Green Sustainable Thin Lift Overlays as a Pavement Preservation Strategy

Northeast Pavement Preservation Partnership Meeting
Boston, MA

November 9th, 2011
8:30 - 9:00 AM

By:

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MassDOT Highway Division

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Highway Sustainability Research Center (HSRC)

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MassDOT Highway Division
Acknowledgements

The following people have been instrumental in completing the research presented here:

Mr. Alexander Austerman, P.E. - UMass Dartmouth HSRC

Mr. Mike Roussel - UMass Dartmouth HSRC

Dr. Robert Kluttz - Kraton Polymers

Mr. Mike Nichols - Aggregate Industries

Mr. Pat Mitchell - Hudson Liquid Asphalt

Mr. Chris Strack - Sonneborn, Inc.
Overall Scope of Research

Develop Economical & Eco-conscious Mixtures by using High Contents of Sustainable Materials and WMA. Mixtures must Perform Similar to 100% Virgin Material Mixtures.
## Projects

<table>
<thead>
<tr>
<th>Year</th>
<th>Mixture Type</th>
<th>Recycled Materials</th>
<th>Binder</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007 - 2009</td>
<td>Superpave 4.75mm &amp; MassDOT Surface Treatment</td>
<td>0% RAP</td>
<td>PG52-34</td>
<td>Mixtures Included WMA Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15% RAP</td>
<td>PG64-28</td>
<td>Sasobit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30% RAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>50% RAP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010 - 2011</td>
<td>Superpave 9.5mm Mixture</td>
<td>0% RAP</td>
<td>PG52-28</td>
<td>Mixtures Repeated with WMA Technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40% RAP</td>
<td></td>
<td>SasneWarmix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5% RAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>35% RAP + 5% RAS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010 - 2011</td>
<td>12.5mm Asphalt Rubber Gap Graded (ARGG) Mixture</td>
<td>0% RAP</td>
<td>Asphalt Rubber (PG52-28 + 17% Rubber)</td>
<td>Mixtures Repeated with WMA Technology</td>
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<tr>
<td></td>
<td></td>
<td>25% RAP</td>
<td></td>
<td>SasneWarmix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40% RAP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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### Projects

<table>
<thead>
<tr>
<th>Year</th>
<th>Mixture Type</th>
<th>Recycled Materials</th>
<th>Binder</th>
<th>WMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Superpave 9.5mm Mixture</td>
<td>0% RAP 40% RAP</td>
<td>PG52-28 PG52-28 + Bio-Binder</td>
<td>Evaluating Bio-Binder as WMA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>Superpave 9.5mm Mixture</td>
<td>0% RAP 40% RAP</td>
<td>PG 52-28 PG 64-34 PG 70-22 + 7.5% SBS PG 58-28 + 7.5% SBS 200 PEN + 7.5% SBS</td>
<td>Mixtures Repeated with WMA Technology SonneWarmix</td>
</tr>
</tbody>
</table>
Experimental Plan

- **RAP Contents**
  - 0% - Control
  - 15%
  - 30%
  - 50%

- **Mixture Designs**
  - Superpave 4.75mm
  - MassDOT Surface Treatment

- **Virgin Binders**
  - PG64-28
  - PG52-33
  - PG52-33 (w/latex)

- **Field Trial**
  - Superpave 4.75mm w/30% RAP
  - PG52-33 w/1.5% Latex & 1.5% Sasobit®

- **Mixture Evaluation**
  - Mixture Workability
    - Asphalt Workability Device
  - Mixture Stiffness
    - Dynamic Modulus |E*|
    - Testing in the AMPT

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# Superpave 4.75mm Mix Volumetrics

