Determining the Correct Mixing and Compaction Temperatures for Using High RAP Content in HMA

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Alejandro Rosales
Erin L. Russell

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3. Material and Test Methods
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Introduction

2017 Idaho Asphalt Conference

- Significant increase in RAP% in HMA designs in Northwest region
  - **Washington**: Less than 20% in 2014 to amount allowed to meet the target PG grade (Based on Blending Chart)
    - Target PG 70-28, RAP grade PG 88.7-16.5
    - 20% RAP: PG 65.8-30.8; 40% RAP: PG 59.8-35.7
  - **Idaho**: Open the 20% limit in 2014 to basically 100% → Cap at 30% currently
    - Based on Blending Chart to the designed grade
  - **ODOT**: 20% RAP and RAS Combined. Pushing for up to 40%.
Introduction

• Problems
  • Too many different low temperature grades
    • PG 52-34, PG 52-40, PG 58-40, PG 64-40, PG 70-34, PG 76-34, etc
  • Mix Design Failures (Repeatability)
    • Hamburg (Washington)
      • Stripping Inflection Point
      • No stripping at 15,000 passes
    • Rut Depth
      • 10 mm at 15,000 passes
    • Immersion-Compression Test (Idaho)
      • 85% Retained Strength

• Current Solutions (It is always the oil):
  • Adding antistrip (up to 1.5%)
  • Changing grade
  • Changing formulation
  • Changing Supplier

• Possible Causes: (It is not always the oil)
  • RAP quality (Source/Grade/Gradation)
  • Interaction between RAP and Virgin Oil (Coating)
Introduction

• Coating of the Agg/RAP
  • Not enough binder → Need more virgin binder
  • Mixing and Compaction (Temperatures too low)
• The mixing and compaction temperatures
  • The virgin binder (Low) **NCHRP 452**
  • The blended virgin/RAP binder (Medium)
  • The RAP binder (High)

Objectives
Objectives

- Will higher mixing and compaction temperatures affect the OAC for HMA using RAP?
  - NCHRP 9-36: SGC compaction process is insensitive to binder stiffness
  - FHWA/TX-11/0-6092-2: Increasing the mixing and compaction temperatures significantly lowers the OAC
- Will higher mixing and compaction temperatures affect the mechanical properties for HMA using RAP?
  - NCHRP 9-36: Mechanical tests on HMA are affected by mixing and compaction temperatures
  - FHWA/TX-11/0-6092-2: Lower temperature $\rightarrow$ higher OAC $\rightarrow$ More Durable Mixes
### Materials and Test Methods

**• Materials**

**• Aggregate:**

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>B Pile (45%)</th>
<th>C Pile (55%)</th>
<th>Combined</th>
</tr>
</thead>
<tbody>
<tr>
<td>45.0%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>37.5</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>25.0</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>19.0</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>12.5</td>
<td>88%</td>
<td>100%</td>
<td>95%</td>
</tr>
<tr>
<td>9.5</td>
<td>62%</td>
<td>100%</td>
<td>83%</td>
</tr>
<tr>
<td>4.75</td>
<td>7%</td>
<td>93%</td>
<td>54%</td>
</tr>
<tr>
<td>2.36</td>
<td>2%</td>
<td>71%</td>
<td>40%</td>
</tr>
<tr>
<td>1.18</td>
<td>2%</td>
<td>52%</td>
<td>30%</td>
</tr>
<tr>
<td>0.6</td>
<td>2%</td>
<td>36%</td>
<td>21%</td>
</tr>
<tr>
<td>0.33</td>
<td>1%</td>
<td>23%</td>
<td>13%</td>
</tr>
<tr>
<td>0.15</td>
<td>1%</td>
<td>14%</td>
<td>8%</td>
</tr>
<tr>
<td>0.075</td>
<td>1.1%</td>
<td>8.3%</td>
<td>5.1%</td>
</tr>
</tbody>
</table>

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![U.S. Sieve Size Graph](attachment:graph.png)
Materials and Test Methods

- **RAP:**
  - RAP was made by blending 4.5% RAP Asphalt with the same aggregate
  - RAP Asphalt: PG64-22 after 40 hrs PAV
  - To eliminate the variances in RAP source and binders
  - RAP Contents: 0%, 15% and 30%

- **Virgin Binders:**
  - PG52-34 (Neat Asphalt)
  - PG64-28ER (SBS modified asphalt)

