EVALUATION OF PAVEMENT RESPONSES OF WARM MIX ASPHALT SECTIONS AT THE NCAT TEST TRACK
Warm Mix Asphalt (WMA)
Problem Statement

- WMA technologies need to be evaluated
- Use of WMA, high RAP mixes and their combination is expected to produce changes in material properties and affect pavement responses
Objective

- To evaluate pavement responses for different pavement sections placed at the NCAT Test Track.
NCAT Test Track

- Full-scale accelerated testing facility
- Opelika, Alabama
- 10 million ESALs applied over a two-year period of time.
- Phase IV research cycle
Dynamic Instrumentation
Scope

- Five NCAT Test Track sections
  - Similar pavement structures
- FWD testing
- Pavement responses measured under live traffic loads
Test Sections

- S9 Control
- S10 WMA-Foamed
- S11 WMA-Additive
- N10 HMA-50% RAP
- N11 WMA-50% RAP

Depth from Surface, in:
- Surface Lift NMAS = 9.5mm
- Intermediate Lift NMAS = 19mm
- Bottom Lift NMAS = 19mm
- Aggregate Base

Surface Lift NMAS = 9.5mm
Intermediate Lift NMAS = 19mm
Bottom Lift NMAS = 19mm
Aggregate Base
Methodology

- Horizontal asphalt strain, vertical aggregate base pressure, vertical subgrade pressure
- Backcalculated AC modulus from FWD testing
- August 2009 to August 2010
Methodology

- Comparison of trends
- Comparison among sections at reference temperature
- Factorial analysis:

<table>
<thead>
<tr>
<th>FACTORS</th>
<th>LEVELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material type</td>
<td>Virgin blends (VB)</td>
</tr>
<tr>
<td></td>
<td>High RAP (RAP)</td>
</tr>
<tr>
<td>Production Temperature</td>
<td>Hot (HMA)</td>
</tr>
<tr>
<td></td>
<td>Warm (WMA)</td>
</tr>
</tbody>
</table>
Results

- AC Modulus highly correlated with mid-depth temperature

\[ E = \alpha_1 e^{\alpha_2 T} \]

- \( E = \) AC Modulus, ksi
- \( T = \) Mid-depth HMA temperature, °F
- \( \alpha_1, \alpha_2 = \) Section-specific regression coefficients
<table>
<thead>
<tr>
<th>Section</th>
<th>( \alpha_1 ) (Intercept)</th>
<th>( \alpha_2 ) (Slope)</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8667.5</td>
<td>-0.034</td>
<td>0.97</td>
</tr>
<tr>
<td>WMA-F</td>
<td>8206.9</td>
<td>-0.034</td>
<td>0.97</td>
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<tr>
<td>WMA-A</td>
<td>7793.0</td>
<td>-0.034</td>
<td>0.97</td>
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<tr>
<td>HMA-RAP</td>
<td>9085.6</td>
<td>-0.031</td>
<td>0.98</td>
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<tr>
<td>WMA-RAP</td>
<td>8728.2</td>
<td>-0.031</td>
<td>0.99</td>
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</tbody>
</table>
AC Modulus at 68F

No statistical difference between these sections.
AC Modulus – Factorial analysis

Material Type

Production Temperature

Material Type

Approximately 220 ksi

Production Temperature

Approximately 56 ksi
Results

- Pavement responses highly correlated with mid-depth temperature

\[ \text{response} = k_1 e^{k_2 T} \]

response = microstrain or pressure (psi)

\[ T = \text{Mid-depth HMA temperature, °F} \]

\[ k_1, k_2 = \text{Section-specific regression coefficients} \]
<table>
<thead>
<tr>
<th>Section</th>
<th>$k_1$ (Intercept)</th>
<th>$k_2$ (Slope)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>63.7</td>
<td>0.024</td>
<td>0.91</td>
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<tr>
<td>WMA-F</td>
<td>61.0</td>
<td>0.025</td>
<td>0.98</td>
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<tr>
<td>WMA-A</td>
<td>56.0</td>
<td>0.025</td>
<td>0.97</td>
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<tr>
<td>HMA-RAP</td>
<td>58.7</td>
<td>0.021</td>
<td>0.90</td>
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<tr>
<td>WMA-RAP</td>
<td>69.9</td>
<td>0.019</td>
<td>0.95</td>
</tr>
</tbody>
</table>
No statistical difference between these sections.

No statistical difference between these sections.
Strain – Factorial analysis

![Graph showing strain analysis with Material Type and Production Temperature]
## Vertical Pressure

### Summary Table

<table>
<thead>
<tr>
<th>Section</th>
<th>$k_1$ (Intercept)</th>
<th>$k_2$ (Slope)</th>
<th>$R^2$</th>
<th>Section</th>
<th>$k_1$ (Intercept)</th>
<th>$k_2$ (Slope)</th>
<th>$R^2$</th>
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</thead>
<tbody>
<tr>
<td>Control</td>
<td>1.80</td>
<td>0.020</td>
<td>0.960l</td>
<td>Control</td>
<td>1.61</td>
<td>0.025</td>
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<td>WMA-F</td>
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<td>0.027</td>
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<tr>
<td>WMA-A</td>
<td>1.71</td>
<td>0.020</td>
<td>0.97-A</td>
<td>WMA-A</td>
<td>1.63</td>
<td>0.025</td>
<td>0.96</td>
</tr>
<tr>
<td>HMA-RAP</td>
<td>1.80</td>
<td>0.015</td>
<td>0.74-RAP</td>
<td>HMA-RAP</td>
<td>1.19</td>
<td>0.022</td>
<td>0.76</td>
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<tr>
<td>WMA-RAP</td>
<td>1.79</td>
<td>0.019</td>
<td>0.97-RAP</td>
<td>WMA-RAP</td>
<td>1.56</td>
<td>0.022</td>
<td>0.95</td>
</tr>
</tbody>
</table>
Vertical pressure at 68F

![Bar chart showing average vertical pressure in psi for different test sections including Control, WMA-F, WMA-A, HMA RAP, and WMA RAP categories.](chart.png)
Pressure – Factorial analysis

Material Type

HMA

RAP

WMA

Production Temperature

≈ 1.5 psi

≈ 0.2 psi

≈ 2 psi

≈ 0.3 psi

Material Type

≈ 0.2 psi

≈ 0.3 psi

≈ 2 psi

Material Type

RAP

VB

HMA

WMA

Production Temperature

≈ 1.5 psi

≈ 0.2 psi

≈ 2 psi
Performance

Average Rut Depth, mm

Test Section

S9 Control
S10 WMA-F
S11 WMA-A
N10 HMA RAP
N11 WMA RAP

No statistical difference

No statistical difference
Conclusions

- WMA mixes can be modeled using conventional pavement models but may require calibration for M-E design.
- WMA mixes had lower modulus at reference temperature, but similar responses than control mix.
- The factors material type and production temperature significantly affect pavement properties. Effect bigger for RAP use.
Conclusions

- Certain combinations of material type and production temperature produce larger changes for pressure.
- All sections performed well after one year.
  - Rutting < 10 mm
  - No cracking
Acknowledgements

- State Departments of Transportation: Alabama, Florida, North Carolina, Oklahoma and Tennessee
- Federal Highway Administration
QUESTIONS?