Producing High Quality Asphalt Mixes with High RAP Contents

Jim Musselman
Asphalt Performance Manager
Oldcastle Materials

• A Division of CRH
• Vertically integrated supplier of cement, aggregates, ready mix concrete and asphalt in North America.
• Supplies:
  • 135 million tons of aggregate, and
  • 45 million tons of asphalt mixtures in North America annually
• Operates 62 asphalt companies throughout North America
• No. 1 asphalt producer in North America
Who are we in Canada?
Oldcastle Materials Operations

- **Aggregate Mines (605)**
- **Asphalt Plants (441)**
- **Ready Mix Plants (351)**
Reclaimed Asphalt Pavement Material

- 75.9 million tons of RAP are used in new pavements annually in the United States
  - Over 99% of the materials removed from an old pavement are reused in new pavements
- Over $2.3 billion savings annually compared to the cost of raw materials
- Conserves annually:
  - ~ 22 million barrels of asphalt binder
  - ~ 68 million tons of aggregate
  - Energy costs associated with producing, processing and transporting aggregate and binder
  - ~ 50 million cubic yards of landfill space

* Data provided by the National Asphalt Pavement Association
Benefits of Using RAP

- Saves money!
- Conserves resources
- Allows milling without generating waste
- Can speed up construction
- Eliminates a potential waste material
How do we make a high quality asphalt pavement with a high RAP content?

Basic steps:
1. Establish goals and expectations for the mixture
2. Understand the Specifications
3. Properly evaluate the materials
4. Engage in good materials management practices
5. Develop a high quality mix design
6. Produce the mix as designed
7. Properly construct the pavement
Establish Goals and Expectations for the Mixture

Considerations:

• What is the intended application? Surface? Binder? Base?
  • Potential impact on aggregate and binder selection
• What are the anticipated loadings?
  • Would a higher stiffness mix be a benefit or a problem?
• Why do we care?
  • Isn’t it the Owner’s problem?
Why is it important to have a High Quality Mix with RAP?

- Higher quality mixes with RAP will create greater confidence in allowing and using increased RAP contents, which will...
- Help to eliminate some of the barriers associated with RAP usage and make its use more commonplace and acceptable, which will...
- Lower construction costs; and...
- Will advance sustainable roadbuilding to new levels of excellence and expertise!
Specifications
In 2002 the FHWA issued a formal policy on the use of recycled materials in highway applications, which was updated in 2015.

Specifically the FHWA policy states:

1. Recycling and reuse can offer engineering, economic and environmental benefits.
2. Recycled materials should get first consideration in materials selection.
3. Determination of the use of recycled materials should include an initial review of engineering and environmental suitability.
4. An assessment of economic benefits should follow in the selection process.
5. Restrictions that prohibit the use of recycled materials without technical basis should be removed from specifications.
Understand the Specifications for the Job!

• Make sure you know what is **allowed** so you can maximize opportunities
  • Try NOT to leave opportunity on the table

• What are the current specifications for each project?
  • Have special provisions been created?
  • Blanket or job specific SP?

• Be actively involved in association/DOT liaison activities.
  • Understand the specifications **as well as** the person who wrote them!
  • Make sure there are good engineering reasons for any limitations.
Average RAP Contents by State

Average RAP Content in US = 21%

Average RAP Content in Ontario = ~15 -20%
Average Percent RAP Used by Sector

![Graph showing the average percent RAP used by sector from 2009 to 2014. The graph includes lines for DOT, Other Agency, Commercial and Residential, and Total.](https://www.asphalt pave.org/PDFs/IS138/IS138-2014_RAP-RAS-WMA_Survey_Final.pdf)
Count of States at Different Average RAP Percentages

Materials Evaluation
Good Information…


NAPA QIP 129: “Best Practices for RAP and RAS Management”
## Recommended RAP Sampling and Testing Guidelines (From NCHRP 752)

