Laboratory and Field Evaluation of Asphalt Mixtures Containing RAP in Phoenix, Arizona

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Overview

- With the High Temperatures in Phoenix, how pavements with RAP contents are going to perform in practice?

- Is RAP going to affect the Mechanical Properties of RAP mixtures in terms of cracking? Permanent Deformation? Moisture Damage?
Presentation Outline

- Introduction
- Plan of Work and Objective
- Materials and Field Sections Construction
- Mixture Level Testing and Analysis
- Field Evaluation and Cores Testing
- Conclusion
Introduction

RAP is a potential solution

Zaumanis, 2013

Al-Qadi et al, 2018
Introduction

CO2 Savings

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>15% RAP</th>
<th>25% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation</td>
<td>8176</td>
<td>8176</td>
<td>8176</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>26306</td>
<td>22360</td>
<td>19729</td>
</tr>
<tr>
<td>Production</td>
<td>11426</td>
<td>11426</td>
<td>11426</td>
</tr>
</tbody>
</table>

Kaloush (2018)
Introduction

Asphalt Aging

- Thermal Degradation

- Chemical Degradation
  - Photo-Oxidation (UV 300-400 nm provide the needed energy)
  - Thermal Oxidation
  - Hydrolytic Degradation

- Asphalt Aging is a complex phenomenon

  Oxidation occurs, Asphalt stiffens and become more brittle
PG 58-34 \rightarrow PG 82-16

In Phoenix PG 70-10 \rightarrow PG 124+26
Plan of Work

- **Construction of 3 test sections:** 0%, 15%, and 25% RAP in the Base Layer. Terminal Blend on the Surface.

- **Sample Loose Asphalt Mixtures During Production:** 0% RAP and 15% RAP with PG 70-10, 25% RAP with PG 64-16.

- **Perform Mixture Testing:**
  - Dynamic Modulus AASHTO TP 62
  - Flow Number AASHTO TP 79
  - IDEAE CT
  - C* Fracture Test
  - Uniaxial Fatigue AASHTO TP 107
  - Tensile Strength Ratio (TSR) AASHTO T 283

- **Pavement Evaluation:**
  - Distress Survey
    - Field Cored
      - Tensile Strength
      - Thickness
      - Air Voids
Materials and Sections Construction

Section 1:
- Asphalt Base Layer-0% RAP (Terminal Blend)
- Asphalt Surface Layer-0% RAP (Terminal Blend)
- Subgrade

Section 2:
- Asphalt Base Layer-15% RAP
- Asphalt Surface Layer-0% RAP (Terminal Blend)
- Subgrade

Section 3:
- Asphalt Base Layer-25% RAP
- Asphalt Surface Layer-0% RAP (Terminal Blend)
- Subgrade
### Materials and Sections Construction

<table>
<thead>
<tr>
<th>Property</th>
<th>0% RAP (Control)</th>
<th>15% RAP</th>
<th>25% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Binder Content (%)</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Marshall Bulk Density (pcf)</td>
<td>148</td>
<td>148.7</td>
<td>149.2</td>
</tr>
<tr>
<td>Max. Theoretical Specific Gravity</td>
<td>2.478</td>
<td>2.481</td>
<td>2.486</td>
</tr>
<tr>
<td>Max. Theoretical Specific Density (pcf)</td>
<td>154.6</td>
<td>154.8</td>
<td>155.1</td>
</tr>
<tr>
<td>Stability</td>
<td>5010</td>
<td>5390</td>
<td>5210</td>
</tr>
<tr>
<td>Marshall Flow (in)</td>
<td>11</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>% Air Voids</td>
<td>4.3</td>
<td>3.9</td>
<td>3.8</td>
</tr>
<tr>
<td>% VMA</td>
<td>14.5</td>
<td>14.5</td>
<td>14.2</td>
</tr>
<tr>
<td>% Air Voids Filled</td>
<td>70.5</td>
<td>72.7</td>
<td>72.8</td>
</tr>
<tr>
<td>% Eff Asphalt Total Mix</td>
<td>4.39</td>
<td>4.52</td>
<td>4.41</td>
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<tr>
<td>Film Thickness (micro)</td>
<td>9</td>
<td>9</td>
<td>9</td>
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<tr>
<td>Dust/Bitumen Ratio</td>
<td>1.1</td>
<td>1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*PG 70-10, PG 70-10, PG 64-16*

### Diagram

**PERCENT PASSING**

**SIEVE SIZES RAISED TO 0.45 POWER**

75 Blows

Hydrated Lime as Anti-stripping agent for base mixtures, and type II cement for surface TR mix.

Section 710.2.3, MAG Specifications, 2013
Materials and Sections Construction

- The base layers were constructed on December 3, 2018.
- The surface layer TR was constructed on the following day.
Materials and Sections Construction
Dynamic Modulus: To determine the Stiffness of the material. Fundamental property for pavement design (temperature and frequency).

Flow Number: To determine the Rutting Potential of the RAP mixtures compared to that of the Control one.

Uniaxial Fatigue: To determine the Fatigue Cracking resistance of the three mixtures.

C* Fracture Test: To determine the crack propagation properties of the 3 mixtures.

Tensile Strength Ratio (TSR): To determine the Moisture Damage susceptibility of the 3 mixtures.

