Asphalt Mixes with RAP, RAS, and Chemical Additives – A Study

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Proven Benefits of Evotherm with Recyclables
Established Benefits

- Improved compaction
- Ability to compact stiffer mixes
- Ability to increase RAP and/or RAS content
- Extended haul / season
- Reduced thermal segregation
- Improved resistance to deformation
- Improved resistance to cracking
- Improved resistance to moisture damage
Common Questions

• Is there sufficient blending of the virgin and oxidized binders?
  • Will the lack of blending lead to dry mixes?
  • Will the lack of blending lead to other performance issues like increased rutting, moisture susceptibility, etc?

• Is lowering a binder grade necessary when using warm mix additives, like Evotherm?
  • What are the additional costs involved with procuring softer asphalts?
  • Are softer asphalts readily available?
Common Questions

• Can we utilize the Evotherm benefits to increase RAP/RAS percentages?
  • What will be the cost benefits of adding additional RAP and/or RAS?
  • What impact can the additional RAP and/or RAS have on the performance of the mix?
Developmental Evotherm Additives

Goals

- Thorough blending of the virgin asphalt with the oxidized asphalt
- Softening of the oxidized binder in RAP and/or RAS to allow thorough blending

| Testing Condition | |E*|, ksi |
|-------------------|-------------------|---------|
|                   | Measured          | Predicted |
| 4C, 10 Hz         |                   |          |
| 4C, 1 Hz          |                   |          |
| 4C, 0.1 Hz        |                   |          |
| 20C, 10 Hz        |                   |          |
| 20C, 1 Hz         |                   |          |
| 20C, 0.1 Hz       |                   |          |
| 40C, 10 Hz        |                   |          |
| 40C, 1 Hz         |                   |          |
| 40C, 0.1 Hz       |                   |          |

PG64-22 EVT

PG64-28

EVOTHERM
Developmental Evotherm Additives

Goals

• Thorough blending of the virgin asphalt with the oxidized asphalt

• Softening of the oxidized binder in RAP / RAS to allow thorough blending

• Ability to add more recyclables to mixes to offset the reduced stiffness due to lower mixing and compaction temperatures

<table>
<thead>
<tr>
<th>Test Type</th>
<th>HMA + 20%RAP</th>
<th>EVO + 20%RAP</th>
<th>EVO + 28%RAP</th>
<th>EVO + 35%RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration (mm)</td>
<td>29</td>
<td>39</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>Viscosity (cP)</td>
<td>25920</td>
<td>16087</td>
<td>16738</td>
<td>23470</td>
</tr>
<tr>
<td>Ductility (mm)</td>
<td>38</td>
<td>79</td>
<td>54</td>
<td>42</td>
</tr>
<tr>
<td>DSR @ 64°C (kPa)</td>
<td>7.35</td>
<td>4.39</td>
<td>5.74</td>
<td>7.56</td>
</tr>
<tr>
<td>MSCR</td>
<td>26</td>
<td>42</td>
<td>37</td>
<td>32</td>
</tr>
<tr>
<td>DSR @ 70°C (kPa)</td>
<td>3.48</td>
<td>2.11</td>
<td>2.91</td>
<td>3.59</td>
</tr>
<tr>
<td>BBR -12°C</td>
<td>0.394</td>
<td>0.437</td>
<td>0.406</td>
<td>0.393</td>
</tr>
</tbody>
</table>
Developmental Evotherm Additives

Goals

- Eliminating the need to lower binder grade when using higher recyclable material contents
Developmental Evoxtherm Additives
RAP / RAS “Solubility”

Viscosities of Chemical Additives Before and After Soaking in RAS at 60 °C for time (t)

Viscosity @ 25 °C (cP)

<table>
<thead>
<tr>
<th>Time (t)</th>
<th>Additive 1</th>
<th>RAS + Additive 1</th>
<th>Additive 2</th>
<th>RAS + Additive 2</th>
<th>Water</th>
<th>RAS + Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-hour Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>One-day Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-day Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Effects on RAS Binder

![Bar Chart]

- **High Critical Temperature, °C**
  - Control RAS: 130°C
  - RAS + 2.5% Additive 2: 100°C

