Asphalt Binder and Mixture Properties Produced with REOB Modified Asphalt Binders

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- Asphalt Institute
  - DENT Testing
- Axeon Specialty Products
  - Ron Corun
Overview of Study

- Research focused on how a binder supplier would utilize REOB in asphalt binder
- Use REOB to modify stiffer asphalt binders to achieve a softer binder grade (PG64-22 and PG58-28 for this study)
  - Usage in cold temperature climates
  - Usage with higher recycled asphalt mixtures (RAP and/or RAS)
- Asphalt binders (base asphalt from Axeon - Paulsboro, NJ)
  - Neat PG64-22
  - Neat PG58-28
  - REOB modified PG58-28 (20% REOB; 80% PG70-22)
  - REOB modified PG58-28 (6% REOB; 94% PG64-22)
  - REOB modified PG64-22 (10% REOB; 90% PG70-22)
- 2 REOB Sources
- Total of 8 binders evaluated
- Mix: NJDOT approved 9.5mm NMAS, 5.4% asphalt content
Overall Workplan – Lab Testing

- Asphalt Binder Testing
  - PG grading (BBR 20 and 40 hr PAV aging)
  - Master Stiffness Curves
    - Original, RTFO, PAV 20 hr, PAV 40 hr
    - Glover-Rowe Parameter, Rheological Properties
  - DENT test (PAV aged)
- Asphalt Mixture Testing (STOA & LTOA)
  - Dynamic Modulus
  - Flow Number
  - Overlay Tester
  - Flexural Beam Fatigue
  - SCB Intermediate Temperature
  - TSRST
Binder Test Results
## PG Grading (1 of 2)

<table>
<thead>
<tr>
<th>REOB Supplier</th>
<th>Target Grade</th>
<th>% REOB</th>
<th>High Temperature</th>
<th>Multiple Stress Creep Recovery (MSCR)</th>
<th>Inter. Temp</th>
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<tr>
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<td></td>
<td>Orig</td>
<td>RFTO</td>
<td>58°C</td>
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<tr>
<td>N.A.</td>
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<td>66.9</td>
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## PG Grading (2 of 2)

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<th>Supplier</th>
<th>REOB Supplier</th>
<th>Target Grade</th>
<th>% REOB</th>
<th>Low Temperature</th>
<th>R49 (20 Hr)</th>
<th>PG Grade</th>
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<td>S (MPa)</td>
<td>m-slope</td>
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<td>-31.3</td>
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<td>RFTO</td>
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<td>94% 64-22</td>
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<td>80% 70-22</td>
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<td>10% REOB +</td>
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<td>90% 70-22</td>
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<td>94% 64-22</td>
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<td>58-28</td>
<td>20% REOB +</td>
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<td>80% 70-22</td>
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<td>64-22</td>
<td>10% REOB +</td>
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</table>
BBR $\Delta T_{crit}$ vs Aging (Source #2)
Master Stiffness (G*) Curves - Form of Master Curve (Christensen & Anderson, 2001)

- Master Stiffness (G*) curves generated using frequency sweep in the DSR
- Shape of master curve related to overall stiffness of the asphat binder
- As binders age, increase in stiffening
PG64-22 & PG76-22 in $\omega_0$ & R-value Space

![Graph showing the relationship between crossover frequency and R-value for PG64-22 and PG76-22 asphalt binders in RTFO, 20 HR PAV, 40 HR PAV, 60 HR PAV conditions. The graph includes markers for different aging and testing conditions.]
Master Curve (R-value & Crossover Frequency) – PG58-28 Source #1
Master Curve (R-value & Crossover Frequency) – PG64-22 Source #1
Master Curve (R-value & Crossover Frequency) – PG64-22 Source #2
Glover-Rowe Parameter (G-R)

- Due to equipment and material size restraints, Ductility testing may not be available
- Rowe (AAPT, 2011) proposed the DSR master curve analysis to calculate the “Glover-Rowe” parameter
  - As G-R parameter increases, the binder is more prone to fatigue cracking
  - Correlates to both ductility and BBR $\Delta T_c$
Glover-Rowe Parameter vs Aging
(Source #1, PG58-28)
Glover-Rowe Parameter vs Aging
(Source #1, PG64-22)

- Onset of Cracking
  - PG64-22 0% REOB - Orig
  - PG64-22 0% REOB - RTFO
  - PG64-22 0% REOB - 20 Hr PAV
  - PG64-22 0% REOB - 40 Hr PAV

