viscometer is very promising. The work will be performed through (i) detailed laboratory investigation with powerful design of experiments, and (ii) field validation and establishing acceptance criteria.