**Graph Description:**
- The graph compares the high critical temperature of Control RAS and RAS + 2.5% Additive 2.
- Control RAS has a higher temperature compared to RAS + 2.5% Additive 2.
Effects on Air Voids – 5% RAS Mix

![Graph showing effects on air voids with different AC (%) and Va (%). The graph compares Control and 1.5% Additive 2 mixtures.](image-url)
Effects on Compactive Effort – 5% RAS Mix

![Diagram showing the effects of AC (%) on CFI for Control and 1.5% Additive 2.](image_url)
Master Curves

E* Master Curves - 40% RAP

Frequency [Hz]

E* [mPa]

Tref = 21.1°C

HMA (PG 58-28)
Master Curves

E* Master Curves - 40% RAP

- HMA (PG 58 -28)
- WMA - EVT [0.5%] (PG 64 -22)

T_{ref} = 21.1^\circ C
Master Curves

E* Master Curves - 40% RAP

- HMA (PG 58 -28)
- WMA - EVT [0.5%] (PG 64 -22)
- WMA - EVT-RCL [1.5%] (PG 64 -22)

Tref = 21.1°C
Master Curves

E* Master Curves - 40% RAP

Tref = 21.1°C

- HMA (PG 58 -28)
- WMA - EVT [0.5%] (PG 64 -22)
- WMA - EVT-RCL [1.5%] (PG 64 -22)
- WMA - EVT-RCL [3%] (PG64 -22)
Recovered Binder Grades

RTFO Grade

G*/sin(delta) [kPa] vs Temperature [C]

- HMA
- WMA - EVT
- WMA - 1.5% EVT-RCL
Effects on Binder Properties

![Chart showing the effects of different% on G*/sin-d @ PG Temp. (kPa) for PG 64-22 and PG 58-28.](image-url)
Effects on Binder Properties

- **G*/sin-d @ PG Temp. (kPa)**
- **PG 58 -22**
  - 0%
  - 1.50%
  - 3%
- **PG 58 -28**
  - 0%
  - 1.50%
  - 3%
Effects on Rutting Potential

- HMA Control
- HMA 1.5% Evoflex CA
- HMA 3% Evoflex CA
- WMA Control
- WMA 1.2% Evoflex CA and 0.3% M1
- WMA 2.7% Evoflex CA and 0.3% M1

AVERAGE RUT DEPTH @ 20000 cycles (mm)
Effects on Binder Properties

- Creep Stiffness (MPa)
- Stiffness and m-value for PG 64-22 (-12 C) and PG 58-28 (-18 C) at 0%, 1.50%, and 3%.
Effects on Binder Properties

Creep Stiffness (MPa)

- PG 64 -22 (-18 C)
- PG 58 -28 (-24 C)

Stiffness

m-value

0%  1.50%  3%  0%  1.50%  3%  0%  1.50%  3%

PG 64 -22 (-18 C)  PG 58 -28 (-24 C)  PG 64 -22 (-18 C)  PG 58 -28 (-24 C)

Stiffness  m-value
Effects on Binder Properties

Creep Stiffness (MPa)

0% 1.50% 3% 0% 1.50% 3% 0% 1.50% 3% 0% 1.50% 3%

PG 58 -22 (-12 C) PG 58 -28 (-18 C) PG 58 -22 (-12 C) PG 58 -28 (-18 C)

Stiffness m-value

EVO THERM
Effects on Binder Properties

- Creep Stiffness (MPa)
  - PG 58 -22 (-18 C)
  - PG 58 -28 (-24 C)

- PG 58 -22 (-18 C)
- PG 58 -28 (-24 C)

Stiffness and m-value comparison:
- Stiffness
- m-value

0% 1.50% 3%
PG 58 -22 (-18 C)
PG 58 -28 (-24 C)
PG 58 -22 (-18 C)
PG 58 -28 (-24 C)

Evotherm
North Carolina Field Trial

- 9.5mm state mix
- PG 64 -22 with 15% RAP and 5% RAS (27% binder replacement)
- Mix produced at 275 °F
- Roughly 200T of control warm-mix, 200T of warm-mix with 1.2% Evoflex CA, and 200T of warm-mix with 0.9% Evoflex CA
- No problems in production and placement
North Carolina Pre - Trial Binder Evaluation

