Influence of RAP and RAS addition on mixture and binder performance: Three years of ALF activity

Asphalt Mixture and Construction Expert Task Group
September, 2017

Pavement Materials Team, TFHRC
RAP/RAS and WMA

• Purpose
  – Advance Use of Recycled Asphalt in Flexible Pavement Infrastructure: Develop and Deploy Framework for Proper Use and Evaluation of Recycled Asphalt in Asphalt Mixtures

• Objective
  – Quantify cracking resistance of high RAP/RAS mixtures that considers the use of lower temperature production with warm-mix asphalt (WMA) technologies
The Experiment

**Structure**
- 10 Lanes (10 Mixes)
- 2 Layers (2 inches each)
- Build in 2013

**Materials**
- 2 Base Binder Grades (PG 64-22 and PG 58-28)
- RAP/RAS
- 2 WMA Technologies
- 3 ABR contents
### ALF experimental design

**Ten lanes total**

<table>
<thead>
<tr>
<th>Drum Discharge Temperature</th>
<th>300°F - 320°F</th>
<th>240°F - 270°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA / WMA</td>
<td>-</td>
<td>Foam</td>
</tr>
<tr>
<td>Warm Mix Technology</td>
<td></td>
<td>Chem.</td>
</tr>
<tr>
<td>Recycle Content</td>
<td>0%</td>
<td>20% ABR RAP</td>
</tr>
<tr>
<td></td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td></td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td>20% ABR RAP</td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td>≈ 23% by weight</td>
<td>PG64-22</td>
<td>PG64-22</td>
</tr>
<tr>
<td>20% ABR RAS</td>
<td>PG64-22</td>
<td>PG58-28</td>
</tr>
<tr>
<td>≈ 6% Shingle by weight</td>
<td>PG58-28</td>
<td>-</td>
</tr>
<tr>
<td>40% ABR RAP</td>
<td>PG64-22</td>
<td>PG58-28</td>
</tr>
<tr>
<td>≈ 44% by weight</td>
<td>PG58-28</td>
<td>PG58-28</td>
</tr>
</tbody>
</table>
Accumulated cracking (inches)

Number of load passes

Lane 1-0% ABR Control PG64-22
Lane 2-40% ABR RAP PG58-28 WMA Foamed
Lane 3-20% ABR RAS PG64-22
Lane 4-20% ABR RAP PG64-22 WMA Evotherm
Lane 5-40% ABR RAP PG58-28 WMA Evotherm
Lane 6-20% ABR RAP PG64-22
Lane 7-20% ABR RAS PG58-28
Lane 8-40% ABR RAP PG64-22
Lane 9-20% ABR RAP PG64-22 WMA Foamed
Lane 11-40% ABR RAP PG58-28 WMA Evotherm

Lanes completed

Lane 1
Lane 2
Lane 3
Lane 4
Lane 5
Lane 6
Lane 7
Lane 8
Lane 9
Lane 11
## Crack Data Summary

<table>
<thead>
<tr>
<th>Lane</th>
<th>Mix</th>
<th>Age when tested (months)</th>
<th>Duration (Days)</th>
<th>Cycles to First Crack (Calculated)</th>
<th>Total Passes</th>
<th>Total Cracking (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0% ABR Control PG64-22</td>
<td>7</td>
<td>286</td>
<td>368,254</td>
<td>400,000</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>40% ABR RAP PG58-28 WMA Foamed</td>
<td>38</td>
<td>79</td>
<td>123,035</td>
<td>200,000</td>
<td>1,336</td>
</tr>
<tr>
<td>3</td>
<td>20% ABR RAS PG64-22</td>
<td>14</td>
<td>28</td>
<td>42,399</td>
<td>100,000</td>
<td>587</td>
</tr>
<tr>
<td>4</td>
<td>20% ABR RAP PG64-22 WMA Evotherm</td>
<td>16</td>
<td>71</td>
<td>88,740</td>
<td>125,000</td>
<td>271</td>
</tr>
<tr>
<td>5</td>
<td>40% ABR RAP PG64-22</td>
<td>11</td>
<td>98</td>
<td>36,946</td>
<td>60,000</td>
<td>670</td>
</tr>
<tr>
<td>6</td>
<td>20% ABR RAP PG64-22</td>
<td>24</td>
<td>81</td>
<td>122,363</td>
<td>175,000</td>
<td>403</td>
</tr>
<tr>
<td>7</td>
<td>20% ABR RAS PG58-28</td>
<td>18</td>
<td>43</td>
<td>23,005</td>
<td>62,200</td>
<td>526</td>
</tr>
<tr>
<td>8</td>
<td>40% ABR RAP PG58-28</td>
<td>31</td>
<td>47</td>
<td>47,679</td>
<td>54,844</td>
<td>602</td>
</tr>
<tr>
<td>9</td>
<td>20% ABR RAP PG64-22 WMA Foamed</td>
<td>2</td>
<td>163</td>
<td>179,167</td>
<td>255,397</td>
<td>1,439</td>
</tr>
<tr>
<td>11</td>
<td>40% ABR RAP PG58-28 WMA Evotherm</td>
<td>3</td>
<td>147</td>
<td>81,044</td>
<td>123,052</td>
<td>512</td>
</tr>
</tbody>
</table>
Field Core Sampling and Testing

