Performance of High RAP Percentage Mixes

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It’s a given...

Must consider recycled materials:

• Control costs
• Remain competitive
• Mitigate material cost variability

High RAP is defined as more than 25% RAP by weight of mix.
Asphalt Production Cost Categories

Greatest Potential for Cost Savings is in the Materials Category.
Top Barriers to High RAP Use

1. FEAR - Overly Conservative Specifications

2. Insuring Performance

3. Using high RAP/RAS with Superpave mix design – meeting volumetric requirements

4. Concerns about quality of the RAP
Common Barriers

**Agency/Specifications**
- Quality Concerns
- Consistency of RAP/RAS
- Binder Grade and Blending
- Mix Design Procedures
- Meeting Volumetric Requirements
- Durability
- Use with Polymers

**Industry**
- State Specifications
- Control of RAP/RAS
- Dust and Moisture Content
- Increased QC
Conservative Agency Specifications
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>

- Calls for virgin binders that may be more expensive, hard to get
- Blending chart analysis is time-consuming!
### RAP/RAS/WMA Survey

**Reclaimed Asphalt Pavement**

<table>
<thead>
<tr>
<th>Year</th>
<th>Average RAP Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>6%</td>
</tr>
<tr>
<td>2010</td>
<td>10%</td>
</tr>
<tr>
<td>2011</td>
<td>23%</td>
</tr>
<tr>
<td>2012</td>
<td>28% Preliminary</td>
</tr>
</tbody>
</table>
How far have we come?

The Industry from 2009 to 2011

• The amount of RAP used in HMA/WMA increased by 18%.
  – Assuming 5% liquid asphalt in RAP, this represents over 3.3 million tons of asphalt binder conserved.

• RAS use increased about 50% (0.7 – 1.2 MT)
  – Assuming 20% liquid asphalt in RAP, this represents over 0.4 MT

• The average percent RAP used in mixes has increased from about 16% to 19%.

• 98% of the contractors/branches reported using RAP and over 88% of these contractors reported excess RAP.
Room to Grow...

- Our comfort level with RAP is less than 20% by weight of mix.

- Still 5 to 10% RAP that can be used under existing specs. We can go further!

- Based on research*, Indiana found they could increase specification to allow up to 20% RAP with no binder grade change.
  - Cost savings of about $1.25 per ton of asphalt mixture.
  - Based on the amount of asphalt mixtures produced in 2010, this can result in savings of $125 million.

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Long-Term Performance
Primary Performance Concerns

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

- Low Temperature Cracking

- Durability (Raveling)
  - Moisture content
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
RAP Mix Performed As Well As or Significantly Better than Virgin Mix

Fatigue Cracking – 71%
Longitudinal Cracking – 85%
Block Cracking – 97%
Raveling – 93%
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.
- Average age of virgin mixes is 11 years. For 30–50% RAP content, the average age ranges from 10–13 years.

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

- 2006 – 4 Sections with 45% RAP
  - PG 67-22
  - PG 76-22
  - PG 76-22s (Sasobit)
  - PG 52-28 (blending chart)

- 20 MESAL
  - Less than 5 mm rutting
  - Very minor cracking after 4 years
    - 52-28 least amount
  - 45% RAP PG52-28 lowest texture change (least raveling)
NCAT 2006 High RAP Sections

- 45% RAP PG 52-28 Crack
- 45% RAP PG 76-22s Crack

Bar chart showing differences in total length cracking between various RAP percentages and types.
2009 NCAT High RAP Sections

• One Mill & Fill (Mississippi)
• Two Structural Sections (50% RAP)
  – HMA & WMA – 7” thick
  – Compare structural response & short term performance
  – Laboratory performance tests
  – Virgin control – PG 76-22 surface & intermediate. PG 67-22 base
  – 50% RAP – PG 67-22 all layers
  – RAP binder replacement
    • 37% surface, 50% intermediate & base
2009 NCAT High RAP Structural Experiment

- Performance
  - Rutting
    - RAP less than 5 mm
    - Control 7.1 mm
  - No cracking
  - Steady IRI
  - Very small changes in texture
- Will remain until threshold distresses reached
2009 NCAT High RAP Structural Experiment

Rut Depth

- Control
- 50% RAP HMA
- 50% RAP WMA

APA Rut Depth

Field Rut Depth

Flow Number Results

- Control
- 50% RAP
- 50% RAP

Fracture Energy

Energy Ratio

Cracking Tests

- Control
- 50% RAP HMA
- 50% RAP WMA

Fracture Energy

Energy Ratio
## 2009 NCAT High RAP Structural Experiment

### Horizontal Longitudinal Microstrain

<table>
<thead>
<tr>
<th>Test Section</th>
<th>50°F</th>
<th>68°F</th>
<th>110°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>S9 Control</td>
<td>214.55</td>
<td>326.22</td>
<td>867.83</td>
</tr>
<tr>
<td>N10 HMA RAP</td>
<td>199.95</td>
<td>294.05</td>
<td>724.59</td>
</tr>
<tr>
<td>N11 WMA RAP</td>
<td>194.34</td>
<td>272.07</td>
<td>597.33</td>
</tr>
</tbody>
</table>