<table>
<thead>
<tr>
<th>Sieve Size</th>
<th>RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh (mm)</td>
<td></td>
</tr>
<tr>
<td>1-1/2&quot;</td>
<td>37.5</td>
</tr>
<tr>
<td>1&quot;</td>
<td>25.0</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>19.0</td>
</tr>
<tr>
<td>1/2&quot;</td>
<td>12.5</td>
</tr>
<tr>
<td>3/8</td>
<td>9.5</td>
</tr>
<tr>
<td>#4</td>
<td>4.75</td>
</tr>
<tr>
<td>#8</td>
<td>2.36</td>
</tr>
<tr>
<td>#16</td>
<td>1.18</td>
</tr>
<tr>
<td>#30</td>
<td>0.6</td>
</tr>
<tr>
<td>#50</td>
<td>0.33</td>
</tr>
<tr>
<td>#100</td>
<td>0.15</td>
</tr>
<tr>
<td>#200</td>
<td>0.075</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Neat Asphalt</th>
<th>15% RAP</th>
<th>30% RAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.0%</td>
<td>4.7%</td>
<td>5.4%</td>
<td></td>
</tr>
<tr>
<td>4.5%</td>
<td>5.2%</td>
<td>5.9%</td>
<td></td>
</tr>
<tr>
<td>5.0%</td>
<td>5.7%</td>
<td>6.4%</td>
<td></td>
</tr>
<tr>
<td>5.5%</td>
<td>6.2%</td>
<td>6.9%</td>
<td></td>
</tr>
</tbody>
</table>
### Materials and Test Methods

<table>
<thead>
<tr>
<th></th>
<th>Mixing Temp</th>
<th>Compaction Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 52-34</td>
<td>143°C (289°F)</td>
<td>132°C (270°F)</td>
</tr>
<tr>
<td>PG 64-28</td>
<td>160°C (320°F)</td>
<td>145°C (293°F)</td>
</tr>
<tr>
<td>PG 76-28</td>
<td>169°C (336°F)</td>
<td>153°C (307°F)</td>
</tr>
<tr>
<td>RAP</td>
<td>177°C (350°F)</td>
<td>169°C (337°F)</td>
</tr>
</tbody>
</table>

### Results and Discussion
Results and Discussion

• Control (PG 52-34)

- PG 52-34 177-169
  - 6.3%
  - R² = 0.9917

- PG 52-34 143-132
  - 5.9%
  - R² = 0.9993

• Control (PG 64-28ER)

- PG 64-28ER 177-169
  - 6.0%
  - R² = 0.9953

- PG 64-28ER 160-145
  - 6.0%
  - R² = 0.9951
Results and Discussion

<table>
<thead>
<tr>
<th></th>
<th>PG52-34</th>
<th>PG64-28ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>135°C</td>
<td>235 mPas</td>
<td>624 mPas</td>
</tr>
<tr>
<td>150°C</td>
<td>127 mPas</td>
<td>326 mPas</td>
</tr>
<tr>
<td>165°C</td>
<td>69 mPas</td>
<td>186 mPas</td>
</tr>
</tbody>
</table>

• Absorption:
  • At 177°C, PG52-34 viscosity around 40 mPas; PG64-28ER, 123 mPas
  • Polymer network may limited the extend of absorption.
Results and Discussion

RAP % has no effect on OAC (Total AC) at temperatures between Neat and target PG

<table>
<thead>
<tr>
<th>Temp</th>
<th>PG52-34</th>
<th></th>
<th>PG64-28ER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>177/169</td>
<td>6.3</td>
<td>6.2</td>
<td>6.4</td>
</tr>
<tr>
<td>160/145</td>
<td>N/A</td>
<td>5.8</td>
<td>5.9</td>
</tr>
<tr>
<td>143/132</td>
<td>5.9</td>
<td>5.9</td>
<td>6.0</td>
</tr>
</tbody>
</table>
Number of Gyration to achieve 92% Gmm. Not much difference at different compaction temperatures, asphalt type or RAP%.

