RAP in HMA Pavements

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Recycled asphalt Pavements

- RAP is obtained by:
  - cold milling
  - heating/softening and removal
  - full depth removal
  - plant waste HMA materials.
Including RAP in HMA

RAP MIX

+ Virgin Aggregate

PG Grade

Target Binder Grade
PG64-22, PG58-34...

RAP before and after Extraction
IMPACT OF RAP ON MIXTURES’ PERFORMANCE PROPERTIES

Impact of RAP on mixtures’ properties

- Stiffness
- Rutting
- Fatigue
- Thermal
- Moisture Damage
Stiffness

- Dynamic Modulus, $|E^*|$

- Li et al. (2004): 10 mixes at 0, 20 and 40% RAP, two virgin asphalt binders (PG58-28 and PG58-34), and two RAP sources (RAP and millings).
  - 20-40% RAP $\rightarrow |E^*| \uparrow$.
  - No significant impact for RAP on $|E^*|$ at low temperatures and high frequencies.
**Stiffness**

- *McDaniel et al. (2006):*
  - 15-25% RAP → No significant impact on $|E^*|$
  - 40% RAP → $|E^*|$ at higher temperatures.

**Rutting**
Rutting

Asphalt Pavement Analyzer (APA)

Fatigue Cracking
Fatigue

- **Flexural Beam Fatigue Test**

![Diagram of Flexural Beam Fatigue Test](image)

<table>
<thead>
<tr>
<th>Cycles to Failure</th>
<th>Strain (micron)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>1,000</td>
</tr>
<tr>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td>1,000,000</td>
<td></td>
</tr>
</tbody>
</table>

**Thermal Cracking**

![Image of Thermal Cracking](image)
Thermal Cracking

- Indirect Tensile (IDT) creep stiffness

Thermal Stress Restraint Specimen (TSRST)

Load to keep beam at a constant height

2''×2''×10'' beam
Evaluate Moisture Damage

3 Conditioned Specimens “Wet Set”

3 Unconditioned Specimens “Dry Set”

\[
\text{TSR} = \frac{\text{Avg wet tensile strength}}{\text{Avg dry tensile strength}} \times 100
\]

UNR – 2007

Source I
Plant waste (4.6% binder)

0% RAP
15% RAP
30% RAP

Source II
15-year old HMA pavement (5.4% binder content)

0% RAP
15% RAP
30% RAP

Source III
20-year old HMA pavement (5.8% binder content)

0% RAP
15% RAP
30% RAP
### Summary of Selected Binder

<table>
<thead>
<tr>
<th>RAP</th>
<th>Target Binder Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PG64-22</td>
</tr>
<tr>
<td></td>
<td>@ 15% RAP</td>
</tr>
<tr>
<td></td>
<td>PG64-28</td>
</tr>
<tr>
<td></td>
<td>@ 30% RAP</td>
</tr>
<tr>
<td></td>
<td>PG64-28NV</td>
</tr>
<tr>
<td>RAP I</td>
<td>PG64-22</td>
</tr>
<tr>
<td></td>
<td>PG58-28</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
</tr>
<tr>
<td></td>
<td>PG58-34</td>
</tr>
<tr>
<td>RAP II</td>
<td>PG64-28</td>
</tr>
<tr>
<td></td>
<td>PG58-28</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
</tr>
<tr>
<td></td>
<td>PG58-34</td>
</tr>
<tr>
<td>RAP III</td>
<td>PG64-28</td>
</tr>
<tr>
<td></td>
<td>PG58-28</td>
</tr>
<tr>
<td></td>
<td>PG64-34</td>
</tr>
<tr>
<td></td>
<td>PG58-34</td>
</tr>
</tbody>
</table>

