Asphalt Binder and Mixture Properties Produced with REOB Modified Asphalt Binders

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Rutgers University
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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>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Orig</td>
<td>RFTO</td>
<td>58°C</td>
</tr>
<tr>
<td>N.A.</td>
<td>58-28</td>
<td>0%</td>
<td>61.3</td>
<td>66.9</td>
<td>2.81</td>
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<tr>
<td></td>
<td>64-22</td>
<td>0%</td>
<td>68.7</td>
<td>70.2</td>
<td>0.78</td>
</tr>
<tr>
<td>Supplier #1</td>
<td>58-28</td>
<td>6% REOB + 94% 64-22</td>
<td>60.5</td>
<td>60.5</td>
<td>2.70</td>
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<tr>
<td></td>
<td>58-28</td>
<td>20% REOB + 80% 70-22</td>
<td>61.4</td>
<td>65.3</td>
<td>2.25</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>10% REOB + 90% 70-22</td>
<td>67.0</td>
<td>73.1</td>
<td>1.28</td>
</tr>
<tr>
<td>Supplier #2</td>
<td>58-28</td>
<td>6% REOB + 94% 64-22</td>
<td>64.5</td>
<td>64.7</td>
<td>1.74</td>
</tr>
<tr>
<td></td>
<td>58-28</td>
<td>20% REOB + 80% 70-22</td>
<td>61.0</td>
<td>62.6</td>
<td>2.32</td>
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<tr>
<td></td>
<td>64-22</td>
<td>10% REOB + 90% 70-22</td>
<td>66.6</td>
<td>67.0</td>
<td>1.27</td>
</tr>
</tbody>
</table>
# PG Grading (2 of 2)

<table>
<thead>
<tr>
<th>REOB Supplier</th>
<th>Target Grade</th>
<th>% REOB</th>
<th>Low Temperature</th>
<th>PG Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>RFTO</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>m-slope</td>
<td>S (MPa)</td>
</tr>
<tr>
<td>N.A.</td>
<td>58-28</td>
<td>0%</td>
<td>-38.0</td>
<td>-34.2</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>0%</td>
<td>-34.4</td>
<td>-31.3</td>
</tr>
<tr>
<td>Supplier #1</td>
<td>58-28</td>
<td>6% REOB + 94% 64-22</td>
<td>-37.9</td>
<td>-34.4</td>
</tr>
<tr>
<td></td>
<td>58-28</td>
<td>20% REOB + 80% 70-22</td>
<td>-39.7</td>
<td>-39.6</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>10% REOB + 90% 70-22</td>
<td>-35.0</td>
<td>-33.3</td>
</tr>
<tr>
<td>Supplier #2</td>
<td>58-28</td>
<td>6% REOB + 94% 64-22</td>
<td>-35.5</td>
<td>-32.2</td>
</tr>
<tr>
<td></td>
<td>58-28</td>
<td>20% REOB + 80% 70-22</td>
<td>-41.5</td>
<td>-42.2</td>
</tr>
<tr>
<td></td>
<td>64-22</td>
<td>10% REOB + 90% 70-22</td>
<td>-35.9</td>
<td>-34.3</td>
</tr>
</tbody>
</table>
BBR S & m-slope vs Aging (Source #1)
BBR S & m-slope vs Aging (Source #2)
Form of Master Curve (Christensen & Anderson)

![Diagram showing the relationship between log of reduced frequency and log of modulus, with labels for viscous asymptote, glassy modulus, rheological index, and log of normalized frequency.](image)
Master Curve (R-value & Crossover Frequency) – PG58-28 Source #2
Master Curve (R-value & Crossover Frequency) – PG64-22 Source #1
Master Curve (R-value & Crossover Frequency) – PG64-22 Source #2

![Graph showing Master Curve (R-value & Crossover Frequency) – PG64-22 Source #2](image-url)
Master Curve (Glover-Rowe Parameter)
Fatigue Binder Test Relationships (PAV Aged)

\[ y = 679.06e^{-0.362x} \]
\[ R^2 = 0.6788 \]

\[ y = 0.633e^{0.5886x} \]
\[ R^2 = 0.7367 \]
Mixture Test Results
Laboratory Mix Design

- Trap Rock aggregate
- 5.4% asphalt content; 0% RAP
- Short-term (STOA) and Long-term (LTOA) oven aged according to AASHTO R30

