Field and Laboratory Evaluation of Warm Mix Asphalt (WMA) Phase I

Prepared by:
Rafi Tarefder, Ph.D., P.E.
Jielin Pan, Ph.D. Candidate
Department of Civil Engineering
Outline

- Introduction
- Current State of WMA Technology
- WMA Technologies Implemented in New Mexico
- Preliminary Survey of NMDOT’s WMA Projects
- Evaluation of WMA Through Field Survey
- Evaluation of WMA Using Pavement Management Data
- Review of WMA Performances
- Conclusions and Recommendations
- Acknowledgements
Introduction

Objectives

- Assess current state of WMA technologies, with particular emphasis on their suitability for the implementation in NM.
- Survey completed and ongoing WMA projects in NM to document difficulties and problems in WMA construction, and suggest changes in NMDOT practices and specifications.
- Review best practices for laboratory and field performance testing of WMA technologies to be used in NM.
Objectives (continued)

- Document the literature and survey information generated in this research and provide recommendations for the best technologies and test methods for WMA technologies to be used in NM.

- Provide recommendations for subsequent research (Phase 2).
Scope of the Study

- Ensure whether the performances of WMA is comparable to, or better than the performances of Hot Mix Asphalt (HMA) in New Mexico (NM).

- Initial attempt to evaluate the best WMA technologies being used in NM through available literature, existing WMA project information and field visual inspection.

- Gather required info for long-term performance testing of WMA mix in the laboratory and in the field for Phase 2.
Current State of WMA Technology

- Background
- State DOT, NCHRP, SHRP, UTC, and FHWA Review
Definition of WMA

- An asphalt mixtures can be produced at 50 to 100 °F lower than typical HMA.
- Reduce production heat by reducing asphalt viscosity by a wide range of WMA technologies.
Background

Brief History

- First developed in Europe with German Bitumen Forum in 1997 to reduce greenhouse and gas emissions.
- First WMA demonstration in USA in 2004.

Categories of WMA Technologies

- Addition of organic additives
- Foaming processes
  - water-containing
  - water-based processes
- Addition of chemical additives
## Categories of WMA Technologies (continued)

### Summary of WMA Products Description

<table>
<thead>
<tr>
<th>Category</th>
<th>Product</th>
<th>Company</th>
<th>Description</th>
<th>Dosage of Additive</th>
<th>Country where product is used</th>
<th>Production Temperature [or Reduction Ranges]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foaming Processes</strong></td>
<td><strong>AQUABlack WMA</strong></td>
<td>MAXAM equipment</td>
<td>Water based</td>
<td>Not necessary, only water</td>
<td>U.S.A.</td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td><strong>Double Barrel Green</strong></td>
<td>Astec</td>
<td>Water based</td>
<td>By choice, anti-stripping agent</td>
<td>U.S.A.</td>
<td>116-135 °C* 120 °C</td>
</tr>
<tr>
<td></td>
<td><strong>Warm Mix Asphalt System</strong></td>
<td>Terex</td>
<td>Water based</td>
<td>Not necessary, only water</td>
<td>U.S.A.</td>
<td>&lt;32 °C*</td>
</tr>
<tr>
<td></td>
<td><strong>Ultrafoam GX</strong></td>
<td>Gencor Industries</td>
<td>Water based</td>
<td>Not necessary, only water</td>
<td>U.S.A.</td>
<td>Not specified</td>
</tr>
<tr>
<td></td>
<td><strong>Low Energy Asphalt</strong></td>
<td>LEACO</td>
<td>Water based</td>
<td>Not necessary, only water</td>
<td>U.S.A.; France, Spain, Italy</td>
<td>≤100 °C* 105-124 °C</td>
</tr>
<tr>
<td></td>
<td><strong>Low Emission Asphalt</strong></td>
<td>McConnaughay Technologies</td>
<td>Combination of chemical and water based</td>
<td>Yes, 0.4% of asphalt binder weight</td>
<td>U.S.A.</td>
<td>90 °C &gt;100 °C</td>
</tr>
<tr>
<td></td>
<td><strong>LT Asphalt Foam</strong></td>
<td>Nynas</td>
<td>Water-based Asphalt binder with hydrophilic additive</td>
<td>Yes, ± 0.5% of asphalt binder weight</td>
<td>U.S.A.</td>
<td>90 °C</td>
</tr>
<tr>
<td></td>
<td><strong>WAM-Foam</strong></td>
<td>Shell and KoloVeidekke</td>
<td>Water based using two binder grades</td>
<td>Anti-stripping agents could be added to soften binder</td>
<td>U.S.A., Norway, worldwide</td>
<td>110-120 °C* 100-120 °C 62 °C</td>
</tr>
<tr>
<td></td>
<td><strong>Advera</strong></td>
<td>PQ Corporation</td>
<td>Water containing Zeolite</td>
<td>0.25% by mixture weight</td>
<td>U.S.A.</td>
<td>[10-20 °C]* [20-30 °C]</td>
</tr>
<tr>
<td></td>
<td><strong>Aspha-Min</strong></td>
<td>Eurovia</td>
<td>Water containing Zeolite</td>
<td>0.3% by mixture weight</td>
<td>U.S.A., France, Germany, worldwide</td>
<td>[30 °C]* [20-30 °C]</td>
</tr>
</tbody>
</table>

Note: *Temperature range from product supplier
## Categories of WMA Technologies (continued)

### Summary of WMA Products Description (continued)

<table>
<thead>
<tr>
<th>Category</th>
<th>Product</th>
<th>Company</th>
<th>Description</th>
<th>Dosage of Additive</th>
<th>Country where product is used</th>
<th>Production Temperature [or Reduction Ranges]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic Additives</td>
<td>Sasobit</td>
<td>Sasol</td>
<td>Fischer-Tropsch wax</td>
<td>2.5-3.0% of asphalt binder weight in Germany, 1-1.5% of asphalt binder weight in US</td>
<td>U.S.A., E.U., worldwide</td>
<td>[10-30 °C]^[10], [20-30 °C]^[11], [18-54 °C]^[12], [130-150 °C]^[13]</td>
</tr>
<tr>
<td></td>
<td>Asphaltan A</td>
<td>Romonta GmbH</td>
<td>Montan wax for mastic asphalt</td>
<td>1.5-2.0% of asphalt binder weight</td>
<td>Germany</td>
<td>[20 °C]</td>
</tr>
<tr>
<td></td>
<td>Asphaltan N</td>
<td>Romonta GmbH</td>
<td>Refined Montan wax with fatty acid amide for rolled asphalt</td>
<td>2.0-4.0% by mass of asphalt binder</td>
<td>Germany</td>
<td>[20-30 °C]</td>
</tr>
<tr>
<td></td>
<td>Asphaltan B</td>
<td>Romonta GmbH</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Licomont BS</td>
<td>Clariant</td>
<td>Fatty acid amide</td>
<td>3.0% by mass of asphalt binder</td>
<td>Germany</td>
<td>[20-30 °C]</td>
</tr>
<tr>
<td></td>
<td>3E LT or Ecoflex</td>
<td>Colas</td>
<td>Fatty acid amide (proprietary)</td>
<td>Yes, but no specified</td>
<td>France</td>
<td>[30-40 °C]</td>
</tr>
<tr>
<td></td>
<td>Evotherm ET</td>
<td>MeadWestvaco</td>
<td>Chemical asphalt binder emulsion</td>
<td>Delivered in form of asphalt binder emulsion</td>
<td>U.S.A., France, worldwide</td>
<td>[50-75 °C]^[16], [37-54 °C]^[17], [85-115 °C]^[18]</td>
</tr>
<tr>
<td></td>
<td>Evotherm DAT</td>
<td>MeadWestvaco</td>
<td>Chemical additive plus water</td>
<td>30% by weight of asphalt binder</td>
<td>U.S.A., France, worldwide</td>
<td>[45-55 °C]^[21], [&gt;93 °C]^[22], [85-115 °C]^[23]</td>
</tr>
<tr>
<td></td>
<td>Evotherm 3G</td>
<td>MeadWestvaco</td>
<td>Water free chemical additive</td>
<td>Not Specified</td>
<td>U.S.A.</td>
<td>[33-45 °C]^[25], [15-27 °C]^[26]</td>
</tr>
<tr>
<td></td>
<td>CECABASE RT</td>
<td>CECA Arkema group</td>
<td>Chemical additive</td>
<td>0.2-0.4% by mixture weight</td>
<td>U.S.A., France</td>
<td>120 °C^[30], 101 °C^[31]</td>
</tr>
<tr>
<td></td>
<td>Rediset WMX</td>
<td>Akzo Nobel</td>
<td>Cationic surfactants and organic additive</td>
<td>1.5-2% of asphalt binder weight</td>
<td>U.S.A., Norway</td>
<td>[≥30 °C]^[34], [≥16 °C]^[35], [126 °C]^[36]</td>
</tr>
<tr>
<td></td>
<td>REVIX</td>
<td>Mathy-Ergon</td>
<td>Surface-active agents, waxes, processing aids, polymers</td>
<td>Not specified</td>
<td>U.S.A.</td>
<td>120 °C^[40]</td>
</tr>
<tr>
<td></td>
<td>Iterlow T</td>
<td>IterChimica</td>
<td>NA</td>
<td>0.3-0.5% by mass of asphalt binder</td>
<td>Italy</td>
<td>120 °C^[44]</td>
</tr>
</tbody>
</table>

