TPF-5(230)
Evaluation of Plant-Produced High-Percentage RAP Mixtures in the Northeast

Dr. Jo Sias Daniel

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Research Team

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Current Participants

- New Hampshire (NHDOT) - Lead Agency
- Maryland (MDOT)
- New Jersey (NJDOT)
- New York (NYSDOT)
- Pennsylvania (PennDOT)
- Rhode Island (RIDOT)
- Virginia (VDOT)
- Pending: Federal Highway Administration (FHWA)
Project Objectives

• Evaluate the performance of plant-produced RAP mixtures (in the laboratory and field) in terms of low temperature cracking, fatigue cracking and moisture sensitivity.

• Provide further understanding of the blending that occurs between RAP and virgin binder in plant-produced mixtures.

• Refine fatigue failure criteria for RAP mixtures that can be used in the Simplified Viscoelastic Continuum Damage (S-VECD) model.
High RAP Pooled Fund Study

- Contractors have volunteered to produce mixtures at different RAP contents
- Mixtures sampled and taken to lab for testing
- SGC specimens compacted at time of production
- Data collected on plant operations, raw material info, placement location & conditions (field cores if possible)
Testing

- Recovered Binder
  - PG grade
  - CCT
  - ABCD
  - 4 mm diameter DSR

- Mixture
  - Dynamic Modulus
  - Hamburg & TSR
  - Low Temperature Creep & Strength
  - Fatigue (AMPT S-VECD protocol): crack initiation
  - Overlay Tester: crack propagation
  - Beam Flexure
Project Timeline

• Year 1: Production of Phase I mixtures, laboratory testing and data analysis.

• Year 2: Phase II mixtures produced, continuation of testing, data analysis, monitoring and construction of field sections, and refinement of fatigue failure criterion.

• Year 3: Final Phase II mixtures produced, completion of testing, monitoring field sections, data analysis and synthesis, and preparation of final report.
Outline

• Summary of completed Phase I testing
  – Stiffness
  – Fatigue
  – Low Temperature

• Phase II Silo storage study
  – Extracted binder
  – Stiffness
## Phase I Mixtures: 2010 Production

<table>
<thead>
<tr>
<th>Plant</th>
<th>NMAS (mm)</th>
<th>PG Grade</th>
<th>RAP Content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Callanan NY (drum)</td>
<td>12.5</td>
<td>64-22</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>58-28</td>
<td></td>
</tr>
<tr>
<td>Pike VT (batch)</td>
<td>9.5</td>
<td>58-28</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52-34</td>
<td>x</td>
</tr>
<tr>
<td>Pike NH (drum)</td>
<td>12.5</td>
<td>64-28</td>
<td>x</td>
</tr>
</tbody>
</table>
Phase I: Published Results Summary

• AAPT 2012 by Mogawer, et al.
• Increased RAP generally increased stiffness
• Increased RAP decreased resistance to crack propagation (OT)
• Softer binder grade effective in some cases for mitigating increase in stiffness and cracking (OT)
• Apparent effect of plant production (silo storage, temperature) on stiffness
• Reheated materials stiffer, effect of RAP and/or silo storage time
Phase I: Current Results Summary

• Fatigue (AMPT S-VECD): crack initiation
• Low Temperature
  – Extracted Binder
  – Low Temperature creep and strength
  – TSRST
• NY Mixtures shown
Fatigue Life Prediction NY PG 64-22
Endurance Limit for NY Mixtures PG 64-22

Endurance Limit at Frequency of 10 Hz (micro-strain)

Percent RAP

Endurance Limit at Frequency of 10 Hz (micro-strain)

Percent RAP
SVECD Fatigue Summary

• Rankings change depending on strain level. Higher RAP better at low strains
• Softer binder grade decreases slope of $N_f$ curve
• Higher RAP contents increase endurance limit
Low Temp Extracted Binder Results

Temperature (°C)

Critical Cracking Temp
Low Continuous PG-grade
ABCD Cracking Temp. (as recovered)
ABCD Cracking Temp. (PAV aged)
Low Temp Mixture Testing Results

<table>
<thead>
<tr>
<th></th>
<th>NYd00</th>
<th>NYd20</th>
<th>NYd30</th>
<th>NYd40</th>
<th>NYb30</th>
<th>NYb40</th>
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</thead>
<tbody>
<tr>
<td>Temperature (°C)</td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>TSRST</td>
<td>-10</td>
<td>-11</td>
<td>-9</td>
<td>-10</td>
<td>-7</td>
<td>-7</td>
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<tr>
<td>TCMODEL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

-20.4   -19.78  -17.88  -23.32  -21.49
# Testing and Analysis Parameters

<table>
<thead>
<tr>
<th>Method</th>
<th>Initial Temp (°C)</th>
<th>Cooling Rate (°C/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder CCT</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>ABCD</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>TCMODEL (mix)</td>
<td>10</td>
<td>5.6</td>
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<tr>
<td>TSRST</td>
<td>5</td>
<td>10</td>
</tr>
</tbody>
</table>
Impact of Cooling Rate
TCMODEL: NY40% PG64-22

Thermal Stress (psi) vs. Temperature °C
- F/L=1.0, 5C, 1 C/hr
- F/L=1.0, 5C, 2 C/hr
- F/L=1.0, 5C, 5.6 C/hr
- F/L=1.0, 5C, 10 C/hr
Impact of Initial Temperature

TCMODEL: NY40% PG64-22

Thermal Stress (psi) vs. Temperature °C

- F/L=1.0, 10C, 5.6 C/hr
- F/L=1.0, 5C, 5.6 C/hr
- F/L=1.0, 0C, 5.6 C/hr
- F/L=1.0, -5C, 5.6 C/hr
TCMODEL: NY Virgin PG 64-22

