Evaluating the Effect of Aging Time and Temperature on the Moisture Characteristics of WMA Mixtures

Warm Mix Asphalt Technical Working Group
May 18th, 2010
NCAT - Auburn, AL

Presented by:
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**Project Objectives**

- Measure the effect of aging time and temperature on the moisture susceptibility of WMA mixtures utilizing:
  - Hamburg Wheel Tracking Device (AASHTO T324)
  - Conditioned/Dry Dynamic Modulus $|E^*|$ Ratio
  - Adhesive Energy Bond Ratio
  - AASHTO T-283

- Measure the effect of WMA technologies on the adhesion characteristics of an asphalt binder to aggregate surface utilizing:
  - Modified pull-off test using the Pneumatic Adhesion Tensile Tester (PATTI)
Experimental Plan

- **Superpave 9.5mm Mixture**
  - Control (No WMA)
  - Add Warm Mix Additives
  - Vary Mixing/Aging Temperatures
    1. Mix: 315°F/Age: 295°F
    2. Mix: 285°F/Age: 265°F
    3. Mix: 255°F/Age: 235°F
  - Vary Aging Time
    2 Hours
    4 Hours
    8 Hours
  - Moisture Susceptibility Testing

- **PG64-22 Binder**
  - 0.25% Advera
  - 1.5% Sasobit
  - 0.5% Evotherm M1
  - 1.0% SonneWarmix (AdRap)

- **Binder Testing**

- **PATTI**
Experimental Plan (cont’d)

Moisture Susceptibility Testing

- Hamburg Wheel Tracking Device
  AASHTO T324
- Conditioned/ Dry Dynamic Modulus |E*| Ratio
- Surface Energy Index
- AASHTO T283

Mixtures Failing Moisture Susceptibility Repeated with Anti-Strip

- Liquid Anti-Strip
- Lime
Internet Survey

- Internet based survey developed to:
  - Assess each state’s experience with Warm Mix Asphalt
  - Identify conditions leading to WMA mixtures failing moisture susceptibility tests in the laboratory
  - Determine if moisture damage related distresses were observed in the field for any WMA mixtures

- Survey sent to 156 state DOT personnel with at least one representative from each of the 50 states.

- Total survey response was 19.2%.
Has Warm Mix Asphalt been used in your state?

![Bar chart showing percentage response]

- Yes: 90%
- No: 10%

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Which WMA Technologies have been used?

- Advera
- AdRap
- Sasobit
- Evotherm
- Rediset
- Low Emission Asphalt
- Aspha-min
- Double Barrel Green System
- Other
Do you have a moisture damage test requirement for mixtures incorporating WMA technologies?

![Bar chart showing responses to the question.]

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Which specific moisture damage test is utilized for WMA mixtures?

- AASHTO T283 "Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage"
- AASHTO T324 "Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)"
- Surface Energy Testing and Analysis
- Other
- Not Answered
Has your state/agency observed any moisture damage related field distress in WMA mixtures?
Does your state/agency have a requirement for how long a WMA mixture is aged (conditioned) prior to compaction in the LAB?
Mixture Design
A 9.5mm mixture was developed in accordance with Superpave specifications as outlined in AASHTO R35.

Design ESALs = 3 to <30 million (N_{des} = 100).

Mixtures developed with PG64-22 binder.

Optimum binder content = 6.2%
## 9.5mm Mixture Design

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>9.5 mm JMF</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>19.0 mm</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>100</td>
<td>100 min.</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>98.6</td>
<td>90-100</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>69.1</td>
<td>90 max.</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>44.0</td>
<td>32-67</td>
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<tr>
<td>1.18 mm</td>
<td>29.8</td>
<td>-</td>
</tr>
<tr>
<td>600 μm</td>
<td>20.5</td>
<td>-</td>
</tr>
<tr>
<td>300 μm</td>
<td>13.5</td>
<td>-</td>
</tr>
<tr>
<td>150 μm</td>
<td>8.4</td>
<td>-</td>
</tr>
<tr>
<td>75 μm</td>
<td>5.5</td>
<td>2-10</td>
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</table>

