Correlation between Laboratory and Plant Produced High RAP/RAS Mixtures

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Reyhaneh Rahbar Rastegar
Motivation

• Specification limitation on using recycled material

• Asphalt Recycling Advantages
  ✓ Economic
  ✓ Environmentally friendly

• Lab vs. Plant
  ✓ Performance-based design
  ✓ Comparison of PMPC and LMLC mixtures performance
Project Overview

- Project No. 15680R, funded by NHDOT

- Objectives:
  - To evaluate the properties of mixtures with RAP and RAS in HMA
  - To revise NHDOT existing specification
  - To compare laboratory and plant produced mixes

- Lab produced specimens, and binder extraction and recovery by NHDOT

- Plant produced specimens by Pike Industries, Inc.
Summary of Mixtures

- Lebanon
  - 11 Mixtures (Plant), 8 Mixtures (Lab)
  - Binder PG Grade (PG 58-28, PG 52-34)
  - Two sources for each binder grade
  - NMAS (12.5 and 19 mm)
  - Recycled Material (20% RAP, 20% RAP/RAS, 30% RAP)

- Hooksett
  - 4 Mixtures (Plant)
  - Binder PG Grade (PG 58-28, PG 64-28)
  - NMAS (9.5 and 12.5 mm)
  - Recycled Material (20% RAP, 25% RAP)
Mixture Properties

• Target Air Void (test specimen): 6% ± 0.5
• RAP Binder Grade: 81.3-19.3
• Tear off Shingles

<table>
<thead>
<tr>
<th>Mixture NMAS (mm)</th>
<th>%AC Design Total</th>
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</thead>
<tbody>
<tr>
<td>19.0</td>
<td>4.7-4.8</td>
</tr>
<tr>
<td>12.5</td>
<td>5.3</td>
</tr>
<tr>
<td>9.5</td>
<td>5.8-6.0</td>
</tr>
</tbody>
</table>
Testing

• Binder Testing (by NHDOT)
  ✓ Extraction and Recovery
  ✓ PG Grading
  ✓ 4mm DSR (by Gerry Reinke, Mathy Construction)

• Mixture Testing (by UNH)
  ✓ Complex Modulus
  ✓ SVECD Fatigue
  ✓ DCT testing
Testing

- Complex Modulus (AASHTO TP-62)
  - 3 replicates
  - Different Temperatures and Frequencies
  - Dynamic Modulus and Phase Angle Mastercurves

- SVECD Fatigue Testing (AASHTO TP-107)
  - 4 replicates
  - C-S and $G^R-N_f$
  - Simplified Viscoelastic Continuum Damage Approach
Summary of the Results
Binder Results

<table>
<thead>
<tr>
<th>Material</th>
<th>PG 58-28</th>
<th>PG 52-34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avery Lane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mc Asphalt</td>
<td>58-28</td>
<td></td>
</tr>
<tr>
<td>Mc Asphalt</td>
<td></td>
<td>52-34</td>
</tr>
<tr>
<td>Suncor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RAP</td>
<td>12.5 mm</td>
<td>12.5 mm</td>
</tr>
</tbody>
</table>

High Temperature PG Grade (°C)

PG 58: 58-28
PG 52: 52-34
## Binder Results

<table>
<thead>
<tr>
<th>Virgin Binder</th>
<th>RAP</th>
<th>12.5 mm</th>
<th>12.5 mm</th>
<th>19 mm</th>
<th>19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td></td>
<td>Mc Asphalt 58-28</td>
<td>Mc Asphalt 52-34</td>
<td>Avery Lane 58-28</td>
<td>Suncor 52-34</td>
</tr>
<tr>
<td>Avery Lane</td>
<td>Mc Asphalt</td>
<td>Mc Asphalt</td>
<td>Suncor</td>
<td>RAP</td>
<td>20% RAP</td>
</tr>
<tr>
<td>PG 52-34</td>
<td></td>
<td>Mc Asphalt 58-28</td>
<td>Mc Asphalt 52-34</td>
<td>Avery Lane 58-28</td>
<td>Suncor 52-34</td>
</tr>
</tbody>
</table>

### Low Temperature PG Grade (°C)

-34.0 \(\rightarrow\) -16.0

1. **12.5 mm\:**
   - Mc Asphalt 58-28: 20% RAP
   - Mc Asphalt 52-34: 20% RAP/RAS
   - Suncor 52-34: 30% RAP

2. **20% RAP\:**
   - Mc Asphalt 58-28
   - Mc Asphalt 52-34
   - Suncor 52-34

3. **20% RAP/RAS\:**
   - Mc Asphalt 58-28
   - Mc Asphalt 52-34
   - Suncor 52-34