Note: *Temperature range from product supplier
Categories of WMA Technologies (continued)

Organic Additives

Waxes (C45 or more)
(high molecular hydrocarbon chains with melting point of 80-120°C)

- Ficher-Tropsch
- fatty acid amide
- Montan wax

Sasobit prills
Liccomont BS 100 granules
Montan wax

Add 2-4% of mass of the binder

Temperature reduction: 20-30 °C

Improvement of the deformation resistance of the asphalt
The foam dissipates in less than a minute and asphalt binder resumes its original properties. This means that the mix must be spread and compacted soon after production.

These methods have been tested for soft and medium asphalt binder grades.
Categories of WMA Technologies (continued)

- Foaming Processes
  - Methods

- **Water-based**
  Such as AQUA Black, Double Barrel Green, and Warm Mix Asphalt, etc.

- **Water-containing**
  using synthetic zeolite to produce the foaming process.
  - Frame work silicates allow the presence of water molecules.
  - When mixed with hot aggregate or asphalt, it releases water, creating a very fine mist or water spray in the mixture.
  - Controlled foaming effect \( \rightarrow \) volume ↑ slightly
  - Provides a 6-7h aided compaction.
  - Two products: Aspha-min & Advera.

Illustration of how to make foamed asphalt
Other Technologies

- Low Energy Asphalt (sequential mixing):
  The final water content is often around 0.5% at 95 °C, which guarantees workability and a sufficient level of compaction.

The Low Energy Process
Other Technologies (continued)

- Low Emission Asphalt:
  - Similar to Low Energy Asphalt
  - Combination of chemical and foaming technology.
  - Two phases:
    - Chemical additive added first to the hot coarse aggregate
    - Wet sand added to create a foaming action.
Mechanism:

- Not viscosity reduction or foaming for lowering mixing and compaction temperatures.
- Improve coating, mixture workability, and compaction, as well as adhesion promoters (anti-stripping agents) by a combination of emulsification agents, polymers, additives, and surfactants.

The additive content and the temperature reduction depend on the type of chemical additives.
Plant Modifications for WMA Technologies

- **Organic Additives and Water Containing Foaming Processes**: fiber feeder or pneumatic for the plant.
- **Water Based Foaming processes**: addition of the foaming equipment.
- **Chemical Additives**: No need for plant modifications except the addition of pump and stirring units.
## Background

- **Differences between WMA and HMA Mix Design**

### Steps in Design of Dense-Graded HMA and WMA

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Major WMA Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gather Information</td>
<td>- WMA process,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Additive rates,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Planned production temperature,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Planned compaction temperature.</td>
</tr>
<tr>
<td>2</td>
<td>Select Asphalt Binder</td>
<td>- Recommended limit on high-temperature stiffness of recycled binders.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- May consider low-temperature grade improvement when using blending charts.</td>
</tr>
<tr>
<td>3</td>
<td>Determine Compaction Level</td>
<td>Same as HMA</td>
</tr>
<tr>
<td>4</td>
<td>Select Nominal Maximum Aggregate Size</td>
<td>Same as HMA</td>
</tr>
<tr>
<td>5</td>
<td>Determine Target VMA and Design Air Voids Value</td>
<td>Same as HMA</td>
</tr>
</tbody>
</table>
Steps in Design of Dense-Graded HMA and WMA (continued)

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Major WMA Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Calculate Target Binder Content</td>
<td>Lower asphalt absorption due to lower temperature.</td>
</tr>
<tr>
<td>7</td>
<td>Calculate Aggregate Volume</td>
<td>Same as HMA</td>
</tr>
<tr>
<td>8</td>
<td>Proportion Aggregate Blends for Trial Mixtures</td>
<td>Same as HMA</td>
</tr>
<tr>
<td>9</td>
<td>Calculate Trial Mixture Proportions by Weight and Check Dust/Binder Ratio</td>
<td>Same as HMA</td>
</tr>
<tr>
<td>10</td>
<td>Evaluate and Refine Trial Mixtures</td>
<td>- WMA process-specific specimen fabrication procedures,&lt;br&gt;- Lower short-term aging temperature.&lt;br&gt;- Evaluate coating and compactability in lieu of viscosity-based mixing and compaction temperatures.</td>
</tr>
<tr>
<td>11</td>
<td>Compile Mix Design Report</td>
<td>Same as HMA</td>
</tr>
</tbody>
</table>
### Background

#### Differences between WMA and HMA Mix Design

#### Evaluate and Refine Trial Mixtures

**Comparison of Trial Specimen Fabrication Procedures for WMA And HMA Design**

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>HMA</th>
<th>WMA</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculate batch weights</td>
<td>X</td>
<td>X</td>
<td>Must calculate WMA additive content for some processes</td>
</tr>
<tr>
<td>2</td>
<td>Batch aggregates</td>
<td>X</td>
<td>X</td>
<td>Must batch WMA additive for some processes</td>
</tr>
<tr>
<td>3</td>
<td>Heat aggregates and asphalt binder</td>
<td>X</td>
<td>X</td>
<td>Use planned production temperature for WMA</td>
</tr>
<tr>
<td>4</td>
<td>Mix aggregates and binder</td>
<td>X</td>
<td>X</td>
<td>Procedure is WMA process specific</td>
</tr>
<tr>
<td>5</td>
<td>Short-term oven conditioning</td>
<td>X</td>
<td>X</td>
<td>WMA uses lower temperature</td>
</tr>
<tr>
<td>6</td>
<td>Compact laboratory specimens</td>
<td>X</td>
<td>X</td>
<td>WMA uses lower temperature</td>
</tr>
<tr>
<td>7</td>
<td>Calculate volumetric composition of laboratory specimens</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Adjust aggregate proportions to meet volumetric requirements</td>
<td>X</td>
<td>X</td>
<td>Used in WMA design in place of viscosity-based mixing and compaction temperatures</td>
</tr>
<tr>
<td>9</td>
<td>Evaluate coating and compactability</td>
<td>NA</td>
<td>X</td>
<td>Moisture sensitivity (<a href="#">AASHTO T 283</a>) for all mixtures</td>
</tr>
<tr>
<td>10</td>
<td>Conduct performance testing</td>
<td>X</td>
<td>X</td>
<td>Rutting resistance (<a href="#">AASHTO TP 79</a>) for design traffic levels of 3 m ESALs or greater</td>
</tr>
</tbody>
</table>
Background

Laydown and Compaction Differences between WMA & HMA

- No differences of **WMA** from **HMA**, other than the operations temperature.

- **More uniform compaction** from **WMA** due to lower operating temperature: Allowing the roller train to have better spacing and ensure proper mat coverage.