- **2013**
  - Top: t = 0m
  - Bottom: t = 0m
  - Fatigue: ✔
  - Monotonic: ✔
  - Binder Extraction & Testing: ✔

- **2014**
  - Top: t = 12m
  - Bottom: t = 12m
  - Fatigue: ✔
  - Monotonic: ✔
  - Binder Extraction & Testing: ✔

- **2015**
  - Top: t = 24m
  - Bottom: t = 24m
  - Fatigue: ✔
  - Monotonic: ✔
  - Binder Extraction & Testing: ✔

- **2016**
  - Top: t = 36m
  - Bottom: t = 36m
  - Fatigue: ✔
  - Monotonic: ✔
  - Binder Extraction & Testing: ✔
Clear variation from construction compaction and

Need to take construction variation into account analyzing performance testing data
Mixture Field Sample Testing

- Reduced Size (38mmx110mm)
- Dynamic Modulus
- Fatigue (AASHTO TP 107)
- Monotonic Direct Tension
- All testing done on AMPT
Testing Conditions and Materials

- **Loading Rates**
  - Actuator displacement control
  - An recent research effort shows 10mm/min ideal
  - This study 10 mm/min

- **Temperature**
  - All tested at 18°C
  - Minimize visco-plasticity effects and no strain decomposition

- **Materials**
  - Loose mix (STOA+ 5-day LTOA)
  - 1-year and 3-year field cores
Testing Results

\[ y = -4.9679x^6 + 32.068x^5 - 82.566x^4 + 107.11x^3 - 71.394x^2 + 20.377x - 0.0612 \]

\[ R^2 = 0.9972 \]

Peak load: \( P \)
Tensile Strength
Energy to peak load: \( E_1 \)
Total Energy: \( E \)
Slope at inflection point: \( IS \)

\( E_1/IS, E/IS, E_1/P, E/P \)
Fracture Energy (Loose + Top Lift)

STOA > LTOA
L3, L5 and L7 lowest
Decrease with time but complicated by construction variation
Fracture Energy (Bottom Lift)

Trend with time complicated by construction variation

<table>
<thead>
<tr>
<th>Lane</th>
<th>Treatment</th>
<th>1-year Bottom</th>
<th>3-year Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H2O foam 40%RAP (58-28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>20%RAS 20%RAP (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Evotherm 20%RAP (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>40%RAP 20%RAP (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>20%RAS 20%RAP (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>40%RAP 20%RAP (58-28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>20%RAS 20%RAS (64-22)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>H2O foam 40%RAS (58-28)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Evotherm 40%RAP (58-28)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Inflection Point Slope (Top Lift)

Lane 1 Lane 2 Lane 3 Lane 4 Lane 5 Lane 6 Lane 7 Lane 8 Lane 9 Lane 11

LTOA >>> 3 year > 1 year > STOA

L3, L5 and L7 highest
Inflection Point Slope (Bottom Lift)

L3, L5 and L7 highest

Trend not as clear as top lift
Fracture Energy 1 / IP Slope (Top)

STOA > 1 year > 3 year > LTOA

L3, L5 and L7 lowest
Fracture Energy / Peak Load (Top)

