PEM Implementation Data in Iowa

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What is PEM?

- AASHTO Provisional Standard PP84
- Performance Engineered Mixtures (PEM)
- Identify critical mix properties for long term durability in environment
- Measure these properties—New Tests
- Develop specifications and limits
- Pooled Fund Research Project
  - 18 states, FHWA, Industry
PEM – Critical Parameters

- Cold weather resistance (cold locations)
  - SAM Air Meter, LTDSC- Salt Resistance
- Transport properties/permeability (everywhere)
  - Resistivity/Formation Factor
- Aggregate stability (everywhere)
  - ASR/D-Cracking
- Workability (everywhere)
  - Box Test/V-Kelly
- Strength (everywhere)
  - Flexural or Compressive
- Shrinkage (dry locations)
  - Ring Test
PEM Pooled Fund Research Project

- Shadow projects
- Investigate ruggedness of test methods
- Develop specification limits
- Collect data for modelling
- Contractor QC Testing
Iowa PEM Shadow Project

- US 20 Woodbury Co.
- Contractor Comprehensive QC Plan
  - Control Charts
  - Air PWL
- SAM Test
- Box Test
- Resistivity/Formation Factor
- Calcium Oxy Chloride Potential
- Trial batch mix design reduced cement
Super Air Meter

- Test at 14.5, 30 & 45 psi
  - Release and repeat
- Report air content and SAM number (Spacing Factor)
- SAM number correlates with freeze thaw testing
Plastic Air Content Standard vs SAM

- **Graph Title**: Plastic Air Content Standard vs SAM
- **Axes**:
  - **Y-axis**: SAM Air Meter
  - **X-axis**: Standard Air Meter

- **Data Points**: The graph shows a scatter plot with data points plotted on the graph. The points are scattered along a trend line, indicating a positive correlation between the SAM Air Meter and the Standard Air Meter.

- **Trend Lines**: The graph includes two trend lines, one solid and one dotted, indicating the relationship between the two variables.

- **Range**: The range for both axes is from 5.0 to 11.0.
Workability

- **Slump Test**
  - Uniformity Test
  - Nothing about response to vibration
- **Box Test & V-Kelly Test**
  - Gives Info on Response to Vibration
- **Factors in Workability**
  - Aggregate Gradation
  - Paste Content
  - Admixtures
Workability - VKelly

• Fill Container
• Ball weight only to depth
• Ball vibration
  • Record Depth every 6 seconds
• Remix and repeat twice
• Avg. depth vs. sq. root of time
• Effect of Aggregate system

Good!

Not so good!
Workability - Box Test

• Fill box to 9.5 inches
• Insert vibrator 12,500 vpms
  • 3 seconds to bottom
  • 3 seconds out
• The edges of the box are then removed and inspected for honeycombing and edge slump

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Less than 10% overall surface voids.</td>
<td>10-30% overall surface voids.</td>
<td>30-50% overall surface voids.</td>
<td>Over 50% overall surface voids.</td>
</tr>
</tbody>
</table>
Combined Aggregate Gradation

Average Project Workability Factor VS Coarseness Factor

Coarseness Factor (percent)

Workability (percent)

III

IV

II

I

V

Boundary Line
Combined Aggregate Gradation

Tarantula Curve Combined Aggregate Gradation, % Retained
Transport Properties - Resistivity

- Cast Two Cylinders
- Place in bucket with (Ca, Na, K) hydroxide solution
- Test Resistivity at 3, 7, 28, 56 and 91 days
Transport Properties – Formation Factor

US 20 Test Results

• Resistivity Low Range
  • 18-20 k-ohm-cm
• Formation Factor Moderate to Low range
  • 957

Table X2.1—Relationship between T 277 (ASTM C1202) Results, Resistivity, and the F Factor, Assuming a Pore Solution Resistivity of 0.1 Ω · m (based on Spragg et al., 2012)

<table>
<thead>
<tr>
<th>ASTM C1202 Classification</th>
<th>Charge Passed (Coulombs)</th>
<th>Resistivity (kΩ · cm)</th>
<th>Formation Factor</th>
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</thead>
<tbody>
<tr>
<td>High</td>
<td>&gt;4,000</td>
<td>&lt;5.2</td>
<td>520</td>
</tr>
<tr>
<td>Moderate</td>
<td>2,000–4,000</td>
<td>5.2–10.4</td>
<td>520–1,040</td>
</tr>
<tr>
<td>Low</td>
<td>1,000–2,000</td>
<td>10.4–20.8</td>
<td>1,040–2,080</td>
</tr>
<tr>
<td>Very low</td>
<td>100–1,000</td>
<td>20.8–207</td>
<td>2,080–20,700</td>
</tr>
<tr>
<td>Negligible</td>
<td>&lt;100</td>
<td>&gt;207</td>
<td>20,700</td>
</tr>
</tbody>
</table>