- **Easy** to achieve **minimum density** from WMA.
Advantages and Disadvantages of WMA

Advantages

- Environmental benefits: lower plant emissions;
- Economic benefits: Reduced energy consumption;
- Pavement benefits: Improvement of workability & compaction efficiency, longer haul distances, and quicker turnover to traffic due to shorter cooling time;
- Production benefits: Increased RAP content and location of plant site in urban areas.

http://www.fhwa.dot.gov/everydaycounts/events/trb/docs/wma/wma_brochure.pdf
Disadvantages

- Cost effectiveness: Initial costs and other costs;
- Rutting and moisture susceptibility: Permanent Rutting of the pavement surface & moisture susceptibility of WMA mixes;
- Long term performance: Short life of WMA pavement, no possibility to evaluate long term performance; and
- Environmental pollution effects of WMA additives: Potential source of pollution by using chemical additives.
Evaluation of Additives (Literature from Washington State DOT & National Center for Asphalt Technology (NCAT)):

It is difficult to decide which additive or warm mix technology is better than others. The concerns about how to select right warm mix technology need to be measured by many factors, such as local environment, economic condition and material available around construction location, etc.
Mix Design: NCHRP Report 691

- Recommendations for WMA mix design practices are included in AASHTO R35 as an appendix, “Special Mixture Design Considerations and Methods for Warm Mix Asphalt (WMA).”

- The HMA mix design results can be applied to WMA for an HMA mixture with 1% binder absorption or less.

- The WMA specimens should be evaluated for compactability, coating, rutting and moisture sensitivity.

- Compactability was found to be different based on the WMA process used as well as the production temperature, especially for mixtures containing RAP.
Mix Design & WMA Performances: State DOTs

For **Michigan**, **Colorado**, **Washington**, **Nebraska** and **Texas** DOTs:

- **NMAS Superpave mix design** were used.
- **Aggregate**: basalt, natural sand blend including RAP, local aggregate and binder were used.
- **Additives**: Sasobit, Evotherm, Aquablack TM WMA foaming system, and Advera zeolite were used.
- **Mixing temperature**: 124-135°C for WMA, 143-163°C for control HMA.
- **Compaction temperature**: 110-124°C for WMA, 121-149°C for control HMA.
- **Performance**: WMA performed equal to or better than the control HMA.
Laboratory Test Procedures: NCHRP Report 691

- Mandatory mixture analysis tests:
  - Evaluation of *moisture sensitivity*: AASHTO T 283 (TSR)
  - Evaluation of *rutting resistance*: AASHTO TP 79 (Flow Number)

- Optional mixture analysis tests
  - dynamic modulus,
  - resistance to fatigue cracking, and
  - resistance to thermal cracking.
WMA Technologies Implemented in New Mexico

- Water Injection Foaming Processes used in NM
- Chemical Technology used in NM
Water Injection Foaming Processes used in NM

- **Water Injection Foaming Processes in New Mexico**
  - **Nozzles** used to inject water into asphalt binder stream.
  - **Equipment** developed by individual company.
  - **Foaming rate** adjusted by the computer controlled nozzles.

![Working Mechanism of Foam Nozzle]
Double Barrel Green (Astec):

- A full installation kit (Astec Green Pac) includes water addition system, control unit and reservoir tank skid for water.
- Can be installed to both continuous mix and batch plants.
Aquablack WMA (MAXAM Equipment):

- A complete installation package includes foaming nozzle, water pump, metering system, control panel.
- One centre convergence nozzle from stainless steel
- High pressure (1000 psi) in the system, allowing low water to binder ration.
Warm Mix Asphalt System (Terex):

- Production kit installed only for drum plants.
- Produce foamed binder just outside of the drum in an expansion chamber and immediately inject it into the drums’ mixing chamber, coating the aggregate.
Water Injection Foaming Processes used in NM

- **Evotherm (MeadWestvaco):**
  - Can be used in any traditional HMA application—from the binder course to the surface course.
  - 100 to 130°F (50 to 75°C) lower than HMA.
  - No equipment changes at the plant or job site.
  - Metered into existing materials and drops into existing HMA job mix formulas.
  - Workability and compaction at reduced temperatures are easier than HMA, especially for coarse mixes and polymer modified asphalts.
Evotherm (continued):

- Three technologies: *Evotherm – Evotherm ET*, eventually replaced by *Evotherm DAT* and *Evotherm 3G*.
- DAT process reduces shipping cost compared to the ET emulsion and allows the contractor to rapidly switch between HMA and WMA.
- 3G is in a water-free form that can be blended directly with the asphalt binder at the terminal or directly injected into the asphalt line at the plant.
Preliminary Survey of NMDOT’s WMA Projects

- General NMDOT’s WMA Projects
- Project Selection
- Preliminary Survey
# General NMDOT’s WMA Projects

## Summary of WMA Projects in New Mexico

### 2011

<table>
<thead>
<tr>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>A300370</td>
<td>I-25</td>
<td>229.249</td>
<td>232.000</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>25%</td>
</tr>
<tr>
<td>6</td>
<td>6100430</td>
<td>NM 264</td>
<td>10.6</td>
<td>13.1</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
</tbody>
</table>

### 2012

<table>
<thead>
<tr>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1C00002</td>
<td>I-10</td>
<td>15.45</td>
<td>20.00</td>
<td>Foaming</td>
<td>Astec</td>
<td>34%</td>
</tr>
<tr>
<td>1</td>
<td>1100530</td>
<td>I-10</td>
<td>108.00</td>
<td>116.02</td>
<td>Foaming</td>
<td>Astec</td>
<td>10%</td>
</tr>
<tr>
<td>1</td>
<td>1100670</td>
<td>US 180</td>
<td>142.50</td>
<td>160.70</td>
<td>Foaming</td>
<td>Astec</td>
<td>35%</td>
</tr>
<tr>
<td>1</td>
<td>1C00003</td>
<td>I-25</td>
<td>71.900</td>
<td>89.000</td>
<td>Foaming</td>
<td>Astec</td>
<td>35%</td>
</tr>
<tr>
<td>1</td>
<td>1C00001</td>
<td>I-25</td>
<td>131</td>
<td>140</td>
<td>Foaming</td>
<td>Astec</td>
<td>25%</td>
</tr>
<tr>
<td>4</td>
<td>4C00001</td>
<td>I-40</td>
<td>335.00</td>
<td>340.65</td>
<td>Foaming</td>
<td>Astec</td>
<td>0%</td>
</tr>
<tr>
<td>6</td>
<td>6100510</td>
<td>NM 118</td>
<td>24.5</td>
<td>27.0</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
<tr>
<td>6</td>
<td>6100450</td>
<td>US 60</td>
<td>73</td>
<td>76</td>
<td>Foaming</td>
<td>Astec</td>
<td>0%</td>
</tr>
<tr>
<td>District</td>
<td>Project Number</td>
<td>Highway</td>
<td>Beg MP</td>
<td>Ending MP</td>
<td>WMA Technology</td>
<td>Company</td>
<td>RAP Percent</td>
</tr>
<tr>
<td>----------</td>
<td>----------------</td>
<td>---------</td>
<td>--------</td>
<td>-----------</td>
<td>----------------</td>
<td>----------------</td>
<td>-------------</td>
</tr>
<tr>
<td>1</td>
<td>E100030</td>
<td>NM 136</td>
<td>-</td>
<td>-</td>
<td>Foaming</td>
<td>Astec</td>
<td>33%</td>
</tr>
<tr>
<td>1</td>
<td>1100320</td>
<td>US 70</td>
<td>145.3</td>
<td>148.0</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>35%</td>
</tr>
<tr>
<td>1</td>
<td>1100550R</td>
<td>US 70</td>
<td>0</td>
<td>15</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>25%</td>
</tr>
<tr>
<td>1</td>
<td>E100030</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Foaming</td>
<td>Astec</td>
<td>30%</td>
</tr>
<tr>
<td>1</td>
<td>1100320</td>
<td>US 70</td>
<td>145.3</td>
<td>148.0</td>
<td>Foaming</td>
<td>Astec</td>
<td>33%</td>
</tr>
<tr>
<td>1</td>
<td>1100320</td>
<td>US 70</td>
<td>145.3</td>
<td>148.0</td>
<td>Foaming</td>
<td>Astec</td>
<td>30%</td>
</tr>
<tr>
<td>2</td>
<td>2100790</td>
<td>US 380</td>
<td>161.789</td>
<td>178.500</td>
<td>Foaming</td>
<td>Astec</td>
<td>33%</td>
</tr>
<tr>
<td>2</td>
<td>2100170</td>
<td>US 82</td>
<td>92.54</td>
<td>95.07</td>
<td>Foaming</td>
<td>MeadWestvaco</td>
<td>28%</td>
</tr>
<tr>
<td>2</td>
<td>2100650</td>
<td>NM 200</td>
<td>3.65</td>
<td>8.38</td>
<td>Foaming</td>
<td>MeadWestvaco</td>
<td>35%</td>
</tr>
<tr>
<td>2</td>
<td>2100880</td>
<td>US 380</td>
<td>178.5</td>
<td>190.8</td>
<td>Foaming</td>
<td>Astec</td>
<td>33%</td>
</tr>
<tr>
<td>2</td>
<td>2101060</td>
<td>US 70/380</td>
<td>301.9</td>
<td>325.6</td>
<td>Foaming</td>
<td>Astec</td>
<td>35%</td>
</tr>
<tr>
<td>2</td>
<td>2100170</td>
<td>US 82</td>
<td>92.54</td>
<td>95.07</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>35%</td>
</tr>
<tr>
<td>2</td>
<td>2100200</td>
<td>NM 48</td>
<td>0.000</td>
<td>3.356</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>25%</td>
</tr>
<tr>
<td>2</td>
<td>2100220</td>
<td>US 70/380</td>
<td>301.9</td>
<td>325.6</td>
<td>Foaming</td>
<td>Astec</td>
<td>35%</td>
</tr>
<tr>
<td>4</td>
<td>4100670</td>
<td>I-40</td>
<td>355.0</td>
<td>359.5</td>
<td>Foaming</td>
<td>Terex</td>
<td>0%</td>
</tr>
<tr>
<td>4</td>
<td>4100660</td>
<td>I-40</td>
<td>-</td>
<td>-</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>0%</td>
</tr>
<tr>
<td>5</td>
<td>5100700</td>
<td>NM 371</td>
<td>61.0</td>
<td>72.7</td>
<td>Foaming</td>
<td>Terex</td>
<td>30%</td>
</tr>
<tr>
<td>5</td>
<td>5100760</td>
<td>US 64</td>
<td>24.5</td>
<td>26.5</td>
<td>Foaming</td>
<td>Terex</td>
<td>30%</td>
</tr>
</tbody>
</table>
Project Selection