- Significant Cracking
  - PG64-22 10% REOB - Orig
  - PG64-22 10% REOB - RTFO
  - PG64-22 10% REOB - 20 Hr PAV
  - PG64-22 10% REOB - 40 Hr PAV
Glover-Rowe Parameter vs Aging (Source #2, PG58-28)

- Onset of Cracking
- Significant Cracking

- PG58-28 0% REOB - Orig
- PG58-28 6% REOB - Orig
- PG58-28 0% REOB - RTFO
- PG58-28 6% REOB - RTFO
- PG58-28 0% REOB - 20 Hr PAV
- PG58-28 6% REOB - 20 Hr PAV
- PG58-28 0% REOB - 40 Hr PAV
- PG58-28 6% REOB - 40 Hr PAV

$G^\ast \cos \frac{2\pi}{\sin t}, 0.005 \text{ rads/sec} \quad 450\text{kPa}$

$G^\ast \cos \frac{2\pi}{\sin t}, 0.005 \text{ rads/sec} \quad 180\text{kPa}$

Phase Angle, degrees
Glover-Rowe Parameter vs Aging
(Source #2, PG64-22)

- Onset of Cracking
  - PG64-22 0% REOB - Orig
  - PG64-22 0% REOB - RTFO
  - PG64-22 0% REOB - 20 Hr PAV
  - PG64-22 0% REOB - 40 Hr PAV

- Significant Cracking
  - PG64-22 10% REOB - Orig
  - PG64-22 10% REOB - RTFO
  - PG64-22 10% REOB - 20 Hr PAV
  - PG64-22 10% REOB - 40 Hr PAV

\[ G^* \cos^2 \sin, 0.005 \text{ rads/sec} \]

- 450kPa
- 180kPa
Glover-Rowe Parameter – 20 Hr PAV (15°C, 0.005 rad/sec)

<table>
<thead>
<tr>
<th></th>
<th>0% REOB</th>
<th>6% REOB</th>
<th>20% REOB</th>
<th>0% REOB</th>
<th>10% REOB</th>
<th>10% REOB</th>
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<td>Source #1</td>
<td>PG58-28</td>
<td>14.9</td>
<td>15.2</td>
<td>98.2</td>
<td>81.4</td>
<td>96.6</td>
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<tr>
<td>Source #2</td>
<td>PG64-22</td>
<td>39.6</td>
<td>136.2</td>
<td>106.1</td>
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Double Edge Notched Tension (DENT) Test – AASHTO TP113

- Test evaluates the energy required for fracturing ductile materials
  - Test measures the Work of Fracture and Critical Opening Displacement (CTOD)
  - CTOD represents ultimate elongation, or strain tolerance, in the vicinity of a crack (i.e. – notch)
  - As CTOD increases, more resistant to fracturing
- Test has been found to correlate well to field cracking performance
DENT CTOD (15°C)
Mixture Test Results
- Trap Rock aggregate
- 5.4% asphalt content; 0% RAP
- Short-term (STOA) and Long-term (LTOA) oven aged according to AASHTO R30

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<td>Sieve Size</td>
<td>Lab Study Design</td>
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<td>1/2&quot; (12.5 mm)</td>
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<td>3/8&quot; (9.5 mm)</td>
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<td>No. 4 (4.75 mm)</td>
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<td>No. 8 (2.36 mm)</td>
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<td>No. 16 (1.18 mm)</td>
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<td>No. 30 (0.600 mm)</td>
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<td>No. 50 (0.425 mm)</td>
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<td>No. 200 (0.075 mm)</td>
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<td>Gmm (g/cm³)</td>
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<td>Design AV%</td>
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<td>Asphalt Content (%)</td>
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<td>VMA (%)</td>
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REOB
Source #1
REOB
Source #2
Flow Number (54°C) – Source #1
# Flow Number (54°C) – Source #2

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<th>Binder Grade</th>
<th>0% REOB</th>
<th>6% REOB</th>
<th>20% REOB</th>
<th>0% REOB</th>
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<td>272</td>
<td>592</td>
<td>621</td>
<td>338</td>
<td>727</td>
<td>566</td>
<td>1000</td>
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APA Rutting (64°C)