- LTOA < 3 year < 1 year < STOA
- L3, L5 and L7 lowest
- An indicator of the averaged deformability
Fracture Energy / Peak Load (Bottom)

Trend not as clear as top lift
L3, L5 and L7 lowest
An indicator of the averaged deformability
Binder Extraction and Testing

- Rheology (PG)
- Double Notched Tension: Ductile Strain Tolerance
  - Loose mix
  - 2-years field core
  - 3-years field core
# HTPG Variation

![Bar chart showing HTPG variation across different lanes and conditions.](chart.png)

**HTPG, °C**

<table>
<thead>
<tr>
<th>Lane</th>
<th>Condition</th>
<th>HTPG, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lane 1</td>
<td>Control (64-22)</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>H2O foam (58-28)</td>
<td>72</td>
</tr>
<tr>
<td>Lane 2</td>
<td>20% RAS (64-22)</td>
<td>84</td>
</tr>
<tr>
<td></td>
<td>Evotherm (64-22)</td>
<td>96</td>
</tr>
<tr>
<td>Lane 3</td>
<td>40% RAP (64-22)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20% RAP (64-22)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 4</td>
<td>40% RAP (58-28)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20% RAP (58-28)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 5</td>
<td>40% RAP (64-22)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20% RAP (64-22)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 6</td>
<td>40% RAP (58-28)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>20% RAP (58-28)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 7</td>
<td>H2O foam (64-22)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Evotherm (64-22)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 8</td>
<td>40% RAP (58-28)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>H2O foam (58-28)</td>
<td>106</td>
</tr>
<tr>
<td>Lane 9</td>
<td>40% RAP (64-22)</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Evotherm (64-22)</td>
<td>106</td>
</tr>
</tbody>
</table>

**Top Lift**

3 Years > 2 Years > Loose Mix
HTPG Variation

![Bar chart showing HTPG variation over lanes and treatments.]

- **Loose**: Control (64-22) Lane 1, H2O foam (58-28) Lane 2, 20% RAS (64-22) Lane 3, 20% RAP (64-22) Lane 4, H2O foam (58-28) Lane 5, 20% RAS (58-28) Lane 6, 20% RAP (58-28) Lane 7, H2O foam (64-22) Lane 8, 20% RAP (58-28) Lane 9, 20% RAP (58-28) Lane 11.

- **2-years**: 40% RAP (64-22) Lane 2, 20% RAP (64-22) Lane 3, 40% RAP (64-22) Lane 4, 40% RAP (58-28) Lane 5, 20% RAP (64-22) Lane 6, 40% RAP (58-28) Lane 7, 40% RAP (64-22) Lane 8, 40% RAP (64-22) Lane 9, 40% RAP (58-28) Lane 11.

- **3-years**: 20% RAP (64-22) Lane 2, 20% RAP (64-22) Lane 3, 20% RAP (64-22) Lane 4, 20% RAP (64-22) Lane 5, 20% RAP (64-22) Lane 6, 20% RAP (64-22) Lane 7, 20% RAP (58-28) Lane 8, 20% RAP (58-28) Lane 9, 20% RAP (58-28) Lane 11.

**Bottom Lift**

**Relative Minor Changes**
LTPG Loss with Aging

<table>
<thead>
<tr>
<th>Lane 1</th>
<th>Lane 2</th>
<th>Lane 3</th>
<th>Lane 4</th>
<th>Lane 5</th>
<th>Lane 6</th>
<th>Lane 7</th>
<th>Lane 8</th>
<th>Lane 9</th>
<th>Lane 11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (64-22)</td>
<td>40%RAP (58-28) H2O foam</td>
<td>20%RAS (64-22) Evotherm</td>
<td>Lane 4 20%RAP (64-22)</td>
<td>Lane 5 40%RAP (64-22)</td>
<td>Lane 6 20%RAP (64-22)</td>
<td>Lane 7 20%RAS (58-28)</td>
<td>Lane 8 40%RAP (58-28)</td>
<td>Lane 9 20%RAP (64-22) H2O foam</td>
<td>Lane 11 40%RAP (58-28) Evotherm</td>
</tr>
</tbody>
</table>