4. **30% RAP\:**
   - Mc Asphalt 58-28
   - Mc Asphalt 52-34
   - Suncor 52-34

5. **Avery Lane 58-28\:**
   - 20% RAP
   - 20% RAP/RAS
   - 30% RAP

6. **Suncor 52-34\:**
   - 20% RAP
   - 30% RAP
   - 20% RAP/RAS

**Legend:**
- LMLC
- PMPC

\[19\ mm\]

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**Note:**

- The binder results are measured in low temperature PG grade (°C). The chart illustrates the performance of various binders and mixes under low temperature conditions, with different percentages of RAP and RAP/RAS. The results are categorized by binder type and mix composition, showing the impact on low temperature performance.
Binder Rheological Parameters

- $T_{cr}$ (Stiffness) = Critical low temp. where $S(60) = 300$
- $T_{cr}$ (m-slope) = Critical low temp. where $m(60) = 0.3$
- $\Delta T_{cr} = T_{cr}$ (Stiffness) − $T_{cr}$ (m-slope)
Binder Results

<table>
<thead>
<tr>
<th>Virgin Binder</th>
<th>RAP</th>
<th>12.5 mm</th>
<th>12.5 mm</th>
<th>19 mm</th>
<th>19 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avery Lane</td>
<td>Mc Asphalt</td>
<td>Suncor</td>
<td>20% RAP</td>
<td>20% RAP/RAS</td>
<td>20% RAP</td>
</tr>
<tr>
<td>PG 58-28</td>
<td>PG 52-34</td>
<td>Mc Asphalt 58-28</td>
<td>Mc Asphalt 52-34</td>
<td>Mc Asp. 58-28</td>
<td>Avery Lane 58-28</td>
</tr>
</tbody>
</table>
Dynamic Modulus (12.5 mm)

PMPC Mixtures, 12.5 mm
- PG 52-34, 30% RAP
- PG 52-34, 20% RAP
- PG 52-34, 20% RAP/RAS
- PG 58-28, 30% RAP
- PG 58-28, 20% RAP
- PG 58-28, 20% RAP/RAS

LMLC Mixtures, 12.5 mm
- PG 52-34, 30% RAP
- PG 52-34, 20% RAP
- PG 58-28, 30% RAP
- PG 58-28, 20% RAP
Dynamic Modulus (19 mm)

PMPC Mixtures, 19 mm

LMLC Mixtures, 19 mm

Dynamic Modulus (MPa) vs. Reduced Frequency (Hz)

PG 52-34, 30% RAP
PG 52-34, 20% RAP/RAS
PG 58-28, 30% RAP
PG 58-28, 20% RAP
PG 58-28, 20% RAP/RAS

10/22/15
Dynamic Modulus, Plant vs. Lab, 12.5 mm

- **PG 52-34, 12.5 mm, 30% RAP**
  - Plant
  - Lab

- **PG 58-28, 12.5 mm, 30% RAP**
  - Plant
  - Lab

- **PG 52-34, 12.5 mm, 20% RAP**
  - Plant
  - Lab

- **PG 58-28, 12.5 mm, 20% RAP**
  - Plant
  - Lab
Dynamic Modulus, Plant vs. Lab, 19 mm

PG 52-34, 19 mm, 30% RAP

PG 58-28, 19 mm, 30% RAP

PG 52-34, 19 mm, 20% RAP/RAS

PG 58-28, 19 mm, 20% RAP/RAS
Black Space, Plant vs. Lab, (12.5 mm)

- **PG 52-34, 12.5 mm, 30% RAP**
  - Plant
  - Lab

- **PG 58-28, 12.5 mm, 30% RAP**
  - Plant
  - Lab

- **PG 52-34, 12.5 mm, 20% RAP**
  - Plant
  - Lab

- **PG 58-28, 12.5 mm, 20% RAP**
  - Plant
  - Lab

Dynamic Modulus (MPa) vs. Phase Angle (Degree) for different grades and percentages of RAP.
Black Space, Plant vs. Lab, (19 mm)

**PG 52-34, 19 mm, 30% RAP**

**PG 52-34, 19 mm, 20% RAP/RAS**

**PG 58-28, 19 mm, 30% RAP**

**PG 58-28, 19 mm, 20% RAP/RAS**

**Dynamic Modulus (MPa)**

**Phase Angle (Degree)**
Fatigue Failure Criterion

Number of cycles ($N_f$)

Gr

Better Performance
Fatigue Failure (12.5 mm mixtures)

