WisDOT Non-Cementitious Repair Materials Study

Prashant Ram
Applied Pavement Technology, Inc.

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Study Objectives

- Develop recommendations regarding proper selection and application of non-cementitious repair materials for concrete pavements
  - Evaluate availability and applicability of non-cementitious materials
  - Evaluate performance of installed non-cementitious repairs
  - Develop recommendations for WisDOT specs and manuals
Project Team

- **Applied Pavement Technology, Inc. (APTech)**
  - Prashant Ram: PI
  - Kurt Smith: Co-PI

- **Consultants:**
  - Dr. Tom Van Dam (NCE)
  - Dr. Larry Sutter

- **Lab Testing: Purdue University**
  - Dr. Jan Olek and Dr. Ayesha Shah
Presentation Outline

- Literature review summary
- Field condition evaluation
- Laboratory testing
- Conclusions
- Recommendations
OH, YOU'RE DOING A LITERATURE REVIEW?

THAT MUST BE REALLY INTERESTING

Literature Review Summary
Non-cementitious materials not as commonly used as cement-based materials

Some agencies have developed limited specifications for acceptance and testing

General properties of non-cementitious materials:
- Low elastic modulus
- High CTE
- High initial shrinkage
- Opening-to-traffic time depends on material composition, generally <6 hours
No discernible relationship between testing temperature and shrinkage, bond strength

Future rehab activities should be given due consideration:

» Bonding issues with concrete overlay
» Diamond grinding issues

Repair performance heavily depends on condition of existing concrete pavement
Field Condition Evaluation of Repairs
<table>
<thead>
<tr>
<th>Repair Material</th>
<th>Material Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>RM-1 (Field)</td>
<td>Hot-applied flexible material formulated with polymer modified resins, fiberglass, mineral fillers, and high-quality aggregates</td>
</tr>
<tr>
<td>RM-2 (Lab, Field)</td>
<td>Polyester polymer concrete</td>
</tr>
<tr>
<td>RM-3 (Field)</td>
<td>Hot-applied polymer modified asphalt repair mastic</td>
</tr>
<tr>
<td>RM-4 (Lab, Field)</td>
<td>Hot-applied polymer-modified synthetic resin with fibers, fillers, fines, and high-quality aggregate</td>
</tr>
<tr>
<td>RM-5 (Lab, Field)</td>
<td>Hot-applied polymer modified asphalt with engineered aggregates and modifiers</td>
</tr>
</tbody>
</table>
Field Condition Evaluation

- Traffic control arrangements coordinated by WisDOT
- Visual investigation: subjective condition evaluation of repair patches and surrounding concrete pavement
- NDT: PSPA Testing
- Coring (2 cores per material)
Total of 23 unique sites visited
# Coring and PSPA Testing Summary

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Core #</th>
<th>Repair Material</th>
<th>Average Ambient Temp, °F (°C)</th>
<th>Coring Summary</th>
<th>PSPA Testing Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Repair Material Thickness (inch)</td>
<td>PCC Thickness (inch)</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>RM-1</td>
<td>87 (31)</td>
<td>2.50</td>
<td>8.50</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>RM-1</td>
<td>88 (31)</td>
<td>2.25</td>
<td>7.75</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>RM-1</td>
<td>83 (28)</td>
<td>3.00</td>
<td>N/A*</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>RM-3</td>
<td>26 (-3)</td>
<td>3.00</td>
<td>N/A*</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>RM-3</td>
<td>13 (-11)</td>
<td>1.50</td>
<td>N/A*</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>RM-4</td>
<td>28 (-2)</td>
<td>2.50</td>
<td>7.25</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>RM-4</td>
<td>12 (-11)</td>
<td>4.0</td>
<td>N/A*</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>RM-5</td>
<td>23 (-5)</td>
<td>3.25</td>
<td>N/A*</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>RM-5</td>
<td>24 (-4)</td>
<td>4.00</td>
<td>N/A*</td>
</tr>
</tbody>
</table>

*Underlying PCC pavement was deteriorated; core could not be extracted

**Average of three readings recorded from one location

*Measurement performed on PCC pavement close to the PDR
RM-1

Hot-applied flexible material formulated with polymer modified resins, fiberglass, mineral fillers, and high-quality aggregates
RM-1 Overview

- 8000 PDRs on the Madison Beltline in 2014 and 2015
- Jan 2016: Several instances of sudden failures
  - WisDOT investigation showed underlying concrete to be in deteriorated condition
- Jan 2018: Another round of failures
- Summer 2018: Removal and replacement of all RM-1 repairs
RM-1 Repairs (1/2)
Considerable amount of substrate concrete material bonded to the bottom of the peeled-off Fibrecrete patch.
RM-1 Cores (1/2)

Substrate concrete still bonded to the Fibrecrete Material
RM-1 Cores (2/2)

- Multiple parallel cracks through the entire depth
- Potentially suggests freeze-thaw-related damage
Coring Issues

Melted binder material accumulating at the bottom of the core
RM-2

Polyester Polymer Concrete
RM-2 Overview

- Not used on PDR applications in Wisconsin
- Used in a few bridge deck overlay projects in the Milwaukee area
  - Overlays typically 0.75-inches thick
  - Used to resurface decks with moderate amounts of cracking and spalling (National Bridge Inventory rating of 5)
RM-2: Issues Noted

- Top 0.25-inches peeling off; isolated to edge
- Potential causes: under-catalyzed binder, moisture in mix aggregates, accumulation of excess moisture
RM-3
Hot-applied polymer modified asphalt repair mastic
RM-3 Overview

