RAP or RAS?
The Differences in Performance of HMA Containing Reclaimed Asphalt Pavement and Reclaimed Asphalt Shingles

Dr. Jo Sias Daniel
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Reclaimed Asphalt Shingles (RAS)
Project Objectives

- Funded by NH Industrial Research Council and RAS-Tech
- Following April 2009 NHDOT specs for HMA with recycled materials
  - 0.8% Total Binder Replacement (TRB) from recycled materials
  - 0.6% TRB from RAS
- Evaluate the behavior and performance of HMA with three different RAS products vs. control mix with RAP only
- Evaluation based upon:
  - Mix design volumetrics
  - Complex Modulus
  - Low temperature testing
  - Extracted binder testing (sources, mix)
Reclaimed Asphalt Shingles (RAS) Materials

- Superpave mix design
- NH Type E, 12.5 mm (1/2”)
  - Aggregate gradation maintained
  - Adjusted total AC
- Virgin binder grade PG 64 – 28
- Recycled binder replacement of 0.8%
  - 0.6% from shingles in RAS mixes
  - 0.2% from RAP for mixes with shingles, 0.8% in RAP only mix
- Target air voids 4% at $N_{des} = 50$
# Reclaimed Asphalt Shingles (RAS) Materials

<table>
<thead>
<tr>
<th></th>
<th>RAP</th>
<th>Normal Ground Shingles</th>
<th>+50 Mesh Shingles</th>
<th>-50 Mesh Shingles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Content (AC)</td>
<td>4.37%</td>
<td>23.6%</td>
<td>12.1%</td>
<td>28.0%</td>
</tr>
<tr>
<td>Max. Aggregate Size</td>
<td>9.5 mm (3/8 inch)</td>
<td>1.18 mm (#16)</td>
<td>1.18 mm (#16)</td>
<td>0.6 mm (#30)</td>
</tr>
<tr>
<td>Recovered Binder PG</td>
<td>88-22 (89.3-22.0)</td>
<td>n/a*</td>
<td>n/a*</td>
<td>n/a*</td>
</tr>
</tbody>
</table>

*PG grade could not be measured

- **Three types of RAS used:**
  - Normal Ground Shingles donated from ERRCO
  - +50 Mesh Shingles
  - -50 Mesh Shingles
Reclaimed Asphalt Shingles (RAS) Performance Evaluation

- PG determination
  - Binder recovered from the source
  - Binder recovered from the mix
- Dynamic Modulus and phase angle master curves
- Binder testing on recovered source binder
  - Shear Binder Modulus and phase angle
  - Creep stiffness and slope values
  - Critical cracking temperatures
- Hirsch Model back-calculation of binder modulus
- Effective PG Determination
- Thermal Stress Restrained Specimen Tensile Strength (TSRST)
## Performance Evaluation

### Mix Design

<table>
<thead>
<tr>
<th>Mix</th>
<th>Total ac</th>
<th>Recycled Binder</th>
<th>Recovered Binder PG</th>
<th>VMA (≥14.0)</th>
<th>VFA (70-80)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Only</td>
<td>5.7%</td>
<td>14.0%</td>
<td>71.0 – 26.5</td>
<td>15.8</td>
<td>76.9</td>
</tr>
<tr>
<td>Normal Ground Shingles</td>
<td>6.5%</td>
<td>12.3%</td>
<td>75.3 – 25.7</td>
<td>17.2</td>
<td>77.0</td>
</tr>
<tr>
<td>+50 Mesh Shingles</td>
<td>6.0%</td>
<td>13.3%</td>
<td>77.1 – 25.4</td>
<td>16.1</td>
<td>75.7</td>
</tr>
<tr>
<td>-50 Mesh Shingles</td>
<td>6.1%</td>
<td>13.1%</td>
<td>76.3 – 25.7</td>
<td>16.6</td>
<td>75.4</td>
</tr>
</tbody>
</table>

- High PG similar for all shingles mixtures
- Low PG grade governed by m value for all four mixtures
Performance Evaluation

Critical Cracking Temperature

Recovered Binder Source

Temperature (°C)

-30
-25
-20
-15
-10
-5
0

RAP Only mix
Normal Ground Shingles mix
+50 Mesh Shingles mix
-50 Mesh Shingles mix
Virgin Binder
Performance Evaluation
$|G^*|$ and $\delta_{\text{binder}}$ Master Curves
Performance Evaluation

$|E^*|$ Master Curve Comparison
Performance Evaluation

\[ \delta \] Master Curve Comparison

![Graph showing performance evaluation of different materials at various reduced frequencies.](image)
Performance Evaluation

$|E^*|$ Blending Evaluation

[Graphs showing modulus vs. reduced frequency for different binders and blending conditions.]
Effective high temperature PG grade = temperature that corresponds with the value of $|G^*|/\sin(\delta) = 2.2$ kPa at 1.6 Hz.