Basic Information of the Seven Selected WMA Projects

<table>
<thead>
<tr>
<th>Construction Date</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beginning MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Manufacturer/Company</th>
<th>% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug. 2011</td>
<td>3</td>
<td>A300370</td>
<td>I 25</td>
<td>229.249</td>
<td>232</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>25%</td>
</tr>
<tr>
<td>May 2011</td>
<td>6</td>
<td>CN 6100430</td>
<td>NM 264</td>
<td>10.6</td>
<td>13.1</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
<tr>
<td>May 2012</td>
<td>6</td>
<td>6100510</td>
<td>NM 118</td>
<td>24.5</td>
<td>27.0</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
<tr>
<td>Jul. 2013</td>
<td>6</td>
<td>6100451</td>
<td>US 60</td>
<td>69</td>
<td>73</td>
<td>Evotherm</td>
<td>MeadWestVaco</td>
<td>0%</td>
</tr>
<tr>
<td>Jun. 2013</td>
<td>2</td>
<td>2100200</td>
<td>NM 48</td>
<td>0.000</td>
<td>3.356</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>25%</td>
</tr>
<tr>
<td>Apr. 2013</td>
<td>4</td>
<td>4100670</td>
<td>I 40</td>
<td>355.0</td>
<td>359.5</td>
<td>Foaming</td>
<td>Terex</td>
<td>0%</td>
</tr>
<tr>
<td>Jul. 2012</td>
<td>6</td>
<td>6100450</td>
<td>US 60</td>
<td>73</td>
<td>76</td>
<td>Foaming</td>
<td>Astec</td>
<td>0%</td>
</tr>
<tr>
<td>Aug. 2011</td>
<td>3</td>
<td>A300370</td>
<td>I 25</td>
<td>229.249</td>
<td>232</td>
<td>HMA Control</td>
<td>—</td>
<td>25%</td>
</tr>
</tbody>
</table>

Note: — indicates data not applicable.

- Seven WMA Projects with One HMA control Project
- Four Evotherm + Three Foaming Projects
- One Evotherm-25% RAP Project + One Foaming-25% RAP Project
Locations of the Selected Seven WMA projects in New Mexico
A questionnaire survey sent to the project managers of NMDOT and paving contractors associated with the seven selected projects.

One paving contractor (Fisher Sand & Gravel Co.) responded the WMA projects on I-25 and I-40.

Two project managers answered some questions about the WMA project on NM 48 and I-25, respectively.
Conclusions

- The WMA tends to remain workable longer than HMA allowing for a greater compaction window and easier handling of the mixture.

- Some WMA technologies cannot handle high RAP contents as adequate mixing of the materials becomes an issue at the lower temperatures. Other technologies allow greater RAP contents with no issues with adequate mixing. In addition, no issues with homogeneity of the blended RAP and virgin binder were found within 25% RAP.

- There are no issues about rutting resistance and moisture damage of WMA projects and WMA laboratory tests so far.

- Evotherm additive and Foaming process are reported that each one has its own benefits. Foaming process is the most cost effective method while Evotherm has a higher cost but also allows for lower temperatures than Foaming. Both products have performed as expected so far so the difference in performance need further investigated.

- The WMA pavements perform as well as HMA pavements so far.
Evaluation of WMA Through Field Survey

- Evotherm WMA Projects
- Foaming WMA Projects
- Conclusions & Discussions
Field Evaluation of Evotherm Projects
Field Evaluation Results of WMA Project on I-25
Evotherm WMA Project vs. Control HMA Project

- Basic Information of the Evotherm Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug. 2011</td>
<td>3</td>
<td>A300370</td>
<td>I-25</td>
<td>229.249</td>
<td>232</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>25%</td>
</tr>
</tbody>
</table>

1) Main traffic road: **3.5" cold milling** and **3" WMA inlay**, SP-III, PG 70-22. Shoulder: **existing HMA** pavement by fog seal.

2) **0.5" Standard OGFC** on the top.

3) **non-QLA** project.

4) Located in **Albuquerque city** with design **ESALs 10.10 million**.

5) **Mixing Temperature**: 270 °F, **Laydown temperature**: roughly 230 °F, and **compacted down** to temperatures of roughly 190 °F.

6) **Asphalt content**: 4.7%, with **3.6% virgin asphalt binder**.
Road Condition after around 2 Years and 4 Months for the Evotherm Project

**Comprehensive Evaluation**

- Pavement is still in good condition.
Road Condition after around 2 Years and 4 Months for the Evotherm Project

Problems/Distresses Found on the Project

- Binder Balls
- Transverse Cracking on Shoulders

Transverse reflection cracking on the edge of OGFC
Road Condition after around 2 Years and 4 Months for the Control HMA Project Description

- Comprehensive Evaluation
  - Pavement is still in good condition.
Road Condition after around 2 Years and 4 Months for the **Control HMA** Project Description

- **Problems/Distresses Found on the Project**
  - **Binder Balls**
  - **Transverse Cracking on Shoulders**

Transverse cracking on shoulder starts extending to the edge of OGFC
Road Condition after around 2 Years and 4 Months for the Control HMA Project Description

- Problems/Distresses Found on the Project
  - Joint Cracking Starts Opening.
  - Pitting Found on the Road
Field Evaluation Results of WMA Project on I-25
Evotherm WMA Project vs. Control HMA Project

Summaries

- OGFCs of WMA & HMA pavements performance nearly the same, both in good condition.
- Binder balls on HMA pavement > WMA pavement (Distribution in all the evaluation sections)
- Pitting on HMA pavement > WMA pavement (Only few pitting were found)
- Shoulders for both projects only treated by fog seal

- Transverse cracking: average severity 3 and extent 2
  - For WMA Project: One transverse reflection cracking was found on the edge of OGFC due to the transverse cracking on the shoulder.
  - For HMA Project, the transverse reflection cracking started to grow on the edge of OGFC.
- Oxidation of OGFC for both projects are almost the same, about 40%-60%.
### Basic Information of the Evotherm Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2011</td>
<td>6</td>
<td>CN 6100430</td>
<td>NM 264</td>
<td>10.6</td>
<td>13.1</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
</tbody>
</table>

1) **Main traffic road:** 2.5" **cold milling** and 2.5" **inlay**, SP-III, PG 70-22.