- LTPG, °C
- Loose
- 2-years
- 3-years

3 Years < 2 Years < Loose Mix
LTPG Loss with Aging

Lane 1
Control (64-22)
Lane 2
40%RAP (58-28) H2O foam
Lane 3
20%RAS (64-22) Evotherm
Lane 4
20%RAP (64-22) H2O foam
Lane 5
40%RAP (64-22) Evotherm
Lane 6
20%RAP (64-22) H2O foam
Lane 7
20%RAP (58-28) Evotherm
Lane 8
40%RAP (58-28) Evotherm
Lane 9
20%RAP (64-22) H2O foam
Lane 11
40%RAP (58-28) Evotherm

LTPG, °C

Loose 2-years 3-years

Bottom Lift
Relative Minor Changes
Delta (T) Variation with Aging

<table>
<thead>
<tr>
<th>Lane</th>
<th>Treatment</th>
<th>Δ (T), °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control (64-22)</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>40%RAP (58-28)</td>
<td>-4</td>
</tr>
<tr>
<td>3</td>
<td>20%RAS (64-22)</td>
<td>-2</td>
</tr>
<tr>
<td>4</td>
<td>Evotherm</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>40%RAP (64-22)</td>
<td>-2</td>
</tr>
<tr>
<td>6</td>
<td>20%RAP (64-22)</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>20%RAS (58-28)</td>
<td>-6</td>
</tr>
<tr>
<td>8</td>
<td>40%RAP (58-28)</td>
<td>-4</td>
</tr>
<tr>
<td>9</td>
<td>20%RAP (64-22)</td>
<td>-2</td>
</tr>
<tr>
<td>11</td>
<td>40%RAP (58-28)</td>
<td>0</td>
</tr>
</tbody>
</table>

Top Lift

Delta (T) Higher for 20% RAS Addition and Aging
Delta (Tc) Variation with Aging

Delta (T), °C

Lane 1: Control (64-22)
Lane 2: 40% RAP (58-28) H2O foam
Lane 3: 20% RAS (64-22)
Lane 4: 20% RAP (64-22) Evotherm
Lane 5: 40% RAP (64-22)
Lane 6: 20% RAP (64-22) 20% RAS (58-28)
Lane 7: 40% RAP (58-28)
Lane 8: 20% RAP (64-22) H2O foam
Lane 9: 20% RAP (58-28)
Lane 10: 40% RAP (58-28)

Loose 2-years 3-years

Delta (T) Higher for 20% RAS Addition and Aging
Change in Ductile Strain Tolerance with Aging

3 Years < 2 Years < Loose Mix  
L3, L5 and L7 smallest
Ductile Strain Tolerance Loss with Aging

CTOD, mm

Lane 1 Lane 2 Lane 3 Lane 4 Lane 5 Lane 6 Lane 7 Lane 8 Lane 9 Lane 11

Control (64-22) H2O foam 20%RAP (64-28) 20%RAS (64-22) Evotherm 20%RAP (64-22) 20%RAP (64-22) 20%RAS (58-28) 40%RAP (58-28) 20%RAP (64-22) 40%RAP (58-28) H2O foam 40%RAP (58-28) Evotherm

Loose 2-years 3-years

Bottom Lift

Relative Minor Changes L3, L5 and L7 smallest
Correlation Between Binder & Mix

CTOD vs. (Fracture Energy/IS)

\[ y = 10.467x - 70.487 \]

\[ R^2 = 0.581 \]
Correlation Between Binder & Mix

CTOD vs. (Fracture Energy/Peak Load)

y = 0.0802x - 0.1853
R² = 0.6868
Correlation Between Binder & Mix

CTOD vs. (Fracture Energy)

\[ y = 0.0986x + 0.5041 \]
\[ R^2 = 0.7575 \]

\[ y = 0.1836x - 0.1598 \]
\[ R^2 = 0.5691 \]
### Laboratory Test + Field Performance