### Table 57 Proposed RAP Sampling and Testing Guidelines for High RAP Content Mixes

<table>
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<tr>
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<td>AASHTO T 30</td>
<td>1 per 1000 tons</td>
<td>10</td>
<td>5.0 all sieves</td>
</tr>
</tbody>
</table>
<pre><code>                                                                                                                          |                          | 15 on 75 micron            |
</code></pre>
<p>| Recovered Aggregate Specific Gravity | AASHTO T 84 and AASHTO T 85           | 1 per 3000 tons | 3                                     | 0.030**                    |
| Binder Recovery and PG Grading  | AASHTO T 319 or ASTM D 5404 and AASHTO R 29 | 1 per 5000 tons | 1                                     | n.a.                       |</p>

* Samples for Superpave aggregate consensus properties or other aggregate testing needs may be obtained by combining the tested aggregates following sieve analyses.

**This is a preliminary value based on limited data and possible impacts to VMA for high RAP content mixes.
Obtain samples from RAP

10 or more samples

Ignition method or solvent extraction tests

Gradations

Combine sample for Gsb and other aggregate tests

Determine averages and standard deviations of properties

Binder Content

Determine the True Grade of the RAP Binder

Extract and recovery RAP binder

At least 1 sample

Determine the appropriate RAP content

From NCHRP 752
Key Parts of the Materials Evaluation:

1) RAP $G_{sb}$
2) RAP Gradation  
3) RAP Binder content
4) RAP & Virgin Binder Characterization

Needs to include averages as well as variability
RAP Bulk Specific Gravity (Gsb)

Gsb

- Substantial VMA errors can occur if the incorrect RAP Gsb is utilized
- Especially critical with high RAP mixes
- VMA errors typically result in lower than calculated effective binder contents.

What is the best way to determine the RAP Gsb?
The current AASHTO standard for Superpave mix design suggests that the following three methods are acceptable for determining the RAP aggregate specific gravity:

1. Recovery of the RAP aggregate using the ignition method (AASHTO T 308) followed by conducting AASHTO T84 and T85 for specific gravity of the fine and coarse aggregate portions, respectively.

2. Recovery of the RAP aggregate using the solvent extraction (AASHTO T 164) followed by conducting AASHTO T84 and T85 for specific gravity of the fine and coarse aggregate portions, respectively.

3. Estimating the Gsb based on the measured maximum specific gravity, measured binder content and assumed asphalt binder absorption.

\[
G_{se}(RAP) = \frac{100 - P_{s(RAP)}}{100 - P_{b(RAP)}} \times G_{mm(RAP)}
\]

\[
G_{sb}(RAP) = \frac{G_{se(RAP)}}{P_{ba} \times G_{se(RAP)}} + 1
\]

Options 1 & 2 are probably more accurate
RAP Gradations

• Sample and test the RAP material to determine average gradations, binder content and standard deviations.
• Use these data to determine potential impact on overall mix gradation at various RAP addition percentages
• Example: No. 8 standard deviation = 3.8%
  
  20% = 0.20 * 3.8% = 0.76% contribution of RAP to overall blend No. 8 deviation
  40% = 1.52%
Many times, graphs can provide a more complete understanding.

Suggestion: plot standard deviation along with Coefficient of Variation (COV) to get complete picture of variation.

COV = \((\text{Std. Dev.} / \text{Average}) \times 100\)

- COVs less than 20% would generally be considered “good”
- Example for Minus 200 (75 µm)
  - Std. Dev. = 1.0%
  - Average = 5.2%
  - COV = \((1.0 \div 5.2) \times 100 = 19.2\%\)
RAP Binder Characterization