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<th>6% REOB</th>
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<th>0% REOB</th>
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<tr>
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<td>PG64-22</td>
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<td>6.6</td>
<td>5.7</td>
<td>6.2</td>
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<td>3.8</td>
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Flexural Beam Fatigue – Source #1
Flexural Beam Fatigue – Source #2
Overlay Tester – Source #1

Error Bars represent one standard deviation from the Mean

<table>
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<th>Binder Grade</th>
<th>0% REOB</th>
<th>6% REOB</th>
<th>20% REOB</th>
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<th>6% REOB</th>
<th>20% REOB</th>
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<td>529</td>
<td>226</td>
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<td>8</td>
<td>89</td>
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Overlay Tester – Source #2

Error Bars represent one standard deviation from the Mean

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<th>20% REOB</th>
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</tbody>
</table>
Semi-Circular Bend (25°C) – Source #2

![Graph showing Jc (kJ/m²) for different percentages and samples.](image-url)
TSRST Low Temp Critical Cracking – Source #1

![Bar chart showing TSRST Critical Cracking Temperature for PG58-28 and PG64-22 asphalt mixes with different rubber contents.](chart.png)
Binder to Mixture Performance Comparisons
Comparisons were made between the binder and mixture fatigue parameters.

Only Overlay Tester showed good correlation

- Some cases, Beam Fatigue was counter intuitive to what was expected

Poor correlation between SCB $J_C$ and binder properties
Overlay Tester (LTOA) vs BBR $\Delta T_{\text{crit}}$

**Diagram Description:**
- The graph compares the Overlay Tester performance with BBR $\Delta T_{\text{crit}}$ differences.
- The x-axis represents Overlay Tester cycles, ranging from 0 to 300.
- The y-axis shows the temperature difference $T_{\text{CRIT, S}} - T_{\text{CRIT, m}}$ in °C, ranging from -30.0 to 5.0.

**Data Points:**
- Open circles represent 20 Hr PAV Aging.
- Filled circles represent 40 Hr PAV Aging.

**Legend:**
- **BBR**
  - S - Controlled
  - m - Controlled
- **Cracking Warning**
- **Cracking Limit**
Overlay Tester (LTOA) vs DENT CTOD (20 Hr PAV)

\[ y = 3.1405x^{0.1901} \]

\[ R^2 = 0.7868 \]

Open Symbol - Virgin Binder
Gray Filled Symbol - REOB Source #1
Black Filled Symbol - REOB Source #2
Overlay Tester (LTOA) vs Glover-Rowe Parameter (20 Hr PAV)

- Open Symbol - Virgin Binder
- Gray Filled Symbol - REOB Source #1
- Black Filled Symbol - REOB Source #2

The graph shows the relationship between Overlay Tester (cycles) and Glover-Rowe 20 Hr PAV (kPa). The fitted line equation is $y = 128.53e^{-0.008x}$ with $R^2 = 0.9176$. The points represent data from different sources.
Overlay Tester (LTOA) vs Cross-over Frequency (20 Hr PAV)

- Open Symbol - Virgin Binder
- Gray Filled Symbol - REOB Source #1
- Black Filled Symbol - REOB Source #2

The line equation is:

\[ y = 0.7845x - 5.3606 \]

with a correlation coefficient of:

\[ R^2 = 0.9606 \]
Low Temperature Critical Cracking – Mixture vs Binder

TSRST Low Temperature Critical Cracking (°C)

- AASHTO R29, m-slope
- AASHTO R29, Stiffness
- AASHTO R49
General Comments on REOB Work

- Degree of aging has a greater impact on REOB modified asphalt performance when compared to Neat binders
- REOB source was found influence the performance of REOB modified asphalt (i.e. – not all REOB created equal)
- REOB dosage rate has a impact on performance, but magnitude not the same for each REOB source
  - Slight differences were found between Neat and 6% REOB binders/mixtures – greater differences found at higher REOB concentrations
General Comments on REOB Work

- Stiffness and aging behavior in E* of REOB and neat binders similar
- Different ranking between fatigue cracking mixture tests
  - Almost complete reverse in ranking between Flexural Beam Fatigue (crack initiation/stiffness-based) and Overlay Tester (crack propagation)
- Low temperature TSRST performance differed based on source
  - Larger differences between REOB and neat binders for Source #2
- Binder “fatigue” tests correlated well with the Overlay Tester and were sensitive to REOB dosage
  - BBR ΔTcrit Difference
  - Cross-over frequency
  - Glover-Rowe
  - DENT CTOD
Thank you for your time!

Questions?

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