#### Statistical Method (Kendall’s Tau)

<table>
<thead>
<tr>
<th>Material</th>
<th>Fracture Energy (E)</th>
<th>E/IS</th>
<th>E/IP</th>
<th>E1/P</th>
<th>E/P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose Unaged</td>
<td>0.94</td>
<td>0.72</td>
<td>0.78</td>
<td>0.83</td>
<td>0.67</td>
</tr>
<tr>
<td>Loose Aged</td>
<td>0.61</td>
<td>0.56</td>
<td>0.50</td>
<td>0.67</td>
<td>0.56</td>
</tr>
<tr>
<td>1-Year Top</td>
<td>0.71</td>
<td>0.79</td>
<td>0.86</td>
<td>0.71</td>
<td>0.71</td>
</tr>
<tr>
<td>3-Year Top</td>
<td>0.78</td>
<td>0.78</td>
<td>0.72</td>
<td>0.72</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Summary and Findings

- Top lift mix was significantly more aged than the bottom lift.
- Top lift ages with time whereas the effect of aging on the bottom lift is not as evident and is partly compromised by construction variability.
- The 5-day 85°C oven aging found to age the mix significantly more severely than the 3-year field climatic aging process.
- The binder PG changes also reflect those of the mix.
- The top lift experienced significant CTOD losses with aging, while no major changes were found in the bottom lift.
- Monotonic mix results correlate reasonably well with binder CTOD results.
Summary and Findings

- Close correlation found between the mix index E/P and the binder CTOD, as indicating the strain tolerance or deformability of the material.

- The three stiff mixtures, L7, L3 and L5, either with high RAP content up to 40% RBR or with 20% RBR RAS, were the earliest to crack, indicating the worst performance in terms of cracking resistance.

- A softer PG grade was effective at improving the performance for 40% RAP BR mixes but ineffective at improving the performance of tear off RAS shingles providing 20% RBR.

- No difference in performance was observed between the HMA and WMA mixtures if other variables are the same.

- Statistical analysis illustrates strong correlation between the direct tension monotonic mix test and ALF field testing in terms of evaluating the cracking resistance of the asphalt mixtures combined with RAP/RAS and WMA.
Juicing RAP Mixes

Asphalt Mixture and Construction
Expert Task Group
September, 2017

Pavement Materials Team, TFHRC
Conducting performance tests on 20% & 40% RAP-RBR +0.25%, +0.5%, +0.75% binder.

Will determine how much binder needs to be added for 20% & 40% RAP-RBR mixes to exhibit equivalent performance.

20% RAP-RBR mix will be the reference mix that should be the equivalent performance target.
Materials and Testing

- **Materials**
  - L1 (0% RBR, control mix)
  - L6 (20% RBR)
  - L5 (40% RBR)

- **Additional Binder**
  - +0.5%, +0.75%, (+0.25%)

- **Testing**
  - Dynamic modulus
  - Direct tension fatigue (AASHTO TP 107)
  - Stress sweep rutting (SSR)
### Volumetrics

<table>
<thead>
<tr>
<th>Dimension (mm)</th>
<th>Sieve Size</th>
<th>Lane 1 (0%RBR)</th>
<th>Lane 6 (20%RBR)</th>
<th>Lane 5 (40%RBR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>3/4 inch</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>12.5</td>
<td>1/2 inch</td>
<td>98.3</td>
<td>98.0</td>
<td>97.1</td>
</tr>
<tr>
<td>9.5</td>
<td>3/8 inch</td>
<td>86.2</td>
<td>85.8</td>
<td>80.6</td>
</tr>
<tr>
<td>4.75</td>
<td># 4</td>
<td>47.6</td>
<td>44.6</td>
<td>37.9</td>
</tr>
<tr>
<td>2.36</td>
<td># 8</td>
<td>28.8</td>
<td>28.1</td>
<td>24.0</td>
</tr>
<tr>
<td>1.18</td>
<td># 16</td>
<td>20.1</td>
<td>20.6</td>
<td>18.6</td>
</tr>
<tr>
<td>0.6</td>
<td># 30</td>
<td>15.0</td>
<td>15.7</td>
<td>14.9</td>
</tr>
<tr>
<td>0.3</td>
<td># 50</td>
<td>11.0</td>
<td>11.7</td>
<td>11.6</td>
</tr>
<tr>
<td>0.15</td>
<td># 100</td>
<td>7.8</td>
<td>8.5</td>
<td>8.9</td>
</tr>
<tr>
<td>0.075</td>
<td>#200</td>
<td>5.3</td>
<td>5.8</td>
<td>6.3</td>
</tr>
</tbody>
</table>

