Performance of High RAP Mixes & Best Practices

86th Annual Transportation Short Course
Texas A&M University
October 17, 2012
19 MILLION. The estimated barrels of asphalt conserved.

THAT’S DUE TO A 10% INCREASE IN THE USE OF RAP IN ONE YEAR.
What’s the National Trend?

• The nation is comfortable using up to 20% RAP, but there’s room to use up to 30% or more.
  – Best opportunity to stabilize material costs.

• The use of RAS and interest in rubber is increasing.
  – Start with low amounts of RAS and maintain quality.

• The use of WMA in the industry has increased by almost 150% from 2009 to 2010!
  – Consistency & best practices are key when combining RAP, RAS, & WMA!
PERFORMANCE OF HIGH RAP MIXTURES
Long-Term Performance of RAP in HMA

Well-designed pavement with high RAP (35%) can perform well during life span.

No significant difference in performance of virgin and recycled pavement sections.

“...in all 3 environmental zones, long term performance of RAP likely to be comparable to other treatments.”

Average age of virgin mixes is 11 years. For 30–50% RAP content, the average age ranges from 10–13 years.
Evaluating RAP Performance

• Long Term Pavement Performance
  SPS-5 sections
    – Virgin
    – 30% RAP
    – Milled and non-milled surface
    – 50 and 125 mm thick
    – Oldest is over 17 years
    – Variety of climates
LTPP Study Results

RAP Mix Performed As Well As or Significantly Better than Virgin Mix

Fatigue Cracking – 71%
Longitudinal Cracking – 85 %
Block Cracking – 97 %
Raveling – 93 %
“In summary, the performance data from LTPP SPS-5 shows that RAP and virgin HMA mixes used in overlays of flexible pavements showed approximately the same performance across a range of climates, traffic, and existing pavement conditions over a period of up to 17 years. **This finding should give agencies confidence in specifying RAP mixtures for overlays when economic and other conditions warrant.**”
Top Roadblocks for High RAP Use

1. FEAR - Overly Conservative Specifications
2. Concerns about quality of the RAP as a material input
3. Using high RAP with Superpave mix design – meeting volumetric requirements
4. Insuring Performance
From what I hear…

- TX is comfortable with high RAP and has pushed limits of RAP and RAS.
- The concerns are how much RAP before cracking may become issue, choosing/getting proper binder grade, and evaluating end mix.
- Local agencies are actually starting to say no to RAP!
- Interest in combining WMA additives with high RAP to get compaction and performance.
BEST PRACTICES
Increasing RAP Use

The question we’re posing...

• *How much RAP can we allow in the mix and meet specification and constructability requirements for performance?*

• Biggest impact can be made in processing and production.
Issues to Consider when Increasing RAP

• Processing & Quality Control (QC)
  – Mill Intelligently
  – Processing RAP
  – Stockpile Management

• Characterizing RAP

• Changing Binder Grade

• Mix Design

• Blending/Co-mingling of Virgin and RAP Binder

• Performance
Quality Control

• RAP mixtures must meet the same mix design specifications required for virgin mixtures.

• Most State DOTs do not have additional means of determining the acceptability of high RAP mixtures.
Obtaining uniform gradation of RAP

• RAP aggregate separation based on size increases control and reduces variability.

• Sizing of RAP materials
  – Screening is used to separate size & control dust
  – Fractionation
  – Allows for adjustments for variability to be made within the RAP
Fractionated RAP (FRAP)

- Fractionation is processing and separating RAP into at least two sizes, typically a coarse fraction and a fine fraction.
Characterizing RAP Materials for High RAP Use

- **Asphalt Content**
  - RAP binder contribution, reduce virgin binder required
  - Ignition oven or solvent extraction

- **Performance Grade of RAP binder**
  - Estimate blended binder properties
  - Evaluate stiffness of RAP
  - Recovered binder is unaged

- **RAP Aggregate Gradation**
  - Ensure quality material
  - Determining Gsb, Gse of RAP aggregate – significant effect on VMA and asphalt content
  - Combined aggregate properties must meet consensus requirements
Binder Grade Selection

- For high RAP contents, the virgin binder Performance Grade (PG) may have to be lowered to account for the aged (stiff) RAP binder OR the RAP % is chosen based on a given virgin binder PG.