<table>
<thead>
<tr>
<th>Volumetric Properties PG64-28 w/1.5% Sasobit®</th>
<th>0% RAP</th>
<th>15% RAP</th>
<th>30% RAP</th>
<th>50% RAP</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Virgin Binder Added</td>
<td>7.0</td>
<td>5.8</td>
<td>4.3</td>
<td>2.3</td>
<td>-</td>
</tr>
<tr>
<td>% Extracted Binder</td>
<td>7.0</td>
<td>7.2</td>
<td>6.8</td>
<td>6.4</td>
<td>-</td>
</tr>
<tr>
<td>% Air Voids</td>
<td>4.6</td>
<td>4.0</td>
<td>4.0</td>
<td>4.1</td>
<td>4.0%</td>
</tr>
<tr>
<td>% VMA</td>
<td>19.5</td>
<td>19.0</td>
<td>17.7</td>
<td>16.5</td>
<td>16-18%</td>
</tr>
<tr>
<td>% VFA</td>
<td>76.3</td>
<td>78.7</td>
<td>77.4</td>
<td>75.0</td>
<td>65-78%</td>
</tr>
<tr>
<td>Dust-to-Binder Ratio</td>
<td>1.15</td>
<td>1.07</td>
<td>1.36</td>
<td>1.63</td>
<td>0.9-2.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volumetric Properties PG52-33 w/1.5% Sasobit®</th>
<th>6.8</th>
<th>5.5</th>
<th>4.0</th>
<th>2.2</th>
<th>-</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Virgin Binder Added</td>
<td>6.8</td>
<td>5.5</td>
<td>4.0</td>
<td>2.2</td>
<td>-</td>
</tr>
<tr>
<td>% Extracted Binder</td>
<td>6.7</td>
<td>6.6</td>
<td>6.4</td>
<td>6.2</td>
<td>-</td>
</tr>
<tr>
<td>% Air Voids</td>
<td>4.0</td>
<td>3.7</td>
<td>3.2</td>
<td>4.5</td>
<td>4.0%</td>
</tr>
<tr>
<td>% VMA</td>
<td>18.8</td>
<td>16.5</td>
<td>16.0</td>
<td>16.8</td>
<td>16-18%</td>
</tr>
<tr>
<td>% VFA</td>
<td>78.7</td>
<td>77.8</td>
<td>80.2</td>
<td>73.3</td>
<td>65-78%</td>
</tr>
<tr>
<td>Dust-to-Binder Ratio</td>
<td>1.17</td>
<td>1.27</td>
<td>1.59</td>
<td>1.65</td>
<td>0.9-2.0</td>
</tr>
</tbody>
</table>
Field Trial

- Field trial of Superpave 4.75mm with 30% RAP utilizing the PG52-33 with 1.5% latex and 1.5% Sasobit® binder.

- Mixture placed in one ¾” lift on a 1,100 foot long by 24 foot wide roadway at the town of recycling center.

- Roadway is subject to heavy loading from waste trucks.

- No issues with laydown, compaction, or workability during construction.

- Examined for visual distress in April 2009 and longitudinal and transverse cracking noted.
Main Project Findings

* The stiffness of the mixtures increased as the amount of RAP increased.

* The addition of the RAP caused a reduction in each mixtures workability.

* Mixtures placed at the main field trial, a heavily truck trafficked recycling center, exhibited transverse (thermal) cracking and limited longitudinal cracking isolated to an uphill incline section of the project after 19 months in service.
“Performance Characteristics of Thin Lift Overlay Mixtures Containing High RAP Content, RAS, and Warm Mix Asphalt Technology”
Project Scope

9.5mm Thin Lift Overlay Mixture

Reclaimed Asphalt Pavement

Recycled Asphalt Shingles (RAS)

Looking at Use of Each Material Both Individually and Collectively

Warm Mix Asphalt Technology

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Experimental Plan

- PG52-28 Binder
- Virgin Aggregates

Superpave 9.5mm Mixture

- Control Mixture [No RAP or RAS]
- 40% RAP Mixture
- 5% RAS Mixture
- 35% RAP + 5% RAS Mixture

Mixtures Prepared without WMA Technology
Mix: 144°C (291°F)
Age/Compact: 132°C (270°F)

Extract Binder from Each Mixture

Mixtures Prepared with WMA Technology
Mix: 124°C (255°F)
Age/Compact: 112°C (235°F)

Performance Testing

- Reclaimed Asphalt Pavement (RAP)
- Recycled Asphalt Shingles (RAS)

WMA Technology
1.0% SonneWarmix

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Experimental Plan (Cont’d)

Performance Testing

- Mixture Stiffness
  - Dynamic Modulus $|E^*|$
  - Testing

- Moisture Susceptibility
  - Hamburg Wheel Tracking Device (HWTD)

- Reflective Cracking
  - Overlay Tester

- Low Temperature Cracking
  - Asphalt Concrete Cracking Device (ACCD)

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## Mixture Volumetrics – Without WMA Technology

<table>
<thead>
<tr>
<th>Properties</th>
<th>Control</th>
<th>40% RAP</th>
<th>5% RAS</th>
<th>35% RAP + 5% RAS</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Binder Content, %</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>Virgin Binder Added, %</td>
<td>6.0</td>
<td>3.6</td>
<td>5.1</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>Air Voids, %</td>
<td>3.9</td>
<td>4.2</td>
<td>3.7</td>
<td>4.2</td>
<td>4.0%</td>
</tr>
<tr>
<td>VMA, %</td>
<td>16.2</td>
<td>16.1</td>
<td>16.0</td>
<td>15.9</td>
<td>15% min.</td>
</tr>
<tr>
<td>VFA, %</td>
<td>76.3</td>
<td>73.8</td>
<td>76.8</td>
<td>73.8</td>
<td>65-78</td>
</tr>
<tr>
<td>Dust to Binder Ratio</td>
<td>0.82</td>
<td>0.89</td>
<td>0.86</td>
<td>1.01</td>
<td>0.6 -1.2</td>
</tr>
</tbody>
</table>

