Recycling Asphalt Materials – US State of the Practice

Dr. J. Richard Willis, National Center for Asphalt Technology
Annual Western Canada Pavement Workshop
Outline

• Background
• RAP usage statistics
• RAP mix design
• Where are we going?
RAP History

• Began in the 1970s
• 1980s: few field trials with high RAP contents
• 2008: 12% was national average
Surface Mixes: % RAP Allowed
Base Mixes: % RAP Allowed
(Pappas, 2011 – RAP Survey Results)
# RAP Usage Statistics

<table>
<thead>
<tr>
<th>RAP</th>
<th>Tons (Millions)</th>
<th>Tons (Millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accepted</td>
<td>23.2</td>
<td>24.0</td>
</tr>
<tr>
<td>Used in HMA/WMA</td>
<td>20.1</td>
<td>21.6</td>
</tr>
<tr>
<td>Used in Aggregate</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Used in Cold Mix</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Used in Other</td>
<td>0.1</td>
<td>0.07</td>
</tr>
<tr>
<td>Landfilled</td>
<td>0.06</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average % Used in Mixes</th>
<th>Average % Used in Mixes</th>
<th>Average % Used in Mixes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average % for DOT Mixes</td>
<td>12.5%</td>
<td>13.2%</td>
</tr>
<tr>
<td>Average % for Other Agency Mixes</td>
<td>14.0%</td>
<td>15.2%</td>
</tr>
<tr>
<td>Average % for Commercial &amp; Residential</td>
<td>17.5%</td>
<td>18.0%</td>
</tr>
<tr>
<td>National Average All Mixes Based on %</td>
<td>15.6%</td>
<td>17.2%</td>
</tr>
<tr>
<td>National Average All Mixes Based on RAP Tons Used in HMA/WMA</td>
<td>16.2%</td>
<td>18.0%</td>
</tr>
</tbody>
</table>

*(Copeland and Hansen, 2013)*

Objectives
• Provide Guidance on RAP Management
• Revise Mix Design Procedure for High RAP Contents
• Recommend Performance Tests
Contents

- Sources of RAP
- Milling for Quality
- Processing RAP
- Inventory Analysis
- Sampling Guidelines
- Handling RAP in the Lab
- Testing Options
- Consistency Guidelines
Testing RAP

For mix designs using RAP, the data needed from tests on the RAP are:

1. asphalt binder content of the RAP,
2. gradation of the aggregate recovered from the RAP,
3. bulk specific gravity of the RAP aggregate,
4. consensus properties of the aggregate recovered from the RAP, and
5. (for high RAP contents) the RAP asphalt binder properties.
Method 1: Recover aggregate using a solvent extraction, then conduct AASHTO T84 and T85 on the fine and course fractions like any other aggregate.

Method 2: Recover aggregate by the ignition method, then conduct AASHTO T84 and T85 on the fine and course fractions like any other aggregate.
# Comparison of VMA Using different Gsb’s

<table>
<thead>
<tr>
<th>RAP Source</th>
<th>RAP content</th>
<th>NMAS (mm)</th>
<th>Centrifuge - T84/85</th>
<th>Ignition - T84/85</th>
<th>Back-calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Hampshire</td>
<td>25%</td>
<td>12.5</td>
<td>16.1</td>
<td>16.1</td>
<td>16.5</td>
</tr>
<tr>
<td></td>
<td>55%</td>
<td>12.5</td>
<td>15.9</td>
<td>15.8</td>
<td>16.3</td>
</tr>
<tr>
<td>Utah</td>
<td>25%</td>
<td>12.5</td>
<td>14.0</td>
<td>13.9</td>
<td>14.4</td>
</tr>
<tr>
<td></td>
<td>55%</td>
<td>12.5</td>
<td>15.1</td>
<td>14.8</td>
<td>16.0</td>
</tr>
<tr>
<td>Minnesota</td>
<td>40%</td>
<td>9.4</td>
<td>15.5</td>
<td>15.4</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.0</td>
<td>13.3</td>
<td>13.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Florida</td>
<td>40%</td>
<td>9.5</td>
<td>15.0</td>
<td>15.2</td>
<td>16.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>19.0</td>
<td>13.6</td>
<td>13.8</td>
<td>15.0</td>
</tr>
</tbody>
</table>
Recommendations