- Bumping a grade may increase cost
- Blending charts
- Standardized PG based on region
How to check for blending?

• No direct method for measuring blending

• Blending Charts
  – AASHTO M 323 Appendix
  – Assumes complete blending
  – Time consuming, hazardous solvents

• Mixture Testing with the Asphalt Mixture Performance Tester (AMPT)
RAP Percentage Based on Binder

- Historically, agency specs limit RAP based on RAP percentage by weight of total mix or weight of aggregate.

- With high RAP contents, the primary issue is amount of binder replacement.
  - Impacts binder properties

- Determine contribution of RAP binder toward total binder in the mix, by weight.
  - Typically specified as “70% of binder content must be virgin” or “no more than 30% binder content can come from RAP or RAP & RAS”.
RAP Aggregate Testing

- Gradation - AASHTO T 30 Mechanical Analysis of Extracted Aggregate
- RAP aggregates must meet the same quality requirements specified for virgin aggregates.
  - Coarse Aggregate Angularity (D 5821)
  - Fine Aggregate Angularity (T 304)
  - Flat & Elongated (D 4791)
  - Sand equivalent requirements (T 176) are waived for RAP aggregate.
- Agency Specifications
  - Source properties
# Superpave Volumetric Mixture Design Requirements

<table>
<thead>
<tr>
<th>Design ESALS (millions)</th>
<th>Required Density (% of Theoretical Max Specific Gravity)</th>
<th>Nominal Max Agg Size, mm</th>
<th>VMA (%), minimum</th>
<th>VFA (%)</th>
<th>Dust-to-binder ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$N_{\text{initial}}$</td>
<td>$N_{\text{design}}$</td>
<td>$N_{\text{max}}$</td>
<td>37.5</td>
<td>25.0</td>
</tr>
<tr>
<td>&lt; 0.3</td>
<td>≤ 91.5</td>
<td></td>
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<tr>
<td>0.3 to &lt; 3</td>
<td>≤ 90.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>3 to &lt; 10</td>
<td>≤ 89.0</td>
<td>96.0</td>
<td>≤ 98.0</td>
<td>11.0</td>
<td>12.0</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>≤ 89.0</td>
<td>96.0</td>
<td>≤ 98.0</td>
<td>11.0</td>
<td>12.0</td>
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<tr>
<td>≥ 30</td>
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</table>
Determining RAP Aggregate BSG

• Bulk Specific Gravity (BSG) is used in the calculation of VMA.
  – Combined BSG of RAP and virgin aggregates

• Not practical to directly determine BSG of RAP aggregate
  – Extraction required
  – Ignition oven – BSG value is too low
  – Solvent extraction – aggregate may contain asphalt or solvent which may influence results
What value should I use for RAP aggregate BSG ($G_{sb}^{RAP}$)?

- Bulk Specific Gravity ($G_{sb}$) of RAP aggregate from original construction records
- Direct Measure
- Use effective specific gravity of RAP aggregate, $G_{se}^{RAP}$
  - This will overestimate the combined aggregate $G_{sb}$ and is not recommended.
  - Based on experience with mix designs for the specific location, assume a typical value for asphalt absorption, $P_{ba}$, and use this value to estimate the bulk specific gravity of the RAP aggregate, $G_{sb}^{RAP}$, from the calculated $G_{se}^{RAP}$.
Dealing with Dust
Dust to Binder Ratio

• Big challenge in using higher RAP contents
  – Fills voids and reduces VMA

• Removing dust increases costs
Insuring Quality

- **Final mixture**
  - Volumetric properties
  - Extraction & recovery
  - Gradation
  - Asphalt content
  - High-RAP
    - PG grade of blended binder
    - Quality of Aggregate