### Diagonram

The graph shows the percent passing as a function of (Sieve Size mm)^0.45 for different lanes and RBR levels. The axes for the graph are labeled as follows:

- Percent Passing (%)
- (Sieve Size mm)^0.45

### Table of Volumetrics

<table>
<thead>
<tr>
<th></th>
<th>L1 (0%RBR)</th>
<th>L6 (20%RBR)</th>
<th>L5 (40%RBR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ AC</td>
<td>+0</td>
<td>+0.25%</td>
<td>+0.5%</td>
</tr>
<tr>
<td>$G_{mm}$</td>
<td>2.747</td>
<td>2.735</td>
<td>2.723</td>
</tr>
<tr>
<td>Air Voids</td>
<td>4.93</td>
<td>---</td>
<td>3.13</td>
</tr>
<tr>
<td>$G_{mb}$</td>
<td>2.612</td>
<td>---</td>
<td>2.638</td>
</tr>
<tr>
<td>$P_b$</td>
<td>5.14</td>
<td>5.39</td>
<td>5.64</td>
</tr>
<tr>
<td>$P_{be}$</td>
<td>4.63</td>
<td>4.89</td>
<td>5.14</td>
</tr>
<tr>
<td>VMA</td>
<td>16.8</td>
<td>---</td>
<td>16.4</td>
</tr>
<tr>
<td>VFA</td>
<td>70.6</td>
<td>---</td>
<td>80.9</td>
</tr>
<tr>
<td>% dust</td>
<td>5.3</td>
<td>5.3</td>
<td>5.3</td>
</tr>
<tr>
<td>DB Ratio</td>
<td>1.14</td>
<td>1.08</td>
<td>1.03</td>
</tr>
</tbody>
</table>
**Volumetrics**

**Requirements**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Voids</td>
<td>3%-5%</td>
</tr>
<tr>
<td>VMA</td>
<td>&gt; 14%</td>
</tr>
<tr>
<td>VFA</td>
<td>65%-78%</td>
</tr>
</tbody>
</table>

**Graphs:**
- Air Voids, %
- VMA, %
- VFA, %

**Legend:**
- +0% AC
- +0.25%
- +0.5% AC
- +0.75% AC
Addition of binder softening the mix; higher RBR stiffer mix
No clear change of fatigue performance with the addition of binder in control mix
Significant improvement of fatigue with the binder addition in L5 (40%RBR)
Stress Sweep Rutting (20ºC)

Higher RBR produces significant lower deformation
Addition of binder increases deformation
Stress Sweep Rutting (54°C)

Higher RBR produces significant lower deformation
Addition of binder increases deformation
Conducting +0.25% binder.

Predicted pavement performance with the fatigue and SSR data (FlexPAVE).

Next step is to determine how much binder is needs to be added for 20% & 40% RAP-RBR mixes to achieve equivalent performance.
Thank You!
+
Questions?
Small Scale Specimen Fabrication

- **TFHRC Experience**
  - Started small scale specimen fabrication and testing in 2011
  - First tried to get 6 little cores from 1 gyratory specimen
  - Modified and have been getting 5 little cores
  - No dimensional tolerances; but need to meet Va criteria (target ±0.5%)

- **NCSU Proposed AASHTO Standard**
  - Get 4 cores from a gyratory specimen
  - No Va criteria, but need to meet dimensional tolerance
TFHRC Experience with 5 Little Cores

- Various mixtures cored and tested (NMAS 4.75-19mm)
- Mix with 12.5mm and below NMAS, 5-core method works satisfactorily
- Need more data for 19.0mm and plus NMAS mix

<table>
<thead>
<tr>
<th>NMAS (mm)</th>
<th>Total Number of Sample Produced</th>
<th>Target ±0.5% Va</th>
<th>Target ±0.75% Va</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.75</td>
<td>5</td>
<td>4  80%</td>
<td>4  80%</td>
</tr>
<tr>
<td>9.5</td>
<td>20</td>
<td>18 90%</td>
<td>18 90%</td>
</tr>
<tr>
<td>12.5</td>
<td>740</td>
<td>573 77%</td>
<td>620 84%</td>
</tr>
<tr>
<td>19</td>
<td>35</td>
<td>12 34%</td>
<td>12 34%</td>
</tr>
<tr>
<td>Total</td>
<td>800</td>
<td>607 76%</td>
<td>654 82%</td>
</tr>
</tbody>
</table>