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## Mixture Volumetrics - with WMA Technology

<table>
<thead>
<tr>
<th>Properties</th>
<th>Control + 1% WMA</th>
<th>40% RAP + 1% WMA</th>
<th>5% RAS + 1% WMA</th>
<th>35% RAP + 5% RAS + 1% WMA</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Binder Content, %</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>Virgin Binder Added, %</td>
<td>6.0</td>
<td>3.6</td>
<td>5.1</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>Air Voids, %</td>
<td>3.9</td>
<td>3.8</td>
<td>4.4</td>
<td>4.7</td>
<td>4.0%</td>
</tr>
<tr>
<td>VMA, %</td>
<td>16.7</td>
<td>15.7</td>
<td>16.8</td>
<td>16.4</td>
<td>15% min.</td>
</tr>
<tr>
<td>VFA, %</td>
<td>76.9</td>
<td>75.7</td>
<td>74.2</td>
<td>71.6</td>
<td>65-78</td>
</tr>
<tr>
<td>Dust to Binder Ratio</td>
<td>0.78</td>
<td>0.90</td>
<td>0.84</td>
<td>1.00</td>
<td>0.6 -1.2</td>
</tr>
</tbody>
</table>

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Performance Testing

- Testing conducted to determine changes in mixture performance due to incorporation of RAP, RAS and/or the WMA Technology.

1. Stiffness – Dynamic Modulus in AMPT
2. Reflective Cracking – Texas Overlay Tester
3. Low Temperature Cracking – ACCD
4. Moisture Susceptibility/Rutting – HWTD
Main Project Findings

- Dynamic modulus testing indicated that the incorporation of high RAP content and/or RAS caused an increase in the stiffness of the mixtures.

- Mixtures incorporating the WMA technology showed generally lower dynamic modulus values than the mixture without the technology.

- Reflective cracking results indicated that mixtures incorporating the RAP and/or RAS had reduced reflective cracking resistance as compared to the control.
Main Project Findings

- Low temperature cracking resistance test results indicated that the addition of RAP, RAS and/or WMA technology did not have a negative impact on the low temperature performance of the mixtures.

- Moisture susceptibility results indicated, for the majority, that the mixtures incorporating RAP and/or RAS had improved moisture susceptibility relative to the control mixtures.
“Performance Characteristics of Asphalt Rubber Mixtures Containing RAP and Warm Mix Asphalt Technology”
Project Scope - Green Design

- Reclaimed Asphalt Pavement
- Crumb Rubber from Waste Tires
- Warm Mix Asphalt Technology - Wax Based

12.5mm Asphalt Rubber Mixture

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Experimental Plan

Asphalt Rubber (AR) Binder

12.5mm Asphalt Rubber Mixture

- Reclaimed Asphalt Pavement (RAP)
-Virgin Aggregates

Mixtures Prepared without WMA Technology
Mix: 177°C (351°F)
Age/Compact: 154°C (309°F)

Mixtures Prepared with WMA Technology
Mix: 160°C (320°F)
Age/Compact: 141°C (286°F)

- Control Mixture [No RAP]
- 25% RAP Mixture
- 40% RAP Mixture

WMA Technology 1.0% SonneWarmix

Mixture Testing
Experimental Plan (Cont’d)

Performance

Mixture Stiffness
Dynamic Modulus $|E^*|$ Testing

Fatigue
1. Beam Fatigue
2. Uniaxial Fatigue

Cracking Resistance
Overlay Tester

Moisture Susceptibility/Rutting
Hamburg Wheel Tracking Device (HWTD)

Mixture Testing

Other

Workability
UMass Dartmouth Asphalt Workability Device

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Mixture Testing

- Testing conducted to determine changes in mixture performance due to incorporation of Asphalt Rubber binder, RAP and/or the WMA Technology.

1. Stiffness – Dynamic Modulus in AMPT
2. Fatigue – Beam Fatigue & Uniaxial Fatigue
3. Reflective Cracking – Texas Overlay Tester
4. Moisture Susceptibility/Rutting – HWTD
5. Workability – AWD
Main Project Findings

- The dynamic modulus and mixture master curve data indicated that addition of 25% and 40% RAP to the control mixture resulted in an increase in mixture stiffness. This stiffness increase was mitigated through the use of the WMA technology and corresponding reduced aging temperatures.

