Moisture Sensitivity of WMA
A Review & Look to the Future

NCHRP 09-49 Performance of WMA
Stage I - Moisture Susceptibility
A. Epps Martin / C. Estakhri

2nd International Warm-Mix Conference
October 12th, 2011
Outline

- Objectives & Research Plan
- Review
  - Literature
  - Agency and Industry Survey
- Future
  - Phase II Work Plan
Objectives

- Assess Effect of WMA Technologies on Moisture Susceptibility
- Develop Guidelines for Identifying and Limiting Moisture Susceptibility in WMA Pavements
Research Plan

PHASE I
Evaluation of WMA Projects
- Task 1. Survey Agencies
- Task 2. Collect & Assess Information
- Task 3. Develop Work Plan
- Task 4. Document Results

PHASE II
Investigation of WMA Moisture Susceptibility
- Task 5. Conduct Experiment
  - 5.1 Reasons & Time Horizon
  - 5.2 Standard Tests & Methods to Minimize
  - 5.3 Specimen Types
- Task 6. Document Results

PHASE III
Guidelines for Minimizing Moisture Susceptibility
- Task 7. Develop Guidelines
- Task 8. Recommended Revisions
- Task 9. Document Results

PHASE IV

Texas Transportation Institute
Research Plan
Phase I – Evaluation of WMA Projects

- DOT’s
- Contractors
- Equipment Manufacturers
- Additive Suppliers
- Internal/External Advisory Groups

**TASK 1.0**
Survey to Identify WMA Pavements

**TASK 2.0**
Information Search & Review

**TASK 3.0**
- PHASE II Work Plan
  - Select Pavements
  - Field Evaluation
  - Laboratory Tests

**TASK 4.0**
Interim Report Panel Meeting
Literature Review

WMA State Usage in 2010

Source: Prowell et al. 2011, Warm-Mix Asphalt: Best Practices
Literature Review

**WMA BENEFITS**
- Decreased
  - Energy consumption
  - Emissions and odors
  - Plant wear
  - Fumes and dust
  - Binder aging
- Increased/Improved
  - Haul distance
  - Construction day/season
  - Compactability
  - Workability
  - Construction conditions

**WMA ISSUES**
- Compaction in the laboratory and the field
- Proper coating of the aggregates with binder
- Conditioning/Curing in the laboratory
- Mix design procedures
- Rutting susceptibility
- Moisture Susceptibility
Literature Review

WMA TECHNOLOGIES

- Foaming
- Additive

MOISTURE MECHANISMS

- Loss of the ADHESIVE bond between the binder or mastic and the aggregates
- Loss of COHESIVE strength in the binder or mastic in the presence of moisture
## Literature Review
### Laboratory Characterization

<table>
<thead>
<tr>
<th>Category</th>
<th>Tests &amp; Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncompacted Loose Mixtures or Component Materials</td>
<td>Boiling Water Test ASTM D3652</td>
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<tr>
<td></td>
<td>Ultrasonic Accelerated Moisture Conditioning (UAMC)</td>
</tr>
<tr>
<td></td>
<td>Net Absorption Test (NAT)</td>
</tr>
<tr>
<td></td>
<td>Surface Free Energy (SFE)</td>
</tr>
<tr>
<td></td>
<td>Bitumen Bond Strength (BBS)</td>
</tr>
<tr>
<td>Comparison of Conditioned and Unconditioned Mixtures</td>
<td>Modified Lottman Test ITS/TSR AASHTO T283</td>
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<tr>
<td></td>
<td>Immersion-Compression Test AASHTO T165</td>
</tr>
<tr>
<td></td>
<td>Energy Ratio (ER)</td>
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<tr>
<td></td>
<td>E*/ECS AASHTO TP 62 &amp; AASHTO TP 34</td>
</tr>
<tr>
<td></td>
<td>Resilient Modulus (M&lt;sub&gt;R&lt;/sub&gt;) ASTM D4123</td>
</tr>
<tr>
<td></td>
<td>Dynamic Mechanical Analyzer (DMA)</td>
</tr>
<tr>
<td>Repetitive Loading in the Presence of Water</td>
<td>Hamburg Wheel-Tracking Test (HWTT) AASHTO T324</td>
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<tr>
<td></td>
<td>Asphalt Pavement Analyzer (APA) AASHTO TP 63</td>
</tr>
<tr>
<td></td>
<td>Model Mobile Load Simulator 3</td>
</tr>
<tr>
<td></td>
<td>Moisture Induced Stress Tester (MIST)</td>
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</tbody>
</table>
Literature Review