- RAP and RAS binder was extracted and blended with virgin asphalt in the lab
- 20% RAP and 5% RAS (32% binder replacement)
- RTFO aging of the blend @ 135°C (planned production temperature)
- PAV aging of the blend @ 100°C for 20 hrs.
## Effects on Unaged Binder

<table>
<thead>
<tr>
<th></th>
<th>Unaged Asphalt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nustar Control</td>
</tr>
<tr>
<td><strong>$G^*$/sin d @ 64°C (Pa)</strong></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>1825</td>
</tr>
<tr>
<td>Trial 2</td>
<td>1735</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>1780.0</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>63.6</td>
</tr>
<tr>
<td><strong>Pass/Fail Temp (°C)</strong></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>68.9</td>
</tr>
<tr>
<td>Trial 2</td>
<td>68.5</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>68.7</strong></td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>0.3</td>
</tr>
</tbody>
</table>
### Effects on Intermediate Temperature Fatigue Properties

<table>
<thead>
<tr>
<th>PAV Aged Asphalt</th>
<th>Nustar + RAP + RAS + 0.25% M1</th>
<th>Nustar + RAP + RAS + 0.25% M1 + 1.2% Evoflex CA</th>
</tr>
</thead>
<tbody>
<tr>
<td><em><em>G</em> sin-d @ 22C (kPa)</em>*</td>
<td><strong>Trial 1</strong></td>
<td><strong>Trial 2</strong></td>
</tr>
<tr>
<td><strong>Pass/Fail Temp (C)</strong></td>
<td><strong>Trial 1</strong></td>
<td><strong>Trial 2</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Effects on Low Temperature Properties

<table>
<thead>
<tr>
<th>PAV Aged Asphalt</th>
<th>Nustar + RAP + RAS + 0.25% M1</th>
<th>Nustar + RAP + RAS + 0.25% M1 + 1.2% Evoflex CA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Creep Stiffness (Mpa) @ -12C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>140</td>
<td>141</td>
</tr>
<tr>
<td>Trial 2</td>
<td>144</td>
<td>137</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>142.0</td>
<td>139.0</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>2.8</td>
<td>2.8</td>
</tr>
<tr>
<td><strong>m-value @ -12C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trial 1</td>
<td>0.34</td>
<td>0.349</td>
</tr>
<tr>
<td>Trial 2</td>
<td>0.328</td>
<td>0.349</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>0.334</td>
<td>0.349</td>
</tr>
<tr>
<td><strong>SD</strong></td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Low Temperature Mix Properties

DC(T) Test @ -12C

![Graph showing CMOD (J/m²) for Control and EVOFLEX CA samples. The graph indicates a significant improvement in CMOD for the EVOFLEX CA sample compared to the Control sample.]
Overlay Test Data

Control  0.9% EVOFLEX CA  1.2% EVOFLEX CA
North Carolina Field Trial

Average Rut Depth (mm) per Cycle

Cycles

Average Rut Depth (mm)

Control  0.9% EVOFLEX CA  1.2% EVOFLEX CA
Dynamic Modulus Master Curve

E* (ksi) vs. Reduced Frequency (Hz)

- Low Speed or High Temperature
- High Speed or Low Temperature

Control
0.9% EVOFLEX CA
1.2% EVOFLEX CA
Missouri Field Trial

- Surface course 12.5mm mix
- PG 64 -22 binder with 19% RAP and 3% RAS
- RAP AC content = 6.0%; RAS AC content = 23.0%
- Sunny, 32F ambient temperature and windy
- Mostly hand work on driveways and shoulders
- Average mix production temp = 330-340F
- 30 – 45 min haul
Missouri Field Trial

- **Control Mix**
  - 0.25% M1
  - Total AC = 5.2%; Virgin AC = 3.5% (32.7% replacement)

- **Evoflex CA Mix**
  - 0.25% M1
  - 1.5% Evoflex CA
  - Total AC = 5%; Virgin AC = 3.2% (36% replacement)
  - This translated to about 4-5% extra RAP or 0.75% extra RAS or 0.3% savings in virgin AC without significantly affecting the final binder properties
## Extracted Binder Properties

