Latest Research Results of RAP Performance on the NCAT Test Track
The NCAT Test Track

- Started operations in 2000
- 3-year Research Cycles
- 46 Test Sections, 200 ft. each
  - 26 sections in straights
  - 20 sections in curves
- Test Sections are “sponsored”
- Research complexity increases each cycle
Construction

• Competitive bids
• Complex coordination of materials
• Plant modifications
• Technical assistance
• Trial mix checks
• High quality construction
NCAT Test Track

Types of Test Sections

1. Surface Layer Performance
2. Full-Depth Structural Studies
Critical Strain Data Acquisition

[Diagram showing longitudinal microstrain over time for a critical strain event, with a backdrop of road construction and a semi-truck.]
2006 45% RAP Test Sections

Surface Layers Only
<table>
<thead>
<tr>
<th></th>
<th>N5</th>
<th>W3</th>
<th>W4</th>
<th>W5</th>
<th>E5</th>
<th>E6</th>
<th>E7</th>
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<tbody>
<tr>
<td><strong>Design Gyrations</strong></td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
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<tr>
<td><strong>Percent RAP</strong></td>
<td>0</td>
<td>20</td>
<td>20</td>
<td>45</td>
<td>45</td>
<td>45</td>
<td>45</td>
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<tr>
<td><strong>Fractionated RAP (Y or N)</strong></td>
<td>n/a</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
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<tr>
<td><strong>Virgin Binder Grade</strong></td>
<td>PG 67-22</td>
<td>PG 76-22</td>
<td>PG 67-22</td>
<td>RA500</td>
<td>PG 67-22</td>
<td>PG 76-22</td>
<td>PG 76-22</td>
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<tr>
<td><strong>Binder Additive</strong></td>
<td>None</td>
<td>SBS</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>SBS</td>
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<tr>
<td><strong>QC Binder Content</strong></td>
<td>5.9</td>
<td>5.7</td>
<td>5.8</td>
<td>5</td>
<td>4.4</td>
<td>4.6</td>
<td>5.2</td>
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<tr>
<td><strong>QC VMA</strong></td>
<td>15.9</td>
<td>14</td>
<td>14.2</td>
<td>12.4</td>
<td>12.9</td>
<td>13.3</td>
<td>14.1</td>
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<td><strong>QC Air Void Percentage</strong></td>
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<td>1.9</td>
<td>2.1</td>
<td>1.7</td>
<td>3.2</td>
<td>3.5</td>
<td>3.6</td>
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</table>
2006 High RAP Surface Mix Study

\[
\begin{align*}
  y &= 7\times 10^{-5}x^{0.5282} \\
  R^2 &= 0.9824 \\
  y &= 8\times 10^{-5}x^{0.5077} \\
  R^2 &= 0.9723 \\
  y &= 0.0001x^{0.4776} \\
  R^2 &= 0.9649 \\
  y &= 0.0002x^{-0.4454} \\
  R^2 &= 0.9332
\end{align*}
\]

Virgin Binder Stiffness
45% RAP Sections

- W5-45%RAP PG52-28
- E5-45%RAP PG67-22
- E6-45%RAP PG76-22
- E7-45%RAP PG76-22 +Sasobit

Total Length of Cracking after 2 cycles

- 3.5’
- 13.9’
- 53.9’
- 145.5’
Bending Beam Fatigue (AASHTO T321)

- Cracking Analyzed
  - Fatigue Cracking
- Repeated load at constant temperature and stress or strain
- Analysis: Crack initiation/loss of stiffness
- Output: $N_f$ and Fatigue Endurance Limit
S-VECD

- Cracking Analyzed:
  - Fatigue Cracking
- Repeated loading at a singular temperature and two strain levels
- Analysis: Crack initiation based on damage
- Output: $N_f$ and Fatigue Endurance Limit at numerous testing parameters
Overlay Tester

- Cracking Analyzed:
  - Reflection cracking
- Repeated loading at a singular temperature one strain level
- Analysis: Crack propagation
- Output: $N_f$
## Laboratory Testing

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Field</th>
<th>Beams</th>
<th>OT</th>
<th>S-VECD</th>
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</thead>
<tbody>
<tr>
<td>45% RAP – PG 52-28</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>45% RAP – PG 67-22</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>45% RAP – PG 76-22</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<td>45% RAP – PG 76-22S</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
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</tbody>
</table>
Thoughts

• Using a softer binder increased the durability of the RAP mixtures
• Beams and OT results had better ranking than S-VECD
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?
Objectives & Scope

- **Objectives**
  - Evaluate full-scale structural characteristics
  - Evaluate full-scale performance

- **Scope**
  - 5 sections
  - Falling weight deflectometer testing
  - Pavement responses measured with embedded gauges
  - Performance monitoring
Test Sections

<table>
<thead>
<tr>
<th>Depth from Surface, in.</th>
<th>Surface Lift</th>
<th>Intermediate Lift</th>
<th>Bottom Lift</th>
</tr>
</thead>
<tbody>
<tr>
<td>N10-RAP-HMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N11-RAP-WMA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S9-Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S10-WMA-Foam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S11-WMA-Additive</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Legend:
- Black: Surface Lift
- Green: Intermediate Lift
- Gray: Bottom Lift
Mix Design & Production