- Sample RAP, and extract, recover and continuously grade the RAP binder
- Binder grades of RAP extracted asphalt can vary significantly depending on many factors, including age, original binder grade, environmental/climatic conditions, etc.
- At higher levels of RAP addition the extracted binder grade results can be used to calculate how much RAP can be used.
<table>
<thead>
<tr>
<th>Location of Study</th>
<th>No. of Stockpile Samples Analyzed</th>
<th>Parameter</th>
<th>Critical Temperature, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg.</td>
<td>Std. Dev.</td>
</tr>
<tr>
<td>Alabama</td>
<td>36</td>
<td>T\text{crit} High</td>
<td>91.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Intermediate</td>
<td>34.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Low</td>
<td>-12.5</td>
</tr>
<tr>
<td>Florida</td>
<td>21</td>
<td>T\text{crit} High</td>
<td>94.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Intermediate</td>
<td>32.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Low</td>
<td>-15.8</td>
</tr>
<tr>
<td>Indiana</td>
<td>33</td>
<td>T\text{crit} High</td>
<td>90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Low</td>
<td>-11</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>13</td>
<td>T\text{crit} High</td>
<td>82.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Intermediate</td>
<td>26.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>T\text{crit} Low</td>
<td>-21.8</td>
</tr>
</tbody>
</table>
Continuous Grading of the Virgin Binder

A continuous PG classification on the virgin binder can be obtained from the binder supplier upon request.

Binder suppliers should have this information on hand for immediate submittal.
Required Binder Determination Using the LTPP Bind Software
Low Temp. 98% Reliability
High Temp. 98% Reliability
Five Closest Weather Stations

![Image of weather station data]

- **General**
  - Station ID: [Station IDs listed]
  - County/District: [Lake Ontario, Brampton, Milton, Lakeview, etc.]
  - Weather Station: [Georgetown WW, Brampton, Lakeview, etc.]
  - Elevation, m: [67, 55, 52, 23, etc.]
  - Latitude, Longitude: [43.6, 79.8, 43.5, 79.6, etc.]

- **Air Temperature**
  - Mean (Std. N): [Values listed for different distances]
  - High Temperature: [30.4 (18.34), 30 (13.17), 28.4 (15.31), etc.]
  - Low Temperature: [24.4 (27.24), 22.1 (36.18), 22 (36.34), etc.]
  - Low Temperature Drop: [24 (28.18), 22.1 (35.49), 24 (27.24), etc.]
  - Degree-Days > 10C: [Values listed for different distances]

- **PG**
  - Pavement Temperature, C: [49.0 (29.1), 46.6 (16.6), etc.]
  - 50% Reliability PG: [52-22 (36,73), 52-22 (36.03), etc.]
  - >50% Reliability PG: [53-28 (36,96), 52-28 (36.90), etc.]

- **Buttons:** PG Chart, Save, Cancel
Recycled Material – Blending Calculation

Based on the binder characteristics, how much RAP can be used?

From AASHTO M 323:

\[
\% \text{ RAP} = \frac{T_{\text{blend}} - T_{\text{virgin}}}{T_{\text{RAP}} - T_{\text{virgin}}}
\]
Recycled Material – Blending Calculation

Given:

- Desire to maintain a -22°C low temperature through the use of a PG 58-28 binder (i.e., a PG binder “bump” from -22 to a -28).
- $T_{blend} = -22.0$
- $T_{virgin} = -28.7$ (from testing of virgin PG 58-28 binder)
- $T_{RAP} = -11.1$ (from extraction/recovery/testing of RAP binder)

\[
\% \text{ RAP} = \frac{-22 - (-28.7)}{-11.1 - (-28.7)} = 38.1\%
\]

- Maximum %RAP allowed to maintain -22°C temperature using a PG 58-28 virgin binder is 38.1%
# Oldcastle Binder Blending Analysis Spreadsheet

## Allowable Binder Blending Development

<table>
<thead>
<tr>
<th>Product</th>
<th>Binder Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>9.1</td>
</tr>
<tr>
<td>RAS</td>
<td>19.8</td>
</tr>
<tr>
<td>Virgin Mix</td>
<td>5.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Critical Low Temp, °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP Binder</td>
<td>-11.5</td>
</tr>
<tr>
<td>RAS Binder</td>
<td>12.0</td>
</tr>
<tr>
<td>Virgin Binder</td>
<td>-24.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>% of Total Binder Replacement (BR)</th>
<th>Composite PG Grade</th>
<th>%BR</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAP</td>
<td>RAS</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>90</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>80</td>
<td>20</td>
<td>100</td>
</tr>
<tr>
<td>70</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
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<td>100</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>100</td>
</tr>
<tr>
<td>0</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

