NCHRP 9-49A Project Update: Performance of WMA Technologies: Stage II – Long-term Field Performance

Binder ETG Meeting
Oklahoma City, OK
Sept 15, 2015
Outline

- Objectives & Research Progress
- Preliminary Findings
  - Transverse Cracking
  - Top-down Longitudinal Cracking
  - Rutting & Moisture Susceptibility
  - Material Property Changes Over Time
    - MT I-15 Project
    - TN SR 125 Project
    - IA US 34 Project
- Summary and Future Work
Research Objectives

- To identify the material and engineering properties of WMA pavements that are significant determinants of their long-term field performance, and

- To recommend best practices for the use of WMA technologies.
New (2011 Construction) Pavement Projects

- 5 Projects = 10 HMA-WMA pairs
- 1\textsuperscript{st} round: pre-overlay distress survey, construction monitoring, on-site sample compaction, field cores, and falling weight deflectometer tests
- 2\textsuperscript{nd} round: field cores and distress survey
In-service (as of 2011) Pavement Projects

- 22 field projects + 1 HVS = 40 HMA-WMA pairs
- 1st round: distress survey, field cores and falling weight deflectometer tests
- 2nd round: distress survey
<table>
<thead>
<tr>
<th>Project</th>
<th>MT I-15</th>
<th>TN SR 125</th>
<th>IA US 34</th>
<th>TX FM 973</th>
<th>LA US 61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Year</td>
<td>2011</td>
<td>2011</td>
<td>2011</td>
<td>2011</td>
<td>2012</td>
</tr>
<tr>
<td>Warm Mix</td>
<td>Sasobit, Evotherm DAT, Foaming</td>
<td>Evotherm 3G</td>
<td>Sasobit, Evotherm 3G</td>
<td>Evotherm 3G, Foaming</td>
<td>Sasobit, Evotherm 3G</td>
</tr>
<tr>
<td>Design Thickness, in.</td>
<td>2.5</td>
<td>1.25</td>
<td>1.5</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Traffic</td>
<td>3 million (3,170 AADT, 26.3% truck)</td>
<td>0.39 million (3,470 AADT, 13% truck)</td>
<td>3 million (6,450 AADT, 10.9% truck)</td>
<td>3 million (11,300 AADT, 4.3% truck)</td>
<td>9 million (34,138 ADT, 14% truck)</td>
</tr>
<tr>
<td>Aggregate</td>
<td>Siliceous</td>
<td>Gravel &amp; Sand</td>
<td>Limestone, Quartzite &amp; Sand</td>
<td>Gravel, Limestone &amp; Dolomite</td>
<td>Granite &amp; Limestone</td>
</tr>
<tr>
<td>NMAS, in.</td>
<td>3/4</td>
<td>1/2</td>
<td>1/2</td>
<td>3/4</td>
<td>1/2</td>
</tr>
<tr>
<td>Asphalt Binder</td>
<td>PG 70-28</td>
<td>PG 70-22</td>
<td>PG 58-28</td>
<td>PG 70-22</td>
<td>PG 76-22</td>
</tr>
<tr>
<td>Anti-stripping Agent</td>
<td>Hydrated Lime, 1.4%</td>
<td>AZZ-MAZ, 0.3%</td>
<td>None</td>
<td>None</td>
<td>0.6%</td>
</tr>
<tr>
<td>Polymer-modified</td>
<td>SBS</td>
<td>Yes</td>
<td>None</td>
<td>N/A</td>
<td>SBS</td>
</tr>
<tr>
<td>Asphalt Content, %</td>
<td>4.6</td>
<td>6.0</td>
<td>5.44</td>
<td>5.2</td>
<td>4.7</td>
</tr>
<tr>
<td>$G_{mm}$</td>
<td>HMA (2.458) Sas (2.466) Evo (2.459) Foam (2.453)</td>
<td>HMA (2.352) Evotherm (2.355)</td>
<td>HMA (2.423) Sasobit (2.428) Evotherm (2.429)</td>
<td>HMA (2.406) Evotherm (2.405) Foaming (2.420)</td>
<td>HMA (2.464) Sasobit (2.468) Evotherm(2.464)</td>
</tr>
<tr>
<td>RAP or RAS</td>
<td>None</td>
<td>10% RAP</td>
<td>17% RAP</td>
<td>None</td>
<td>15% RAP</td>
</tr>
<tr>
<td>Structure</td>
<td>2.5&quot; overlay + 7&quot; existing HMA + 16.2&quot; base (non-stabilized) + infinite subgrade</td>
<td>1.25&quot; overlay + 8&quot; bituminous base + 6&quot; min. aggregate base + infinite subgrade</td>
<td>HMA &amp; Sasobit: 1.5&quot;overlay + 5&quot; existing HMA + 7&quot; PCC + subgrade Evotherm: 1.5&quot; overlay + 3&quot; existing HMA + 9&quot; PCC + subgrade</td>
<td>2&quot; overlay + 8&quot; existing HMA + 10&quot; base + 141.1&quot; subgrade (lean clay)</td>
<td>2&quot; overlay + 8&quot; existing HMA + 8&quot; PCC + 6&quot; cement treated soil subgrade</td>
</tr>
</tbody>
</table>
## Mixture Test Summary

