Engineering Properties, Emissions and Performance of Warm Mix Asphalt Technologies and Best Practices

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2003 NCAT Study
Objectives

• Evaluate Warm Asphalt Technologies for U.S. Paving Practices
  – High production
  – Rapid Turn-over to traffic

• Potential Concerns
  – “Curing” Time
  – Increased Potential for Moisture Damage
  – Binder effects
Seeing is Believing!
First U.S. WMA Test Section
February 2004

Hot Mix 314 F  Warm Mix 254 F

138.1 pcf  138.5 pcf
Benefits of WMA

- **Paving Benefits**
  - Compaction aid
  - Cold-weather paving
  - Longer haul distances
  - Use of higher percentages of RAP
  - Less restriction, potentially more production in non-attainment areas
  - Specific pavement rehabilitations

- **Reduced Fuel Usage**
- **Reduced Emissions**
- **Improved Working Conditions**
Mix Design
WMA Mix Design

AASHTO Appendix to R30:

- Perform design with WMA additive or lab foaming device
- Mixing temp. based on coating
- Compaction temp based on gyrations to 92% $G_{mm}$
- Rutting evaluation

None of the NCHRP 9-47A field projects were designed with the Appendix to R30
Research Plan

- To compare results with field results, samples batched to match average of field extracted gradation for mix/technology
- Determine optimum asphalt content
- Evaluate coating and compactability at laboratory optimum AC%
- Evaluate TSR and FN (lab opt. AC%)
Making Foamed Asphalt in the Lab
Binder Absorption

- Binder absorption observed to be less for WMA vs. HMA for early TX project.
- Percent binder absorption calculated knowing $G_{mm}$, AC%, $G_b$, and $G_{sb}$.
- Comparisons:
  - WMA to HMA
  - Lab to Field
Loop 368 One-Year Cores
Binder Absorption WMA - HMA

Asphalt absorption similar after 1-2 years

Field Avg. -0.11%; Lab Avg. -0.17%
The Last Great Quandary: Selecting Production Temperatures

• In many cases HMA produced too hot
  – Excessive temperatures age/stiffen binder, making compaction more difficult

• Many WMA suppliers wish to minimize temperatures to maximize fuel savings and offset cost of additives

• Some Agencies specify maximum temperatures for “warm mix” regardless of other production considerations

• RAP and RAS?

SC-M-408 specifies 220 – 285 °F
Production Temperatures
AASHTO Appendix R30

- Based on Ross Count coating test after 90 seconds mixing with planetary mixer
- NCHRP 9-43 research completed with planetary mixer
- Concern more common bucket mixer may not provide adequate mixing or may need different time.
Foaming processes resulted in slightly less coating. Can coat with bucket mixer.
SGC Compactability Ratio

- Compactability Ratio used to assess proposed WMA compaction temperatures
- Ratio of number of gyrations to 92% Gmm at 30°C (54°F) below production to proposed compaction temperature
- Supposed to be less than 1.25
SGC Compactability Ratio – Compaction Temperature

<table>
<thead>
<tr>
<th>SGC Compactability Ratio</th>
<th>Opt. AC% Draft AASHTO R35</th>
<th>Field AC%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.74% decrease in AC%</td>
<td>0.39% increase in AC%</td>
<td>0.17% increase in AC%</td>
</tr>
<tr>
<td>Sample tested at 250F,  Field production avg. 273F</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In-place Density, % of Gmm

0.90% decrease in AC%
Mix verification from both MI and FL resulted in lower Opt. AC%.
WMA vs HMA Tensile Strength
2-2.5 year cores

Number of Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Same</th>
<th>Lower</th>
<th>Higher</th>
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</thead>
<tbody>
<tr>
<td>Number</td>
<td>11</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

AMS LLC
National Center for Asphalt Technology at Auburn University
WMA vs HMA Tensile Strength
> 3 year cores
Summary

- Binder absorption less for WMA, approx. 0.10% field; 0.16% lab. Binder absorption the same after 1-2 years
- Recovered binder from cores not different after 1-2 years
- Rutting performance similar
- NCHRP 9-47A recommends “drop-in” approach for WMA where WMA technologies are used with existing HMA designs
Field Performance
<table>
<thead>
<tr>
<th>Test Section</th>
<th>Field Rut Depth, mm</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>6 Months</td>
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<tr>
<td>Control</td>
<td>0.4</td>
</tr>
<tr>
<td>Evotherm™</td>
<td>1.1</td>
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<tr>
<td>Sasobit®</td>
<td>0.8</td>
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<tr>
<td>Aspha-min®</td>
<td>0.3</td>
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## MEPDG Predicted Rutting