- Popular repair material for asphalt pavements
  - Widely used in SE Region
- Limited use on PCC pavements
  - Maintenance personnel noted good performance in joint and spall repairs
  - Mostly used as stop-gap fix
RM-3 Repairs
RM-4

Hot-applied polymer-modified synthetic resin with fibers, fillers, fines, and high-quality aggregate
RM-4 Overview

• Most popular non-cementitious material used in PCC PDR applications
  » Particularly popular in NC and NE Regions
• Also used for bridge deck repairs
• Big marketing presence in Wisconsin
• Material very similar to RM-1 in chemical composition
RM-4 Repairs—Pavement

Site #9, Grafton
Core Location

Site #10, Menomonee Falls

Site #11, Stevens Point
Core Location

Site #12, Marinette

Site #15, Appleton

Site #17, Fond du Lac
RM-4 Repairs—Bridge

Surface map cracking on some bridge deck repairs
RM-5

Hot-applied polymer modified asphalt with engineered aggregates and modifiers
RM-5 Overview

- Only used in experimental demonstrations in Wisconsin at five sites
- Material appears to be similar to RM-3 with larger aggregates
- Mastic formulation also available: “Gap Mastic”
  » Primarily for crack repair applications
RM-5 Repairs
Laboratory Testing
Overview

- Limited testing to study bond and dimensional stability aspects of: RM-2, RM-4, and RM-5
- Primary intent was to evaluate behavior at different testing temperatures
Bond Testing

- Pull-off method (ASTM C1583)
- Testing temperatures:
  - 23 °C, -23 °C, and -10 °C
Bond Testing Issues: RM-4 and RM-5

- Specimen prep issues due to material melting
- Specimen too soft; unable to support loading from testing equipment
- Test largely unsuccessful
# Bond Strength Results

<table>
<thead>
<tr>
<th>Material</th>
<th>Average Pull-off Bond Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23 °C</td>
</tr>
<tr>
<td>RM-2</td>
<td>172*</td>
</tr>
<tr>
<td>RM-4</td>
<td>NR</td>
</tr>
<tr>
<td>RM-5</td>
<td>NR</td>
</tr>
</tbody>
</table>

NR: No Result, test was unsuccessful
*Average value of three specimens tested, failure within repair material at 23 °C and -10 °C
**Only one specimen resulted in a successful test and failure was observed at interface b/w PCC and repair material, bond between specimen and steel disc failed for other specimens tested
#Average value of two specimens tested (219 psi and 99 psi); pull-off test performed from concrete side.
##Only one specimen tested; pull-off test performed from concrete side.
Static Elastic Modulus

- Performed in accordance with ASTM C469
- Testing temperatures:
  - 23 °C, -23 °C, and -10 °C
- Test applicable only for KwikBond:
  - 1.4 million psi at 23 °C
  - 3.3 million psi at -10 °C
  - 3.6 million psi at -23 °C
- Test not suitable for flexible materials like TechCrete and Gap Patch
Dynamic Elastic Modulus

- Performed in accordance with AASHTO T342
- Suitable for materials exhibiting viscoelastic behavior
- Material stiffness varies with time, temperature, loading frequency
- Testing temperatures:
  - RM-2: 37 °C, 21 °C, 4 °C, and -10 °C
  - RM-4, RM-5: 21 °C, 3 °C, -10 °C, and -22 °C
Mastercurves

[Graph showing measured $|E^*|$, MPa, against reduced frequency ($T_{ref} = 10^\circ C$, Hz). The graph includes data points for RM-2, RM-4, RM-5, and HMA.]
**Dynamic Modulus Testing Summary**

- RM-2 at lower temperatures: behavior similar to hot mix asphalt
- All materials become stiffer at lower temperatures, but modulus values still lower than PCC
- RM-4 and RM-5 very sensitive to temperature and loading rate
  - Rutting concerns at very high temperatures
  - Higher flexibility → better ability to withstand thermal stresses at lower temperatures
Ultrasonic Pulse Velocity vs. Temperature and Modulus

- Good correlations between UPV and testing temperature, modulus
Concluding Remarks
Summary (1/2)

- Non-cementitious repair materials typically used to repair heavily distressed areas in Wisconsin: spalled joints, transverse cracks, corner breaks, MRD
- Repair boundaries not demarcated using saw-cuts for vast majority of repairs
- Coring materials was challenge since binder melts and gums up coring drill
  » Diamond grinding concerns
Potential reasons for abrupt failure of some RM-1 PDRs:

- Failure to remove all unsound concrete
- Continued deterioration of substrate
- Inconsistency in site-produced mixes

Materials become stiffer at colder temperatures

- Modulus variations not expected to adversely impact bond between repair material and sound substrate concrete
- Bond failures are very likely for repairs on unsound substrate
Recommendations (1/2)

- Minimize size of repairs ($\leq 4 \text{ ft}^2$), particularly in severely distressed areas
- Remove all unsound concrete
- Surface must be clean and dry, use bonding agent specified by manufacturer
- Strictly adhere to mixing and placement temperature requirements
- Surface of repaired area may be covered with surfacing aggregate per manufacturer guidelines
- Take extra care for hot-applied materials: heat, fumes
Recommendations (2/2)

- Diamond grinding of flexible materials
  - Reducing loading and time of grinding operations to the extent possible
  - Avoid grinding at high ambient temperatures
  - Keep grinding head as cool as possible
- For long-term repairs consider petrographic evaluation of existing concrete to check for materials/durability issues
I've seen these protest signs for years. I don't think they are working.

Prashant Ram
Applied Pavement Technology, Inc.
pram@appliedpavement.com