Number of Cycles (Nf)

12.5 mm, PMPC

Number of Cycles (Nf)

12.5 mm, LMLC
Fatigue Failure (19 mm mixtures)

![Graph showing fatigue failure data for different mixtures and percentages of RAP and RAS.](image)
Fatigue Failure (Plant vs. Lab), 12.5 mm

PG 52-34, 12.5 mm, 30% RAP

R² = 0.77578

PG 52-34, 12.5 mm, 20% RAP

R² = 0.96596

PG 58-28, 12.5 mm, 30% RAP

R² = 0.94799

PG 58-28, 12.5 mm, 20% RAP

R² = 0.99745
Fatigue Failure (Plant vs. Lab), 19 mm

PG 52-34, 19 mm, 30% RAP

- Plant: $R^2 = 0.98874$
- Lab: $R^2 = 0.86312$

PG 58-28, 19 mm, 30% RAP

- Plant: $R^2 = 0.99879$
- Lab: $R^2 = 0.99798$

PG 52-34, 19 mm, 20% RAP/RAS

- Plant: $R^2 = 0.97716$
- Lab: $R^2 = 0.70869$

PG 58-28, 19 mm, 20% RAP/RAS

- Plant: $R^2 = 0.97716$
- Lab: $R^2 = 0.70869$
Conclusion

• Binder results
  o LMLC have warmer high and low PG temperature.
  o The binders extracted from the 19 mm mixtures have warmer temperatures than those extracted from 12.5 mm mixtures.
  o $\Delta T_{cr}$ of 19 mm and PG 52-34 mixtures are generally higher than 12.5 mm and PG 58-28, respectively.
  o Generally, $\Delta T_{cr}$ of the mixtures containing RAS are larger than those for the mixtures with RAP only.
Conclusion

- **Complex Modulus**
  - Dynamic Modulus of lab produced mixtures are higher than plant produced mixtures.
  - In most cases, lab produced mixtures show slightly more elastic behavior, less relaxation capability.
  - The variation of mixtures stiffness are as expected in terms of stiffer binder, higher recycled materials and coarser aggregate.
  - Inclusion of higher RAP increases dynamic modulus, while incorporating RAS does not follow a consistent trend.
Conclusion

- **Fatigue Cracking**
  - There is no consistent trend between Lab and plant produced mixtures, but:
    - There is larger difference between PG 58-28 plant and lab mixes than PG 52-34 mixes.
  - The fatigue performance (fatigue life) of 20% RAP and 30% RAP mixtures are similar.
  - Most 20% RAP/RAS mixes show higher $G^R$, but lower $N_f$. 
Future Work

• Additional Testing and Mixtures
  ✓ DCT testing
  ✓ Binder test results
  ✓ Hooksett mixtures

• Evaluate impact of long term aging
Acknowledgement

- Dr. J. Daniel,
  Professor, University of New Hampshire
- Dr. E. Dave,
  Assistant Professor, University of New Hampshire
- New Hampshire Department of Transportation
- Pike Industries, Inc.
- Asphalt Research Group, University of New Hampshire
Thank You!

Questions?
## Mixtures

<table>
<thead>
<tr>
<th>Binder PG Grade</th>
<th>Binder Source (mm)</th>
<th>NMSA</th>
<th>%Total Binder Replacement</th>
<th>% RAP Binder</th>
<th>% RAS Binder</th>
<th>PMPC (Pike)</th>
<th>LMLC (NHDOT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>58-28</td>
<td>McAphalt</td>
<td>12.5</td>
<td>18.9</td>
<td>18.9</td>
<td>0</td>
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<tr>
<td>2013</td>
<td>McAphalt</td>
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<td>7.4</td>
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<td>31.3</td>
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<td>20.4</td>
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<td>McAphalt</td>
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<td>21.3</td>
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<td>-</td>
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<td>2014</td>
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<td>2014</td>
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<td>12.5</td>
<td>-</td>
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<td>-</td>
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</tr>
</tbody>
</table>
Damage Characteristic Curve (12.5 mm)

12.5 mm, PG 52-34

12.5 mm, PG 58-28
Damage Characteristic Curve (19 mm)

![Graph showing Damage Characteristic Curve for two types of pavement: 19 mm, PG 52-34 and 19 mm, PG 58-28. The graph compares the pseudo stiffness (C) with the damage (S) for different combinations of RAP (Recycled Asphalt Pavement) and RAS (Recycled Asphalt Shingles).]

- Plant, 30% RAP
- Plant, 20% RAP/RAS
- Lab, 30% RAP
- Lab, 20% RAP/RAS