The PEM Concept and Initiative

- A partnership of agency and industry to
  - Understand what makes concrete “good”
  - Specify the critical properties and test for them
  - Design the paving mixtures to meet those specifications

Performance Engineered Mixtures (PEM) Testing in Wisconsin

Kevin W. McMullen, P.E.
President
Wisconsin Concrete Pavement Association

Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

AASHTO Designation: PP 64.17
Tech Section: 3c, Hardened Concrete
Release: Group 1 (April 2017)

INTRODUCTION

Specifications for concrete pavement mixtures have traditionally been prescriptive, with state highway agencies (SHA) specifying means and methods for both constituent selection and specific requirements for proportioning. This places the majority of the performance risk on the SHA and limits innovation. Recent trends of allowing innovative materials, relaxing production control, using modern admixtures and additives, and developing or adopting new performance measures have increased the need to develop and adopt new specifications for concrete pavement mixtures. These new methods of evaluating concrete performance have been developed, and others are being formulated, that can result in improved performance and economics. Shifting the responsibility for performance to the contractor provides an opportunity for innovation.
Performance Engineered Mixtures in Wisconsin

- More than a National priority, we have made it a state priority
- FHWA Pooled Fund Study – WisDOT and WCPA are both participating and funding.
- Our Joint Concrete Pavement Technical Committee is in the lead
  - We are getting beyond the decades old practice of blue book mixes, ACI 211 and tests of air, strength and slump.
  - WisDOT and contractors are supporting the emphasis on durability and performance based specifications
- Wisconsin Highway Research Program project to verify what we are doing

PEM Research in Wisconsin


Aggregate Quality and Stability

OUR FIRST PRIORITY
Optimized Aggregate Gradation and Concrete Mixtures

- National Research
- Tarantula Curve – Dr. Tyler Ley, OSU
- Promoted by NCPTC
- WisDOT and WCPA jointly developed the Standard special provisions (STSP) and specifications for WisDOT work
- Used on some construction projects in 2017 and has been incorporated into all concrete pavement projects by STSP since 2018.

The TARANTULA curve!!!!

Optimized Aggregate Gradation and Concrete Mixtures

- The GOALS
  - Stronger
  - More durable
  - Less permeable more dense concrete
  - Easier consolidated/workability
  - Improved ride

<table>
<thead>
<tr>
<th>TABLE 1  TARANTULA CURVE GRADATION BAND</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIEVE SIZES</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>2 in.</td>
</tr>
<tr>
<td>1 1/2 in.</td>
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<tr>
<td>1 in.</td>
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<td>3/4 in.</td>
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<tr>
<td>1/2 in.</td>
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<tr>
<td>3/8 in.</td>
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<tr>
<td>No. 4</td>
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<tr>
<td>No. 8**/</td>
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<tr>
<td>No. 16**/</td>
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<td>No. 50**/</td>
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<tr>
<td>No. 100**/</td>
</tr>
<tr>
<td>No. 200**/</td>
</tr>
</tbody>
</table>

[**] Minimum of 15% retained on the sum of the #8, #16, and #30 sieves. Conform to 24-34% retained of fine sand on the #30-200 sieves.
Optimized Aggregate Gradation Spec

**TABLE 2 JMF WORKING RANGE**

<table>
<thead>
<tr>
<th>SIEVE SIZES</th>
<th>WORKING RANGE (PERCENT)</th>
</tr>
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<tbody>
<tr>
<td>2 in.</td>
<td>±5</td>
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<tr>
<td>1 1/2 in.</td>
<td>±5</td>
</tr>
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<tr>
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<td>±5</td>
</tr>
<tr>
<td>No. 8</td>
<td>≤4</td>
</tr>
<tr>
<td>No. 16</td>
<td>±6</td>
</tr>
<tr>
<td>No. 30</td>
<td>±5</td>
</tr>
<tr>
<td>No. 100</td>
<td>≤2</td>
</tr>
<tr>
<td>No. 200</td>
<td>≤2.3</td>
</tr>
</tbody>
</table>

*Working range limits of composite gradation based on moving average of 4 tests.*

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

**PART 1**

- Defines optimized gradation
- Outlines spec and testing requirements
- Contractor eligible for 3% incentive
- Sample on the belt leading to the weigh hopper
- Or, working face of the stockpile
- Test each component aggregate once per 1,500 CY of concrete production
- Moving average of four tests

What does the research project say?

![Graphs showing optimized mix designs](image)

**Concrete Pavement Mixture Design and Analysis (MDA): An Innovative Approach To Proportioning Concrete Mixtures**

**Technical Report**

March 2015

Sponsored by:
- Iowa State University
- National Concrete Pavement Technology Center

IOWA STATE UNIVERSITY
WisDOT Optimized Aggregate Gradation and Mixture Design STSP

PART 2

• Once aggregate gradation is optimized contractor can elect to go to mixture optimization
• Can reduce cementitious content to 520 lbs/CY.
• Utilizes new national design procedure
• Up to 30% replacement with fly ash, slag or combination
• Need to include the departments Flexural Strength for Mix Design STSP or the Concrete Pavement Flexural Strength SPV

1. Utilizes mix design procedure and spreadsheet developed by the National Concrete Pavement Technology Center
2. Utilize the spreadsheet to obtain an aggregate gradation system that fits within the Tarantula Curve and is relatively close to the power 45 curve.
3. Determine the volume of voids in the selected aggregate gradation system.
   a) Run ASTM C29 Specific Gravity on the proposed proportions of each aggregate.
4. Select the paste parameters; binder type, percentages, air content, w/cm.
5. Select an initial \( V_{\text{paste}} / V_{\text{voids}} \) value (1.25 – 2.00).