<table>
<thead>
<tr>
<th></th>
<th>PG52-34</th>
<th></th>
<th>PG64-28ER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>0%</td>
<td>15%</td>
<td>30%</td>
</tr>
<tr>
<td>177/169</td>
<td>28</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>160/145</td>
<td>N/A</td>
<td>25</td>
<td>28</td>
</tr>
<tr>
<td>143/132</td>
<td>25</td>
<td>24</td>
<td>26</td>
</tr>
<tr>
<td>177/169</td>
<td>22</td>
<td>18</td>
<td>23</td>
</tr>
<tr>
<td>169/153</td>
<td>N/A</td>
<td>23</td>
<td>22</td>
</tr>
<tr>
<td>160/145</td>
<td>21</td>
<td>18</td>
<td>25</td>
</tr>
</tbody>
</table>

Summary:
- Will higher mixing and compaction temperatures affect the OAC for HMA using RAP?
  - Depends on the grade of the virgin binder and how high the temperatures are.
  - For regular grade, we can consider that the OAC to be the same between Virgin Binder range to target PG grade range.
Results and Discussion
Performance Testing: Hamburg

Performance Testing: Hamburg

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AASHTO T324
• 62.0 mm height
• 150 mm diameter
• 7.0%±1.0% air voids

• Minimum Criteria WSDOT
  • 50°C
  • 10 mm Rut Depth at 15,000 passes
  • No stripping at 15,000 passes
## Performance Testing: Hamburg

### PG 52-34

<table>
<thead>
<tr>
<th></th>
<th>177-169°C</th>
<th>143-132°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5000</td>
<td>-10.39</td>
<td>-12.06</td>
</tr>
<tr>
<td>10000</td>
<td>-12.47</td>
<td>-12.07</td>
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<tr>
<td>15000</td>
<td>-12.76</td>
<td>-13.68</td>
</tr>
<tr>
<td>20000</td>
<td>-12.79</td>
<td>-13.68</td>
</tr>
</tbody>
</table>

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### Performance Testing: Hamburg

![Graph showing Rut Depth (mm) versus Number of Passes for different PG 52-34 grades and RAP contents.](image-url)
Performance Testing: Hamburg

<table>
<thead>
<tr>
<th>Passes</th>
<th>PG 64-28ER</th>
<th>177-169°C</th>
<th>160-145°C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0% RAP</td>
<td>15% RAP</td>
<td>30% RAP</td>
</tr>
<tr>
<td>5000</td>
<td>-3.10</td>
<td>-2.36</td>
<td>-2.49</td>
</tr>
<tr>
<td>10000</td>
<td>-5.38</td>
<td>-2.90</td>
<td>-2.93</td>
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<tr>
<td>15000</td>
<td>-7.53</td>
<td>-3.25</td>
<td>-3.22</td>
</tr>
<tr>
<td>20000</td>
<td>-9.01</td>
<td>-3.54</td>
<td>-3.49</td>
</tr>
</tbody>
</table>
Performance Testing: Hamburg

PG 64-28ER

# of Passes

Rut Depth (mm)

-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2000 4000 6000 8000 10000 12000 14000 16000 18000 20000

0% 177-169
15% 177-169
30% 177-169
0% 160-145
15% 160-145
30% 160-145
Limit

Performance Testing: Hamburg

PG 64-28ER 0% RAP 177-169°C
PG 64-28ER 15% RAP 177-169°C
PG 64-28ER 30% RAP 177-169°C
Performance Testing: Hamburg

PG 64-28ER 0%RAP 160-145°C

PG 64-28ER 15%RAP 160-145°C

PG 64-28ER 30%RAP 160-145°C

<table>
<thead>
<tr>
<th>30% RAP</th>
<th>177-169°C</th>
<th>169-153°C</th>
<th>160-145°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>5000</td>
<td>-2.49</td>
<td>-2.50</td>
<td>-2.66</td>
</tr>
<tr>
<td>10000</td>
<td>-2.93</td>
<td>-2.97</td>
<td>-3.42</td>
</tr>
<tr>
<td>15000</td>
<td>-3.22</td>
<td>-3.29</td>
<td>-4.58</td>
</tr>
<tr>
<td>20000</td>
<td>-3.49</td>
<td>-3.59</td>
<td>-5.95</td>
</tr>
</tbody>
</table>
Performance Testing: Hamburg

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![Graph showing Rut Depth vs. Number of Passes](image)

- PG 64-28ER 30% RAP 177-169
- PG 64-28ER 30% RAP 169-153
- PG 64-28ER 30% 160-145°C
- Limit

10/26/2017

Performance Testing: Hamburg

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- PG 64-28ER 30% RAP 160-145°C
- PG 64-28ER 30% RAP 169-153°C
- PG 64-28ER 30% RAP 177-169°C

10/26/2017
Results and Discussion
Performance Testing: Tensile Strength Ratio

AASHTO T283 (Modified Lottman Test)
- Method 1: Freeze Thaw Cycle
  - 70%-80% Vacuum Saturation
  - 16 hr -18°C Freeze Cycle
  - 24 hr 60°C Thaw Cycle
  - 2 hr 25°C Equilibration Cycle
- Method 2: No Freeze Thaw Cycle
  - 70%-80% Vacuum Saturation
  - 24 hr 60°C Conditioning Cycle
  - 2 hr 25°C Equilibration Cycle