- The push-pull test and beam fatigue test showed similar trends and correspondingly showed good agreement between them. The fatigue life of the mixtures improved as the RAP content increased.
“Performance Characteristics of High RAP Bio-Modified Asphalt Mixtures”
Project Scope – Green Design

9.5mm Thin Lift Overlay Mixture

Reclaimed Asphalt Pavement

Bio - Modified Binder

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Experimental Plan

PG52-28 Binder

Virgin Aggregates

Superpave 9.5mm Mixture

Control Mixture [No RAP]

PG52-28 Binder + 5% Bio-Oil (Bio-Modified Binder)

Reclaimed Asphalt Pavement (RAP)

Control Mixture + Bio-Modified Binder

40% RAP Mixture + Bio-Modified Binder

Testing

Mixture Stiffness
Dynamic Modulus |E*| Testing

Moisture Susceptibility & Rutting
Hamburg Wheel Tracking Device (HWTD)

Cracking Overlay Tester

Workability
UMass Dartmouth Asphalt Workability Device

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Performance Testing

Testing conducted to determine changes in mixture performance due to incorporation of RAP, RAS and/or the WMA Technology.

1. Stiffness – Dynamic Modulus in AMPT
2. Cracking – Texas Overlay Tester
3. Moisture Susceptibility/Rutting – HWTD
4. Workability – AWD
Main Project Findings

- 9.5 mm mixtures incorporating a bio-modified binder with and without 40% RAP were able to be developed to meet Superpave specifications.

- The introduction of the bio-modified binder decreased the mixture stiffness for both the control and 40% RAP mixtures and therefore indicated that the bio-modified binder, at reduced mixing and compaction temperatures, can help reduce the stiffening effects caused by the introduction of high percentages of RAP.
Main Project Findings

- The addition of the bio-modified binder to the mixtures showed improvement in the cracking susceptibility of the control and 40% RAP mixture.

- The HWTD rutting and moisture susceptibility data suggested that the use of a bio-modified binder in conjunction with high percentages of RAP performed similarly or better than a similar mixture fabricated with the virgin binder and better than the control mixture without RAP and virgin binder.
“Performance and Workability Characteristics of High Performance Thin Lift Overlays Incorporating High RAP Content and Warm Mix Asphalt Technology”
HPThinOL

High Performance Thin Asphalt Overlays (HPThinOL) are defined as having a thickness of one inch or less and are used in applications requiring higher levels of rutting and fatigue resistance.

HPThinOL are used as a pavement preservation strategy and are placed on pavements that have remaining structural capacity that is expected to outlive the pavement preservation strategy.

Current specifications for HPThinOL generally require a Polymer Modified Asphalt (PMA).

Sustainable HPThinOL incorporate high RAP content (40%), a WMA technology, and PMA binders.
Project Scope

9.5mm Thin Lift Overlay Mixture

Reclaimed Asphalt Pavement

Polymer Modified Asphalt (PMA)

Warm Mix Asphalt Technology
Project Objectives

- Measure the effect of RAP, WMA technology, and PMA binders on the dynamic modulus (stiffness) of the mixtures.

- Measure the reflective cracking resistance of the mixtures using the Texas Overlay tester.

- Measure the moisture susceptibility and rutting resistance of the mixtures using the Hamburg Wheel Tracking Device (HWTD).

- Evaluate the effect of high RAP content, WMA, and PMA on the workability of the HPThinOL mixtures.
Experimental Plan

High Performance Thin Lift Overlay Mixture

Binders
1. PG 52-28
2. PG 64-34
3. PG 70-22 + 7.5% SBS
4. PG 58-28 + 7.5% SBS
5. 200 PEN + 7.5% SBS

Virgin Aggregates

Superpave 9.5 mm Mixture

Reclaimed Asphalt Pavement (RAP)

Virgin Aggregates

Mixtures with WMA Technology
1.0% SonneWarmix

Mixtures without WMA Technology

Control Mixture (0% RAP)

Control + 40% RAP Mixture

Control + WMA Mixture

Control + 40% RAP + WMA Mixture

Testing

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Experimental Plan

Testing

Performance
- Reflective Cracking Overlay Tester
- Moisture Susceptibility/Rutting
- Hamburg Wheel Tracking Device

Stiffness & Workability
- Mixture Stiffness Dynamic Modulus $|E^*|$
- Workability Asphalt Workability Device (AWD)
The control binder was a PG52-28 unmodified conventional binder.

Softest grade available that met the low temperature requirement of a PGXX-28 binder that is typically specified in the Northeast.