- Superpave mix design
  - 80 gyrations & 4% air voids
  - Limestone & granite virgin aggregates
  - Fractionated RAP
    - Surface Mixtures = 15% Fine / 35% Coarse
    - Intermediate & Base Mixtures = 20% Fine / 30% Coarse

<table>
<thead>
<tr>
<th>Section-Lift</th>
<th>Target Mixing Temperature (°F)</th>
<th>WMA Technology</th>
<th>RAP Percentage</th>
<th>NMAS</th>
<th>Virgin Binder PG</th>
<th>Effective Asphalt Content (%)</th>
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</thead>
<tbody>
<tr>
<td>N10-1</td>
<td>325</td>
<td>None</td>
<td>50</td>
<td>9.5</td>
<td>67-22</td>
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<tr>
<td>N10-2</td>
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<td></td>
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<td>19.0</td>
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<td>67-22</td>
<td>4.1</td>
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<td>N11-3</td>
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<td></td>
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<td>S9-1</td>
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<td>5.4</td>
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<td>19.0</td>
<td>76-22</td>
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<td>S11-3</td>
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<td></td>
<td></td>
<td>19.0</td>
<td>67-22</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Data Collection

- High Speed
  - Weekly
  - 3 passes of each truck on each section
- Slow Speed
  - 1 reading/minute
  - Hourly summary
- Performance
  - Weekly
    - Rut depth
    - Cracking
- FWD
  - Multiple Mondays/month
Temp Normalized AC Modulus

Average AC Modulus, ksi

- N10-50% RAP-50F
- S9-Control-50F
- S10-WMA-Foam-50F
- S11-WMA-Additive-50F
- N10-50% RAP-68F
- S9-Control-68F
- S10-WMA-Foam-68F
- S11-WMA-Additive-68F
- N10-50% RAP-110F
- S9-Control-110F
- S10-WMA-Foam-110F
- S11-WMA-Additive-110F

Changes:
- 22%
- 15%
- 27%
- 10%
- 41%
- 8%
Average Microstrain

Temp-Normalized Strain @ 7”

- 50F
- 68F
- 110F
Temp-Normalized Subgrade Pressure

- 50°F
- 68°F
- 110°F

Subgrade Pressure, psi

N10-50% RAP-50F  S9-Control-50F  S10-WMA-Foam-50F  N11-50% RAP-50F
N10-50% RAP-68F  S9-Control-68F  S10-WMA-Foam-68F  N11-50% RAP-68F
N10-50% RAP-110F S9-Control-110F  S10-WMA-Foam-110F  N11-50% RAP-110F

S9-Control-50F  S10-WMA-Additive-50F  S11-WMA-Additive-50F
S10-WMA-Additive-68F  S9-Control-68F  S11-WMA-Additive-68F
S10-WMA-Additive-110F  S9-Control-110F  S11-WMA-Additive-110F
Rutting Performance

- N10-50%RAP
- N11-50%RAP WMA
- S9-Control
- S10-WMA-Foam
- S11-WMA-Additive

MESALs
• Rutting Performance – Final Wireline

Rutting Performance

Average Wire Line Rut Depth, mm

- N10-50% RAP
- N11-50% RAP WMA
- S9-Control
- S10-WMA-Foam
- S11-WMA-Additive

Values:
- 2.0
- 3.6
- 7.2
- 8.5
- 10.5
Pavement Smoothness

- N10-50%RAP
- S9-Control
- S11-WMA-Additive
- N11-50%RAP WMA
- S10-WMA-Foam
- MESALs

Date

IRI, in/mile

Million ESALs (MESALs)
## Updated Field Performance

<table>
<thead>
<tr>
<th>Section</th>
<th>15 Million ESALs</th>
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<tr>
<td></td>
<td>Cracking</td>
<td>Rutting</td>
</tr>
<tr>
<td></td>
<td>% of Lane Area</td>
<td>(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
NCHRP REPORT 752


Google NCHRP Report 752 for the full report
Best Practices for RAP Management

Contents

- Sources of RAP
- Milling for Quality
- Processing RAP
- Inventory Analysis
- Sampling Guidelines
- Handling RAP in the Lab
- Testing Options
- Consistency Guidelines
The NCAT Test Track
The 5th Cycle
2012 Green Group Experiment

• Rut resistant, durable surface layers
  • SMA with recycled materials, no fibers
• Stiff intermediate layers
  • High modulus mixes with high RAP, RAP & RAS
• Strain tolerant base layers
  • Arizona-type gap-graded asphalt rubber
  • High polymer content mix with RAP
  • Traditional rich-bottom mix with RAP
• Thinner Overall Cross Section
All Asphalt Mixes Produced with a WMA Technology

Control

- 20% RAP DGAC
- 35% RAP
- 35% RAP

Aggregate Base

Subgrade

RAS Feature

- 5% RAS SMA
- 5% RAS + 30% RAP
- 25% RAP + PMA

Aggregate Base

Subgrade

RAP Feature

- 25% RAP SMA
- 50% RAP
- 35% RAP + HiMA

Aggregate Base

Subgrade

GTR Feature

- GTR SMA
- 35% RAP + GTR
- Asphalt-Rubber

Aggregate Base

Subgrade
End-of-Cycle Track Conference

- WMA & high RAP/RAS/GTR mixes
- Optimized structural design
- Pavement preservation
- Implementation

Pavement Test Track Conference

March 3-5, 2015

The Hotel at Auburn University and Dixon Conference Center

www.ncat.us
THANK YOU!

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