## Binder Blending Chart (Low Temperature)

\[
y = 0.368x - 24.8
\]

\[
y = 0.321x - 24.8
\]

\[
y = 0.274x - 24.8
\]

\[
y = 0.227x - 24.8
\]

\[
y = 0.18x - 24.8
\]

\[
y = 0.135x - 24.8
\]
Values plotting above the threshold curve indicate a composite PG binder grade (from the input recycle addition) that fails to meet the specified low temperature grade.
Materials Management
Aggregate Stockpiling & Handling

Stockpiling best practices should be utilized at all times to help minimize segregation and maintain quality.

- Use of a moveable or programmable stacker is recommended if using a stacker to place your stockpiles.

Moisture can be reduced from the top and/or bottom:

- Consider covering stockpiles to minimize moisture.
  - If it is not economically feasible then consider just covering the fine pile(s).
- Consider paving and sloping underneath the piles, especially the fine pile(s).
RAP Sources

1. Pavement Milling – The upper pavement layers are removed by a milling operation
2. Full-Depth Removal – The entire asphalt pavement is removed in larger pieces
3. Wasted plant material
Millings

Millings from single project are usually very consistent in:

- Gradation
- Binder content
- Aggregate properties
- Binder properties

Recommended Processing Options:

- Sample and test multiple locations of the millings stockpile to determine RAP quality/uniformity
- If the max aggregate size is too large either:
  - Scalping
  - Fractionate the RAP for use in different mixes
  - Process by crushing to the desired aggregate size
Stockpiled (Unprocessed) RAP from Various Sources

- Sources:
  - Full Depth Removal;
  - Plant Waste,
  - Millings from small projects

- Typically require processing
  - Crushing
  - Screening
  - Fractionating

- Contaminated RAP should not be tolerated
Plant Waste

Plant waste should be MINIMIZED, but can and should be utilized with the following considerations:

What type of waste?
- Reject mix
- Start up
- Switch over
- Asphalt coating
  - Uncoated
  - Partially coated
  - Fully coated
Principles of RAP Management

- Good materials management practices should **always** be part of the quality control program for any asphalt mix production operation.
- As RAP contents increase, it becomes more important to accurately determine properties of RAP and control its consistency.
- Treat recycled products during production the same as virgin aggregates. At higher recycled percentages (>25%), this becomes more critical.
  - Cover/paved stockpiles
  - Multiple recycle bins
- Goals of processing RAP are to:
  - Create uniform stockpile from a collection of different RAP materials
  - Break apart large agglomerations of RAP particles to a size that can be used during production
  - Reduce the max aggregate size so RAP can be used in surface mixes
  - Minimize the generation of additional P-200 (75 µm)
    - Screening prior to crushing will help reduce unnecessary aggregate break-down
Screening RAP During Processing

• Crushing RAP will create more aggregate fines
  • Ideally RAP should be screened before crushing to remove particles which do not need to be processed (i.e., removing the fines prior to the recirculating circuit)
• In-line RAP crushers are often used at plants with limited plant footprint area (no room for RAP processing/stockpiling)
• Can be used successfully, but it’s important to understand the potential for and address changes in RAP gradation when these systems are used

• Ideally in-line crushing circuits will be designed to only break up agglomerations
• Caution with in-line crushers - Crushed/screened RAP goes directly into plant.
  • Sample frequently to ensure consistency
  • Pay attention to feed to ensure uniformity
Utilize RAP Fractionation When Beneficial

- When should fractionating be considered?
  - Plants can produce mixes with more than 25% RAP
  - RAP is readily available
  - Plant site has space for multiple RAP stockpiles
  - Problems meeting mix design requirements
  - Problems meeting project QC requirements