Laboratory Characterization

- **Modified Lottman Test**
  - Currently used in the majority of states
  - Able to discriminate mixtures with very different moisture susceptibility

- **Resilient Modulus Test**
  - Non-destructive
  - Measure tensile stiffness
  - Easy to perform, inexpensive

- **Hamburg Wheel-Tracking Test**
  - Good repeatability
  - Improved correlation with field performance
Literature Review

Moisture Susceptibility of WMA

- Incorporation of additional moisture with foaming
- Incomplete aggregate drying during production
- Reduced binder absorption by the aggregates
- Reduced binder-aggregate bond strength with some chemical additives
Literature Review

WMA Mixture Performance

- **Rutting**
  - Mixed results
  - Lime/anti-strip agents improve rutting resistance

- **Moisture susceptibility**
  - WMA more moisture susceptible
  - Improved WMA ITS and TSR values with longer/higher curing time/temperature & field aging
  - Lime/anti-strip agents reduce moisture susceptibility
Literature Review

WMA Mixture Performance

- Incomplete drying of the aggregates
  - Decreased ITS values
  - Function of aggregate type, WMA technology, initial aggregate moisture content, production temperature

- Binder-Aggregate bond strength
  - Reduced adhesion with some chemical additives
  - Function of binder type
Literature Review

WMA Mixture Performance

- Field Performance
  - Equal or better than HMA
  - No sign of premature moisture damage

- Trial project in Kimbolton, OH (2006)
  - Signs of raveling, especially WMA additive section
  - Poor construction practices and lower placement temperatures

- Trial project in Franklin, TN (2007)
  - Raveling on HMA and WMA sections after 1 yr
  - WMA additive affected in shaded areas
  - Poor construction practices, variable densities
Agency and Industry Survey
Web-Based Survey

- **Objective**
  - Identify WMA pavements with moisture damage
- **Contacts**
  - 50 State DOTs (+Washington DC and Puerto Rico)
- **Topics**
  - WMA use and materials
  - Mix design
  - Field performance
  - Upcoming WMA projects
- **Response rate 92% of states**
Agency and Industry Survey

Current Use of WMA

Current Use of WMA:
- Green: Routine Projects
- Yellow: Trial Projects
- Red: Have not used WMA
- Blue: No Response

Map showing the current use of WMA across the United States, with states colored according to the legend.
<table>
<thead>
<tr>
<th>Current Use of WMA</th>
<th>52% Trial Projects</th>
<th>41% Routine Use</th>
<th>7% Not used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity of WMA</td>
<td>35% 2-5 Projects</td>
<td>28% 5-10 Projects</td>
<td>22% Routine</td>
</tr>
<tr>
<td>Preferred Technologies</td>
<td>DBG, Evotherm, Sasobit, Advera, Terex, and AQUABlack</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use of Anti-stripping Additives</td>
<td>52% Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organizational Practice</td>
<td>80% Allow</td>
<td>11% Not Allow</td>
<td>5% Require</td>
</tr>
<tr>
<td>Moisture Susceptibility Testing in Mix Design</td>
<td>69% Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferred Moisture Susceptibility Tests</td>
<td>65% TSR</td>
<td>20% HWTT</td>
<td>15% Others</td>
</tr>
<tr>
<td>Observed Field Pavement Failure or Distress</td>
<td>93% None (Moisture Damage)</td>
<td>5% Compaction Issues</td>
<td>2% Thermal Cracking</td>
</tr>
</tbody>
</table>
Agency and Industry Survey
Phone Interviews

- **Objective**
  - Identify candidate WMA pavements w/HMA control, multiple technologies, environmentally diverse

- **Contacts**
  - 16 State DOTs/Researchers
  - 3 Equipment Manufacturers/Additive Suppliers
  - 6 Contractors

- **Topics**
  - Materials and WMA Technology/Process
  - Mix Design and Location
  - Construction
  - Performance
### Agency and Industry Survey
**Web & Phone Interview Results**