Based on the viscosity of the binder, the mixture mixing temperature was 144°C (291°F) and the compaction temperature was 132°C (270°F).
PMA Binders

- A PG64-34 obtained from Road Science, LLC. Based on the manufacturers recommendations the mixture mixing temperature was 154ºC (309ºF) and the compaction temperature was 143ºC (289ºF).

- The three remaining polymer modified binders were obtained from Kraton Polymers U.S. LLC: PG70-22 + 7.5% SBS, PG58-28 + 7.5% SBS and 200 PEN +7.5% SBS.

- The base binders for the three Kraton binders were selected in order to meet the potential existing pavement conditions where the HPThinOL would be placed. For pavement with high severity distresses, the softest binder would be used.
Based on the manufacturers recommendations, the mixture mixing temperature was 166°C (331°F) and the compaction temperature was 149°C (300°F) for all three of these binders.
Warm Mix Asphalt Technology

▶ Waxed based additive known as SonneWarmix™.

▶ Previously utilized in numerous field projects in Massachusetts and other New England states.

▶ SonneWarmix™ added at a dosage rate of 1.0% by weight of total binder (Virgin +RAP).

▶ Mixtures incorporating the warm mix technology were fabricated with a reduction in mixing and compaction temperatures as compared to the mixtures without the technology.
WMA Temperature Selection

The reduced WMA temperatures were selected based on the workability of the mixtures. The workability test will be described later.

The workability (torque) values will increase as the temperature drops. The temperature at which the rate of increase changed was used as an estimate for the aging temperatures.

The mixing temperature was selected at a range of 10 - 20 °C higher than the aging temperature.
# Mixing & Compaction Temperatures

<table>
<thead>
<tr>
<th>Binder</th>
<th>Without WMA Technology</th>
<th>With WMA Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mixing</td>
<td>Compaction</td>
</tr>
<tr>
<td><strong>PG52-28</strong></td>
<td>144°C (291°F)</td>
<td>132°C (270°F)</td>
</tr>
<tr>
<td><strong>PG64-34</strong></td>
<td>154°C (309°F)</td>
<td>143°C (289°F)</td>
</tr>
<tr>
<td><strong>PG70-22 + 7.5% SBS</strong></td>
<td>166°C (331°F)</td>
<td>149°C (300°F)</td>
</tr>
<tr>
<td><strong>PG58-28 + 7.5% SBS</strong></td>
<td>166°C (331°F)</td>
<td>149°C (300°F)</td>
</tr>
<tr>
<td><strong>200 PEN +7.5% SBS</strong></td>
<td>166°C (331°F)</td>
<td>149°C (300°F)</td>
</tr>
</tbody>
</table>
RAP

- RAP was obtained from same contractor that supplied the virgin aggregates.

- RAP average binder content = 5.26% (AASHTO T308 - Ignition)
# Aggregate & RAP Properties

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>9.5mm</th>
<th>Natural Sand</th>
<th>Stone Sand</th>
<th>Stone Dust</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0 mm</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>99.4</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>93.8</td>
<td>100</td>
<td>10</td>
<td>100</td>
<td>99.8</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>29.7</td>
<td>99.7</td>
<td>99.8</td>
<td>99.7</td>
<td>74.3</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>5.2</td>
<td>98.3</td>
<td>83.7</td>
<td>83.7</td>
<td>56.5</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>2.8</td>
<td>93.3</td>
<td>54.3</td>
<td>57.1</td>
<td>43.2</td>
</tr>
<tr>
<td>0.600 mm</td>
<td>2.3</td>
<td>73.3</td>
<td>33.8</td>
<td>38.6</td>
<td>31.9</td>
</tr>
<tr>
<td>0.300 mm</td>
<td>2.1</td>
<td>29.7</td>
<td>19.0</td>
<td>24.9</td>
<td>20.5</td>
</tr>
<tr>
<td>0.150 mm</td>
<td>1.8</td>
<td>4.8</td>
<td>9.4</td>
<td>15.9</td>
<td>12.5</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>1.5</td>
<td>0.9</td>
<td>4.3</td>
<td>10.9</td>
<td>8.5</td>
</tr>
<tr>
<td>Bulk Specific Gravity</td>
<td>2.642</td>
<td>2.624</td>
<td>2.644</td>
<td>2.629</td>
<td>2.638</td>
</tr>
<tr>
<td>Absorption, %</td>
<td>0.43</td>
<td>0.45</td>
<td>0.53</td>
<td>0.60</td>
<td>0.76</td>
</tr>
</tbody>
</table>
### Mixture Gradations