2) **Standard OGFC** on the top.

3) **QLA** project.

4) Located in **Rural Area** with design **ESALs 2.10 million**.

5) **Mixing Temperature:** 270 °F, Laydown temperature: 230 +/- 22 °F.

6) **Asphalt content:** 4.9%, no **RAP**.
Road Condition after 2 Years and 7 Months

- Comprehensive Evaluation
  - Pavement is still in good condition.
Road Condition after 2 Years and 7 Months

- Problems/Distresses Found on the Project

- Raveling and Weathering
- Reflective Cracking & Joint Cracking

Cracking along the Edge of Pavement after Milling and Inlay

Normal Joint Cracking
Road Condition after 2 Years and 7 Months

- Problems/Distresses Found on the Project

- **Longitudinal Cracking**

- **Binder Balls**

Lots of binder balls last hundred feet of the project
Summaries

- **OGFC** Top of the **WMA** project still in *good condition*.
- **Raveling and weathering** on OGFC: *severity 1* and *extent 1*
- **Longitudinal cracking** on OGFC: *severity 1* and *extent 1*
- **Oxidation of OGFC**: about *60%-70%*
# Field Evaluation Results of WMA Project on NM 118

## Basic Information of the Evotherm Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 2012</td>
<td>6</td>
<td>6100510</td>
<td>NM 118</td>
<td>24.5</td>
<td>27.0</td>
<td>Evotherm</td>
<td>MeadWestvaco</td>
<td>0%</td>
</tr>
</tbody>
</table>

1) Main traffic road: 3" cold milling and 3" WMA inlay, SP-III, PG 70-22.

2) No OGFC on the top.

3) QLA project.

4) Located in Town with design ESALs 3.20 million.

5) Mixing Temperature: 260 °F, Laydown temperature: 230 +/- 22 °F.

6) Asphalt content: 4.3%, no RAP.
Road Condition after 1 Year and 7 Months

- Comprehensive Evaluation
  - Pavement is still in good condition.

The old HMA road appears minor to intermediate cracking and typical bleeding throughout its project.
Road Condition after 1 Year and 7 Months

Problems/Distresses Found on the Project

- Binder Balls
- Segregation
Problems/Distresses Found on the Project

- Transverse Cracking
- Longitudinal Cracking

Road Condition after 1 Year and 7 Months
Road Condition after 1 Year and 7 Months

- Problems/Distresses Found on the Project
  - Moisture Stripping
Field Evaluation Results of WMA Project on NM 118

Summaries

- **WMA** project still in *good condition*.
- **Binder Balls** and **Segregation (near the edge)** throughout the project.
- **Reflective Cracking:**
  - **Transverse Cracking**: *severity 1-2 and extent 1*
  - **Longitudinal Cracking**: *severity 1-2 and extent 1*
- **Oxidation**: *pink color* throughout the project due to the aggregate source.
# Field Evaluation Results of WMA Project on US 60

## Basic Information of the Evotherm Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 2013</td>
<td>6</td>
<td>6100451</td>
<td>US 60</td>
<td>69</td>
<td>73</td>
<td>Evotherm</td>
<td>MeadWestVaco</td>
<td>0%</td>
</tr>
</tbody>
</table>

1) Main traffic road: 3.5" cold milling and 3" WMA inlay, SP-III, PG 76-28 with polymer. Shoulder: existing HMA pavement by fog seal.

2) 0.5" Standard OGFC on the top.

3) non-QLA project.

4) Located in Rural Area with design ESALs 2.90 million.

5) Mixing Temperature: 280 °F, Laydown temperature: 240 +/- 22 °F.

6) Asphalt content: 5.8%, no RAP.
The range of laydown temperatures are around 240 °F to 272 °F.
Road Construction

Pavement just after construction
Road Condition after about 5 months

Comprehensive Evaluation

- Pavement is still in good condition.

Beginning Milepost

Middle Milepost

Ending Milepost

HMA Pavement

WMA Pavement
Road Condition after about 5 months

- Problems/Distresses Found on the Project
  - White Marks & Cinders
  - Transverse Cracking on Shoulders

- Marks left by Snow Plow
- Cinders for De-icing Operation
- Transverse Cracking
Road Condition after about 5 months

- Problems/Distresses Found on the Project
  - Binder Balls
  - Longitudinal Cracking on Shoulders
Summaries

- **WMA** project still in very *good condition*.
- **No distresses** found on the **OGFC** pavement.
- Several **Binder Balls** found on the section around **milepost 70**.
- Distresses on Shoulder:
  - Transverse cracking: *throughout this project*, with **severity 3** and **extent 3**.
  - Longitudinal Cracking: *a few*, with **severity 2** and **extent 1**.
- **Oxidation**: *new* pavement, **no** obvious oxidation.
Field Evaluation of Foaming Projects
## Field Evaluation Results of WMA Project on US 60

### Basic Information of the Foaming Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 2012</td>
<td>6</td>
<td>6100450</td>
<td>US 60</td>
<td>73</td>
<td>76</td>
<td>Foaming</td>
<td>Astec</td>
<td>0%</td>
</tr>
</tbody>
</table>

1) **Main traffic road**: 3" *cold milling* and 3" *WMA inlay*, *SP-III, PG 76-28* with polymer. **Shoulder**: existing *HMA* pavement by fog seal.

2) **Standard OGFC** on the top.

3) **QLA** project.

4) Located in *Rural Area* with design **ESALs 2.50 million**.

5) **Mixing Temperature**: 275 °F, Laydown temperature: 275 +/- 22 °F.

6) **Asphalt content**: 5.7%, no RAP.
Road Condition after around 17 Months

- Comprehensive Evaluation
  - Pavement is still in good condition.
Road Condition after around 17 Months

Problems/Distresses Found on the Project

- Binder Balls
- Pitting
Road Condition after around 17 Months

Problems/Distresses Found on the Project

- Longitudinal Cracking due to underneath Joint
- Longitudinal Cracking on Shoulder
Problems/Distresses Found on the Project

- Transverse Cracking

Road Condition after around 17 Months

Due to Outside Expansive Clay

Connecting to the Longitudinal Cracking

Micro transverse cracking shown on both eastbound and westbound road tends to connect together.
Field Evaluation Results of WMA Project on US 60

**Summaries**

- **WMA project still in good condition.**
- Lots of **Binder Balls** found on the section around **milepost 73**
- Several **Pitting** found at the **beginning** and **end** of the project
- **Distresses on the Edge of OGFC**: Most are reflective cracking.
  - **Transverse Cracking**: *a few*, with **severity 1** and **extent 1**.
  - **Longitudinal Cracking**: *around all the evaluation sections*, with **severity 1** and **extent 1**.
- **Transverse Cracking on the Shoulder**: *throughout the project*, with **severity 2-3** and **extent 2-3**
- **Oxidation**: *pink color* throughout the project due to the aggregate source
Field Evaluation Results of WMA Project on NM 48

### Basic Information of the Foaming Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun. 2013</td>
<td>2</td>
<td>2100200</td>
<td>NM 48</td>
<td>0.000</td>
<td>3.356</td>
<td>Foaming</td>
<td>MAXAM Equipment</td>
<td>25%</td>
</tr>
</tbody>
</table>

1) Main traffic road: 2" cold milling and 2" WMA inlay, SP-IV, PG 76-22.

2) No Standard OGFC on the top.

3) QLA project.

4) Located in Town with design ESALs 3.15 million.

5) Mixing Temperature: 307 °F, Laydown temperature: 287 +/- 22 °F.

6) Asphalt content: 5.4%, with 4.2% virgin asphalt binder.
Road Condition after about 6 Months

**Comprehensive Evaluation**

- Pavement is still in good condition.