- $|G^*|$ master curve shifted to the appropriate temperature and determine $|G^*|$ value at 1.6 Hz for that temperature
- Same procedure for $\delta$ at test temperatures
- $|G^*|/\sin(\delta)$ values calculated and plotted against temperature, interpolate or extrapolate to get ‘effective’ PG grade
- In this study, both the measured values of the $|G^*|$ from the extracted (fully blended) mix binder and the back-calculated $|G^*|$ using the Hirsch model used to determine the effective PG grade
## Performance Evaluation
### Effective PG Determination

| Mixture                     | High PG Temperature: Measured | |G*| | High PG Temperature: Back Calculated | |G*| |
|-----------------------------|-----------------------------|---|---|--------------------------------------|---|
| RAP Only                    | 61.5                        |   |   | 100.5                                |   |
| Normal Ground Shingles      | 78.5                        |   |   | 126.0                                |   |
| +50 Mesh Shingles           | 76.0                        |   |   | 94.0                                 |   |
| -50 Mesh Shingles           | 80.0                        |   |   | 112.0                                |   |
Performance Evaluation

RAP Only
Normal Ground Shingles
+50 Mesh Shingles
-50 Mesh Shingles

Temperature at Failure (°C)

Load at Failure (kg)
Performance Evaluation
Fatigue Testing

Strain Amplitude (10^-6)

Number of Cycles

+50 mesh shingles mix, 20 C
+50 mesh shingles mix, -20 C
RAP mix, 20 C
RAP mix, -20 C
Continuous PG grade shows that RAS mixtures are stiffer at the high temperature end, and that RAP and RAS have comparable stiffness at the low temperature end.

CCT for the recovered RAS mixture binder were lower than the RAP mixture binder, indicating that the RAS mixtures would have better low temperature performance.

|G*| master curves for the three recovered RAS mixture binders were very similar. The recovered binder from the RAP mixture was softer than the RAS mixtures at low reduced frequencies, but was comparable to the RAS mixture binders at the higher reduced frequencies.

The recovered binder from the RAP mixture had a higher phase angle and steeper rate of change than the RAS mixture binders.
Reclaimed Asphalt Shingles (RAS)

Conclusions: *Mixture Testing*

- $|E^*|$ master curves for the three RAS mixtures are statistically the same over most of the reduced frequency range. The RAP mix shows a stiffer average response, but is only statistically different than the +50 and -50 mesh RAS mixtures. The phase angle curves for all mixtures were statistically similar.

- TSRST tests showed that the load and temperature at failure for the four mixtures were not significantly different, indicating similar low temperature performance.

- Fatigue tests and subsequent evaluation using S-VECD analysis indicated that +50 mesh shingles mixture performs better and has a higher fatigue endurance limit than the RAP mixture. The difference in performance decreases as the temperature decreases.
Reclaimed Asphalt Shingles (RAS)
Ongoing/Future Work

- Testing of other shingles sources
  (Katie Gray poster)
- Testing of higher shingles replacement values for the +50 mesh shingles source
  (Kelly Barry poster)
- Testing of plant produced mixtures
Acknowledgements

- NHIRC & RASTech for funding
- Pike Industries, Inc. and ERRCO for donating materials
- AAT for binder testing
- NHDOT for research support & input
- Students: Jennifer Foxlow, Aravind Krishna Swamy, Marcelo Medeiros Jr., Katie Gray, Kelly Barry
Northeast High RAP Pooled Fund Study Update
Background

- 2009 extracted binder study on plant mixtures by NHDOT and Pike Industries, Inc.
- Presented last year at NEAUPG
- RAP Task Force developed scope of work for expanded mixture & binder testing study on plant produced mixtures ~$750,000
- Scope of work to include 60 plant produced mixtures
Current Participants

- NHDOT lead agency
- States: MD, NH, NJ, NY, PA, and VA ($90k each over 3 years)
- FHWA at $150k for NCSU work
- Full funding for Phase I
- Phase II not completely funded – need at least one more state for full 60 mixtures
- Research Team: UNH, Rutgers, UMass Dartmouth, NC State
- Pike doing extraction & recovery for Phase I
High RAP Pooled Fund Study

- Producers 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
- Mixture
  - Dynamic Modulus
  - Hamburg & TSR
  - Low Temperature Creep & Strength
  - Fatigue (S-VECD protocol)
- Additional testing
# Phase I

- 19 Mixtures
- Focus on evaluating effect of binder grade and plant type

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

*NMAS = Nominal Maximum Aggregate Size, PG = Pressure Gradation, RAP = Recycled Asphalt Pavement
Callanan mixtures have been produced and delivered to research group
Testing starting on these mixtures
Pike mixtures will be produced in next ~month
Phase I testing completed over winter/spring
Plan for Phase II developed in early 2011
Phase II mix production & testing 2011-2013
Questions?

Contact Info: jo.daniel@unh.edu