- **Performance Testing**
Primary Performance Concerns

• Fatigue Cracking
  – Aging characteristics – virgin vs. RAP binder

• Low Temperature Cracking

• Durability (Raveling)
  – Moisture content
# Performance Testing Options

<table>
<thead>
<tr>
<th>Distress</th>
<th>Test</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permanent Deformation</strong>*</td>
<td>Asphalt Pavement Analyzer (APA)</td>
<td>AASHTO TP 63</td>
</tr>
<tr>
<td></td>
<td>Hamburg Wheel Tracking Device</td>
<td>AASHTO T 324</td>
</tr>
<tr>
<td></td>
<td>Flow Number (AMPT)</td>
<td>AASHTO TP 79</td>
</tr>
<tr>
<td><strong>Moisture Sensitivity</strong></td>
<td>Tensile Strength Ratio (TSR)</td>
<td>AASHTO T 283</td>
</tr>
<tr>
<td></td>
<td>Hamburg Wheel Tracking Device (wet)</td>
<td>AASHTO T 324</td>
</tr>
<tr>
<td><strong>Fatigue</strong></td>
<td>??</td>
<td>??</td>
</tr>
<tr>
<td><strong>Thermal Cracking</strong></td>
<td>Creep Compliance &amp; Strength Using Indirect Tensile Test (IDT)</td>
<td>AASHTO T 322</td>
</tr>
</tbody>
</table>

* If softer binder or rejuvenator is used.
** For surface mixes in climates prone to thermal cracking.
RESOURCES
Resources

• Designing HMA Mixtures with High RAP Content: A Practical Guide, Publication QIP-124

• How to Increase RAP Usage and Ensure Pavement Performance, NAPA Publication PS 34

• Uses of Waste Shingles in HMA: State-of-the-Practice, Special Report 179

• Guidelines for the Use of Reclaimed Asphalt Shingles in Asphalt Pavements, Information Series 136
Resources from FHWA

Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

PUBLICATION NO. FHWA-HRT-11-021
APRIL 2011

With changes in construction materials economics, stricter environmental regulations, and an emphasis on "green" technologies (e.g., warm mix asphalt) and sustainable pavements, the highway community is reassessing the economic and environmental benefits of allowing higher percentages of reclaimed asphalt pavement (RAP) in premium pavements and asphalt surfaces while maintaining high-quality pavement infrastructure. In 2001, the Federal Highway Administration created the RAP Expert Task Group (ETG) to address the use of recycled materials such as RAP and recycled asphalt stingers in asphalt paving applications. The purpose of this ETG is to provide state transportation department and the industry with information that emphasizes the production of high-quality, high-content RAP mixtures, the performance of asphalt mixtures containing RAP technical guidance on high-content RAP projects, and RAP mixture activities. Members of the ETG consist of representatives from state highway agencies, industry, and academia. This Infobrief summarizes the accomplishments of the ETG and resources available for improved RAP use. More information may be found online at www.fhwa.dot.gov/pavement/recycling or on www.morerap.us, as well as in the National Asphalt Pavement Association and the Asphalt Institute.

INFORBrief

High Reclaimed Asphalt Pavement Use
FHWA Publication No. FHWA-HRT-11-067
FHWA Contact: Audrey Copeland, HRT-10, (202) 493-3097, audrey.copeland@FHWA.dot.gov

RAP Defined
Existing asphalt materials are commonly removed during resurfacing, rehabilitation, and reconstruction operations. Once removed and processed, the pavement materials become reclaimed asphalt pavement (RAP), which contains valuable asphalt binder and aggregate. RAP is a valuable, high-quality material that can replace more expensive virgin aggregates and binders. The most economical use of RAP is in the intermedias and surface layers of flexible pavements where the low expensive binder from RAP can replace a portion of the more expensive virgin binder. While RAP has been used for decades, there is a current interest in using higher RAP contents. High RAP content mixtures have greater than 25 percent RAP by weight of the mix.

RAP Use Today
The RAP ETG, in partnership with the American Association of State Highway and Transportation Officials (AASHTO), conducts a RAP use survey every 2 years. The survey was conducted in 2007, 2009, and 2011. In 2007, the typical hot mix asphalt (HMA) mixture contained about 12 percent RAP. From 2007 to 2009, about 27 States increased the amount of RAP permitted in asphalt mixtures, and, as of 2009, 22 States have experience with high RAP mixtures. The results of the 2007 and 2009 surveys are summarized in the Public Roads article "Reclaiming Roads." As of 2011, the majority of State highway agencies (more than 40) allow more than 30 percent RAP; however, only 11 report actually using 25 percent RAP or more.