Beginning Milepost

Middle Milepost

Ending Milepost
Road Condition after about 6 Months

- Problems/Distresses Found on the Project
  - Binder Balls
  - Segregation
Road Condition after about 6 Months

- Problems/Distresses Found on the Project

  - Pitting
  - Fines picked up
Problems/Distresses Found on the Project

- An Isolated Patching due to Repair of Underground Water Main Leak on the Northbound Road around Milepost 2.5
**Field Evaluation Results of WMA Project on NM 48**

- **Summaries**
  - WMA project in *good condition without any cracking, bleeding & Rutting*.
  - Binder Balls found *throughout* the project, may due to *high laydown T + tight rollers*.
  - Several Pitting & Segregation found with *severity 1* and *extent 1*.
  - Fines picked up lines due to roller picking up asphalt rich fines.
  - Oxidation: *high oxidation* (grey color or the WMA pavement), may due to *high mixing temperature & RAP*.
### Basic Information of the Foaming Project

<table>
<thead>
<tr>
<th>Year</th>
<th>District</th>
<th>Project Number</th>
<th>Highway</th>
<th>Beg MP</th>
<th>Ending MP</th>
<th>WMA Technology</th>
<th>Company</th>
<th>RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr. 2013</td>
<td>4</td>
<td>4100670</td>
<td>I-40</td>
<td>355.0</td>
<td>359.5</td>
<td>Foaming</td>
<td>Terex</td>
<td>0%</td>
</tr>
</tbody>
</table>

1) Driving Lanes: **6.5" cold milling** and **6" WMA inlay**; Passing Lanes: **3.5" cold milling** and **3" WMA inlay**; **SP-III**, **PG 76-22**.

2) **0.5" WMA OGFC** on the top.

3) **QLA** project.

4) Located **in Rural Area** with design **ESALs 44.20 million**.

5) **Mixing Temperature**: **300 °F**, Laydown temperature: **271 +/- 22 °F**.

6) **Asphalt content**: **4.2%**, no **RAP**.
Old HMA Road Condition before WMA Project
New WMA Road Condition after Roadway Rehabilitation
Road Condition after around 8 Months

- Comprehensive Evaluation

- Pavement is in very good condition.

Road Conditions of Outside Shoulder and Traffic Lanes (Westbound Road)

- Beginning Milepost

- Ending Milepost

Road Conditions of Outside Shoulder and Traffic Lanes (Eastbound Road)

- Beginning Milepost

- Ending Milepost
Road Condition after around 8 Months

- Problems/Distresses Found on the Project

- **Transverse Cracking**
  - Lots of sealed transverse cracks on Existing HMA Pavement

- **Binder Ball**
Road Condition after around 8 Months

- Problems/Distresses Found on the Project

- Works done on the WMA Shoulder around the End of Project
Field Evaluation Results of WMA Project on I-40

- **Summaries**

  - **WMA OGFC** in *very good condition without any distresses*.
  - Only **one Binder Ball** found on the WMA shoulder
  - A few **Transverse Cracks** (reflective cracking) found on the **WMA Shoulder**, with *severity 1* and *extent 1*
  - Sealed **Transverse Cracking** found on the **Existing HMA** (outside the WMA shoulder) throughout the project with *severity 3* and *extent 3*
  - **Oxidation**: No obvious *oxidation*, very *black* color of *traffic lanes*; **WMA shoulder** oxidized *a little bit*. 
Conclusions & Discussions
## Conclusions

### Summary of Field Survey

<table>
<thead>
<tr>
<th>Technology</th>
<th>WMA Project [RAP content (%)]</th>
<th>Old</th>
<th>OGFC</th>
<th>WMA Thickness (in.) [ESAL (million)]</th>
<th>Overall Condition</th>
<th>Pavement Traffic Lanes</th>
<th>Pavement edge</th>
<th>Pavement Shoulder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evotherm</td>
<td>I-25 [25]</td>
<td>2 yrs 4 mons</td>
<td>Yes</td>
<td>3 [10.10]</td>
<td>Good</td>
<td>•Binder ball</td>
<td>•Transverse cracking</td>
<td>•Transverse cracking</td>
</tr>
<tr>
<td></td>
<td>NM264 [0]</td>
<td>2 yrs 7 mons</td>
<td>Yes</td>
<td>2.5 [2.10]</td>
<td>Good</td>
<td>•Raveling, •Weathering, •Longitudinal cracking</td>
<td>•Reflective cracking</td>
<td>•No cracking</td>
</tr>
<tr>
<td></td>
<td>NM118 [0]</td>
<td>1yr 7 mons</td>
<td>No</td>
<td>3 [3.20]</td>
<td>Good</td>
<td>•Binder ball, •Transverse cracking, •Stripping</td>
<td>•Segregation</td>
<td>•None</td>
</tr>
<tr>
<td></td>
<td>US60 [0]</td>
<td>5 mons</td>
<td>Yes</td>
<td>3 [2.90]</td>
<td>Good</td>
<td>•Binder ball</td>
<td>•None</td>
<td>•Transverse cracking, •Longitudinal cracking</td>
</tr>
<tr>
<td></td>
<td>NM48 [25]</td>
<td>6 mons</td>
<td>No</td>
<td>2 [3.15]</td>
<td>Good</td>
<td>•Binder ball, •Segregation, •Oxidation</td>
<td>•None</td>
<td>•None</td>
</tr>
<tr>
<td>Foaming</td>
<td>I-40 [0]</td>
<td>8 mons</td>
<td>Yes</td>
<td>6 for driving lanes, 3 for passing lanes [44.20]</td>
<td>Good</td>
<td>•Binder ball</td>
<td>•Transverse cracking</td>
<td>•Transverse cracking</td>
</tr>
<tr>
<td></td>
<td>US60 [0]</td>
<td>1 yr 5 mons</td>
<td>Yes</td>
<td>3 [2.50]</td>
<td>Good</td>
<td>•Binder ball, •Transverse cracking</td>
<td>•Longitudinal cracking</td>
<td>•None</td>
</tr>
<tr>
<td>Control</td>
<td>HMA I-25 [0]</td>
<td>2 yrs 4 mons</td>
<td>Yes</td>
<td>3 [10.10]</td>
<td>Good</td>
<td>•Binder ball</td>
<td>•Transverse cracking</td>
<td>•Transverse cracking</td>
</tr>
</tbody>
</table>

*Notes:*
- [RAP content (%)]: Percentage of Reclaimed Asphalt Pavement content in the mixture.
- [ESAL (million)]: Equivalent Single Axle Load in millions.
- [Condition]: Overall condition of the pavement, coded as Good.
- [Transverse cracking]: Condition of the pavement edge.
- [Transverse cracking]: Condition of the pavement shoulder.
Overall, WMA performed well.

Sections with OGFC performed well than non OGFC sections.

Most Pavements have cracks on the edge and shoulders due to cracks reflected from old pavements.

No clear distinction between Evotherm WMA and Foamed WMA.
The WMA project on I-25 performances *similarly to* the control HMA project on I-25.
Evotherm vs. Foaming

Distresses & Oxidation

- (Comparison between two WMA pavements without OGFC: NM 118 & NM 48)
- NM 118 (Evotherm) & NM 48 (Foaming) show similar distresses.
- Much severe Oxidation of NM 48 (Foaming) due to higher mixing T
Mixing & Laydown Temperatures

- Mixing and laydown temperatures of the Foaming projects are much higher than the Evotherm project.
Evotherm vs. Foaming

- **Tensile Strength Ratio (TSR)**

- **TSR of Foaming WMA > TSR of Evotherm WMA**

- **Further research** is needed to compare the *moisture sensitivity* and *stripping potential* of the two WMA technologies is necessary due to *higher mixing T & laydown T* of the *Foaming* projects.
Discussions

- Not Accurate *Field Evaluation* of WMA Projects due to OGFC

- Difficulties in Comparisons between *Foaming* & *Evotherm*
  - Different *Asphalt Content* & *Aggregate Source*
  - Different *Service Lengths*

- Difficulties to determine best WMA technology for NM
  - Difficulty in cost evaluation at the initial stage
  - Difficulty in comparisons of different WMA technologies in such a short service length
  - Lack of lab test results

- Further *Lab Testing* is needed for better comparing *Foaming* & *Evotherm* technologies.
Evaluation of WMA Using Pavement Management Data

- Methodology
- WMA Condition Data Analysis
- PSI Values
- Remarks from Pavement Management Data Analysis
Data collection: automatic survey vehicles

Two Measure

- Roughness: International Roughness Index (IRI)
- Pavement Distresses (8 types): raveling and weathering, bleeding, longitudinal cracking, transverse cracking, fatigue cracking, edging cracking, patching, and rutting.