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>Control</th>
<th>40% RAP</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0 mm</td>
<td>100</td>
<td>100.0</td>
<td>-</td>
</tr>
<tr>
<td>12.5 mm</td>
<td>99.7</td>
<td>99.8</td>
<td>100 min.</td>
</tr>
<tr>
<td>9.5 mm</td>
<td>97.1</td>
<td>97.7</td>
<td>90-100</td>
</tr>
<tr>
<td>4.75 mm</td>
<td>66.8</td>
<td>64.6</td>
<td>90 max.</td>
</tr>
<tr>
<td>2.36 mm</td>
<td>47.8</td>
<td>44.8</td>
<td>32-67</td>
</tr>
<tr>
<td>1.18 mm</td>
<td>33.5</td>
<td>31.7</td>
<td>-</td>
</tr>
<tr>
<td>0.600 mm</td>
<td>23.0</td>
<td>21.9</td>
<td>-</td>
</tr>
<tr>
<td>0.300 mm</td>
<td>13.3</td>
<td>12.9</td>
<td>-</td>
</tr>
<tr>
<td>0.150 mm</td>
<td>7.1</td>
<td>6.7</td>
<td>-</td>
</tr>
<tr>
<td>0.075 mm</td>
<td>4.4</td>
<td>4.4</td>
<td>2-10</td>
</tr>
</tbody>
</table>

For the 40% RAP mixtures the virgin binder replaced with recycled binder was 35.1%.
## Mixture Volumetric Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Control Mixtures</th>
<th>Control + 1% WMA Mixtures</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PG52-28 Control Binder</td>
<td>PG64-34</td>
<td>PG70-22 + 7.5 SBS</td>
</tr>
<tr>
<td>Air Voids, %</td>
<td>3.9</td>
<td>3.1</td>
<td>3.3</td>
</tr>
<tr>
<td>VMA, %</td>
<td>16.2</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>VFA, %</td>
<td>76.3</td>
<td>80.7</td>
<td>79.4</td>
</tr>
</tbody>
</table>

### Control Mixtures

- **PG52-28** Control Binder
- **PG64-34**
- **PG70-22 + 7.5 SBS**
- **PG58-28 + 7.5% SBS**
- **200PEN + 7.5% SBS**

### Control + 1% WMA Mixtures

- **PG52-28 Control Binder**
- **PG64-34**
- **PG70-22 + 7.5 SBS**
- **PG58-28 + 7.5% SBS**
- **200PEN + 7.5% SBS**

- **9.5 mm Superpave Specification**
- **Air Voids, %**
- **VMA, %**
- **VFA, %**

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# Mixture Volumetric Properties

## Control + 40% RAP Mixtures

<table>
<thead>
<tr>
<th>Properties</th>
<th>Control Binder</th>
<th>PG64-34</th>
<th>PG70-22 + 7.5 SBS</th>
<th>PG58-28 + 7.5% SBS</th>
<th>200PEN + 7.5% SBS</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids, %</td>
<td>4.2</td>
<td>3.1</td>
<td>3.1</td>
<td>2.9</td>
<td>3.3</td>
<td>4.0%</td>
</tr>
<tr>
<td>VMA, %</td>
<td>16.1</td>
<td>15.5</td>
<td>15.4</td>
<td>15.1</td>
<td>15.7</td>
<td>15% min.</td>
</tr>
<tr>
<td>VFA, %</td>
<td>73.8</td>
<td>80.1</td>
<td>80.0</td>
<td>80.6</td>
<td>79.1</td>
<td>65-78</td>
</tr>
</tbody>
</table>

## Control + 40% RAP + 1% WMA Mixtures

<table>
<thead>
<tr>
<th>Properties</th>
<th>Control Binder</th>
<th>PG64-34</th>
<th>PG70-22 + 7.5 SBS</th>
<th>PG58-28 + 7.5% SBS</th>
<th>200PEN + 7.5% SBS</th>
<th>9.5 mm Superpave Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids, %</td>
<td>3.8</td>
<td>3.6</td>
<td>3.9</td>
<td>3.1</td>
<td>3.2</td>
<td>4.0%</td>
</tr>
<tr>
<td>VMA, %</td>
<td>15.7</td>
<td>16.1</td>
<td>16.0</td>
<td>15.4</td>
<td>15.5</td>
<td>15% min.</td>
</tr>
<tr>
<td>VFA, %</td>
<td>75.7</td>
<td>77.6</td>
<td>75.9</td>
<td>80.2</td>
<td>79.4</td>
<td>65-78</td>
</tr>
</tbody>
</table>
Mixture Stiffness - Dynamic Modulus

Conducted to determine changes in mixture stiffness due to the incorporation of a PMA binder, RAP and/or the WMA technology.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>4°C</td>
<td>10 Hz, 1Hz, 0.1Hz</td>
</tr>
<tr>
<td>20°C</td>
<td>10 Hz, 1Hz, 0.1Hz</td>
</tr>
<tr>
<td>35°C*</td>
<td>10 Hz, 1Hz, 0.1Hz, 0.01Hz</td>
</tr>
</tbody>
</table>

*35°C for PG52-28, 40°C for PG64-34 & 45°C for remaining PMA binders.