Cracking Temperature, C

Cooling Rate C/hr

1 2 5.6 10

0 1 2 5.6 10

10C 5C 0C -5C
Low Temperature Summary

• Generally warmer cracking temperatures with increase in RAP content
• Softer virgin binder may help mitigate
• Impact of starting temperature and cooling rate used for testing and analysis
• Further investigation and analysis continuing
Silo Storage Study

- Callanan 12.5 mm mixture with PG 64-22
  - Virgin: 0, 2.5, 5.0, 7.5 hours storage (~340 F)
  - 25% RAP: 0, 2.5, 5.0, 7.5, 10.0 hours storage (~340 F)
- Mix testing
  - Plant compacted specimens
  - Loose mix collected and compacted in lab
  - $|E^*|$, fatigue, TSRST
- Binder extracted & recovered from plant compacted specimens
  - PG grading, 4 mm $|G^*|$
  - Special thanks to Gerry Reinke
High Temp Grade 25% RAP Recovered
LOW TEMP GRADE 25% RAP RECOVERED BINDER

-26.5
-27.0
-27.5
-28.0
-28.5
-29.0
-29.5

Low Temp PG Grade, C

1 2 3 4 5

25% RAP, 0 HR
25% RAP, 2.5 HR
25% RAP, 5 HR
25% RAP, 7.5 HR
25% RAP, 10 HR
|E*|, MPa

### Plant Compacted Dynamic Modulus: 25% RAP

<table>
<thead>
<tr>
<th>Reduced Frequency, Hz</th>
<th>25% RAP, 0 hr, PC, 6.6% AV</th>
<th>25% RAP, 2.5 hr, PC, 6.5% AV</th>
<th>25% RAP, 5 hr, PC, 6.0% AV</th>
<th>25% RAP, 7.5 hr, PC, 5.8% AV</th>
<th>25% RAP, 10 hr, PC, 5.5% AV</th>
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<td>1.00E+02</td>
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<td>1.00E+05</td>
<td>1.00E+06</td>
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<tr>
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<td>1.00E+03</td>
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<td>1.00E+18</td>
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</table>
Lab Compacted Dynamic Modulus: 25% RAP

| Reduced Frequency, Hz | |E*|, MPa |
|----------------------|------------------------------|
| 25% RAP | 0 hr, LC |
| 25% RAP | 2.5 hr, LC |
| 25% RAP | 5 hr, LC |
| 25% RAP | 7.5 hr, LC |
| 25% RAP | 10 hr, LC |
Lab- versus Plant-Compacted Dynamic Modulus

RAP Comparison

% of LC to PC Dynamic Modulus

Temperature (Celsius) and Frequency (Hz)
TSRST Results

Critical Temperature, °C

Silo Storage, hrs

-16.5
-17
-17.5
-18
-18.5
-19
-19.5
-20
-20.5
-21

0  2.5  5  7.5  10
25% RAP Silo Storage Summary

- Stiffening of binder with increase in storage time
- General stiffening trend with increase in storage time for mix
- Reheat mixtures stiffer than plant compacted but difference decreases with storage time
High Temp Grade Virgin Recovered

<table>
<thead>
<tr>
<th>RTFO Based High PG, C</th>
<th>Silo Storage Time (hrs)</th>
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<tbody>
<tr>
<td>82.0</td>
<td>0</td>
</tr>
<tr>
<td>79.0</td>
<td>2.5</td>
</tr>
<tr>
<td>76.0</td>
<td>5</td>
</tr>
<tr>
<td>73.0</td>
<td>7.5</td>
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</table>
LOW TEMP GRADE VIRGIN MIX RECOVERED BINDER

0 RAP, 0 HR

0 RAP, 2.5 HR

0 RAP, 5 HR

0 RAP, 7.5 HR
COMPLEX BINDER MODULUS AT +20°C REFERENCE TEMPERATURE

- 05-18-12-H 0 RAP, 0 hr
- 05-18-12-S 0 RAP, 2.5 hr
- 05-18-12-T 0 RAP, 5 hr
- 05-18-12-U 0 RAP, 7.5 hr
COMPLEX BINDER MODULUS AT +20°C REFERENCE TEMPERATURE

Complex Modulus, $G^*$, Pa

REDUCED FREQUENCY, radians/sec

05-18-12-H 0 RAP, 0 hr
05-18-12-S 0 RAP, 2.5 hr
05-18-12-T 0 RAP, 5 hr
05-18-12-U 0 RAP, 7.5
07-10-12-Q 0 RAP, 7.5 hr RETEST
07-10-12-M 0 RAP, 0 hr RETEST
Plant Compacted Dynamic Modulus: Virgin

| Reduced Frequency, Hz | $|E^*|$, MPa |
|-----------------------|------------|
| 0 RAP, 0 hr, PC, 6.8% AV |
| 0 RAP, 2.5 hr, PC, 6.1% AV |
| 0 RAP, 5 hr, PC, 6.7% AV |
| 0 RAP, 7.5 hr, PC, 7.4% AV |
Lab Compacted Dynamic Modulus: Virgin

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>E*</td>
<td>MPa</td>
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</tbody>
</table>

- Reduced Frequency, Hz

Lab Compacted Dynamic Modulus: Virgin

- 0 RAP, 0 hr, LC
- 0 RAP, 2.5 hr, LC
- 0 RAP, 5 hr, LC
- 0 RAP, 7.5 hr, LC
So, what happened?
Continuing work

• Phase II mixtures
  – NH mixtures – field sections
  – VA mixtures (higher PG grades)
• New virgin silo storage study mixtures
• NCSU work refining fatigue criterion for RAP mixtures in SVECD approach
• Low temperature analysis, actual cooling rates and temperatures
• Additional mixtures: impact of asphalt content
Questions?