Evaluation of Performance Properties of Asphalt Mixes Containing RAP Produced with Re-refined Heavy Vacuum Distillate Bottoms Modified Binder

John D’Angelo, D’Angelo Consulting LLC
Ken Grzybowski, Christine Feaster PRI
Steve Lewis, Mark Bouldin, Safety-Kleen
The Refinery
The Refining Process

- Used Oil Feedstock
- Guard Tanks for Quality Testing
- Safety-Kleen
  - Protection + Choices + People
  - Make Green Work
- Dehydration
- Fuel Stripping
- Vacuum Distillation
- Hydrotreating
- Industrial Fuels
- Vacuum Distillation Bottoms
- Re-refined Oil Base Stocks
Re-refined Product
Results from Previous Studies

- RHVDB has been shown effective in reducing high and low temperature properties of a binder.
- Mixes produced with RHVDB modified binder have shown improved fatigue and low temperature fracture properties.
## Component makeup of RHVDB’s

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Method</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic Composition: As Received</td>
<td></td>
<td>RHVDO 1</td>
</tr>
<tr>
<td>Ash, %</td>
<td>AASHTO T 111</td>
<td>5.7</td>
</tr>
<tr>
<td>Component Fractions, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphaltenes</td>
<td>ASTM D 4124, SARA Fractions by Iatroscan</td>
<td>2.6</td>
</tr>
<tr>
<td>Polar Aromatics</td>
<td></td>
<td>44.7</td>
</tr>
<tr>
<td>Naphthene Aromatics</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Saturates</td>
<td></td>
<td>52.7</td>
</tr>
<tr>
<td>Wax, %</td>
<td>EN 12606-1</td>
<td>0.28</td>
</tr>
<tr>
<td>Solubility, %</td>
<td>ASTM D 2042</td>
<td>99.3</td>
</tr>
</tbody>
</table>
RHVDB affect on Intermediate DSR Marathon & RHVDB 1

\[ y = -0.6147x + 21.871 \]
\[ R^2 = 0.9609 \]
Linear trend 20hr/PAV

\[ y = -0.5627x + 23.901 \]
\[ R^2 = 0.9821 \]
Linear trend 35hr/PAV

Continuous grade °C vs. RHVDO %

- 20hr/PAV
- 35hr/PAV
RHVDB affect on Intermediate DSR properties

- RHVDB reduced the Intermediate DSR values.
- Linear relationship between % RHVDB and reduction.
- Rate of aging is controlled by the base asphalt.
- RHVDB does not increase aging.
Can EcoAddz be used as a Rejuvenator for RAP Mixes

- How will the EcoAddz Affect RAP Mix Properties?
- How will EcoAddz Affect Aging of RAP Mixes?
Mix Testing of EcoAddz Modified Material with RAP

- Use mix from U. Illinois Moisture damage study N70, 70 gyration Mix
- Use Illinois stone, Dolomitic Limestone
- RAP Local Florida Mix Tampa
  - Recovered binder PG 92.1-14.3
- Control binder BP PG 64-22
- Modify BP PG 64-22 with 2, 6 & 10 % EcoAddz
Mix Testing of RHVDB Modified Material

- High temperature testing Hamburg Wheel tracking
- Intermediate temperature testing 4 Point Bending Beam
- Dynamic Modulus testing
- Low temperature testing Disk Shape Compact Tension
- Short term and long term aging of mix
Accelerated Pavement Weathering System (APWS)
Aging

- Compare short-term aged to long-term aged performance properties and the asphalt performance grade

- Short-term aged:
  - 2 hours at 135°C prior to compaction

- APWS Aged
  - 3,000 hours total (≈ 15+ years)
  - High Temperature = 60-65°C (simulated pavement surface temperature)
  - Continuous sunlight
  - 1 cycle = 51 minutes dry, 9 minutes wet (‘rain’)
    - Thermal shock = Δ temperature ≈ 30-40°F
  - 24 cycles each day
N70, and N70 + 20% RAP Mix Gradation

Percent Passing, %

Sieve Size, mm, Raised to 0.45 Power

- N70 with 20% RAP
- Min.
- Max
- N70
### N70 RAP Mix Properties

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Illinois Standard Specification</th>
<th>Control</th>
<th>2% EcoAddz</th>
<th>6% EcoAddz</th>
<th>10% EcoAddz</th>
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</thead>
<tbody>
<tr>
<td>Design Gyrations</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
<td>70</td>
</tr>
<tr>
<td>True PG Grade Recovered</td>
<td>--</td>
<td>69.3-24.8</td>
<td>66.0-26.8</td>
<td>66.3-27.8</td>
<td>66.7-28.2</td>
</tr>
<tr>
<td>Percent Binder, Pb(%)</td>
<td>4.0 to 7.0</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Absorbed Asphalt, Pba, %</td>
<td>--</td>
<td>1.2</td>
<td>1.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>Effective Asphalt Content, Pbe, %</td>
<td>--</td>
<td>4.2</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Air Voids in Compacted Mixture, Va, %</td>
<td>--</td>
<td>4.0</td>
<td>3.6</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Volume of Voids in Mineral Aggregate, VMA, %</td>
<td>13 minimum</td>
<td>13.8</td>
<td>13.8</td>
<td>14.1</td>
<td>14.1</td>
</tr>
<tr>
<td>Dust Proportion, DP, %</td>
<td>1.4 max</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
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</table>
## Blends Continuous Grades

