Impact of Recycling Agents on the Design of Asphalt Mixtures Containing Roofing Shingles

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- Louisiana Department of Transportation and Development
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Outline

- Background
- Objective/Scope
- Testing
- Results
- Conclusions

http://www.shinglerecycling.org/
Sustainability

- Meeting the needs of the present without compromising the needs of the future
- Economic Sustainability
  - Cost effective in long-term
- Social Sustainability
  - Meeting society’s needs
- Environmental Sustainability
  - Reduce use of natural resources
  - Reduce greenhouse gas emissions
Sustainability and Transportation

- **Materials**
  - Natural resource conservation
  - Reduction of virgin materials
  - Reduction of hazardous materials/chemicals
  - Use of Recyclable material
    - Recycled asphalt pavement, recycled asphalt shingles, recycled steel

- **Construction Practice**
  - Conserve energy in highway construction
  - Reduce Greenhouse gas emissions
  - Increase roadway capacity
  - Extending roadway lifespans

- **Benefit environment, users, industry**
Sustainability and Transportation

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Recycled Asphalt Shingles and Sustainability

- Reduces amount of aggregate in mixture
- Reduces amount of virgin asphalt binder in mixture
  - Virgin asphalt binder from Petroleum
  - Natural resource
- Prevents waste shingles from being discarded or combusted
  - Reduces greenhouse gas emissions
- Reduces cost of mixture

Reclaimed Asphalt Shingles

- About 10 million tons of asphalt shingles are removed from roofs each year.
  - Post-Consumer Waste Shingles (PCWS)
- About 1 million tons of “factory scrap” are produced each year.
  - Manufactured Waste Shingles (MWS)
- Wasted Shingles are either placed in landfills or combusted.

http://www.roofingshinglerecycling.com/author/lena/
Reclaimed Asphalt Shingles

Composition
- Asphalt cement: 19-36%
- Fiberglass or Organic Felt: 2-15%
- Fine Aggregate: 20-38%
- Mineral Filler: 8-40%

Asphalt obtained from post-consumer waste shingles has very high stiffness due to extreme aging.

http://www.explodedhome.com/composition-roofing-shingles/
Benefits of using RAS

- **Cost reduction**
  - Reduce amount of virgin asphalt binder and aggregate needed

- **Improve stiffness of asphalt binder**
  - Reduce rutting
  - Increase Sustainability

Concerns with using RAS

- Consistency, availability, and quality of asphalt binder
- Limited Guidance in design methods
  - AASHTO PP 23-14
  - AASHTO PP 78-14
- The shingle asphalt availability factor needs to be verified
  - 70-85%
- Reduction of intermediate and low temperature performance
  - Increases stiffness of asphalt binder
  - Increases susceptibility to fatigue and transverse cracking

Availability Factor = \[
\frac{\text{Amount of Asphalt Retained in Mixture}}{\text{Amount of Asphalt in mixture}}
\]
Recycled Binder Ratio

- Recycled asphalt Binder divided by total asphalt binder content
- RBR of 0.30-0.50 is desired
  - Maximum RAS content without compromising mixture
- RBR can be increased by adding Recycling Agents
  - Softening Agents- soften the asphalt binder by reducing viscosity
  - Rejuvenators- restore maltene content that was lost during aging
Objective

- To evaluate the effectiveness of introducing RAS into a mixture to increase the sustainability of the asphalt binder mixture design process
- To ascertain the influence of recycling agents on restoring asphalt binder properties

Scope
Evaluate laboratory performance for five mixtures with a nominal maximum aggregate size of 12.5 mm