One method of determining RAP aggregate Gsb will not work for all material types. Agencies will need to evaluate options to find the best method for their materials. The method that gives the lowest Gsb will result in the lowest mix VMA. This is desirable since it will lead to higher asphalt contents and better durability.
Volumetric Results

- Fractionated RAP was necessary to get 55% RAP in the mixes. The coarse RAP fraction was used exclusively in some cases.
- Percent binder replacement ranges:
  - 25% RAP (by weight of agg.): 25 to 27% binder repl.
  - 55% RAP (by weight of agg.): 33 to 49% binder repl.
- Changing the virgin binder source or PG does not appear to affect volumetric properties.
  - Using a different binder grade should not effect Opt. Pb.
  - Incompatibility of binders may not be evident in volumetric mix design.
Moisture Damage Susceptibility (AASHTO T283)

- Increasing RAP increased tensile strengths
- TSR can be misleading.
  - TSR values can decrease with increase in strength.
  - A lower TSR criterion (e.g. 0.75) with a minimum conditioned tensile strength (e.g. 689 kPa) can help.
- Antistripping agent can improve low TSR.
Flow Number Procedure

- FHWA original protocol
- No tertiary deformation
- Total strain for High RAP mixes was statistically equal to virgin mix counterparts in 8 of 9 cases.

- Although not statistically significant, using a lower virgin PG binder grade generally resulted in greater deformation.
Dynamic Modulus (E*) Testing

Two purposes:

1. To try to estimate the “effective” (combined RAP and virgin) binder properties.
   1. Not effective
2. To assess how RAP content influences mix stiffness through the range of temperatures expected in service.
Summary of E* Statistical Analyses

- E* of high RAP content mixes were significantly higher than for virgin mixes at all temperatures.
- Virgin binder grade did not have a significant effect on E* at low temperatures, only higher temperatures.
- Virgin binder source was significant on E* only at the lowest and highest temperatures.
Fracture Energy (FE)

- Simple sample preparation
- Quick test, 10°C
- In most cases, FE decreased with increasing RAP content
- “Good” FE results can be obtained with high RAP mixes.
- Fracture Energy was higher for smaller NMAS mixes
Low Temperature Cracking

- Semi-Circular Bend (SCB) test
  - Fracture Toughness ($K_{IC}$) $\uparrow$ RAP
  - Fracture Energy ($G_f$) $\downarrow$ RAP
- Critical thermal cracking temperature is dominated by the virgin binder low PG
- Adequate thermal cracking resistance can be obtained with high RAP content mixes
2006 45% RAP Test Sections

Surface Layers Only

52-28
76-22 + Sasobit
67-22
76-22
45% RAP Sections

Total Length of Cracking after 2 cycles

W5-45%RAP PG52-28

E5-45%RAP PG67-22

E6-45%RAP PG76-22

E7-45%RAP PG76-22 +Sasobit

1 m

4.2 m

16.4 m

44.3 m
2009 RAP Study Background

- RAP is a green technology
  - Reduce virgin material consumption
  - Reuse paving materials
- Potential disadvantages
  - Increased cracking?
Key Questions

• Can 50% RAP mixes be successfully produced & have good performance?

• Can WMA & RAP be combined to improve fatigue & rutting performance?

• Are load responses of these materials comparable to conventional materials?
  – Do they need special modeling consideration?