<table>
<thead>
<tr>
<th>Mixture Test</th>
<th>IDT Dynamic Modulus/Creep Compliance</th>
<th>Fatigue- IDT Fracture at Room Temp</th>
<th>Thermal Cracking- IDT Fracture at Low Temp</th>
<th>Rutting/Moisture - Hamburg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Conditions</td>
<td>Temp.: −4, 14, 32, 50, 68, 86ºF; Frequency: 20, 10, 5, 1, 0.1, 0.01 Hz Duration: 100 seconds</td>
<td>Temp.: 68ºF Loading rate: 2 in./min</td>
<td>Temp.: 14ºF Loading rate: 0.1 in./min</td>
<td>Temp.: 122ºF Wet condition</td>
</tr>
<tr>
<td>Material Properties</td>
<td>Dynamic modulus; Creep compliance</td>
<td>IDT strength; Fracture work density; Vertical failure deformation Horizontal failure strain</td>
<td>IDT strength; Fracture work density; Vertical failure deformation; Horizontal failure strain</td>
<td>Rut depth; Stripping inflection point (SIP); Cycles</td>
</tr>
<tr>
<td>References/ Standards</td>
<td>AASHTO T322 Wen et al. 2002</td>
<td>AASHTO T322</td>
<td>AASHTO T322 Wen 2012</td>
<td>AASHTO T324</td>
</tr>
</tbody>
</table>

### References/Standards

- AASHTO T322 (2002)
- Wen et al. (2012)
- AASHTO T324

### Diagram

**Vertical Failure Deformation**

- **Load**
- **Peak Stress**
- **Fracture Work**
- **Vertical Displacement**
# Binder Test Summary

<table>
<thead>
<tr>
<th>Binder Test</th>
<th>PGs</th>
<th>Rutting: MSCR</th>
<th>Fatigue: Monotonic at Room Temp</th>
<th>Thermal Cracking: Monotonic at Low Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing Conditions</td>
<td>Different temp depending on the test (DSR, BBR)</td>
<td>Stress: 0.1, 3.2kPa Temp.: 98% Reliability from LTPP Bind</td>
<td>Temp.: 68ºF Shear strain rate: 0.3 s⁻¹</td>
<td>Temp.: 41ºF Shear strain rate: 0.01s⁻¹</td>
</tr>
<tr>
<td>Material Properties</td>
<td>PG; BBR stiffness; m-value</td>
<td>Jnr₀.₁, Jnr₃.₂; R₀.₁, R₃.₂</td>
<td>Maximum stress; Fracture energy; Failure strain</td>
<td>Maximum stress; Fracture energy; Failure strain</td>
</tr>
<tr>
<td>References/Standards</td>
<td>AASHTO MP1/T240/T313</td>
<td>AASHTO T350</td>
<td>Wen et al. 2010</td>
<td>Wen 2012</td>
</tr>
</tbody>
</table>

![Diagram showing Shear Stress, Fracture energy, and Failure strain]
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- Summary and Future Work
Transverse Cracking

Existing crack in the shoulder

Reflective

Surface-initiated

Evotherm

Advera

Underlying

Overlay
1st Round HMA/WMA Transverse Cracking Comparison

14 (21 H-W Pairs) out of 28 projects exhibited transverse cracking

- H>W: HMA has more cracking than WMA
- HMA has slightly more transverse cracks than WMA.
2nd Round HMA/WMA Transverse Cracking Comparison

22 (35 H-W pairs) out of 28 projects exhibited transverse cracking

- H>W: HMA has more cracking than WMA
- HMA has slightly more transverse cracks than WMA
Significant Determinants of Transverse Cracking

Compare Material Properties
- $H > W$, $H = W$, $H < W$ (t-test)

Compare Field Performance
- $H > W$, $H = W$, $H < W$ (t-test)

Compare the two rankings
- Consistent trend
- No consistent trend

- Summarize the number of pairs with consistent trend and determine the promising indicator
Significant Determinants for Transverse Cracking Based on 1st Round Results