### Original and Recovered

<table>
<thead>
<tr>
<th>Control</th>
<th>Control + RAP</th>
<th>2% EcoAdd z</th>
<th>2% EcoAdd z + RAP</th>
<th>6% EcoAdd z</th>
<th>6% EcoAdd z + RAP</th>
<th>10% EcoAdd z</th>
<th>10% EcoAdd z + RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series 1</td>
<td>66.2</td>
<td>69.3</td>
<td>64.6</td>
<td>66.0</td>
<td>62</td>
<td>66.3</td>
<td>59.8</td>
</tr>
<tr>
<td></td>
<td>-25.6</td>
<td>-24.8</td>
<td>-26.9</td>
<td>-26.8</td>
<td>-27.5</td>
<td>-27.8</td>
<td>-28.8</td>
</tr>
<tr>
<td>Series 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Graph:**
- X-axis: Grade Temp °C
- Y-axis: Blend Grades
- Control and Control + RAP
- 2% EcoAdd z and 2% EcoAdd z + RAP
- 6% EcoAdd z and 6% EcoAdd z + RAP
- 10% EcoAdd z and 10% EcoAdd z + RAP

**Legend:**
- Series 1
- Series 2
Recovered Binder after APWS
N70 RAP Mix

True Performance Grade

Temperature, °C

-20
-40
0
20
40
60
80
100

Control

69.3
-24.8

87.4
-20.13

66.3
-27.8

75.7
-22.63

6% EcoAddz
Recovered Binders

- The addition of 20% RAP only had a minor affect on recovered binder grades.
- EcoAddz modified binders had almost no loss of low temperature properties for the recovered binders.
RHVDB Blend Results

N70 Hamburg Loaded Wheel Results

Rut Depth, mm

0 2000 4000 6000 8000 10000 12000 14000 16000 18000 20000

Cycles

Control
4% EcoAddz
6% EcoAddz & 0.5% AS
PG 58-XX

2% EcoAddz
Control6
10% EcoAddz
PG 64-XX

Control4
6% EcoAddz
Failure

Illinois Spec limit

Illinois Spec limit
N70 Mix 20% RAP HWT

The graph shows the rutting mm of different mixtures over a range of repetitions. The x-axis represents the number of repetitions, and the y-axis shows the rutting mm. The graph includes data for Control, 2% EcoAddz, 6% EcoAddz, 10% EcoAddz, and Failure. The PG 64-XX is also indicated on the graph.
N70 RAP mixes After APWS

- Control
- Control APWS
- 6% EcoAddz
- 6% EcoAddz APWS
- Failure
- PG 64-XX
The addition of RAP only caused minor increases in stiffness and minor reduction rutting.

The RHVDB mixes did not cause significant reduction of the high temperature properties.

Long term aging provided similar increased stiffness of control and 6% EcoAddz mixes.
N70 Mix 20% RAP Master Curves 20C

Dynamic Modulus, $E^*$, ksi

Frequency, Hz

- Control
- 2% EcoAddz
- 6% EcoAddz
- 10% EcoAddz
N70 Mix no RAP Master Curves 20°C

Dynamic Modulus, $E^*$, ksi

Frequency, Hz

- Control
- 2% EcoAddz
- 6% EcoAddz PG Equiv.
- 6% EcoAddz
- 6% EcoAddz, 0.5% AS
- 10% EcoAddz

N70 Master Curves at 20°C
Master Curves

- The master curve data strictly matches binder PG grade.
- Softer binder lower E* data.
- RAP only shows minor increase in mix stiffness.
N70 Mix 4 Point Bending Beam

Cycles to Failure, (nf) vs. Microstrain

- control
- 2% EcoAddz
- 6% EcoAddz
- control + RAP
- 2% Eco Addz + RAP
- 6% EcoAddz + RAP
- 10% EcoAddz + RAP
N70 Mix + RAP 4 Point Bending Beam Before and After APWS

Cycles to Failure (Nf) vs. Microstrain graph showing performance of different mixes and treatments: Control, 2% EcoAddz, 6% EcoAddz, 10% EcoAddz, Cont APWS, and 6% EcoAddz APWS.
Beam Fatigue Testing

- The four point bending beam data clearly shows the mixes produced with RHVDB have better fatigue response than control binder.

- The Addition of RAP Clearly reduces fatigue response. EcoAddz improved Fatigue response of the RAP mix.

- Accelerated aging only showed minor loss in fatigue response.
DCT Fracture Energy N70 Mix

<table>
<thead>
<tr>
<th></th>
<th>Fracture Energy J/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>434</td>
</tr>
<tr>
<td>Control + RAP</td>
<td>385</td>
</tr>
<tr>
<td>2% EcoAdd z</td>
<td>540</td>
</tr>
<tr>
<td>2% EcoAdd z + RAP</td>
<td>521</td>
</tr>
<tr>
<td>6% EcoAdd z</td>
<td>854</td>
</tr>
<tr>
<td>6% EcoAdd z + RAP</td>
<td>485</td>
</tr>
<tr>
<td>10% EcoAdd z</td>
<td>683</td>
</tr>
<tr>
<td>10% EcoAdd z + RAP</td>
<td>494</td>
</tr>
</tbody>
</table>
Fracture Energy tested at -12°C

MN Research indicates 400 J/m² to be an acceptable minimum Fracture Energy for Unaged Samples
N70 RAP Mixes Fracture Energy -12 C

Fracture Energy, J/m²

Before APWS

After APWS

Control

6% EcoAddz
Fracture Energy Results

- On unaged samples the addition of RAP created a smaller reduction in Fracture Energy on base binder than EcoAddz modified binder.
- On long term aged mix RAP caused significant loss in Fracture Energy of base binder. EcoAddz modified binder indicated only minor loss of fracture energy.
Summary

- The recovered binder of RAP mixes indicate that the RAP has only minor affect on binder properties. EcoAddz provides minor improvement.
- Mix properties correlate well recovered binder properties on unaged samples.
- Long term aging indicates significant change in properties of mix with RAP.
- EcoAddz modified binder mitigated some of the long term aging effects.
Thank you

Questions