• How do these materials perform in full-scale testing?
### Updated Field Performance

<table>
<thead>
<tr>
<th>Section</th>
<th>15 Million ESALs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cracking % of Lane Area</td>
<td>Rutting (mm)</td>
</tr>
<tr>
<td>Control HMA</td>
<td>2%</td>
<td>9 mm</td>
</tr>
<tr>
<td>50% RAP HMA</td>
<td>0%</td>
<td>4 mm</td>
</tr>
<tr>
<td>50% RAP WMA</td>
<td>3%</td>
<td>5 mm</td>
</tr>
</tbody>
</table>
Conclusions & Recommendations

• 50% RAP sections successfully produced & placed
• AC moduli were as expected
  – RAP > RAP WMA > Control
• Sections responded to temperature in similar manner
  – Modulus, strain and pressure
• Strain levels in RAP sections lower than others
• Pressure levels in RAP sections lower than others
• 50% RAP sections had lower rutting
• Today, the HMA – RAP mix has the best cracking performance
Recommended Revisions to AASHTO R 35 and M323
High RAP Content Mix Design

- Aggregates properties – meet Superpave criteria
- Virgin Binder Selection: based on RAP Binder Ratio

\[ RAP\ Binder\ Ratio: \ RBR = \frac{(Pb_{\text{RAP}} \times \text{RAP}\%)}{\text{Total Pb}} \]

- \( RBR < 0.25 \) - use binder grade required for environment, traffic, and structural layer (i.e. may include polymer modified binder)
When \( RBR > 0.25 \),

\[
T_{\text{crit (virgin)}} = T_{\text{crit (need)}} - RBR \times T_{\text{crit (RAP Binder)}} \cdot \frac{1 - RBR}{1 - RBR}
\]

\( T_{\text{crit (virgin)}} \) = critical temperature (high, intermediate, or low) of the virgin asphalt binder

\( T_{\text{crit (need)}} \) = critical temperature (high, intermediate, or low) needed for the climate and pavement layer.

\( T_{\text{crit (RAP Binder)}} \) = critical temperature (high, intermediate, or low) of the RAP binder determined from extraction, recovery, and PG grading
Recommendations for Performance Testing for Mixes with RBR ≥ 0.25

- Moisture Susceptibility (always)
  - TSR or Hamburg

- Permanent Deformation (mixes within top 50 mm)
  - AMPT Flow Number, APA, or Hamburg

- Fatigue (surface or base mixes) for information purposes only
  - Fracture Energy or other cracking test

- Low Temperature (for cold climates)
  - IDT Creep Compliance & Strength, SCB, or BBR with mix beams
2009 RAP Study Background

• RAP is a green technology
  – Reduce virgin material consumption
  – Reuse paving materials

• Potential disadvantages
  – Increased cracking?
Key Questions

• Can 50% RAP mixes be successfully produced & have good performance?

• Can WMA & RAP be combined to improve fatigue & rutting performance?

• Are load responses of these materials comparable to conventional materials?
  – Do they need special modeling consideration?

• How do these materials perform in full-scale testing?
# Updated Field Performance

<table>
<thead>
<tr>
<th>Section</th>
<th>15 Million ESALs</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cracking % of Lane Area</td>
<td>Rutting (mm)</td>
<td></td>
</tr>
<tr>
<td>Control HMA</td>
<td>2%</td>
<td>9 mm</td>
<td></td>
</tr>
<tr>
<td>50% RAP HMA</td>
<td>0%</td>
<td>4 mm</td>
<td></td>
</tr>
<tr>
<td>50% RAP WMA</td>
<td>3%</td>
<td>5 mm</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions & Recommendations

• 50% RAP sections successfully produced & placed
• AC moduli were as expected
  – RAP > RAP WMA > Control
• Sections responded to temperature in similar manner
  – Modulus, strain and pressure
• Strain levels in RAP sections lower than others
• Pressure levels in RAP sections lower than others
• 50% RAP sections had lower rutting
• Today, the HMA – RAP mix has the best cracking performance
Summary and the Future

• The use of RAP is growing
• We are overcoming the challenges to reap the benefits
• We must continue to evolve our mix designs and testing to grow
• Overcome business as usual mentality towards volumetrics
• Rejuvenators?
J. Richard Willis
willi59@auburn.edu

QUESTIONS