November 13, 2009

RAP Plant Mix Study
Progress Report
Outline

• Review of Phase I
• Review of Work Plan
• Summary of Results
• Discuss Potential Recommendations
## Experimental Design

<table>
<thead>
<tr>
<th>Binder Grade</th>
<th>0%</th>
<th>15%</th>
<th>25%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 58-28</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>PG 64-22</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reclaimed Asphalt Pavement
## Critical Cracking Temperatures

<table>
<thead>
<tr>
<th>Mix</th>
<th>RAP Content</th>
<th>Tc (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A – PG64-22</td>
<td>0</td>
<td>-28.9</td>
</tr>
<tr>
<td>B – PG64-22</td>
<td>15</td>
<td>-23.3</td>
</tr>
<tr>
<td>C – PG64-22</td>
<td>25</td>
<td>-25.6</td>
</tr>
<tr>
<td>D – PG64-22</td>
<td>40</td>
<td>-22.8</td>
</tr>
<tr>
<td>E – PG58-28</td>
<td>25</td>
<td>-27.2</td>
</tr>
<tr>
<td>F – PG58-28</td>
<td>40</td>
<td>-23.9</td>
</tr>
</tbody>
</table>
For these materials and this plant, the RAP mixes were not as stiff as expected.

The binder did not stiffen linearly with increasing RAP content.

In this case, dropping the virgin grade to PG58-28 for 25% RAP was not necessary.
Tests (being) Conducted

- Dynamic Modulus $|E^*|$
  - High and intermediate modulus, blending

- Indirect Tension
  - Low temperature

- Binder extraction/recovery and PG grade
  - Blending analysis

- Fatigue Testing – at FHWA TFHRC
  - Samples delivered November 19, 2008
Phase 2 Results
E&B Mix $|E^*|$
E&B Mix $|E^*|$

PG64-22 versus PG58-28

Log $|E^*|$, MPa vs. Log Reduced Frequency, Hz

- MixC (25% RAP)
- MixE (25% RAP)
- MixD (40% RAP)
- MixF (40% RAP)
E&B Mix $|E^*|$

Log $|E^*|$, MPa

Log Reduced Frequency, Hz

PG64-22

Mix A (0% RAP)
Mix B (15% RAP)
Mix C (25% RAP)
Mix D (40% RAP)
JHR Mix $|E^*|$"
JHR Mix $|E^*|$
JHR Mix $|E^*|$

Log $|E^*|$, MPa vs. Log Reduced Frequency, Hz for different mixes:
- MixA (0% RAP)
- MixB (15% RAP)
- MixC (25% RAP)
- MixD (40% RAP)
P&B Mix | E* |
P&B Mix $|E^*|$
P&B Mix | $|E^*|$

Log $|E^*|$, MPa vs. Log Reduced Frequency, Hz

PG64-22

MixA (0% RAP)
MixB (15% RAP)
MixC (25% RAP)
MixD (40% RAP)
RR Mix |E*|

Control versus PG58-28

Log |E*|, MPa

Log Reduced Frequency, Hz

MixA (0% RAP)
MixE (25% RAP)
MixF (40% RAP)
RR Mix $|E^*|$

Log $|E^*|$, MPa

Log Reduced Frequency, Hz

PG64-22 versus PG58-28

- MixC (25% RAP)
- MixE (25% RAP)
- MixD (40% RAP)
- MixF (40% RAP)
E&B IDT Strength

The graph shows the relationship between strength, kPa, and temperature, C, for different mixes labeled EB-A to EB-F. The green line represents the strength, and the yellow line represents the temperature. The graph indicates fluctuations in strength and temperature across the mixes.
E&B IDT Stiffness

Mixes

EB-A
EB-B
EB-C
EB-D
EB-E
EB-F

Stiffness, GPa

Pvmt. Cracking Temperature, °C

Stiffness

Temperature
JHR IDT Strength

![Graph showing JHR IDT Strength]

**Strength, kPa**

- **Mixes:** JH-A, JH-B, JH-C, JH-D, JH-E, JH-F

- **Pvmt. Cracking Temperature, °C:**
  - JH-A: ~-10
  - JH-B: ~-16
  - JH-C: ~-22
  - JH-D: ~-28
  - JH-E: ~-22
  - JH-F: ~-16
JHR IDT Stiffness

![Graph showing stiffness and cracking temperature for different mixes.]


- Stiffness (GPa)
- Cracking Temperature (°C)

Stiffness:
- JH-A: 26
- JH-B: 24
- JH-C: 22
- JH-D: 28
- JH-E: 30
- JH-F: 32

Temperature:
- JH-A: -16
- JH-B: -18
- JH-C: -20
- JH-D: -22
- JH-E: -24
- JH-F: -26
P&B IDT Strength

Strength, kPa

Mixes

PB-A  PB-B  PB-C  PB-D  PB-E  PB-F

Strength
Temperature

Pvn. Cracking Temperature, C
P&B IDT Stiffness

Stiffness, GPa

Mixes

Pvmt. Cracking Temperature, C

PB-A  PB-B  PB-C  PB-D  PB-E  PB-F

Stiffness
Temperature
RR IDT Strength

Mixes

Strength, kPa

Pvmt. Cracking Temperature, °C

RR-A RR-B RR-C RR-D RR-E RR-F

2000 2400 2800 3200 3600 4000

-16 -22 -28 -34 -40 -46

Strength
Temperature
What does this mean?