Criteria for the first 7 types of distresses: NMDOT’s distress evaluation chart for flexible pavements.

Criteria for rutting

<table>
<thead>
<tr>
<th>Rut Depth</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate (high traffic volume)</td>
<td>NM and US Roads (low traffic volume)</td>
</tr>
<tr>
<td>0 – 0.125 in.</td>
<td>0 – 0.125 in.</td>
</tr>
<tr>
<td>0.125 in. – 0.25 in.</td>
<td>0.125 in. – 0.25 in.</td>
</tr>
<tr>
<td>0.25 in. – 0.50 in.</td>
<td>0.25 in. – 0.50 in.</td>
</tr>
<tr>
<td>&gt;0.50 in.</td>
<td>&gt;0.65 in.</td>
</tr>
</tbody>
</table>
Methodology

Pavement Serviceability Index (PSI)

The empirical expressions for PSI calculation are given below:

\[ \text{PSI} = 0.041666 X, \quad \text{if } X \leq 60 \]  \hspace{2cm} (1)

or

\[ \text{PSI} = [0.0625(X - 60)] + 2.4999, \quad \text{if } X > 60 \]  \hspace{2cm} (2)

where \( X \) is given by

\[ X = 100 - [(0.6(\text{IRI} - 25) + (0.4\text{DR}))/2.9] \]  \hspace{2cm} (3)

where IRI is International Roughness Index, and DR is the Distress Rate defined as

\[ \text{DR} = \sum_{i=1}^{n} [(\text{Severity Rating}_i)(\text{Extent Factor}_i)(\text{Weight Factor}_i)] = \sum_{i=1}^{n} (\text{DR}_i) \]  \hspace{2cm} (4)
<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Weight Factor</th>
<th>Extent Level</th>
<th>Extent Rating</th>
<th>Extent Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raveling and Weathering</td>
<td>3</td>
<td>Low</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Bleeding</td>
<td>2</td>
<td>Low</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>Low</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Rutting and Shoving</td>
<td>14</td>
<td>Low</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Longitudinal Cracking</td>
<td>9</td>
<td>Low</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Transverse Cracking</td>
<td>12</td>
<td>Low</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Alligator Cracking</td>
<td>25</td>
<td>Low</td>
<td>1</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Edge Cracking</td>
<td>3</td>
<td>Low</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
<tr>
<td>Patching</td>
<td>2</td>
<td>Low</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium</td>
<td>2</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High</td>
<td>3</td>
<td>1.0</td>
</tr>
</tbody>
</table>

NMDOT’s Ranking of Pavement Condition Based on PSI Values

<table>
<thead>
<tr>
<th>New Mexico PSI Range</th>
<th>Pavement Condition</th>
<th>Interstate Highways</th>
<th>Non-Interstate Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00 ≤ PSI ≤ 5.00</td>
<td>Very Good</td>
<td>Non-deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>3.00 ≤ PSI &lt; 4.00</td>
<td>Good</td>
<td>Non-deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>2.50 ≤ PSI &lt; 3.00</td>
<td>Fair</td>
<td>Deficient</td>
<td>Non-deficient</td>
</tr>
<tr>
<td>1.00 ≤ PSI &lt; 2.50</td>
<td>Poor</td>
<td>Deficient</td>
<td>Deficient</td>
</tr>
<tr>
<td>0.00 ≤ PSI &lt; 1.00</td>
<td>Very Poor</td>
<td>Deficient</td>
<td>Deficient</td>
</tr>
</tbody>
</table>
WMA Condition Data Analysis

- **WMA Pavements service lengths: ≤ 3 years**

<table>
<thead>
<tr>
<th>Evotherm</th>
<th>Construction Date</th>
<th>Evaluation Date</th>
<th>Service Length</th>
<th>Foaming</th>
<th>Construction Date</th>
<th>Evaluation Date</th>
<th>Service Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>I 25</td>
<td>2011.8</td>
<td>2013.9</td>
<td>2.08 years</td>
<td>NM 48</td>
<td>2013.6</td>
<td>2013.9</td>
<td>0.25 year</td>
</tr>
<tr>
<td>NM 264</td>
<td>2011.5</td>
<td>2013.11</td>
<td>2.5 years</td>
<td>I 40</td>
<td>2013.4</td>
<td>2014.1</td>
<td>0.75 year</td>
</tr>
<tr>
<td>NM 118</td>
<td>2012.5</td>
<td>2013.11</td>
<td>1.5 years</td>
<td>US 60</td>
<td>2012.7</td>
<td>2013.9</td>
<td>1.17 years</td>
</tr>
</tbody>
</table>

- **Pavement Roughness (IRI)**

![Graph showing Pavement Roughness (IRI)]
WMA Condition Data Analysis

- **Raveling and Weathering**
  - All the WMA projects have shown to have the same raveling and weathering distress rate, which is 3, along with severity 1 and extent 3.

- **Bleeding**
  - The bleeding distress rates of all the six WMA projects are calculated to be 0, with an exception to the evotherm project on NM 118 P (positive direction). The distress rate of bleeding on this evotherm pavement is found towards the end of the project to with severity 1 and extent 1.

- **Edge Cracking**
  - All the WMA pavements have no edge cracking as expectation except Foaming project on I 40 P. The edge cracking on I 40 P was found towards the end of the project with severity 1 and extent 1.
WMA Condition Data Analysis

**Patching**

- The distress rates of patching on the six WMA projects were found to be 0 with the exception of the evotherm project on NM 264 M (minus direction) with severity 1 and extent 1.

**Transverse Cracking**
WMA Condition Data Analysis

- **Fatigue Cracking**
- **Longitudinal Cracking**

![Fatigue Cracking Chart](chart1)

- **Rutting**

![Rutting Chart](chart2)

**NOTE:** 1 in. = 25.4 mm
PSI Values

Average PSI Value per Mile on I 25 (Evotherm Pavement)

Average PSI Value per Mile on NM 264 (Evotherm Pavement)
PSI Values

Average PSI Value per Mile on NM 118 (Evotherm Pavement)

Average PSI Value per Mile on NM 48 (Foaming Pavement)
PSI Values

Average PSI Value per Mile on I 40 (Foaming Pavement)

Average PSI Value per Mile on US 60 (Foaming Pavement)
Remarks from Pavement Management Data Analysis

- **Distresses**
  - No significant difference in IRI values between WMA and HMA
  - No bleeding, edge cracking, and patching observed for most WMA
  - Same raveling and weathering distress rate for all the WMA and HMA
  - No obvious difference between WMA and WMA-RAP pavements except less longitudinal cracking of WMA-RAP
  - Foamed WMA pavements performed slightly better than the evotherm WMA pavements except for fatigue life.
  - HMA pavement performed better than WMA pavements.

- **PSI**
  - HMA performed slightly better than foamed WMA, which performed slightly better than evotherm WMA.
Review of WMA Performances

- Mix Design Tests
- Rut Testing
- Dynamic Modulus Testing
- Fatigue Cracking Testing
- Low Temperature Testing
- Moisture Susceptibility Testing
- Other WMA Performance Testing
Mix Design Tests

- **Laboratory Mixer**
  - NCHRP Project 9-43 required either a planetary or a bucket mixer should be used for sample preparation.
  - NCHRP Project 9-43 suggested a laboratory scale asphalt foaming device to simulate plant WMA foaming processes. NCHRP Project 9-47A states an option of using mix produced during a trial run at an asphalt plant.