Asphalt Mixture Performance Tester (AMPT)
Dynamic Modulus Master Curve

Control Mixture

Dynamic Modulus $E^*$, ksi

Reduced Frequency, Hz

- PG52-28
- PG64-34
- PG70-22 + 7.5% SBS
- PG58-28 + 7.5% SBS
- 200PEN + 7.5% SBS
Dynamic Modulus Master Curve

Control + 40% RAP Mixture

Dynamic Modulus $E^*$, ksi

Reduced Frequency, Hz

- PG52-28
- PG64-34
- PG70-22 + 7.5% SBS
- PG58-28 + 7.5% SBS
- 200PEN + 7.5% SBS

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Dynamic Modulus Master Curve

PG52-28 Binder

Dynamic Modulus $E^*$, ksi

Reduced Frequency, Hz

- **Control**
- **40% RAP**
- **Control + WMA**
- **40% RAP + WMA**
Reflective Cracking - Overlay Tester

- Test Temperature = 15°C (59°F)
- Test Termination at 1,200 cycles or 93% Load reduction
- Testing in accordance with Tex-248-F

### Overlay Tester Results – NO WMA

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Binder</th>
<th>Average Overlay Test (OT) Cycles to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control</strong></td>
<td>PG52-28</td>
<td>1,004</td>
</tr>
<tr>
<td>Control</td>
<td>PG64-34</td>
<td>1200</td>
</tr>
<tr>
<td>Control</td>
<td>PG70-22 + 7.5% SBS</td>
<td>2</td>
</tr>
<tr>
<td>Control</td>
<td>PG58-28 + 7.5% SBS</td>
<td>38</td>
</tr>
<tr>
<td>Control</td>
<td>200 PEN + 7.5% SBS</td>
<td>387</td>
</tr>
<tr>
<td><strong>40% RAP</strong></td>
<td>PG52-28</td>
<td>3</td>
</tr>
<tr>
<td>40% RAP</td>
<td>PG64-34</td>
<td>195</td>
</tr>
<tr>
<td>40% RAP</td>
<td>PG70-22 + 7.5% SBS</td>
<td>3</td>
</tr>
<tr>
<td>40% RAP</td>
<td>PG58-28 + 7.5% SBS</td>
<td>4</td>
</tr>
<tr>
<td>40% RAP</td>
<td>200 PEN + 7.5% SBS</td>
<td>104</td>
</tr>
</tbody>
</table>
## Overlay Tester Results - WMA

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Binder</th>
<th>Average Overlay Test (OT) Cycles to Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Control + WMA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG52-28</td>
<td></td>
<td>936</td>
</tr>
<tr>
<td>PG64-34</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td>PG70-22 + 7.5% SBS</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>PG58-28 + 7.5% SBS</td>
<td></td>
<td>156</td>
</tr>
<tr>
<td>200 PEN + 7.5% SBS</td>
<td></td>
<td>1200</td>
</tr>
<tr>
<td><strong>40% RAP + WMA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG52-28</td>
<td></td>
<td>143</td>
</tr>
<tr>
<td>PG64-34</td>
<td></td>
<td>453</td>
</tr>
<tr>
<td>PG70-22 + 7.5% SBS</td>
<td></td>
<td>425</td>
</tr>
<tr>
<td>PG58-28 + 7.5% SBS</td>
<td></td>
<td>12</td>
</tr>
<tr>
<td>200 PEN + 7.5% SBS</td>
<td></td>
<td>439</td>
</tr>
</tbody>
</table>
The addition of 40% RAP to the control mixture reduced the reflective cracking resistance of the mixture regardless of type the binder utilized.

The use of the WMA technology could improve the reflective cracking resistance as compared to the control.