TFHRC Recommendations

- 5-core method can fabricate more specimens with quality
- Volumetric criteria needed?
PAVEMENT TESTING FACILITY

STATUS REPORT
SEPTEMBER/2017
CURRENT PROJECT 2

Asphalt Concrete Field Density and Aggregate Base Geosynthetic Reinforcement
AC Field Density and CAB Geosynthetic Reinforcement

• Purpose
  – The compaction of asphalt concrete (AC) mixtures is a critical component in the process of achieving optimal pavement performance.
  – The quality and strength of the substructure (base and subgrade) have great influence of pavement performance.

• Objectives
  – Investigation of Asphalt Concrete Compaction and Its Impact on Performance of Pavements Built with and without Geosynthetic Base Reinforcement
The Experiment

- One AC mixture
- Four Lanes (4 different AC compaction levels)
  - High (>92% compaction)
  - Medium (90-92%)
  - Low (< 90%)
- Two structures per lane
  - Unreinforced
  - Reinforced with a Standard BS-1200
- Performance measures
  - Cracking
  - Rutting
Pavement Structure

No Reinforcement

- 4 in Asphalt Concrete
- 12 in New Crushed Aggregate Base
- 10 in Remaining Crushed Aggregate Layer
- Subgrade

With Reinforcement

- 4 in Asphalt Concrete
- 12 in New Crushed Aggregate Base
- GeoSynthetic
- 10 in Remaining Crushed Aggregate Layer
- Subgrade
# Air voids of field cores

<table>
<thead>
<tr>
<th>Lane</th>
<th>SSD Whole</th>
<th>SSD Bottom Trimmed</th>
<th>CoreLok Whole</th>
<th>CoreLok Bottom Trimmed</th>
</tr>
</thead>
<tbody>
<tr>
<td>L9 (Low)</td>
<td>10.6</td>
<td>0.8</td>
<td>10.2</td>
<td>0.8</td>
</tr>
<tr>
<td>L10 (Mid)</td>
<td>8.6</td>
<td>1.2</td>
<td>8.3</td>
<td>1.1</td>
</tr>
<tr>
<td>L11 (High)</td>
<td>7.9</td>
<td>0.7</td>
<td>7.7</td>
<td>0.7</td>
</tr>
<tr>
<td>L12 (High)</td>
<td>7.1</td>
<td>0.9</td>
<td>6.8</td>
<td>1.0</td>
</tr>
</tbody>
</table>
Air voids of field cores (cont’d)

![Bar chart showing air void contents for different lanes and materials.](chart.png)
Proposed Testing

• Rutting
  – Terminal state: 1.5 to 2 inches of total permanent deformation
  – Loading temperature:
    • Variable temperature:
      – 10K passes at 40°C
      – 5K passes at 50°C (estimated)
      – Cycle until terminal state is reached
  – All lanes will have at least one rutting test at one unreinforced base site
  – Two lanes will be tested twice:
    • Impact of base reinforcement on performance
Proposed Testing (Cont’d)

• Cracking
  – Loading temperature: 20°C
  – Terminal state: total cracking length > 1,000 inches
    • Early stages of cracking in which preventive maintenance would be optimum intervention in real pavements
  – All lanes will be tested at least twice for fatigue cracking:
    • One at one unreinforced base site, and
    • One at one geosynthetic reinforced base site
  – Effects of aging
    • Two lanes will have one extra fatigue test at aged conditions
Layout and Current Status

- F<sub>i</sub> – Fatigue test at aged conditions
- R – Rutting test

**Current Status (Rutting):**
- Lane 9 Site 1, 10,000 passes completed
- Lane 11 Site 3, 7,000 passes completed

**Next Steps (Rutting):**
- Lane 10, Site 2
- Lane 12, Site 4
- Lane 11, Site 1
Preliminary Results
Total Rutting

Load Passes

Permanent Deformation (mm)

L09S1 - Total
L11S3 - Total
Preliminary Results
AC & Substructure Rutting

![Graph showing permanent deformation vs load passes for different scenarios: L09S1 - Substructure, L09S1 - AC, L11S3 - Substructure*, L11S3 - AC*]
Thank you.