### Summary Final PG Grades

<table>
<thead>
<tr>
<th>Mix</th>
<th>Final Physically Blended</th>
<th>Final Extracted from Mixture</th>
<th>Mix</th>
<th>Final Physically Blended</th>
<th>Final Extracted from Mixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>PG64-22</td>
<td>PG64-22</td>
<td>B0</td>
<td>PG64-28</td>
<td>PG64-28</td>
</tr>
<tr>
<td>A115</td>
<td>PG64-22</td>
<td>PG70-16</td>
<td>B115</td>
<td>PG64-34</td>
<td>PG64-34</td>
</tr>
<tr>
<td>A130</td>
<td>PG64-22</td>
<td>PG70-16</td>
<td>B130</td>
<td>PG64-34</td>
<td>PG70-34</td>
</tr>
<tr>
<td>AII15</td>
<td>PG64-22</td>
<td>PG70-22</td>
<td>BII15</td>
<td>PG64-34</td>
<td>PG70-34</td>
</tr>
<tr>
<td>AII30</td>
<td>PG64-22</td>
<td>PG70-22</td>
<td>BII30</td>
<td>PG64-28</td>
<td>PG70-34</td>
</tr>
<tr>
<td>AIII15</td>
<td>PG70-22</td>
<td>PG76-22</td>
<td>BIII15</td>
<td>PG64-34</td>
<td>PG70-34</td>
</tr>
<tr>
<td>AIII30</td>
<td>PG64-22</td>
<td>PG76-22</td>
<td>BIII30</td>
<td>PG64-28</td>
<td>PG70-34</td>
</tr>
</tbody>
</table>
**Rutting**

- **UNR - 2007: APA Tests**
  Passed NDOT APA criterion of 8 mm at 60°C → good rutting resistance

![Graph showing rutting depth at 60°C for different RAP percentages](image)

**Fatigue**

- **UNR - 2007: mixtures with 0, 15 and 30% RAP.**
  - PG64-22 (neat):
    15% RAP → better or equivalent fatigue resistance.
  - PG64-28 (polymer modified):
    15-30% RAP → significant ↓ in fatigue resistance.
Thermal Cracking

- **UNR - 2007**: RAP mixes with 0,15 and 30% RAP using TSRST

![Thermal Cracking Graph]

Moisture Damage

- **UNR- 2007**: RAP mixtures with 0,15 and 30% RAP, AASHTO T283 test.
Moisture Damage

- UNR - 2007 (cont’d)

- 15 and 30% RAP → acceptable moisture resistance (TSR>70).

- 15 and 30% RAP → ↓ TS conditioned and unconditioned.
Field performance

- **CALTRANS**: Evaluated life expectancy of 15% RAP pavements in California

<table>
<thead>
<tr>
<th>Environmental Zone</th>
<th>Expected Service Lives (years) Based on</th>
<th>Triggering Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Structural Performance</td>
<td>Distress Performance</td>
</tr>
<tr>
<td>North Coast</td>
<td>18</td>
<td>21</td>
</tr>
<tr>
<td>Desert</td>
<td>15</td>
<td>9</td>
</tr>
<tr>
<td>Mountain</td>
<td>11</td>
<td>13</td>
</tr>
</tbody>
</table>
Field performance

- **Louisiana DOT:** Compared the performances of 5 RAP sections (20-50%) and 4 virgin mix pavement sections
  - after 6 - 9 years: long & trans cracking and rutting were the Major type of distresses.
  - 20-50% RAP sections perform equally to virgin sections.
  - No significant diff. between recovered binder from virgin and RAP sections.

Field performance

- **Connecticut DOT:** 3 Connecticut sections Containing 20% RAP.
  - Good field performance after 8 years in service.
  - No fatigue and transverse cracking.
  - Lower rutting than other sections.
  - Slightly higher non-wheel path longitudinal cracking.
Field performance

- **Boston Logan International airport:**
  - 20 feet above sea level
  - Loads up to 873,000 lb
  - Tire pressure in excess of 200 psi

Field performance

**Boston Logan International airport: (cont’d)**

- In 2001: 18.5% RAP mix was used as a surface course on a section of Taxiway November.
- In 2003 RAP mix showed good performance.
- Good experience → Logan airport mix design specs include 15-20% RAP in all surface mixes
RAP in HMA Surface Mixes
(After NCDOT)