<table>
<thead>
<tr>
<th>Layer(s)</th>
<th>Prediction Interval, years</th>
<th>Mix</th>
<th>Mean Rut Depth, mm</th>
<th>Variance</th>
<th>t-test p-value</th>
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</thead>
<tbody>
<tr>
<td>Sub-Total all Asphalt Layers</td>
<td>12</td>
<td>HMA</td>
<td>4.84</td>
<td>15.0</td>
<td>0.08</td>
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<tr>
<td></td>
<td></td>
<td>WMA</td>
<td>5.03</td>
<td>15.6</td>
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<tr>
<td></td>
<td>20</td>
<td>HMA</td>
<td>6.96</td>
<td>22.4</td>
<td>0.06</td>
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<td></td>
<td></td>
<td>WMA</td>
<td>7.23</td>
<td>23.2</td>
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<tr>
<td>Experimental (Surface) Layer</td>
<td>12</td>
<td>HMA</td>
<td>1.65</td>
<td>0.36</td>
<td>0.16</td>
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<tr>
<td></td>
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<td>WMA</td>
<td>1.80</td>
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<td></td>
<td>20</td>
<td>HMA</td>
<td>2.22</td>
<td>0.65</td>
<td>0.14</td>
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<td></td>
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<td>WMA</td>
<td>2.45</td>
<td>1.31</td>
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</table>
Summary of Observed and Predicted Field Performance

• No difference in opening times for WMA vs. HMA

• Rutting
  – < 5 mm of rutting for all sections after 2 years
  – MEPDG predicts slightly more (0.2 mm) rutting over life
  – WMA performed well at accelerated loading facilities
  – Appears to be discrepancy between laboratory predicted and observed field rutting
Summary of Observed and Predicted Field Performance

- No evidence of moisture damage in field projects, including saturated CA HVS sections

- **Cracking**
  - Very little observed after 2 years; similar for WMA and HMA
  - MEPDG predicts slightly more cracking for HMA
  - Where Level 1 data used, MEPDG predicts less thermal cracking
Fuel Savings

• Theoretical calculations indicate a 50°F reduction in production temperature should result in an 11% reduction in fuel usage
• Actual savings average 13% for average reduction of 50°F
• Based on preliminary analyses, savings distributed as:
  – 14% from reduction in stack temperature
  – 51% from reduction in mix temperature
  – 37% from reduction in casing loss
Best Practice: Reduce Stockpile Moisture

- Saves fuel – 2% decrease = savings of 0.48 gal/ton
- Drier aggregate in = drier aggregate out, reducing potential for moisture damage
Best Practice Benefit

2% Reduction in stockpile moisture saves 0.58 gal. diesel per ton

Based on field data from five sites.
Reduced Emissions
Fuel Usage Vs. CO₂

- Reduction in CO₂ Emission, %
- Reduction in Fuel Usage, %

- Literature
- WMA D
- NCHRP 9-47A

Line of Equality
Reduced Emissions

NCHRP 9-47A data indicate:

- Reduced fuel usage = reduced CO$_2$
- With one exception, NO$_x$ emissions from WMA were lower than for HMA
- VOC’s significantly lower for parallel-flow drum plant
- 50% reduction in SO$_2$ with recycled oil
Best Practice: Burner Tuning

- Elevated levels of CO and VOCs can indicate incomplete combustion
- Stack emissions data indicate examples of improperly tuned burners
- 32% fuel saving for HMA production at one plant after tuning for WMA project!
Worker Exposure

- NIOSH uses Benzene Soluble Matter (BSM) to measure worker exposure to asphalt emissions
- In many cases, results for BSM below detectable limits for both HMA and WMA – hard to quantify benefits
- For NCHRP 9-47A, Heritage Research Group used a more discriminative test for Total Organic Matter
- Tests on 6 WMA and 2 HMA at 2 sites showed WMA reduced exposure by 33 to
Summary

• Warm Mix technologies most frequently used as compaction aids and to improve coating
  – Stiff mixes with polymer modified binders or higher recycle content
  – Longer hauls/cooler weather
  – Can combine chemical and foaming technologies

• Warm mix technologies are a component of asphalt’s sustainability
  – Reduced fuel usage = reduced emissions
  – Better for workers
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Thanks!