± 1σ
Balanced Mix Design
Balanced RAP Mix Design

- Asphalt binder
- Aggregates
- RAP

3 trial asphalt contents

Gradation

TGC/SGC

Mold specimens at 93% density

Volumetric information

Performance Test

- HWTT
- OT

Air voids

Fail

Pass

Balanced asphalt content
Field Test Sections to Demonstrate Balanced Design for High RAP Mixes

- RAP test sections on IH40, Amarillo, Texas
  - 4-inch overlay
  - Very cold weather
  - Extremely high traffic
  - Severe transverse cracking before overlay

- RAP test sections on FM1017, Pharr, Texas
  - 1.5 inch surface HMA layer and new construction
  - Hot weather
  - Low volume road
Four Test Sections on IH40, Amarillo

- Section 0: 20% RAP section designed by contractor
- Section 1: 0% RAP section designed by contractor
- Section 2: 35% RAP section designed by TTI
- Section 3: 20% RAP section designed by TTI

severe transverse cracks even after 4 inch milling
Balanced RAP Mix Design for Section 2: 35% RAP+PG58-28

**TEXAS DEPARTMENT OF TRANSPORTATION**

**HMACP MIXTURE DESIGN : SUMMARY SHEET**

<table>
<thead>
<tr>
<th>SAMPLE ID</th>
<th>31290</th>
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</thead>
<tbody>
<tr>
<td>LOT NUMBER</td>
<td></td>
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<tr>
<td>SAMPLE STATUS</td>
<td>CONTROLLING CJS: 168-08-156</td>
</tr>
<tr>
<td>COUNTY</td>
<td>RANDALL</td>
</tr>
<tr>
<td>SPEC YEAR</td>
<td>2004</td>
</tr>
<tr>
<td>SAMPLED BY</td>
<td></td>
</tr>
<tr>
<td>SAMPLE LOCATION</td>
<td></td>
</tr>
<tr>
<td>MATERIAL CODE</td>
<td>HMAC</td>
</tr>
<tr>
<td>MATERIAL NAME</td>
<td></td>
</tr>
<tr>
<td>PRODUCER</td>
<td>R.K. HALL CONSTRUCTION LTD.</td>
</tr>
<tr>
<td>AREA ENGINEER</td>
<td>JOE CHAPPELL P.E.</td>
</tr>
<tr>
<td>CONTRACTOR DESIGN #</td>
<td>31290</td>
</tr>
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</table>

**TEST SPECIMENS**

<table>
<thead>
<tr>
<th>Asphalt Content (%)</th>
<th>Specific Gravity Of Specimen (Gs)</th>
<th>Maximum Specific Gravity (Gm)</th>
<th>Effective Specific Gravity (Ge)</th>
<th>Theo. Max. Specific Gravity (Gt)</th>
<th>Density from Gt (Percent)</th>
<th>VMA (Percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7</td>
<td>2.382</td>
<td>2.477</td>
<td>2.660</td>
<td>2.464</td>
<td>96.7</td>
<td>14.2</td>
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<tr>
<td>5.2</td>
<td>2.367</td>
<td>2.449</td>
<td>2.637</td>
<td>2.456</td>
<td>97.5</td>
<td>14.1</td>
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<tr>
<td>5.7</td>
<td>2.363</td>
<td>2.423</td>
<td>2.538</td>
<td>2.429</td>
<td>96.1</td>
<td>15.0</td>
</tr>
</tbody>
</table>

**Mixture Evaluation @ Optimum Asphalt Content**

<table>
<thead>
<tr>
<th>Indirect Tensile Strength (psi)</th>
<th>Hamburg Wheel Tracking Test</th>
<th>Overlay Tester Min. Number of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of cycles</td>
<td>Rut depth (mm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Effective Specific Gravity: 2.645
- Optimum Asphalt Content: 5.6%
- VMA @ Optimum AC: 14.9%

5.6% Upper limit for AC@98% Density
Balanced RAP Mix Design for Section 2: **35% RAP + PG58-28**

- **Upper AC limit:** 5.6%
- **Hamburg:** no problem
- **OT:** min. 100
- **Final AC:** 5.5%
<table>
<thead>
<tr>
<th>Section</th>
<th>RAP (%)</th>
<th>Virgin binder</th>
<th>Mix design approach</th>
<th>AC (%)</th>
<th>Hamburg rut depth @20000</th>
<th>OT cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20</td>
<td>PG64-28</td>
<td>Item 340-Type C</td>
<td>5.0</td>
<td>3.7 mm</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>PG64-28</td>
<td>Item 340-Type C</td>
<td>4.8</td>
<td>4.4 mm</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>PG58-28</td>
<td>Balanced mix design</td>
<td>5.5</td>
<td>8.0 mm</td>
<td>200</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>PG64-28</td>
<td>Balanced mix design</td>
<td>5.3</td>
<td>7.4 mm</td>
<td>125</td>
</tr>
</tbody>
</table>
Performance of 4 Sections on IH40