<table>
<thead>
<tr>
<th>Mixtures without Recycling Agents</th>
<th>Mixtures with Recycling Agents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mixture 1: 70CO</strong></td>
<td><strong>Mixture 3: 70PG5P-RA1</strong></td>
</tr>
<tr>
<td>- PG 70-22m asphalt binder</td>
<td>- PG 70-22m asphalt binder</td>
</tr>
<tr>
<td>- Conventional mix- 0% RAS</td>
<td>- RAS Content= 5%</td>
</tr>
<tr>
<td><strong>Mixture 2: 70PGP5P</strong></td>
<td>- RAS type= PCWS</td>
</tr>
<tr>
<td>- PG 70-22m asphalt binder</td>
<td>- RA 1 content= 5%</td>
</tr>
<tr>
<td>- RAS Content = 5%</td>
<td>- Non-fossil fuel based - Vegetable oil</td>
</tr>
<tr>
<td>- RAS type= PCWS</td>
<td><strong>Mixture 4: 70PG5P-RA2</strong></td>
</tr>
<tr>
<td></td>
<td>- PG 70-22m asphalt binder</td>
</tr>
<tr>
<td></td>
<td>- RAS Content= 5%</td>
</tr>
<tr>
<td></td>
<td>- RAS type= PCWS</td>
</tr>
<tr>
<td></td>
<td>- RA 2 content= 12%</td>
</tr>
<tr>
<td></td>
<td>- Fossil fuel based – Naphthetic oil</td>
</tr>
<tr>
<td></td>
<td><strong>Mixture 5: 52PG5P</strong></td>
</tr>
<tr>
<td></td>
<td>- PG 52-28 asphalt binder</td>
</tr>
<tr>
<td></td>
<td>- RAS content= 5%</td>
</tr>
<tr>
<td></td>
<td>- RAS type = PCWS</td>
</tr>
<tr>
<td></td>
<td>- Softer asphalt binder used as softening agent</td>
</tr>
</tbody>
</table>
Determine:

- What happens if 5% RAS is added to a mixture with no recycling agent?
  - Compare mixtures 1 and 2
- What if 5% RA-1 is added to a mixture with 5% RAS?
  - Compare mixtures 2 and 3
- What if 12% RA-2 is added to a mixture with 5% RAS?
  - Compare mixtures 2 and 4
- What if 12% RA-2 and 5% RA-1 are added to two different mixtures with 5% RAS?
  - Compare Mixtures 3 and 4
- What if a softening agent is used instead of a rejuvenator?
  - Compare mixtures 3, 4, and 5
Methodology - Design

AASHTO R 35
- Practice for Superpave volumetric design for hot mix asphalt (HMA)
- Does not consider quality of asphalt binder
  - Mechanical tests performed in laboratories to determine quality of asphalt binders used in mixtures
- Design of 70CO

AASHTO PP 23-14

AASHTO PP 78-14
- Standard practice for Design Considerations when using RAS in asphalt mixtures
- Considers RAS size, fibers in RAS, and virgin asphalt binder
- Maintained aggregate structure and asphalt cement content of 70CO but added RAS
HMA Mixture Preparation

- Oven, 163°C
- 25°C or 163°C
- 195°C
- Oven, 163 °C
Recycled Asphalt Availability

- **No RA**

- **Asphalt Binder Content (%)**
  - 70CO: 0%
  - 70PGSP: 0.5%, 36%

- Mixture Type:
  - RAS
  - Virgin Asphalt Binder

- Calculations:
  - $0.05 \times 28\% = 1.4\%$
  - $\frac{0.5}{1.4} = 36\%$
Recycled Asphalt Availability

![Bar chart showing the asphalt binder content for different mixture types.]

- **70CO**: 5.3% RAS, 0% Virgin Asphalt Binder
- **70PG5P**: 36% RAS, 4.8% Virgin Asphalt Binder
- **70PG5P-1**: 100% RAS, 3.9% Virgin Asphalt Binder
- **70PG5P-2** and **52PG5P**: 0% RAS, 0% Virgin Asphalt Binder

**No RA**

\[ \frac{1.4}{1.4} = 100\% \]

\[ 0.05 \times 28\% = 1.4\% \]
Recycled Asphalt Availability

Asphalt Binder Content (%)  

Mixture Type  

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>No RA</th>
<th>0.05 x 28% = 1.4%</th>
<th>1.2/1.4 = 86%</th>
</tr>
</thead>
<tbody>
<tr>
<td>70CO</td>
<td>5.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70PGSP</td>
<td>4.8</td>
<td>0.5</td>
<td>1.2</td>
</tr>
<tr>
<td>70PGSP-1</td>
<td>3.9</td>
<td>1.4</td>
<td>4.1</td>
</tr>
<tr>
<td>70PGSP-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52PGSP</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Recycled Asphalt Availability

![Bar chart showing asphalt binder content for different mixture types.]