15 out of 21 HMA/WMA pairs

- BBR stiffness
- Binder shear strength (41°F)
- Binder fracture energy (41°F)
- Mix E* (14°F)
- Binder shear strength (68°F)
- Binder shear strength (68°F)
- Binder failure strain (41°F)
- BBR m-value
- Binder failure strain (41°F)
- Mix horizontal failure strain (68°F)
- Binder failure strain (68°F)
- Mix vertical failure deformation (68°F)

- Mix Work Density (14°F)
- Mix E* (14°F)

- No. of Pairs
- Positive
- Negative
Verification: Significant Determinants for Transverse Cracking Based on 2nd Round Results

25 out of 35 HMA/WMA pairs

- BBR stiffness
- Binder shear strength (41°F)
- Binder failure strain (41°F)
- Mix E* (14°F)
- Binder shear strength (68°F)
- Binder shear strength (68°F)
- Mix work density (14°F)
- Binder failure strain (41°F)
- BBR m-value
- Binder failure strain (68°F)
- Mix horizontal failure strain (68°F)
- Mix vertical failure deformation (68°F)
Outline

■ Objectives & Research Progress
■ Preliminary Findings
  ■ Transverse Cracking
  ■ Top-down Longitudinal Cracking
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  ■ Material Properties Changes
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    □ IA US 34 Project

■ Summary and Future Work
Top-down Fatigue Cracking
8 (17 H-W pairs) out of 24 projects exhibited top-down longitudinal cracking. HMA and WMA are comparable in top-down fatigue cracking performance.
2\textsuperscript{nd} Round HMA/WMA Top-down Cracking Comparison

14 (24 H-W pairs) out of 28 projects exhibited top-down longitudinal cracking.

WMA has slightly more top-down fatigue cracking performance than HMA
Significant Determinants for Top-down Longitudinal Cracking Based on 1st Round Results

Vertical failure deformation (68°F), 15 out of 17 pairs

- Mix IDT strength (68°F)
- Mix creep compliance (68°F)
- Mix horizontal failure strain (68°F)
- Mix vertical failure deformation (68°F)
Verification: Significant Determinants for Top-down Cracking Based on 2\textsuperscript{nd} Round Results

Vertical failure deformation and horizontal failure strain (68\(^\circ\)F), 17 out of 24 pairs
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Rutting
2nd Round HMA/WMA Rutting Performance Comparison

23 projects (43 H-W pairs) exhibited measurable rut depth.

HMA and WMA are comparable in rut depth
Significant Determinants for Rutting Resistance

34 out of 41 HMA/WMA pairs

39 out of 43 HMA/WMA pairs
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Summary and Future Work
MT I-15 Project: Chip Seal On the Surface
MT I-15 Project: 2013 Vs 2011 Field Cores

Binder PG Tests

High Temp. PG

Low Temp. PG

HMA 2011
HMA 2013
Sas 2011
Sas 2013
Evo 2011
Evo 2013
Foam 2011
Foam 2013
MT I-15 Project: 2013 Vs 2011 Field Cores

Binder MSCR Tests

2013 vs 2011

<table>
<thead>
<tr>
<th></th>
<th>HMA</th>
<th>Sasobit</th>
<th>Evotherm</th>
<th>Foaming</th>
</tr>
</thead>
<tbody>
<tr>
<td>d2s, Jnr3.2 (31.3%)*</td>
<td>18.4% (=)</td>
<td>55.8% (&lt;)</td>
<td>14.5% (=)</td>
<td>26.6% (=)</td>
</tr>
<tr>
<td>d2s, R3.2 (17.3%)*</td>
<td>23.8% (&gt; )</td>
<td>9.2% (=)</td>
<td>0.12% (=)</td>
<td>11.8% (=)</td>
</tr>
</tbody>
</table>

* Source (Anderson 2014)
http://www.webpages.uidaho.edu/bayomy/IAC/54th/Presentations_54th/2.%20IAC2014_MSCR_Mike%20Anderson.pdf
MT I-15 Project: 2013 Vs 2011 Field Cores

Binder Fracture Tests at Intermediate Temperature

Maximum Stress, kPa

Fracture Energy, kPa
MT I-15 Project: 2013 Vs 2011 Field Cores

Binder Fracture Tests at Low Temperature

![Bar chart showing failure strain in mm/mm for different binders and treatments in 2011 and 2013.]
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- Summary and Future Work
TN SR 125 Project: HMA Pavement

Before Construction

During Construction

After Construction

3 years After Construction

Transverse Cracking

Longitudinal Cracking (Non-wheel path)
TN SR 125 Project: 2014 Vs 2011 Field Cores