- Fractionating should not be mandated
  - It should be the contractor’s decision if and when to fractionate RAP based on ability to meet specification requirements (i.e., reward good contractor process control and decisions)
### Table 57 Proposed RAP Sampling and Testing Guidelines for High RAP Content Mixes

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Mix Design
Pendulum of Performance

Diagram showing the pendulum of performance with points labeled as Pb for optimum performance, Pb for cracking, and Pb for rutting, with states of dry and wet conditions.
Key Parts of the High RAP Mix Design Process

1. Conduct a good materials characterization – RAP, Virgin Binder and Aggregate
2. Design with actual materials
3. Use the correct binder
4. Consider the plant’s ability to produce what is designed
5. Consider performance testing with high RAP contents
Match the Test to the Distress

- Four-point Bending
- Disc Shaped Compact Tension
- Texas Overlay Test
- Fatigue
- Thermal
- Reflective
- Indirect Tension
- Semi-Circular Bending

From: Louay Mohammad, LTRC
Performance Space Diagrams

Performance space diagrams show the performance of a mix related to multiple tests
  • Rutting vs Cracking tests

Allows the mix designer to visualize the mix performance and how to properly engineer the mix to provide the desired performance

Illustrates the impact of varying mix factors on performance.

From: Performance-Space Diagram for the Evaluation of High and Low Temperature Asphalt Mixture Performance, Buttlar et al, AAPT 2016
Production
Moisture Impact on Production Capacity

1% Moisture = 13% Production Rate Change
Construction
Paving Best Practices

- Important to recognize that high RAP mixtures are different, which doesn’t necessarily make them bad
- Education of customers (internal and external) on changes to the mixture is key
- High binder replacement mixtures can be very sensitive to production temperatures, production at “WMA” temperatures may be an issue
Importance of Quality Construction

A great mix’s field performance can be sabotaged by poor construction techniques.

Likewise, a “marginal” mix’s performance can be improved by good construction techniques (e.g., achieving target, uniform density!)

Many times, communication of the mix type and characteristics can help construction personnel adjust procedures to help ensure optimal mix laydown.

• For example, inform the field that a mix may be less workable so an additional roller or roller passes can be used or perhaps the paver speed slowed.
Pavement Layer Mix Type and Condition Influence on Tack Coat Application

Mix Binder and Recycle Content

- An under asphalted mix will typically require slightly more tack material for good bonding. This is due to the mix “soaking” up some of the tack material and effectively lowering the residual application rate.
- Under asphalted mixes could be a result of a design compactive effort which is too high or perhaps using higher recycle (especially recycled asphalt shingles, RAS) contents in mixes.
  - Some limited findings from the National Center for Asphalt Technology’s (NCAT) test track point to the need to increase the tack coat application rate for higher recycle mixes.

The National Asphalt Pavement Association has recently published the Quality Improvement Publication 128: Best Practices for Emulsion Tack Coats. This publication provides guidelines for the selection of tack coat emulsion type, application rate, and placement.
Moving Forward with Recycling

Be an Advocate for Recycling!

- Maximize the existing funding sources
  - RAP use will help mitigate increases in mix costs allowing more of the infrastructure to be addressed
- Poor road conditions cost motorist $65 billion in repairs every year
  - $413 per urban motorist
- Declare increasing the percentage of recycle materials used a priority within your province
  - Help drive the initiative at the local level
Conclusions

• Oldcastle Materials has had no significant production or placement problems with high RAP mixes
  • Have achieved in excess of 40% binder replacement in some locations
• Percentage used is based on mix type, surface vs. binder
  • Need to make good choices!
• Marshall and Superpave mix designs have been developed with high RAP contents
• High recycle content mixtures have been produced at batch and drum facilities
• High RAP mixes have a proven record of performance when properly characterized, designed, produced and constructed.
• Use of recycle materials will keep asphalt competitive and provide value to owners
• Always use best management practices to ensure quality mixes are produced while maximizing the value opportunity of the recycle materials
Thank You