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# 9.5mm Mixture Design

<table>
<thead>
<tr>
<th></th>
<th>9.5mm Mix Design</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>Percent Binder</td>
<td>6.2%</td>
<td>-</td>
</tr>
<tr>
<td>% Air Voids</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>%VMA</td>
<td>16.8</td>
<td>15.0 min.</td>
</tr>
<tr>
<td>%VFA</td>
<td>77.2</td>
<td>73-76</td>
</tr>
<tr>
<td>Dust-to-Binder Ratio</td>
<td>0.7</td>
<td>0.6-1.2</td>
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</table>

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**Binder Information**

**PG64-22**

- **Mixing Temperature Range:**
  165-161°C (329-322°F)

- **Compaction Temperature Range:**
  156-152°C (313-306°F)
<table>
<thead>
<tr>
<th>Technology</th>
<th>Dose</th>
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<tr>
<td>Advera</td>
<td>0.25% by weight of mixture</td>
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<tr>
<td>Sasobit</td>
<td>1.5% by weight of binder</td>
</tr>
<tr>
<td>Evotherm M1</td>
<td>0.5% by weight of binder</td>
</tr>
<tr>
<td>AD-RAP 390 (SonneWarmix)</td>
<td>1.0% by weight of binder</td>
</tr>
</tbody>
</table>

Note: All additives introduced to the heated binder/aggregates immediately before mixing the specimen.
Two different anti-stripping agents (liquid anti-strip and lime) were used for mixtures failing the HWTD test.

Liquid anti-strip (ArrMaz Ad-Here XL900) was added at a dose of 0.5% by weight of binder.

Lime was added dry at a rate of 1.0% by weight of batched aggregate.

Adding lime dry to the aggregate required a new mixture design which yielded an optimum binder content of 6.0% for the lime mixtures (vs. 6.2% for all other mixtures).
Moisture Susceptibility Testing
Moisture susceptibility testing conducted using the Hamburg Wheel Tracking Device (HWTD).

Testing performed in accordance with AASHTO T324 “Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA).”

Water temperature of 50ºC (122ºF) during testing

30 min soak time at 50ºC prior to testing

Test conducted for 20,000 cycles or until specimens exhibited high amounts of rutting.
HWTD Testing

- Data analyzed to determine the Stripping Inflection Point (SIP).

- SIP gives an indication of the onset of moisture damage (stripping).

- Specimen air voids at 7.0 2.0%.
HWTD Results - Control

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HWTD Results - Evotherm

9.5mm SP 0.5% Evotherm Mixtures

<table>
<thead>
<tr>
<th></th>
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<td>8</td>
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</tr>
</tbody>
</table>

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HWTD RESULTS - AD-RAP

9.5mm SP 1.0% AD-RAP 390 Mixtures

Hamburg Cycles to SIP

Aging Time (hrs)

PASS

PASS

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HWTD Results - M315F/A295F

9.5mm SP Mixtures - Mixed 315F (157C)/Aged 295F (146C)

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HWTD - M285F/A265F 4HRS

9.5mm SP Mixtures - Mixed 285F (141C)/Aged 265F (129C) - 4 Hour Aging

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9.5mm SP Mixtures - Mixed 285F (141C)/Aged 265F (129C) - 8 Hour Aging

- CONTROL
- CONTROL + LA
- CONTROL + LIME
- ADAVERA
- ADAVERA + LA
- SASBIT
- SASBIT + LA
- SASBIT + LIME
- EVOTHERM
- EVOTHERM + LA
- EVOTHERM + LIME
- AD-RAP390
- AD-RAP390 + LA

莞HAMycles to SIP vs Aging Time (hrs)

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HWTD - M255F/A235F 4HRS

9.5mm SP Mixtures - Mixed 255F (124C)/Aged 235F (113C) - 4 Hour Aging

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HWTD - M255F/A235F 8HRS

9.5mm SP Mixtures - Mixed 255F (124C)/Aged 235F (113C) - 8 Hour Aging

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## 4 Hour Aging HWTD - Results