- **Construction**
  - August 11, 2009

- **1st survey**
  - April 22, 2010

- **2nd survey**
  - September 8, 2010

- **3rd survey**
  - April 5, 2011

April 5, 2011
No rutting but cracking
## Performance of 4 Sections on IH40

### Reflective Cracking Rate (%)

<table>
<thead>
<tr>
<th>Sections</th>
<th>Reflective Cracking Rate (%)</th>
<th>OT cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>20% RAP-contractor</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0% RAP-contractor</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>35% RAP-TTI</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20% RAP-TTI</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### IH40 RAP Sections: OT vs. Reflective Cracking

- **Equation:** \( y = -0.2678x + 81.501 \)
- **R²:** 0.84

![Graph showing the relationship between OT cycles and reflective cracking rate with a trend line and data points.](image-url)
Three Test Sections on FM1017, Pharr

- 0% RAP: contractor designed
- 20% RAP: contractor designed
- 35% RAP: TTI designed

Mix Design Summary

<table>
<thead>
<tr>
<th>Section</th>
<th>RAP (%)</th>
<th>Virgin binder</th>
<th>Mix design approach</th>
<th>AC (%)</th>
<th>Hamburg rut depth @20000</th>
<th>OT cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>PG64-22</td>
<td>Item 340-Type D</td>
<td>5.0</td>
<td>3.4 mm</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>PG64-22</td>
<td>Balanced mix design</td>
<td>6.4</td>
<td>9.3 mm</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>PG76-22</td>
<td>Item 340-Type D</td>
<td>4.9</td>
<td>2.2 mm</td>
<td>4</td>
</tr>
</tbody>
</table>
Performance of 3 Sections on FM1017

- Construction:  
  April 6, 2010

- Latest survey:  
  March 1, 2012
  - No rutting
  - Minor raveling on 35% RAP section
Lessons from Field Test Sections

- High RAP mixes can be designed with better performance than virgin mixes, but it must be engineered (i.e. balanced mix design approach).

- Mix cracking requirement should vary, depending on:
  - Traffic level
  - Weather
  - Overlay vs. new construction
  - Location within pavement structure
Summary and Conclusions

- Texas’ RAPs, in terms of aggregate gradation and asphalt content, have low variability.

- Use of RAP improves rutting/moisture damage resistance, but decreases cracking resistance.

- High RAP mixes can be designed with better performance using balanced mix design approach.

- Mix cracking requirement should vary, depending on application scenarios.
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:** \( RBR = \frac{(P_{\text{RAP}} \times \text{RAP}\%)/\text{Total Pb}}{\text{RAP Binder Ratio}} \)

- **RBR < 0.25** - use the virgin binder grade required for the environment, traffic, and structural layer (i.e. may include polymer modified binder)
Virgin Binder Selection:

- **RBR ≥ 0.25** - determine the virgin binder grade using the formula:

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

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

  \[ T_{\text{crit (RAP Binder)}} = \text{critical temperature (high, intermediate, or low) of the RAP binder determined from extraction, recovery, and PG grading.} \]
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*
  - No cracking test or criteria recommended at this time
- Low Temperature (for cold climates)
  - IDT Creep Compliance & Strength, SCB, or DCT
Reclaimed Asphalt Pavement in Asphalt Mixtures: State of the Practice

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 2007, the Federal Highway Administration created the RAP Expert Task Group (ETG) to advance the use of recycled materials such as RAP and recycled asphalt shingles in asphalt paving applications. The purpose of the ETG is to provide State transportation departments 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 research activities. Members of the RAP ETG consist of representatives from State highway agencies, industry, and academia. This InfoBrief summarizes the accomplishments of the RAP ETG and resources available for increased RAP use. More information may be found online at www.fhwa.dot.gov/pavement/recycling or at www.moresap, as well as through the National Asphalt Pavement Association and the Asphalt Institute.

High Reclaimed Asphalt Pavement Use

FHWA Publication No.: FHWA-HRT-11-057
FHWA Contact: Audrey Copeland, HRDI-10, (202) 493-3097, audrey.copeland@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 intermediate and surface layers of flexible pavements where the less expensive binder from RAP can replace a portion of the more expensive virgin binder.

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, 23 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 HMA 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
Designing HMA Mixtures with High RAP Content
A Practical Guide

How to Increase RAP Usage and Ensure Pavement Performance
High RAP Mixes

- High RAP mixes can perform as well as or better than virgin mixes.
- Changing binder grade at 15% too conservative.
- Performance testing of mixes can move us to higher RAP content.
- View RAP as a valuable resource.
- Treat RAP as you would other ingredients.
- Offer yourself maximum flexibility in using RAP.