<table>
<thead>
<tr>
<th>Separate WMA Mix Design Specification</th>
<th>Yes (1 State)</th>
<th>None or Under Development (Others)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compaction Issues</strong></td>
<td>Different roller pattern</td>
<td>High densities</td>
</tr>
<tr>
<td><strong>Observed Performance</strong></td>
<td>Thermal cracking during first winter season (1 State)</td>
<td>No observed moisture susceptibility distresses</td>
</tr>
<tr>
<td><strong>Costs</strong></td>
<td>For the state, $WMA = $HMA</td>
<td>For the contractor, $WMA &gt; $HMA due to initial capital investment</td>
</tr>
</tbody>
</table>
PHASE I
Evaluation of WMA Projects
Task 1. Survey Agencies
Task 2. Collect & Assess Information
Task 3. Develop Work Plan
Task 4. Document Results

PHASE II
Investigation of WMA Moisture Susceptibility
Task 5. Conduct Experiment
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PHASE III
Guidelines for Minimizing Moisture Susceptibility
Task 7. Develop Guidelines
Task 8. Recommended Revisions
Task 9. Document Results

PHASE IV
Task 10. Prepare Final Report
Phase II Work Plan

- Select WMA pavements
- Evaluate moisture susceptibility of different specimen types (LMLC, PMLC, PMFC)
- Identify laboratory conditioning/curing protocols before compaction (LMLC, PMLC)
- Evaluate time horizon for WMA (LMLC, PMFC)
- Identify effect of anti stripping agents on WMA moisture susceptibility (LMLC)
- Evaluate effect of free water content on WMA moisture susceptibility (PMLC)
Phase II Work Plan

WMA Pavements Selection

- Iowa (Wet, Freeze)
- Texas (Wet, No-Freeze)
- Montana (Dry, Freeze)
- New Mexico (Dry, No-Freeze)
- Florida (Wet, No-Freeze)

Specimen type evaluation: all 5 Pavements
Conditioning/curing, time horizon, anti stripping agents: IA and TX
Free water content: FL
Phase II Work Plan

WMA Pavements Selection

Environmental Zones

- Wet-Freeze
- Dry-Freeze
- Dry-No Freeze
- Wet-No Freeze
Phase II Work Plan
Moisture Susceptibility Evaluation

- AASHTO T283 Modified Lottman Test (TSR)
  - 1 Freeze-Thaw (F/T) Cycle

- Resilient Modulus Test ($M_R$)

- Hamburg Wheel-Tracking Device (HWTT)
## Phase II Work Plan

### Overall (Specimen Type)

- **LMLC (IA, TX)**
  - As designed (anti strip)
  - Moisture content
  - \( M_R \), TSR, & HWTT
- **PMLC @ TTI (all 5)**
- **PMLC on site (IA, TX, MT, FL-TSR only, NM?)**
- **PMFC (Cores)**
  - Total and accessible AV
  - At construction, after 3-4 months, after 1 yr

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>LMLC</th>
<th>PMLC @ 2 locations</th>
<th>PMFC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M_R )</td>
<td>TSR</td>
<td>HWTT</td>
</tr>
<tr>
<td>WMA 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WMA2</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HMA</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>
Phase II Work Plan

Laboratory Conditioning/Curing Protocol

**Field Mixture**
- **WMA**
- **HMA**

**Laboratory Mixture**

- **Stiffness vs. Log Time (days)**
- **Stiffness vs. Time @ 275°F (hours)**

<table>
<thead>
<tr>
<th>WMA</th>
<th>Log Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 10 100 1000 10000 100000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HMA</th>
<th>Log Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 10 100 1000 10000 100000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time @ 275°F (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 4 6 8 10</td>
</tr>
</tbody>
</table>
Phase II Work Plan
Laboratory Conditioning/Curing Protocol

\( M_R \) tests & N to 7%AV for IA, TX

**LMLC** (as designed) Specimens

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>( 2hr@T_{wc} + 16hr@60 \ C ) +( 2hr@T_{wc} * )</th>
<th>( T_{wc} )</th>
<th>225 F</th>
<th>275 F (135 C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X X X X X X X</td>
</tr>
<tr>
<td>WMA 2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X X X X X X X</td>
</tr>
<tr>
<td>HMA</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

**PMLC** (@ TTI) Specimens

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>( 16hr@60 \ C + 2hr@T_{wc} * )</th>
<th>( T_{wc} )</th>
<th>275 F (135 C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WMA 2</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HMA</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</tbody>
</table>
Phase II Work Plan