- In some cases, it appears binder grade does not affect IDT (E&B)
- In some cases, similar temperature and modulus/stiffness/strength through 15%, others through 25%
- PG58 usually but not always softer than PG64
Blending - Bonaquist approach

- Measure mix dynamic modulus
- Develop master curve
  - Stiffness over range of temps and loading rates
- Extract/recover binder (total blending)
- Measure binder shear modulus
Blending - Bonaquist approach

- Estimate mix modulus for that binder (if totally blended)
  - Hirsch model uses binder shear modulus and mix volumetrics to estimate mix stiffness
- Compare estimated(from binder) and measured mix moduli
  - Overlap indicates good mixing
9.5 mm with PG 64-22, Batch Plant

Reduced Frequency, rad/sec

Binder G*, kPa

From Mix
Recovered Binder

Advanced Asphalt Technologies, LLC
“Engineering Services for the Asphalt Industry”
9.5 mm with PG 64-22 + 5% RAS, Batch Plant

Reduced Frequency, rad/sec

Binder $G^*$, kPa

From Mix

Recovered Binder

Advanced Asphalt Technologies, LLC
“Engineering Services for the Asphalt Industry”
9.5 mm with PG 64-22 + 35 % FRAP, Double Barrel

Advanced Asphalt Technologies, LLC
"Engineering Services for the Asphalt Industry"
E&B Mix A

|G*|, Pa

Reduced Frequency, Hz
E&B Mix B

Reduced Frequency, Hz

$|G^*|, \text{Pa}$

[Graph showing data points and labels for Meas. B-EB, Est. B-EB, and PG64-22]
E&B Mix C

Reduced Frequency, Hz

$|G^*|, \text{Pa}$
E&B Mix D

|G*|, Pa

Reduced Frequency, Hz

- Meas. D-EB
- Est. D-EB
- PG64-22
E&B Mix E

<table>
<thead>
<tr>
<th>Reduced Frequency, Hz</th>
<th>Meas. E-EB</th>
<th>Est. E-EB</th>
<th>PG58-28</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$|G^*|, \text{ Pa}$
JHR Mix A

\[ |G^*, \text{Pa} | \]

Reduced Frequency, Hz

- Meas. A-JH
- Est. A-JH
- PG64-22
JHR Mix B

\(|G'|, \text{Pa}\)

Reduced Frequency, Hz

Meas. B-JH
Est. B-JH
PG64-22
JHR Mix C

Reduced Frequency, Hz

$|G^*|, \text{Pa}$
JHR Mix D

\[ |G^*|, \text{Pa} \]

Reduced Frequency, Hz
JHR Mix E

![Graph showing reduced frequency versus modulus (G') in Pa on a log-log scale with markers for different conditions and a legend indicating Meas. E-JH, Est. E-JH, and PG58-28.]
JHR Mix F
P&B Mix A

\[ |G^*|, \text{Pa} \]

Reduced Frequency, Hz

- Meas. A-PB
- Est. A-PB
- PG64-22
P&B Mix B

Reduced Frequency, Hz

$|G^*|, \text{Pa}$

Meas. B-PB

Est. B-PB

PG64-22
P&B Mix C

|G*|, Pa

Reduced Frequency, Hz

- Meas. C-PB
- Est. C-PB
- PG64-22
P&B Mix D

![Graph showing |G*|, Pa vs. Reduced Frequency, Hz]

- Meas. D-PB
- Est. D-PB
- PG64-22
P&B Mix E

\[ |G^*|, \text{Pa} \]

Reduced Frequency, Hz

<table>
<thead>
<tr>
<th>Meas. E-PB</th>
<th>Est. E-PB</th>
<th>PG58-28</th>
</tr>
</thead>
</table>

\[ 1.0 \times 10^0 \] to \[ 1.0 \times 10^{11} \]
P&B Mix F

- Reduced Frequency, Hz
- Meas. F - PB
- Est. F - PB
- PG58-28

Graph showing the relationship between |G'\|^{}, Pa and Reduced Frequency, Hz.
RR Mix A

\(|G^*|, \text{Pa}\)

Reduced Frequency, Hz

- Meas. A-RR
- Est. A-RR
- + PG64-22
RR Mix B

|G*|, Pa

Reduced Frequency, Hz

Meas. B-RR

Est. B-RR

+PG64-22
RR Mix C

|\(G^*\), Pa |
|\(\text{Reduced Frequency, Hz}\)

- Meas. C-RR
- Est. C-RR
- PG64-22
RR Mix D

|G*|, Pa

Reduced Frequency, Hz
RR Mix E

|G*|, Pa

Reduced Frequency, Hz
RR Mix F
What Does This Mean?

- Two cases indicated pretty good blending, two maybe questionable
- Relates to other comparisons
  - IDT indicated little effect of binder grade in the cases with questionable blending
Impacts of Blending on Performance

- If we assume there is blending and there isn’t, virgin binder grade may be softer than desired.
  - Increased chance for rutting
  - Decreased chance for cracking

- If we assume there is no blending and there is, effective binder grade may be stiffer than desired.
  - Decreased chance for rutting
  - Increased chance for cracking
Risks of False Assumptions

- Assuming there is blending may be more conservative.
  - Shouldn’t rely on binder to control rutting
  - Increased cracking can have performance and economic impacts

- But, if the RAP binder does not blend and act like binder, mix could be under-asphalted.
Recovered RAP Binder Comparison

Recovered RAP Binders

- JH PG64
- RR PG64
- PB PG64
- EB PG64

|\(G'\), Pa | Reduced Frequency, Hz | Recovered RAP Binders

The graph shows the comparison of \(G'\), Pa values for recovered RAP binders across different reduced frequencies.
Percent of Mix or Binder?

• Compared three different RAPs from P&B
  • Surface Millings 5.4% binder
  • Full Depth Millings 4.2%
  • Crushed and Screened 3.7%

• As binder content decreases, could use more RAP on % binder replacement basis
DISCUSSION