* Calculated using first principles.
Transport Properties - Resistivity

![Graph showing resistivity over days](image-url)
Calcium Oxychloride Potential

- Salts can cause chemical attack
  - Reaction between Ca(OH)$_2$ and CaCl$_2$ or MgCl$_2$ expands ~30% and will form above 32F

- Low temperature differential scanning calorimetry (LT-DSC)
  - 10 gms hydrated paste ground to minus #200
  - Mix with 10 mg 20% CaCl2 solution and seal
  - Place in LT-DSC - low temperature cycling

- Reduce potential with use of SCM’s
Calcium Oxychloride Potential

- Limiting the CaOXY formation to values lower than 0.15 (g/100g) reduces oxychloride formation
- 20% Class C fly ash replacement met the limit
- Higher percentage slag/ fly ash replacements will lower results further
### PEM Mix Design w Lower Cement Content

<table>
<thead>
<tr>
<th>PEM Mix</th>
<th>Abs. Vol.</th>
<th>lbs/CY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENT:</td>
<td>0.078</td>
<td>412</td>
</tr>
<tr>
<td>FLY ASH:</td>
<td>0.024</td>
<td>103</td>
</tr>
<tr>
<td>WATER: w/c=0.40</td>
<td>0.122</td>
<td>206</td>
</tr>
<tr>
<td>FINE AGGREGATE (44%):</td>
<td>0.315</td>
<td>1401</td>
</tr>
<tr>
<td>COARSE AGGREGATE (44%):</td>
<td>0.315</td>
<td>1422</td>
</tr>
<tr>
<td>INTERMEDIATE AGG. (12%):</td>
<td>0.086</td>
<td>387</td>
</tr>
<tr>
<td>AIR:</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Paste Content, %</td>
<td></td>
<td>22.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A Mix</th>
<th>Abs. Vol.</th>
<th>lbs/CY</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEMENT:</td>
<td>0.083</td>
<td>440</td>
</tr>
<tr>
<td>FLY ASH:</td>
<td>0.025</td>
<td>110</td>
</tr>
<tr>
<td>WATER: w/c=0.474</td>
<td>0.155</td>
<td>261</td>
</tr>
<tr>
<td>FINE AGGREGATE (45%):</td>
<td>0.305</td>
<td>1357</td>
</tr>
<tr>
<td>COARSE AGGREGATE (55%):</td>
<td>0.372</td>
<td>1680</td>
</tr>
<tr>
<td>INTERMEDIATE AGG.:</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>AIR:</td>
<td>0.06</td>
<td>0</td>
</tr>
<tr>
<td>Paste Content, %</td>
<td>26.3</td>
<td></td>
</tr>
</tbody>
</table>

Dr. Peter Taylor estimated cement content based on dry rodded unit weight of combined aggregate.
PEM Mix Design

• Contractor had concerns lowering cement content of standard A mix for shoulder
• Performed trial batch
  • Box Test
• Placement went very well
• Wished they had a chance to try on mainline
PEM Mix Design
FHWA Mobile Lab PEM Open House
What We Learned

Iowa DOT Current Practices QMC

- Strength – avg 640 PSI Flexural
- Volume of Paste = 24.3%
- w/c Ratio = 0.42 max.
- Air Content 6 to 10%
  - SAM Results all below 0.30
- Calcium Oxychloride Limit =0.15 g/100g
- Formation Factor ~1000 w 20% C ash
- Aggregates – Iowa DOT Methods
  - Combined Aggregate Grading
Where are we going?

- Iowa QMC Paving fairly close to PEM Requirements
  - Ternary mixes & Combined Gradation
- Now have 6 SAM Air Meters
  - PC Techs monitor tests & compare with hardened air
- Resistivity
  - Monitor
- Contractor Mixes at Reduced Cement Content
  - Box Test or V-Kelly to approve

For More Information

https://cptechcenter.org/performance-engineered-mixtures-pem/
Questions?

Special Thanks to

Cedar Valley Corp., LLC

ICPA - Iowa Concrete Paving Association