### Table:

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<th>Aging Temperature</th>
<th>No LA</th>
<th>295°F</th>
<th>265°F</th>
<th>235°F</th>
<th>With LA</th>
<th>295°F</th>
<th>265°F</th>
<th>235°F</th>
<th>With Lime</th>
<th>295°F</th>
<th>265°F</th>
<th>235°F</th>
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<tbody>
<tr>
<td>Control</td>
<td></td>
<td>16,500</td>
<td>9,000</td>
<td>7,500</td>
<td>NT</td>
<td>13,700</td>
<td>6,500</td>
<td>NT</td>
<td>15,600</td>
<td>10,500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advera</td>
<td></td>
<td>17,500</td>
<td>5,500</td>
<td>3,400</td>
<td>NT</td>
<td>9,400</td>
<td>4,200</td>
<td>NT</td>
<td>11,200</td>
<td>6,900</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sasobit</td>
<td></td>
<td>20,000</td>
<td>16,800</td>
<td>7,200</td>
<td>NT</td>
<td>17,200</td>
<td>6,500</td>
<td>NT</td>
<td>17,000</td>
<td>9,800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evotherm</td>
<td></td>
<td>20,000</td>
<td>16,900</td>
<td>8,900</td>
<td>NT</td>
<td>12,300</td>
<td>8,800</td>
<td>NT</td>
<td>15,400</td>
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<tr>
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<td>13,400</td>
<td>4,300</td>
<td>NT</td>
<td>15,900</td>
<td>9,800</td>
<td>NT</td>
<td>16,600</td>
<td>7,400</td>
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NT = Not Tested
# 8 Hour Aging HWTD - Results

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<th>Mix Type</th>
<th>Aging Temperature</th>
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<th>265 F</th>
<th>235 F</th>
<th>295 F</th>
<th>265 F</th>
<th>235 F</th>
<th>295 F</th>
<th>265 F</th>
<th>235 F</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>No LA</td>
<td>20,000</td>
<td>16,400</td>
<td>8,800</td>
<td>NT</td>
<td>20,000</td>
<td>16,000</td>
<td>NT</td>
<td>20,000</td>
<td>13,100</td>
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<tr>
<td>Advera</td>
<td>No LA</td>
<td>20,000</td>
<td>10,600</td>
<td>4,600</td>
<td>NT</td>
<td>13,100</td>
<td>7,200</td>
<td>NT</td>
<td>20,000</td>
<td>8,500</td>
</tr>
<tr>
<td>Sasobit</td>
<td>No LA</td>
<td>20,000</td>
<td>20,000</td>
<td>9,100</td>
<td>NT</td>
<td>NT</td>
<td>11,200</td>
<td>NT</td>
<td>NT</td>
<td>15,500</td>
</tr>
<tr>
<td>Evotherm</td>
<td>No LA</td>
<td>20,000</td>
<td>20,000</td>
<td>13,100</td>
<td>NT</td>
<td>NT</td>
<td>10,800</td>
<td>NT</td>
<td>NT</td>
<td>9,500</td>
</tr>
<tr>
<td>AD-RAP</td>
<td>No LA</td>
<td>20,000</td>
<td>20,000</td>
<td>9,100</td>
<td>NT</td>
<td>NT</td>
<td>8,600</td>
<td>NT</td>
<td>NT</td>
<td>10,500</td>
</tr>
</tbody>
</table>

NT = Not Tested

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Proposed Aging Trial
Performed on Advera & SonneWarmix Mixtures - No Anti-Strip

Day 1
- Mixtures mixed at 255°F (124°C)
- Loose mixture aged 4 hours at 235°F (113°C)
- Loose mixture compacted in SGC
- Specimens allowed to cool at room temperature for 6 hours
- Specimens aged at 140°F (60°C) for 14 hours

Day 2
- Specimens allowed to cool to room temperature
- Specimens cut for HWTD testing
- Specimen volumetric properties measured

Day 3
- Specimens tested in the HWTD
## Proposed Aging Trial - Results

<table>
<thead>
<tr>
<th></th>
<th>M315°F/A295°F</th>
<th>M285°F/A265°F</th>
<th>M255°F/A235°F</th>
<th>Proposed Aging</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>16,500</td>
<td>9,000</td>
<td>7,500</td>
<td>Not Tested</td>
</tr>
<tr>
<td>Advera</td>
<td>17,500</td>
<td>5,500</td>
<td>3,400</td>
<td>4,000</td>
</tr>
<tr>
<td>SonneWarmix</td>
<td>16,200</td>
<td>13,400</td>
<td>4,300</td>
<td>4,200</td>
</tr>
</tbody>
</table>

Comparison of 4 hour aging HWTD SIP.
Asphalt Binder Moisture Sensitivity Testing

Bitumen Bond Strength (BBS) Test

University of Wisconsin Madison
Professor Hussain Bahia, Ph.D.
Enad Mahmoud, Ph.D.