<table>
<thead>
<tr>
<th>Property</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieve Size</td>
<td>Lab Study Design</td>
</tr>
<tr>
<td>1/2&quot; (12.5 mm)</td>
<td>100.0</td>
</tr>
<tr>
<td>3/8&quot; (9.5 mm)</td>
<td>95.0</td>
</tr>
<tr>
<td>No. 4 (4.75 mm)</td>
<td>68.0</td>
</tr>
<tr>
<td>No. 8 (2.36 mm)</td>
<td>46.6</td>
</tr>
<tr>
<td>No. 16 (1.18 mm)</td>
<td>32.4</td>
</tr>
<tr>
<td>No. 30 (0.600 mm)</td>
<td>23.1</td>
</tr>
<tr>
<td>No. 50 (0.425 mm)</td>
<td>16.7</td>
</tr>
<tr>
<td>No. 100 (0.15 mm)</td>
<td>11.7</td>
</tr>
<tr>
<td>No. 200 (0.075 mm)</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Gsb (g/cm³) 2.862
Gmm (g/cm³) 2.680
Design AV% 4.0
Asphalt Content (%) 5.4
VMA (%) 15.0
No REOB
REOB
Source #1
REOB
Source #2
Flow Number – Source #1

![Flow Number Graph](image)

- **Flow Number (cycles)**
- **Binder Grade**
  - PG58-28
  - PG64-22

<table>
<thead>
<tr>
<th>REOB</th>
<th>STOA</th>
<th>LTOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>194</td>
<td>272</td>
</tr>
<tr>
<td>6%</td>
<td>221</td>
<td>373</td>
</tr>
<tr>
<td>20%</td>
<td>217</td>
<td>395</td>
</tr>
<tr>
<td>0%</td>
<td>338</td>
<td>338</td>
</tr>
<tr>
<td>6%</td>
<td>740</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>566</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>1160</td>
<td></td>
</tr>
</tbody>
</table>
Flow Number – Source #2

- Binder Grade: STOA, LTOA, PG58-28, PG64-22
- Flow Number (cycles): 0%, 6%, 20% REOB

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>Flow Number (cycles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA 0% REOB</td>
<td>194</td>
</tr>
<tr>
<td>STOA 6% REOB</td>
<td>307</td>
</tr>
<tr>
<td>STOA 20% REOB</td>
<td>227</td>
</tr>
<tr>
<td>LTOA 0% REOB</td>
<td>272</td>
</tr>
<tr>
<td>LTOA 6% REOB</td>
<td>592</td>
</tr>
<tr>
<td>LTOA 20% REOB</td>
<td>621</td>
</tr>
<tr>
<td>STOA 0% REOB</td>
<td>338</td>
</tr>
<tr>
<td>STOA 10% REOB</td>
<td>727</td>
</tr>
<tr>
<td>LTOA 0% REOB</td>
<td>566</td>
</tr>
<tr>
<td>LTOA 10% REOB</td>
<td>1000</td>
</tr>
</tbody>
</table>
Flexural Beam Fatigue – Source #1
Flexural Beam Fatigue – Source #2
Overlay Tester – Source #1

[Bar graph showing Overlay Tester Fatigue Life (cycles) for different Binder Grades and REOB percentages. Error Bars represent one standard deviation from the Mean.]
Overlay Tester – Source #2

Error Bars represent one standard deviation from the Mean

Overlay Tester Fatigue Life (cycles)

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>0% REOB</th>
<th>6% REOB</th>
<th>20% REOB</th>
<th>0% REOB</th>
<th>6% REOB</th>
<th>20% REOB</th>
<th>0% REOB</th>
<th>10% REOB</th>
<th>0% REOB</th>
<th>10% REOB</th>
</tr>
</thead>
<tbody>
<tr>
<td>STOA</td>
<td>529</td>
<td>95</td>
<td>310</td>
<td>271</td>
<td>147</td>
<td>11</td>
<td>89</td>
<td>58</td>
<td>90</td>
<td>19</td>
</tr>
<tr>
<td>PG58-28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LTOA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG64-22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Semi-Circular Bend – Source #1

![Graph showing Jc (kJ/m²) values for different combinations of REOB and asphalt types.](chart)