<table>
<thead>
<tr>
<th>High Temperature Grade</th>
<th>Control w/M1</th>
<th>M1 w/ 1.5% Evoflex CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Binder Replacement</td>
<td>32.7%</td>
<td>36%</td>
</tr>
<tr>
<td>Mean SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass Fail Temp (° C)</td>
<td>81.8 0.42</td>
<td>82.3 0.14</td>
</tr>
<tr>
<td>Grade</td>
<td>76</td>
<td>82</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intermediate Temperature Grade</th>
<th>Pass Fail Temp (° C)</th>
<th>Inter Grade Temp (° C)</th>
<th>G*/sin(delta) @ 25° C</th>
<th>G*/sin(delta) @ 22° C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24.2 0.14</td>
<td>25</td>
<td>4620 56.6</td>
<td>6230 99.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Low Temperature Grade</th>
<th>M value @ 12c &gt; 0.300</th>
<th>Stiffness @ 12c &lt; 300</th>
<th>M value @ 6c &gt; 0.300</th>
<th>Stiffness @ 6c &lt; 300</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.288 0.001</td>
<td>171.0 0</td>
<td>0.308 0.003</td>
<td>92.2 2.0</td>
</tr>
<tr>
<td></td>
<td>0.284 0.001</td>
<td>181.0 11.3</td>
<td>0.300 0.001</td>
<td>100.0 2.8</td>
</tr>
</tbody>
</table>

| Grade                  | -6                    | -6                    |

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![EVO THERM](image)
## Moisture Susceptibility Data

<table>
<thead>
<tr>
<th></th>
<th>AASHTO T283</th>
<th>MiST Conditioning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry St. (psi)</td>
<td>Wet St. (psi)</td>
</tr>
<tr>
<td>Control w/ M1</td>
<td>176.2</td>
<td>163</td>
</tr>
<tr>
<td>M1 w/ Evoflex CA</td>
<td>178.6</td>
<td>170.6</td>
</tr>
</tbody>
</table>

*MiST Conditioning values reflect changes after additional conditioning.*
Rutting Resistance

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>AVERAGE RUT DEPTH @ 20000 cycles (mm)</th>
<th>STANDARD DEVIATION (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONTROL w/ M1</td>
<td>-2.10</td>
<td>0.33</td>
</tr>
<tr>
<td>M1 w/ 1.5% Evoflex CA</td>
<td>-1.91</td>
<td>0.49</td>
</tr>
</tbody>
</table>
Dynamic Modulus

![Graph showing dynamic modulus vs. reduced frequency for Control and EVOFLEX CA](image-url)
Mix BBR

Creep Stiffness (MPa)

Control  EVOFLEX CA
Creep Stiffness @ 3C

Control  EVOFLEX CA
m-Value @ 3C

- Stiffness
- m-Value
DC(T) Test Results

DC(T) Test @ -6C

![Bar chart showing CMOD (J/m^2) for Control and EVOFLEX CA at -6C temperature. The chart indicates that EVOFLEX CA has a higher CMOD compared to the control.](image-url)
Proposed Benefits

• Improved low and intermediate temperature properties
  • Lower creep stiffness and higher m-values
  • Improved fatigue and thermal cracking resistance

• Higher ‘effective binder’ from RAP and RAS
  • Improved blending
  • Lower virgin asphalt contents

• Ability to use PG64 with high RAP and/or RAS mixes instead of using PG58

• Improved compaction of stiff mixes
  • Improved pavement performance
Conclusions
Evotherm Difference

Easy to Use
- Any mix plant
- No equipment to purchase or maintain
- Drop-in laboratory evaluations

Lowest Temperatures
Proven Performance
Evotherm Difference

Easy to Use

Lowest Temperatures
- Reduced thermal segregation
- Lower emissions
- Reduced fuel consumption
- Long hauls
- Extended season

Proven Performance
Evotherm Difference

Easy to Use

Lowest Temperatures

Proven Performance

- Improved Compaction
- Increased RAP/RAS Content
- Improved thermal / fatigue properties
Questions?

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