6. Calculate the paste content utilizing the spreadsheet. WisDOT requires a minimum cement content of 520 lbs so the \( V_{\text{paste}} / V_{\text{voids}} \) value may need to be adjusted to meet this minimum cement content
7. Prepare trial batches and assess fresh properties and workability.
8. Prepare final trial batch and assess hardened properties.

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

Workability
Assess Workability

- Box Test
- V Kelly Ball

From the research project

<table>
<thead>
<tr>
<th>Over 50% overall surface voids.</th>
<th>30-50% overall surface voids.</th>
</tr>
</thead>
<tbody>
<tr>
<td>![image]</td>
<td>![image]</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>10-30% overall surface voids.</th>
<th>Less than 10% overall surface voids.</th>
</tr>
</thead>
<tbody>
<tr>
<td>![image]</td>
<td>![image]</td>
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</table>
ASR Testing

- First time incorporated into the standard specifications

501.2.5.4.4 Alkali Silica Reactivity Testing and Mitigation Requirements

1. If using coarse aggregate from sources containing significant amounts of fine-grained granitic rocks including felsic-volcanics, felsic-metavolcanics, rhyolite, diorite, gneiss, or quartzite, test coarse aggregate according to ASTM C1260 for alkali silica reactivity. Gravel aggregates are exempt from this requirement.

2. If ASTM C1260 tests indicate a 14-day expansion of 0.15 percent or greater, perform additional testing according to ASTM C1567. Test mortar bars made with coarse aggregate and the blend of cementitious materials proposed for concrete placed under the contract. The department will reject the aggregate if ASTM C1567 tests confirm mortar bar expansion of 0.15 percent or greater at 14 days.

WisDOT Optimized Aggregate Gradation and Mixture Design STSP

- WisDOT Spreadsheet
- Originally developed at National Center for Concrete Pavement Technology
- Adapted for WisDOT use
- STSP requires use and submittal of this spreadsheet for approval

New Aggregate System
**Flexural Strength**

- WisDOT basis for design is flexural strength in AASHTO pavement design procedure.
- Makes sense to assure we are achieving what was designed for.

**Special Provision Flexural Strength**

Maximum resistance of a concrete specimen to bending.
- 6-inch x 6-inch x 21-inch concrete beams
- Third-point loading in accordance with AASHTO T 97.

**Flexural Strength**

- Two SPV’s
  - SPV for mix qualification
  - SPV for strength acceptance
- Incentive/disincentive pay model for flexural strength is based on data from pilot projects over the last decade.

**Flexural Strength**

- [http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/qmp/default.aspx](http://wisconsindot.gov/Pages/doing-bus/eng-consultants/cnslt-rsrces/qmp/default.aspx)
- Requires design of a mix using flexural strength
- Replaces all 28-day compressive strengths with flexural strengths
- New pay equations
Flexural Strength Challenges

- Molds
- Equipment – breakers
- Curing facilities to assure QC and QV are cured equally
- Sensitivity of flexural beams
- Risk Management (beam and mold can weigh as much as 110 pounds)

Flexural Strength Moving Forward

- Limited use
- Interstate/freeway only type projects
- Greater than 20,000 square yards
- Coordination with central office

From the research project:

FREEZE THAW RESISTANCE

![Graph showing compressive strength vs. 28-day modulus of rupture.](image)
SUPER AIR METER (SAM)

- Incorporated into specifications in December 2017
- Requires doing SAM during Mix Design (715.2.3.1)
- Requires SAM test once per lot during concrete paving (715.3.1.1)
- Shadow specification to begin building database of where WI mixes are
- Does not impact acceptance
- Timeline to move to acceptance in 2021?
- WisDOT moving to structure specifications. Shadow testing begins in 2020

2021 SAM spec?

- 2 years of shadow specification
- 587 data points
- 72.7% <= 0.2
- 19.4% >0.2 and <=0.25
- 2.9% >0.25 and <=0.3
- 4.9% >0.3

Acceptance Specifications

- Draft Specs:
  - 0.2 – Accept
  - >0.2 to 0.25 – Corrective action.
  - >0.25 to 0.3 – Remain in place, consider price reduction.
  - >0.3 – Remove and Replace.
  - A minimum of 4% air would also be required.

From the research project:

- Figure 12: air content changes throughout production and placement from the plant to before and after the pour.
- Figure 13: SAM value changes throughout production and placement from the plant to before and after the pour.
TRANSPORT PROPERTIES (the next priority)

Electric Resistivity
- Durability measurement
- Correlates very well with Rapid Chloride Permeability.
- RPC 28-day test
- This can be used on any cylinder or concrete.

Formation Factor
- Resistivity
  - Store a cylinder in a fixed salt solution
  - Pull out at desired age
  - Read and put back
  - Repeat
  - Calculate formation factor (x10)

  \[ F = \frac{\text{Resistivity (bulk)}}{\text{Resistivity (solution)}} \]

From the research project:
After that?

- Resistance to deicing salt attack?
  - Calcium Oxychloride test
  - SCM use

- Shrinkage (the last piece of the puzzle)
  - Is this impacting pavement performance?

Shrinkage

- Paste content (read the batch sheet)
  - Easy
  - Fast

Shrinkage Discussion
To Date With WisDOT

- Pavements
  - Low priority
  - Short joint spacing
  - Early cracking not a performance problem/concern

- Structures
  - Higher priority
  - Reduction in bridge deck cracking is a high priority

QUESTIONS?

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