Providing Technical Information
Designing High RAP Mixes
The RAP ETG developed and disseminated technical information for high RAP use. In the first major effort, the Federal Highway Administration partnered with AASHTO and the National Asphalt Pavement Association to create Designing MMS Mixtures with High RAP Content: A Practical Guide, which provides guidance for designing high RAP mixtures. As a follow-up and in conjunction with the Transportation Research Board, the RAP ETG conducted the webinar Design and Production of High Reclaimed Asphalt Pavement Mixes.

Management and Production Best Practices
There are two best practices reports available. In addition, presentations by three RAP ETG members are available, which provide a historical

High RAP Mix Design

- NCHRP 9-46 Mix Design and Evaluation Procedure for High Reclaimed Asphalt Pavement Content in Hot Mix Asphalt

Coming Soon:
- Final Report
- Best Practices for RAP Management

www.moreRAP.us
Funding available for State DOT participants!
THANK YOU!

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Phone: 301.731.4748
www.asphaltpavement.org
www.asphaltroads.org
Defining High RAP

- Reclaimed Asphalt Pavement
- Removed and/or reprocessed pavement materials containing:
  - binder (5%)
  - aggregates (95%)

High RAP is defined as more than 25% RAP by weight of mix.
Current Guidelines

- **AASHTO M 323 Standard Specification for Superpave™ Volumetric Mix Design**

<table>
<thead>
<tr>
<th>Recommended Virgin Asphalt Binder Grade</th>
<th>Percent (%) RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in binder selection</td>
<td>&lt; 15</td>
</tr>
<tr>
<td>Select virgin binder grade one grade softer than normal</td>
<td>15 – 25</td>
</tr>
<tr>
<td>Follow recommendations from blending charts</td>
<td>&gt; 25</td>
</tr>
</tbody>
</table>

- Based on significant blending between virgin and RAP binder
- Effects of plant production unknown
- Calls for virgin binders that may be more expensive, hard to get
- Blending chart analysis is time-consuming!
The ultimate value of RAP is in its use:

• **As a roadbed/base material**
  – Roughly equal to granular base with some additional value

• **In new pavement**
  – Replaces portion of expensive virgin binder and aggregate
  – Virgin aggregate + asphalt value – costs
How do States deal with high RAP content on projects?

• Asphalt mixtures with RAP must *always* meet the same volumetric mix design requirements as virgin mixtures.

• RAP aggregate must meet specifications
  – Specify fractionation to produce uniform gradation
  – RAP may be limited with high polish aggregate

• Limit RAP content with polymer modified binders

• Case-by-case basis
Life Cycle Cost Using RAP
11" AC vs. 9" PCC
Determining $G_{sb}^{RAP}$ of the RAP Aggregate

- Determine the maximum theoretical specific gravity of the RAP mixture, $G_{mm}^{RAP}$
  
  \[ G_{mm}^{RAP} = \frac{\text{mass of asphalt & aggregate mixture}}{\text{volume of asphalt coated particles}} \]

- Using $G_{mm}^{RAP}$, the asphalt content of the RAP mixture, $P_b$, and an assumed asphalt specific gravity, $G_b$, calculate the effective specific gravity of the RAP aggregate $G_{se}^{RAP}$
  
  \[ G_{se}^{RAP} = \frac{(P_{mm} - P_b)}{\left(\frac{P_{mm}}{G_{mm}}\right) - \left(\frac{P_b}{G_b}\right)} \]

- Now….you could stop here and use $G_{se}^{RAP}$, but this will overestimate the combined aggregate $G_{sb}$ and is not recommended.
Determining $G_{sb}^{RAP}$ of the RAP Aggregate, cont...

- Based on experience with mix designs for the specific location, assume a typical value for asphalt absorption, $P_{ba}$, and use this value to estimate the bulk specific gravity of the RAP aggregate, $G_{sb}^{RAP}$, from the calculated $G_{se}^{RAP}$.

\[
G_{sb}^{RAP} = \frac{G_{se}^{RAP}}{\left[\frac{(P_{ba} - G_{se}^{RAP})}{100 \times G_b}\right] + 1}
\]
Laydown and Compaction

– No special requirement/techniques
  • May require more attention than conventional mixes

– Mix Workability - Stiffer
  • Density

– Cooler temperatures
  • Reduced compaction times