The use of a polymer modified binder may improve the reflective cracking resistance of the mixture.
Moisture Susceptibility/Rutting - Hamburg Wheel Tracking Device (HWTD)

- HWTD testing conducted in accordance with AASHTO T324
- Water temperature of 40ºC (104ºF) during testing for control PG52-28 binder
- Water temperature of 50ºC (122ºF) during testing for PMA binder mixtures
- Test duration of 20,000 cycles

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Stripping Inflection Point (SIP)

Number of Passes to Stripping Inflection Point (SIP)

Number of Passes Failure, \( N_f \)

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<table>
<thead>
<tr>
<th>Mixture</th>
<th>Binder</th>
<th>Stripping Inflection Point</th>
<th>Avg. Rut 10,000 Cycles (mm)</th>
<th>Avg. Rut 20,000 Cycles (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>PG52-28*</td>
<td>16,800</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
<td>10,500</td>
<td>2.7</td>
<td>MRD&gt;20mm</td>
</tr>
<tr>
<td></td>
<td>PG70-22 + 7.5% SBS</td>
<td>NONE</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>PG58-28 + 7.5% SBS</td>
<td>NONE</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>200 PEN + 7.5% SBS</td>
<td>17,500</td>
<td>1.4</td>
<td>2.9</td>
</tr>
<tr>
<td>40% RAP</td>
<td>PG52-28*</td>
<td>NONE</td>
<td>1.6</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
<td>NONE</td>
<td>1.6</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>PG70-22 + 7.5% SBS</td>
<td>NONE</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>PG58-28 + 7.5% SBS</td>
<td>NONE</td>
<td>0.8</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>200 PEN + 7.5% SBS</td>
<td>NONE</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>

* = HWTD testing conducted at 40ºC for mixtures fabricated with this binder.
MRD>20mm = Testing did not reach specified cycles due to the maximum rut depth exceeding 20 mm.
## HWTD Test Results - WMA

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Binder</th>
<th>Stripping Inflection Point</th>
<th>Avg. Rut 10,000 Cycles (mm)</th>
<th>Avg. Rut 20,000 Cycles (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control + WMA</td>
<td>PG52-28*</td>
<td>6,200</td>
<td>MRD&gt;20mm</td>
<td>MRD&gt;20mm</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
<td>6,500</td>
<td>MRD&gt;20mm</td>
<td>MRD&gt;20mm</td>
</tr>
<tr>
<td></td>
<td>PG70-22 + 7.5% SBS</td>
<td>NONE</td>
<td>1.0</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>PG58-28 + 7.5% SBS</td>
<td>15,000</td>
<td>1.7</td>
<td>9.2</td>
</tr>
<tr>
<td></td>
<td>200 PEN + 7.5% SBS</td>
<td>4,500</td>
<td>MRD&gt;20mm</td>
<td>MRD&gt;20mm</td>
</tr>
<tr>
<td>40% RAP + WMA</td>
<td>PG52-28*</td>
<td>NONE</td>
<td>0.9</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
<td>13,000</td>
<td>2.1</td>
<td>12.4</td>
</tr>
<tr>
<td></td>
<td>PG70-22 + 7.5% SBS</td>
<td>NONE</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>PG58-28 + 7.5% SBS</td>
<td>NONE</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>200 PEN + 7.5% SBS</td>
<td>16,750</td>
<td>1.5</td>
<td>3.1</td>
</tr>
</tbody>
</table>

* = HWTD testing conducted at 40°C for mixtures fabricated with this binder.
MRD>20mm = Testing did not reach specified cycles due to the maximum rut depth exceeding 20 mm.
Workability Evaluation

UMass Dartmouth AWD

AWD Paddle Configuration
Workability Results – 40% RAP

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Overall Project Conclusions

Control mixtures incorporating only PMA showed increased stiffness as compared to the control mixtures. The higher stiffness mixtures may be more susceptible to cracking if placed over a pavement that will be exposed to high amount of deflections.

The addition of 40% RAP to the control mixture increased the mixture stiffness as compared to the control mixture without RAP for all binder types, although the magnitude of the increase in stiffness was small for some PMA binder tested.

WMA can be utilized to reduce the mixture stiffness for these HPThinOL mixtures which may lead to enhanced workability and performance characteristics.
Overall Project Conclusions

- The use of a WMA technology could improve the reflective cracking resistance of HPThinOL that is designed with PMA and incorporates high RAP contents. This may be a result of the technology itself or the associated reducing mixing and aging temperatures.

- The use of a polymer modified binder and/or the addition of RAP may improve the moisture susceptibility and rutting characteristics of the mixture. The use of the WMA technology in combination with the PMA and/or RAP may result in reduced mixture moisture susceptibility and rutting performance.
Overall Project Conclusions

- The addition of 40% RAP did not significantly decrease the mixture workability of the PMA mixtures, whereas the workability of the control binder mixtures was reduced.

- The introduction of the WMA technology to the mixtures did marginally improve the workability of all mixtures tested and may be attributed to the reduced mixing and compaction temperatures utilized for these type of mixtures.
Thank You!