Specified use of RAP

Average use of RAP
**RAP in HMA Intermediate Mixes (After NCDOT)**

- **Specified use of RAP**
  - 0%
  - 10%
  - 15%
  - 20%
  - ≥ 30%
  - n/a

- **Average use of RAP**
  - 0%
  - 1 - 10%
  - 10 - 20%
  - ≥ 30%
  - n/a

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**RAP in HMA Base Mixes (After NCDOT)**

- **Specified use of RAP**
  - 0%
  - 10%
  - 15%
  - 20%
  - ≥ 30%
  - n/a

- **Average use of RAP**
  - 0%
  - 1 - 10%
  - 10 - 20%
  - ≥ 30%
  - n/a
State highway agencies use of RAP

- Most highway agencies allow max 10-25% of RAP in surface mixes and a higher %RAP in base mixes.
- Some highway agencies restrict or limit RAP to 10% with PMB mixes.
- Most highway agencies require an adjustment to the binder grade when > 15-20% RAP is used.

RAP Variability

- **Kallas (1984):** RAP composition

<table>
<thead>
<tr>
<th>Sample</th>
<th>No. of samples tested</th>
<th>% Passing</th>
<th>Asphalt binder content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>No. 8 sieve Ave</td>
<td>No. 200 sieve Ave</td>
</tr>
<tr>
<td>California Road cores</td>
<td>12</td>
<td>54</td>
<td>9.9</td>
</tr>
<tr>
<td>California stockpile after milling</td>
<td>5</td>
<td>69</td>
<td>11.8</td>
</tr>
<tr>
<td>North Carolina Road cores</td>
<td>12</td>
<td>69</td>
<td>6.1</td>
</tr>
<tr>
<td>NC stockpile after milling</td>
<td>5</td>
<td>72</td>
<td>8.0</td>
</tr>
<tr>
<td>Utah Road cores</td>
<td>12</td>
<td>52</td>
<td>8.7</td>
</tr>
<tr>
<td>Utah stockpile after milling</td>
<td>10</td>
<td>58</td>
<td>9.9</td>
</tr>
<tr>
<td>Virginia Road cores</td>
<td>12</td>
<td>41</td>
<td>9.7</td>
</tr>
<tr>
<td>Virginia stockpile after milling</td>
<td>6</td>
<td>52</td>
<td>13.0</td>
</tr>
<tr>
<td>Typical HMA surface variability</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>HMA surface variability on Airport Pavements (P-401-6.5)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
RAP Variability

- Solaimanian and Tahmoressi (1996), TxDOT

Mean deviations from job mix formula target gradation for sieve No. 10:

Mean deviations from target job mix formula asphalt content:

...
**RAP Variability**

- **Solaimanian and Tahmoressi (1996) (cont’d)**

![Graph showing standard deviations for air voids as a function of RAP content in the mix.](image)

Standard deviations for air voids as a function of RAP content in the mix.

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**RAP Variability**

- **Estakhri et al. (1998):** 33 projects with RAP containing FDOT mixes.
  
  - At the asphalt plant site: variability of RAP is not statistically different from that of stockpiled virgin aggregates.
  
  - RAP did not show an adverse effect on the variability of HMA (*Based on aggregate gradations*).
1. Measuring RAP aggregate SG would require:

- Extracting the RAP
- Sieving it into coarse and fine fractions
- Determining the specific gravity of each fraction.
- Measured BSG of RAP aggregate may not accurately present actual value.

2. $G_{sb}$ of RAP aggregate may be estimated by determining $G_{mm}$ of the RAP mix & using an assumed asphalt absorption for the RAP aggregate.

\[
G_{sw} = \frac{100 - P_s}{P_b} \times \frac{G_{sw}}{G_b} \\
G_{sb} = \frac{G_{sw}}{100 \times G_b} + 1
\]
**RAP materials evaluation**

3. RAP aggregate $G_{se}$ may be used in lieu of the $G_{sb}$ at the discretion of the engineering consultant or agency.

- This may introduce an error into the combined aggregate BSG $\rightarrow$ VMA calculations.
- An increase in minimum VMA may be required.

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**Current Activities**

**Nevada - Wisconsin**

- Develop a procedure to determine binder grade without extraction/recovery
- Define the proper method for evaluating aggregate properties
- Define the proper method of lab mixing