IDEAL CT: To determine the cracking properties of the 3 mixtures.
• Sinusoidal repetitive load
• 4 Temp. : 4.4, 21.1, 37.8 and 54.4°C.
• For 6 frequencies: 25, 10, 5, 1, 0.5 and 0.1 Hz.
• The dynamic modulus, $|E^*|$ & phase angle $\delta$
Dynamic Modulus Results

![Graph showing dynamic modulus results with different percentages of RAP]
Flow Number
AASHTO TP 79
\[ \varepsilon_p(N) = a \cdot N^b + c(e^{d \cdot N} - 1) \]

### Flow Number Results

- **0%**
- **15%**
- **25%**

<table>
<thead>
<tr>
<th>Flow Number</th>
<th>0%</th>
<th>15%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td></td>
<td></td>
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</tbody>
</table>
IDEAL CT

\[ CTI = \frac{G_f}{|m_{50}|} \times \left( \frac{t_{50}}{D} \right) \]  

where \( G_f \) = fracture energy (J/m²); \( W_f = G_f \times \frac{t}{D} \), where \( W_f \) = work of fracture (J), area under the load-displacement curve as shown in Fig. 1(b); \( t \) = specimen thickness (m), and \( D \) = specimen diameter (m); \( t_{50} \) = displacement corresponding to \( P_{75} \), where \( P_{75} = 0.75 \times P_{100} \); where \( P_{100} \) = peak load; and \( |m_{50}| \) = postpeak slope corresponding to the \( P_{75} \) and \( t_{50} \) curve location.

\[ |m_{50}| = \frac{|P_{75} - P_{65}|}{|t_{65} - t_{65}|} \]  

where \( P_{65} = 0.85 \times P_{100} \); \( P_{65} = 0.65 \times P_{100} \); \( t_{65} \) = displacement corresponding to \( P_{65} \); and \( t_{55} \) = displacement corresponding to \( P_{65} \).
IDEAL CT Results

CTI

<table>
<thead>
<tr>
<th>Control</th>
<th>15% RAP</th>
<th>25% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>12</td>
<td>NS</td>
</tr>
</tbody>
</table>
C* Fracture Test
C* Fracture Test Results

- **Control**
  - Equation: $y = 0.0093x - 0.0106$
  - $R^2 = 0.9963$

- **15% RAP**
  - Equation: $y = 0.0048x + 0.006$
  - $R^2 = 0.9914$

- **25% RAP**
  - Equation: $y = 0.0031x + 0.0205$
  - $R^2 = 0.8929$
To assess the resistance fatigue damage.

The test was performed at an intermediate temperature of 18°C

run at four strain levels.

The strain levels were estimated such that the material fails in less than 10,000 cycles, between 10,000 - 50,000 cycles, between 50,000 – 100,000 cycles and greater than 100,000 cycles.

The fatigue test data was analyzed using simplified viscoelastic continuum damage theory (S-VECD) formulation as

The first step in this approach is to establish the damage characteristic (C vs. S) curve.

The C vs. S curve is a unique relationship to a given asphalt concrete mixture and it is independent of test conditions.
Uniaxial Fatigue Results

![Graph showing strain level (100th cycle) vs. number of cycles (Nf) for different mixes. The graph compares Control Mix, 15% RAP Mix, and 25% RAP Mix.]
Tensile Strength Ratio
AASHTO T 283

16 hours @ -16 °C ± 2 °C

24 hours @ 60 °C ± 2 °C
Tensile Strength Ratio Results

<table>
<thead>
<tr>
<th>TSR</th>
<th>0%</th>
<th>15%</th>
<th>25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NS</td>
<td></td>
<td></td>
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</tbody>
</table>
Surface Evaluation (Distress Survey)

Photos Taken on April 24, 2019
Field Cores

Cores taken from 15% RAP Section

Cores taken from the Control Section

Cores taken from 25% RAP Section
<table>
<thead>
<tr>
<th>Percentage</th>
<th>Air Voids (%)</th>
<th>Thickness (in)</th>
<th>TS (kPa)</th>
<th>Laboratory TS (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15% RAP</td>
<td>8.14</td>
<td>3.24</td>
<td>1012</td>
<td>1540</td>
</tr>
<tr>
<td>25% RAP</td>
<td>8.33</td>
<td>2.82</td>
<td>797</td>
<td>1242</td>
</tr>
<tr>
<td>0% RAP</td>
<td>7</td>
<td>4.04</td>
<td>1203</td>
<td>1672</td>
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Conclusion

<table>
<thead>
<tr>
<th>Property</th>
<th>Test</th>
<th>Support</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>Stiffness</td>
<td>Dynamic Modulus (E*)</td>
<td>Yes</td>
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<tr>
<td>Rutting Resistance</td>
<td>Flow Number</td>
<td>Yes</td>
<td></td>
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<tr>
<td>Cracking</td>
<td>Initiation (IDEAL CT)</td>
<td>Yes</td>
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<tr>
<td></td>
<td>Propagation (C* Test)</td>
<td>Questionable</td>
<td>Could be arguable, yet the 25% RAP mix was comparable to the control one</td>
</tr>
<tr>
<td></td>
<td>Fatigue (Uniaxial Fatigue)</td>
<td>Yes</td>
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<tr>
<td>Moisture</td>
<td>Tensile Strength Ratio</td>
<td>Yes</td>
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</tbody>
</table>

Final Recommendation: 15% RAP can be incorporated to the City mixtures while keeping the same grade (PG 70-10). 25% RAP can be incorporated while using a softer binder (PG 64-16)
Acknowledgments

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Thank you!

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Questions?