- **0% REOB**
  - STOA: 0.325
  - LTOA: 0.280

- **6% REOB**
  - STOA: 0.323
  - LTOA: 0.311

- **20% REOB**
  - STOA: 0.261
  - LTOA: 0.212

- **0% REOB**
  - STOA: 0.318
  - LTOA: 0.396

- **10% REOB**
  - STOA: 0.509
  - LTOA: 0.553

Asphalt types:
- PG58-28
- PG64-22
Semi-Circular Bend – Source #2

![Graph showing Jc (kJ/m²) values for different conditions.](image)

- **0% REOB STOA PG58-28**: 0.325
- **6% REOB STOA PG58-28**: 0.302
- **20% REOB STOA PG58-28**: 0.239
- **0% REOB LTOA PG58-28**: 0.311
- **6% REOB LTOA PG58-28**: 0.327
- **20% REOB LTOA PG58-28**: 0.262
- **0% REOB STOA PG64-22**: 0.318
- **10% REOB STOA PG64-22**: 0.391
- **0% REOB LTOA PG64-22**: 0.509
- **10% REOB LTOA PG64-22**: 0.586
TSRST Low Temp Critical Cracking – Source #1
TSRST Low Temp Critical Cracking – Source #2

<table>
<thead>
<tr>
<th></th>
<th>PG58-28</th>
<th></th>
<th>PG64-22</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STOA</td>
<td>LTOA</td>
<td>STOA</td>
<td>LTOA</td>
</tr>
<tr>
<td>0% REOB</td>
<td>-26.4</td>
<td>-23.5</td>
<td>-23.5</td>
<td>-25.1</td>
</tr>
<tr>
<td>6% REOB</td>
<td>-26.5</td>
<td>-23.8</td>
<td>-17.2</td>
<td>-23.5</td>
</tr>
<tr>
<td>20% REOB</td>
<td>-27.3</td>
<td>-25.1</td>
<td>-25.1</td>
<td>-25.1</td>
</tr>
<tr>
<td>0% REOB</td>
<td>-25.1</td>
<td>-17.2</td>
<td>-23.5</td>
<td>-25.1</td>
</tr>
<tr>
<td>6% REOB</td>
<td>-26.5</td>
<td>-23.8</td>
<td>-23.5</td>
<td>-25.1</td>
</tr>
<tr>
<td>20% REOB</td>
<td>-26.4</td>
<td>-23.5</td>
<td>-23.5</td>
<td>-25.1</td>
</tr>
</tbody>
</table>

TSRST Critical Cracking Temperature (°C)
Binder to Mixture Performance Comparisons
Comparisons were made between the binder and mixture fatigue parameters. Only Overlay Tester showed good correlation.
Overlay Tester (LTOA) vs BBR $T_{crit}$ Difference

![Graph showing Overlay Tester (cycles) vs. $T_{CRIT, S} - T_{CRIT, m}$ (°C)]

- **Legend**:
  - **Black Circles (•)**: 40 Hr PAV Aging
  - **White Circles (○)**: 20 Hr PAV Aging
  - **Red Dashed Line**: Cracking Warning
  - **Red Solid Line**: Cracking Limit

- **Axes**:
  - **Y-axis**: $T_{CRIT, S} - T_{CRIT, m}$ (°C)
  - **X-axis**: Overlay Tester (cycles)

- **Data Points**:
  - 20 Hr PAV Aging:
    - Around -10.0°C at 0 cycles
    - Increases to around -20.0°C at 150 cycles
  - 40 Hr PAV Aging:
    - Around -5.0°C at 0 cycles
    - Increases to around -15.0°C at 150 cycles

- **Important Points**:
  - Cracking Warning: Approximately -10.0°C
  - Cracking Limit: Approximately -15.0°C
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)

\[ y = 128.53e^{-0.008x} \]

\[ R^2 = 0.9176 \]

Graph showing Overlay Tester (cycles) vs Glover - Rowe 20 Hr PAV (kPa). Points for Virgin Binder, REOB Source #1, and REOB Source #2 are marked with different symbols.
Overlay Tester (LTOA) vs Cross-over Frequency (20 Hr PAV)

\[ y = 0.7845x - 5.3606 \]

\[ R^2 = 0.9606 \]

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

- 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 Tcrit Difference
  - Cross-over frequency
  - Glover-Rowe
  - DENT CTOD
- Stiffness based tests do not show much difference between binders with and without REOB
- REOB dosage rate has an impact on performance, but magnitude not the same for each REOB source – impact of binder source(?)
Thank you for your time! Questions?

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