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Bitumen Bond Strength (BBS) Test

- Testing conducted by University of Wisconsin-Madison using the Pneumatic Adhesion Tensile Tester (PATTI).

- PATTI is used to evaluate adhesive failures at the binder-aggregate interface and cohesive failures of the binder.

- Procedure originally developed by Youtcheff and Aurilio. Modified procedure includes changes to the pull-out stub and a different surface (aggregate plate).
BBS Testing - PATTI

Picture Courtesy: Enad Mahmoud, Ph.D.- University of Wisconsin-Madison
Figure Courtesy: http://www.engr.wisc.edu/centers/wsmtl/WSMTL-WEB-pg02J-NEWS-Kanitpong.htm

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Bitumen Bond Strength (BBS) Test

- Upward force is applied by the PATTI to the binder specimen though the pull-out stub. The maximum pressure (failure pressure) is recorded.

- Pull-Off Tensile Strength (POTS) is then calculated.
**Binders tested for this project:**
- PG64-22 [Control]
- PG64-22 + 4.0% Advera (0.25% by weight of mix)
- PG64-22 + 1.5% Sasobit
- PG64-22 + 0.5% Evotherm M1
- PG64-22 + 1.0% AD-RAP 390

Each binder was tested “DRY” at 20°C (68°F).

Each binder was tested “WET” after 24 hours of moisture conditioning at 40°C (104°F).

A limestone aggregate plate was used for each test.
BBS Test Results

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Moisture Susceptibility Tests - Ongoing

- **Conditioned/ Dry Dynamic Modulus |E*| Ratio**
  Comparing dry dynamic modulus to moisture conditioned dynamic modulus to give an indication of moisture susceptibility of mixtures.

- **Adhesive Energy Bond Ratio [Surface Energy]**
  Fine portion of the mix is being tested by Texas A&M University.

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Conclusions

- Internet survey of state DOTs indicated that there have been no cases of Warm Mix Asphalt mixtures exhibiting moisture damage related distress in the field.

- Internet survey showed that most state DOTs have moisture susceptibility test requirement for warm mixes.

- The main moisture susceptibility tests being utilized by state DOTs are: AASHTO T283 (TSR), ASTM D4867 (TSR), AASHTO T324 (Hamburg), modified TSR tests, and AASHTO T165 (Immersion Compression Test).
HWTD testing indicated WMA mixtures are sensitive to aging temperature and aging time.

WMA mixtures tested in this study had the best moisture damage performance when aged for 8 hrs at high temperatures.
Acknowledgements

Mike Nichols – Aggregate Industries

Annette Smith - PQ Corporation

Neil Miller - PQ Corporation

Chris Strack – Sonneborn, Inc.

Pat Mitchell – Hudson Liquid Asphalts

Tejash Ghandi - MeadWestvaco Corp

John Shaw - Sasol Wax
Thank you!
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## 2 Hour Aging HWTD - Results

<table>
<thead>
<tr>
<th>Mix Type</th>
<th>No LA</th>
<th>With LA</th>
<th>With Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>295 F</td>
<td>265 F</td>
<td>235 F</td>
</tr>
<tr>
<td>Control</td>
<td>12,600</td>
<td>5,800</td>
<td>4,300</td>
</tr>
<tr>
<td>Advera</td>
<td>9,700</td>
<td>3,100</td>
<td>2,300</td>
</tr>
<tr>
<td>Sasobit</td>
<td>13,700</td>
<td>6,800</td>
<td>3,700</td>
</tr>
<tr>
<td>Evotherm</td>
<td>14,200</td>
<td>7,900</td>
<td>4,500</td>
</tr>
<tr>
<td>AD-RAP</td>
<td>10,300</td>
<td>4,900</td>
<td>2,300</td>
</tr>
</tbody>
</table>

NT = Not Tested