- **70CO**: 5.3%
- **70PG5SP**: 4.8% (RAS), 36% (Virgin Asphalt Binder)
- **70PG5SP-1**: 3.9% (RAS), 100% (Virgin Asphalt Binder)
- **70PG5SP-2**: 4.1% (RAS), 86% (Virgin Asphalt Binder)
- **52PG5SP**: 4.6% (RAS), 50% (Virgin Asphalt Binder)

No RA

- 0.05 x 28% = 1.4%
- \( \frac{0.7}{1.4} = 50\% \)

Mixture Type

- RAS
- Virgin Asphalt Binder
Performance Testing

- High Temperature
  - Loaded-Wheel Test

- Intermediate Temperature
  - Semi-circular Bending Test

- Low temperature
  - Thermal Stress Restrained Specimen

http://www.pavementinteractive.org/article/rutting/
http://www.coastalroadrepair.com/Knowledgebase/Alligator(Fatigue)Cracking.aspx
http://www.roadscience.net/services/distress-guide
Loaded Wheel Test

- **AASHTO T 324**
- Steel wheel rolls over surface of sample
  - 20,000 passes or until rut depth of 20mm
  - Wheel load= 703 N
  - Speed= 1.1 km/hr
  - Performed at 50°C
  - Submerged in water to observe moisture sensitivity
- Deformation is recorded
- Performance characteristic observed: rutting

![Graph showing rutting performance](image.png)
Semi-Circular Bend Test

- Semi-circular specimen simply supported and loaded at mid-point
  - 150mm X 57mm specimen
  - Aged at 85°C for five days
  - Loaded monotonically until fracture (0.5mm/minute)
  - Performed at 25°C

- Notches are added to specimen to control crack propagation path
  - 25.4, 31.8 and 38.0 mm notches

- Load and Vertical Strain Deformation
- Property obtained: Critical Strain Energy, J_c
- Performance characteristic observed: fatigue cracking
Thermal Stress Restrained Specimen Test

- AASHTO TP10-93
- Rectangular specimen restrained by two supports and subjected to thermal loading until fracture
  - $-10^\circ C \pm 1^\circ C$ per hour
- Load, Displacement, and Temperature
- Performance characteristic observed: thermal cracking

[Graph: Load vs Temperature]

Slope = $\delta S / \delta T$

37°C, 1150 lbs
Results
Loaded Wheel Test Results
@ 50°C

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>Depth (mm) after 20,000 passes</th>
</tr>
</thead>
<tbody>
<tr>
<td>70CO</td>
<td>3.0</td>
</tr>
<tr>
<td>70PG5P</td>
<td>2.1</td>
</tr>
<tr>
<td>70PG5P-1</td>
<td>1.4</td>
</tr>
<tr>
<td>70PG5P-2</td>
<td>4.4</td>
</tr>
<tr>
<td>52PG5P</td>
<td>7.0</td>
</tr>
</tbody>
</table>

No RA
Semi-Circular Bend Test Results @ 25°C

Mix Type | Jc (kJ/m²)
---|---
70CO | 0.50
70PG5P | 0.50
70PG5P-1 | 0.23
70PG5P-2 | 0.36
52PG5P | 0.22

No RA
Thermal Stress Restrained Specimen Test Results

Fracture Temperature (°C)

- 70CO -19.7
- 70PG5P -22.6
- 70PG5P-1 -14.2
- 70PG5P-2 -14.0
- 52PG5P -21.0

No RA
## Summary

<table>
<thead>
<tr>
<th>Mixture Type</th>
<th>Performance Comparison to Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loaded Wheel Test</td>
</tr>
<tr>
<td>70PG5P</td>
<td>+</td>
</tr>
<tr>
<td>70PG5P-RA1</td>
<td>+</td>
</tr>
<tr>
<td>70PG5P-RA2</td>
<td>+</td>
</tr>
<tr>
<td>52PG5P</td>
<td>-</td>
</tr>
</tbody>
</table>
Conclusions

- Is introducing RAS to a mix an effective way to increase the sustainability of asphalt mix design?
  - Yes, if properly designed and evaluated
Conclusions

- Do recycling agents effectively restore properties of asphalt?
  - Not for the ones we evaluated
Conclusions

- **LWT**
  - Performance of mixtures containing RAS was similar or improved
  - RAS mixtures are not moisture susceptible

- **SCB**
  - Inclusion of RAS with rejuvenators reduced $J_c$ value of all mixtures
  - RA 2 better at restoring properties of the binder than RA 1

- **Inclusion of RA**
  - Increased the recycled asphalt availability but not the quality of the asphalt binder
Thank You!