Binder PG Tests

High Temp. PG

Low Temp. PG

HMA 2011
HMA 2014
Evo 2011
Evo 2014
TN SR 125 Project: 2014 Vs 2011 Field Cores

Binder MSCR Tests

- HMA 2011
- HMA 2014
- Evo 2011
- Evo 2014
TN SR 125 Project: 2014 Vs 2011 Field Cores

Binder Fracture Tests at Intermediate Temperature

- Maximum Stress, kPa
- Fracture Energy, kPa
TN SR 125 Project: 2014 Vs 2011 Field Cores

Binder Fracture Tests at Low Temperature

![Graph showing failure strain comparison between HMA and Evotherm for 2011 and 2014 samples.](image)

- HMA 2011
- HMA 2014
- Evo 2011
- Evo 2014
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    - TN SR 125 Project
    - IA US 34 Project
- Summary and Future Work
IA US 34 Project: 2014 Vs 2011 Field Cores

Binder PG Tests

<table>
<thead>
<tr>
<th></th>
<th>High Temp. PG</th>
<th>Low Temp. PG</th>
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<tbody>
<tr>
<td>HMA 2011</td>
<td>72</td>
<td>-12</td>
</tr>
<tr>
<td>HMA 2014</td>
<td>72</td>
<td>-12</td>
</tr>
<tr>
<td>Sas 2011</td>
<td>60</td>
<td>-18</td>
</tr>
<tr>
<td>Sas 2014</td>
<td>60</td>
<td>-18</td>
</tr>
</tbody>
</table>

Legend:
- HMA 2011
- HMA 2014
- Sasobit 2011
- Sasobit 2014
- Evotherm 2014
IA US 34 Project: 2014 Vs 2011 Field Cores

Binder MSCR Tests


Jnr3.2, kPa


R3.2
IA US 34 Project: 2014 Vs 2011 Field Cores

Binder Fracture Tests at Intermediate Temperature
IA US 34 Project: 2014 Vs 2011 Field Cores

Binder Fracture Tests at Low Temperature

![Graph showing failure strain comparison between HMA, Sasobit, and Evotherm for 2011 and 2013.]
Carbonyl area (function of aging temperature and time)

Inverse of log crossover modulus

Crossover frequency

G* and δ

Arrhenius Equation

\[ CA = C_{A_{tank}} + M(1 - \exp(-k_f t)) + k_c t \]

\[ k_f = A_f \exp(-E_{af}/RT) \]

\[ k_c = A_c \exp(-E_{ac}/RT) \]

\[ G^*(\omega) = G_g \left[ 1 + \left(\frac{\omega_c}{\omega}\right)^{\frac{\log 2}{R}}\right]^{-\frac{R}{\log 2}} \]

\[ \delta(\omega) = \frac{90}{1 + \left(\frac{\omega}{\omega_c}ight)^{\frac{\log 2}{R}}} \]
Aging

- Asphalt Binder:
  - IA PG58-22, MT PG70-28 (SBS)
  - LA PG76-22 (SBS)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Aging time, days</th>
</tr>
</thead>
<tbody>
<tr>
<td>55°C</td>
<td>2, 5, 10, 18, 26, 35, 45, 60, 90</td>
</tr>
<tr>
<td>70°C</td>
<td>1, 3, 6, 10, 15, 22, 30, 40</td>
</tr>
<tr>
<td>85°C</td>
<td>1, 3, 5, 8, 13, 18, 24, 30</td>
</tr>
<tr>
<td>100°C</td>
<td>1, 2, 4, 6, 8, 11, 14, 17</td>
</tr>
</tbody>
</table>

≤1mm
Analysis of crossover modulus data

Figure 1/log Gc* growth of PG binders at four temperature in air
Predicted master curve of $G^*$ and $\delta$ (CA model) (aged 40 days at 70°C)

- **PG58-28 $G^*$**
- **PG58-28 $\delta$**
- **PG70-28 $G^*$**
- **PG70-28 $\delta$**
Use Universal Model Parameters

- **CA Shear Modulus**
  - Predicted CA (a.u.) vs. Measured CA (a.u.)
  - Line of equality
  - $y = 0.99x$
  - $R^2 = 0.94$

- **Shear Modulus**
  - Predicted $1/\log |G'c^e|$ vs. Measured $1/\log |G'c^e|$ (1/log Pa)
  - Line of equality
  - $y = 1.00x$
  - $R^2 = 0.96$

- **Performance Grade**
  - Predicted Performance grade (PG) vs. Measured Performance grade (PG)
  - Line of equality
  - $y = 1.00x$
  - $R^2 = 0.91$

- **DSR Function**
  - Predicted $G'/(\eta'/G')$ vs. Measured $G'/(\eta'/G')$ (log Pa/s)
  - Line of equality
  - $y = 1.00x$
  - $R^2 = 0.97$
Thank You!
Any questions?