Time Horizon

FIRST STEP
- IA, TX
- $M_R$ tests on LMLC
- after selected lab conditioning/curing
- same specimen
  - Aged at 140°F (60°C) for 1w, 2w, 4w, 8w
- time to achieve equivalent stiffness
Phase II Work Plan

Time Horizon

SECOND STEP

- IA, TX
- TSR, HWTT, and \( M_R \) tests on LMLC
- \( t_{\text{equivalent}} \) within \( t_A \) and \( t_B \)
- Aging
  - 5 days @ 185°F (85°C)
  - \( t_A \) & \( t_B \) @ 140°F (60°C)
- Compare to \( M_R \) on PMFC
Phase II Work Plan

Time Horizon

1st Step: $M_R$ tests for IA, TX

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>Selected cond/cure</th>
<th>1 wk @ 60 C</th>
<th>2 wks @ 60 C</th>
<th>4 wks @ 60 C</th>
<th>8 wks @ 60 C</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WMA 2</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HMA</td>
<td>X</td>
<td>X</td>
<td>X</td>
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</table>

2nd Step: TSR, HWTT, and $M_R$ tests for IA, TX

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>5 days @ 185 F (85 C)</th>
<th>$t_A @ 140 F$ (60 C)#</th>
<th>$t_B @ 140 F$ (60 C)#</th>
</tr>
</thead>
<tbody>
<tr>
<td>WMA 1</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>WMA 2</td>
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<tr>
<td>HMA</td>
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<td>X</td>
<td>X</td>
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</tbody>
</table>
Phase II Work Plan

Anti Stripping Agents

- IA, TX
- LMLC specimens
- Common amine-based liquid anti stripping agent

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>As Designed</th>
<th>+ Lime</th>
<th>+ Liquid</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>$M_R$</td>
<td>TSR</td>
<td>$M_R$</td>
</tr>
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<td>WMA</td>
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<td>X</td>
<td>X</td>
</tr>
<tr>
<td>HMA</td>
<td>X</td>
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</table>
## Phase II Work Plan

### Free Water Content Effects (FL, PMLC)

<table>
<thead>
<tr>
<th>Aggregate Type</th>
<th>Rap Content, %</th>
<th>Mixture Type</th>
<th>Water Content, %</th>
<th>$M_R$</th>
<th>TSR</th>
<th>HWTT</th>
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<tbody>
<tr>
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<td>0</td>
<td>2</td>
<td>6</td>
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<td>Granite</td>
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<td>HMA</td>
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<td>35</td>
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<td>WMA</td>
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<td>X</td>
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<td>Limestone</td>
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<td>HMA</td>
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<td>X</td>
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<td>X</td>
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<td></td>
<td>35</td>
<td>HMA</td>
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<td>X</td>
<td>X</td>
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</tr>
<tr>
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<td></td>
<td>WMA</td>
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<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Phase II Work Plan
Analysis and Anticipated Results

Laboratory Conditioning/Curing
  – Recommended protocol

Time Horizon
  – Relationship between stiffness of PMFC cores @ construction and stiffness of LMLC specimens
    • At construction, after 3-4 months and 1 year
  – Continued monitoring of existing WMA pavements exhibiting moisture damage
    • Performance data
    • Coordination with NCHRP 9-47 and 9-49A
Phase II Work Plan

Analysis and Anticipated Results

Effectiveness of Standard Test Methods to Predict and Materials and Methods to minimize moisture susceptibility

- Inclusion/Exclusion of lime & anti stripping agents
- Recommended test

Effect of Specimen Type

- Volumetrics, stiffness, & mixture performance
- Recommendation for acceptance testing
Contacts

- Amy Epps Martin a-eppsmartin@tamu.edu
- Cindy Estakhri c-estakhri@tamu.edu
- Edith Arambula e-arambula@ttimail.tamu.edu
- Jon Epps j-epps@tamu.edu
- Bob Lytton r-lytton@civil.tamu.edu
- Eun Sug Park e-park@ttimail.tamu.edu
- Fan Yin
- Lorena Garcia
QUESTIONS?
Backup

Number of Gyrations Required to Achieve Target Density (Estakhri, 2011)
Backup

Effect of Curing Time on Rut Depth for WMA Cured at 250 F (121 C) (Estakhri, 2011)
Effect of Curing Time on Rut Depth for WMA Cured at 275°F (135°C) (Estakhri, 2011)