- **Mix Volumetrics**
  - Missouri, Ohio, and Wisconsin State DOTs showed that WMA has lower air voids than HMA.
  - NCHRP Project 9-47A indicated no need to reduce asphalt content during mix design due to similar asphalt absorption of WMA and HMA over time.
Mix Design Tests

- Laboratory Testing Protocols
  - NCHRP Project 9-43, 9-47, and 9-49 in conjunction with the AASHTO Highway Subcommittee on Materials, the FHWA, and the NAPA recommended a core set of criteria, methods, and protocols for WMA studies.
Rut Testing

Methods

- Asphalt Pavement Analyzer (APA) test, Hamburg Wheel Tracking Device (HWTD) test, and Flow Number (FN) test.

APA  HWTD  Material Testing System (MTS) for FN Test
Rut Testing

- WMA Rutting Resistance Evaluated by State DOTs
  - Most results showed that rutting resistance of WMA are equal to or slightly lower than HMA.
Dynamic Modulus Testing

- **Methods**
  - AASHTO TP 79
  - Indirect tension (IDT) resilient modulus, Spectral analysis of seismic waves (SASW) testing for plant-mixed and field-compacted specimens

- **Dynamic Modulus (E*) of WMA**
  - Studies from State DOTs and researchers showed that dynamic modulus for most WMA is smaller than HMA.
Fatigue Cracking Testing

- **Methods**
  - Dynamic Mechanical Analyzer (DMA) for fine aggregate matrix (FAM)
  - Beam Fatigue Test (BFT)
  - Overlay Test

**Beam Flexural Fatigue Apparatus by GCTS Testing Systems**

**Schematic of Overlay Test**
Fatigue Cracking Testing

- Fatigue Cracking of WMA
  - Studies from State DOTs showed that fatigue cracking resistance of most WMA mixtures are better than HMA mixtures.
Low Temperature Cracking

Methods
- IDT test, AASHTO T 322
- Semi-circular bending (SCB) test

Low Temperature Cracking of WMA
- Studies from State DOTs and researchers showed that low temperature cracking resistance of WMA is equal to or better than HMA.
Moisture Susceptibility Testing

Methods
- TSR test, AASHTO T 283
- HWTD test

Moisture Susceptibility of WMA
- Study from NCHRP Project 9-49 showed that the studied state DOTs’ WMA pavements do not experience failure or distress from moisture damage so far.
- Also compared to HMA, WMA pavements are more susceptible to moisture-related damage during early life.
- The difference between WMA and HMA decreases as WMA experience aging.
Other WMA Performance Testing

- **Workability and Compactability of WMA**
  - Methods: NCHRP suggested coating evaluation is enough without workability evaluation. Compactability should be evaluated using gyratory compactor.
  - Performance: Better coating and compactability than HMA

- **WMA with RAP Incorporation**
  - Methods: rutting, moisture susceptibility, fatigue cracking, and low temperature cracking tests, etc.
  - Performance:
    - Improvement of rutting resistance and moisture damage resistance
    - Longer fatigue life
    - Reduction of low temperature cracking resistance
Other WMA Performance Testing

- Oxidative aging of WMA
  - Methods: binder testing
  - Performance: reduction of short-term aging and binder stiffness

- WMA OGFC
  - Methods: Compaction, permeability, abrasion resistance, dynamic modulus, and IDT tests, etc.
  - Conclusions:
    - Higher RAP content can be used
    - Fibers can be removed based on improved performance on permeability and aged abrasion resistance.
Conclusions and Recommendations

- Conclusions
- Recommendations for Phase II
Conclusions

- Mix design procedures for WMA and HMA are similar. There are some differences:
  - Additional information: WMA process, additive dosage, planned production and compaction temperatures.
  - Higher high-temperature grade for RAP binder than compaction temperature of WMA
  - Low-temperature grade improvement of WMA using blending charts
  - Necessary evaluation tests for: coating, compactability, rutting and moisture susceptibility

- Questionnaire and field survey:
  - High mixing and laydown temperatures of foaming WMA projects (>300 °F for mixing), which might affect the WMA pavement performances
Conclusions

- Questionnaire and field survey (continued):
  - It is difficult to determine the best WMA technology for NM because pavements evaluated were new, covered by OGFC and visual inspection was used as the evaluation tool.
  - WMA pavements evaluated perform well so far.
  - No enough laboratory and field testing data available now for WMA evaluation

- Evaluation of WMA projects using pavement management data:
  - HMA performed slightly better than foamed WMA, which performed slightly better than evotherm WMA.
  - This result is limited by the OGFC layer covering WMA layer in the field.
Conclusions

- Review of WMA performances:
  - No reduction in asphalt content for WMA mix design.
  - Rutting resistance of WMA is equal to or slightly lower than HMA.
  - Most dynamic modulus of WMA mix is smaller than HMA.
  - Fatigue cracking resistance of most WMA is equal to or better than HMA.
  - Low temperature cracking resistance of most WMA is equal to or better than the HMA.
  - WMA is more susceptibility to moisture damage during early life as compared to HMA. The differences decreases as WMA experience aging.
Conclusions

Review of WMA performances (continued):

- Coating is enough to evaluate WMA workability.
- Compactability of WMA should be evaluated by gyratory compactor at 92% relative density under the field compaction temperature and temperature at 54 °F lower than it.
- RAP in WMA can improve fatigue cracking, moisture and rutting resistance of WMA. However, there is an opposite effect of RAP on low temperature cracking of WMA.
- WMA additives reduce short-term aging of WMA and also slow down the growing rate of binder stiffness over time.
- WMA OGFC can contain higher RAP percentage. Fibers could be removed from OGFC based on the improved performance on permeability and aged abrasion resistance.
Recommendations

Long term performances of WMA need to be evaluated in the laboratory before NMDOT makes significant field investments in WMA paving.

- For WMA binder and mixtures:
  - Laboratory testing for the evaluations of coating, compactability, rutting resistance, and moisture susceptibility at least to understand the effects of different water injection rate, additive dosage, mixing and compaction temperatures, binder and aggregate types on the properties of WMA.

- For WMA pavements:
  - Field testing such as FWD, field survey, and permeability, and so on should be conducted to evaluate the physical properties of WMA.
  - Field cores need to be gathered for further laboratory testing such as rutting, modulus, fatigue, low temperature, and moisture susceptibility tests.
Recommendations for Phase II

- Field cores testing for foaming WMA projects with high production and compaction temperature as well as non-destructive testing of field pavements to examine the effect of high temperatures.

- A comprehensive study to differentiate the stripping and oxidative performance between evotherm and foaming WMA technologies in NM.

- Determination of asphalt binder film thickness of evotherm and foaming technologies by taking cores from the WMA projects evaluated in Phase 1.

- Conduct dynamic modulus, creep, drain-down, etc. laboratory tests to investigate the effect of RAP on WMA and WMA OGFC as well as field tests such as FWD and GPR.

- Other WMA technologies except evotherm and foaming should be encouraged to implement in NM and to be tested.
Acknowledgements

The authors would like to thank the Project Advocates Mr. James Gallegos and Mr. Parveez Anwar, Project Manager Mr. Virgil Valdez, and the Project Technical Panel Mr. Jeff Mann, Ms. Kelly R. Montoya, Mr. Cliff Lucas, Mr. Bryce Simons of NMDOT and Mr. Shawn Hammer of Fisher Sand & Gravel Co. for their support and guidance. Thanks go to Mr. Jerry Hickman at District 2, Mr. Kenneth Murphy at District 3, Mr. David Gonzales at District 4, Mr. Frank Salazar, Mr. Donald R. Abeyta, Mr. Morris H. Williams, and Mr. Johnny Gallegos at District 6 for their participations in written surveys, emails, and for providing information of selected WMA projects.

The authors would like to thank Mr. Mohammad Moabed and Mr. Bob Hicks of HollyFrontier Refining & Marketing LLC., Mr. Mike O’Leary of MeadWestvaco Corporation and Mr. Shawn Hammer of Fisher Sand & Gravel Co. for participating in the field evaluation trips of WMA projects and sharing their expertise.

The authors also extend their thanks to Mr. Melgoza of the New Mexico Division Office of the Federal Highway Administration (FHWA).

This research project was funded by the NMDOT Research Bureau in cooperation with the FHWA.
Thank You!