Minimum TSR value 80%

\[ S = \frac{2P}{\pi t D} \]

\[ TSR(\%) = \frac{S_{t, wet}}{S_{t, dry}} \]

\( S = \text{Tensile Stress at Failure (psi)} \)
\( P = \text{Peak Load at Failure (lb)} \)
\( t = \text{Thickness of specimen (in)} \)
\( D = \text{Diameter of specimen (in)} \)

Loading Rate: 2 in/min (50 mm/min)
Results and Discussion

Performance Testing: TSR

![Graph 1: PG 52-34 177-169 Dry vs. PG 52-34 143-132 Dry]

![Graph 2: PG 52-34 177-169 Wet vs. PG 52-34 143-132 Wet]

![Graph 3: PG 64-28ER 177-169 Dry vs. PG 64-28ER 160-145 Dry]

![Graph 4: PG 64-28ER 177-169 Wet vs. PG 64-28ER 160-145 Wet]
Results and Discussion

Performance Testing: TSR

![Graph showing retained strength ratio (%) vs. RAP content (%). The graph compares PG 52-34 177-169 and PG 52-34 143-132 retained strength ratios.]

For PG 52-34 177-169, the retained strength ratio remains relatively consistent, with slight variations. Conversely, PG 52-34 143-132 shows a more pronounced decrease in retained strength ratio as RAP content increases.

![Graph showing retained strength ratio (%) vs. RAP content (%). The graph compares PG 64-28ER 177-169 and PG 64-28ER 160-145 retained strength ratios.]

For PG 64-28ER 177-169, the retained strength ratio shows a slight decrease at higher RAP contents. PG 64-28ER 160-145, on the other hand, maintains a higher and more consistent retained strength ratio across the range of RAP contents.
Results and Discussion
Performance Testing: Immersion Compression

Compressive Load (lbf) vs. Time (sec)

- Peak Load at Failure

Loading Rate: 0.2 in/min (5.08 mm/min)

AASHTO T165/T167
ASTM D1074/1075

- Set of 3 samples for each condition are prepared
- Wet sample conditioned at 60°C (140°F) for 24 hrs
- Wet sample is transferred to 25°C (77°F) for 2 hrs
- Dry sample conditioned at 25°C (77°F) air bath for 4 hrs

Minimum IC Ratio value 85% (ITD)
Results and Discussion

Performance Testing: Immersion Compression

Graphs showing the relationship between RAP content and compressive strength for different asphalt binders in dry and wet conditions.
Results and Discussion
Performance Testing: Immersion Compression

![Graph showing retained strength ratio against RAP content for different asphalt grades.]

- **PG 52-34 177-169 IC Retained Strength Ratio**
- **IC Retained Strength Ratio Limit**
- **PG 52-34 143-132 IC Retained Strength Ratio**
- **PG 64-28ER 177-169 IC Retained Strength Ratio**
- **IC Retained Strength Ratio Limit**
- **PG 64-28ER 160-145 IC Retained Strength Ratio**
• Hamburg
  • Higher mixing and compaction temperatures lead to less rutting
    • Not necessary to target RAP temperature
      • Data suggests Target Blend yields same results
  • Tensile Strength Ratio (TSR)
    • Higher mixing and compaction temperatures lead to higher tensile strength
    • Mixtures at higher mixing and compaction temperatures have higher tensile strength ratios
    • Target PG Blend yields better results
• Immersion Compression (IC)
  • Higher mixing and compaction temperatures yield higher compressive strength
  • Compressive strength ratios were higher when mix and compacted at hotter temperatures
  • Target PG Blend yielded same if not better results than hottest temperature
Summary of Findings

- Will higher mixing and compaction temperatures affect the mechanical properties for HMA using RAP?
  - Yes. Higher temperatures $\rightarrow$ less Distresses (Rut and Stripping)
  - **We should target the mixing and compact temperatures of final/blend PG grade.**

Going Forward

- Finish performance tests at target blend temperature
- Include testing with other asphalt grades
  - Include other types of polymers
- Investigate the effect of Warm Mix Additives and temperature on mixture performance
- Include higher RAP content (50% RAP)
- Include field RAP
- Investigate Viscosity Temperature Curve
  - Recommended minimum viscosity to achieve better mixture performance
Questions?

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