Performance Based Specification for High RAP Mixes in Cold Climates

Andrew Hanz – MTE Services Inc.
Ervin Dukatz – Mathy Construction
Gerald Reinke – MTE Services Inc.

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Acknowledgements

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  – Steve Engber, Doug Herlitzka, Alex Engstler

• WisDOT High RAM Committee
  – Chaired by Barry Paye, WisDOT and Deb Schwerman, WAPA
WisDOT High Recycle Pilot Program

• Proposed to WisDOT management by industry in winter of 2013.
  – Pavement Sustainability
  – Economic Benefits

• Specification was developed for 2014 construction season and modified for 2015.
  – Includes performance tests and mix design changes.

• 4 projects let. Two were constructed in 2014, two in 2015.
High RAM SPV Mix Design Changes

Maximum % Binder Replacement (PBR)

<table>
<thead>
<tr>
<th>Material</th>
<th>Lower Lift</th>
<th>Upper Lift*</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAS</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>RAM (max 5% RAS by wt. of agg.)</td>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

* Reduce upper and lower plan PG grade by one grade for PBR >25% (i.e. PG 58-28 becomes PG 52-34)

Mix Design and QC

• Design Air Voids decreased from 4.0% to 3.5%
• TSR increased from 0.70 to 0.75
• Increase maximum Dust to Binder Ratio to 1.6
• Add daily monitoring of asphalt content via extraction.
WisDOT SPV - Selected Performance Tests

**Thermal Cracking**
- DC(t)

**Fatigue**
- Semi-Circular Bend

**Rutting**
- Hamburg

- LT (-18 or -24°C)
- IT (25°C)
- HT (50°C)

**Long Term Aging – AASHTO R30 (5 days at 85°C)**
- SCB and DCT
- Recovered binder grade and ΔTc
Testing Requirements

• Timing of submittals
  – Preliminary: Mix Design and Test Strip
  – Construction: $1^{st}$ 600 ton and every 10k ton after.

• Logistical Challenges
  – Agency approval of mix design and test strip results required.
  – Minimum time lag between test strip and construction ~ 10 days.
STH 77 Project Overview

- Design High PBR Mixes Using RAP
- Meet or exceed performance of standard mix
- Meet performance testing requirements for rutting, fatigue, and thermal cracking.

**Project Overview:**
- 13 Miles
- 9 Miles Standard - E3 Mixture
- 4 Miles High RAM SPV- E3 Mixture
- 60K Ton Total (16K High RAM)
- Table 460.2 Modified – Target AV = 3.5%
Pavement Section Details

Location: Ashland County - Clam Lake to STH 13

- Standard Mix ~ 9.5 miles
  - 3” pavement depth
  - 1.25” Leveling Layer 12.5mm E3 PG 58-34
  - 1.75” Upper Layer 12.5mm E3 PG 58-34

- High Recycle Length – 4.08 miles (West End)
  - 4” total pavement depth
  - 2.25” Lower Layer 19mm E3 High Recycle
  - 1.75” Upper Layer 12.5mm E3 High Recycle

- Constructed in August/Sept of 2014.
## Approach to Project

### Materials Selection and Mix Design

| 1. Characterize RAP | • Obtain millings from project.  
|                    | • Extract/RAM binder and determine true PG. |
| 2. Determine Binder Properties | • Apply Blending Charts: Target PG 58-34.  
|                                | • Virgin Grade Binder: PG 52-40, -40 grade made with bio-derived oil. |
| 3. Volumetric Mix Design | • Same process as conventional mix design.  
|                         | • Target AV is 3.5% for high RAM. |
Approach to Project
Performance Testing

4. Verify Binder Properties
   • In mix design compact pill to 6.5% AV
   • 5 Days Aging at 85°C, extract and recover binder.
   • Target is PG 58-34, ΔTc > -5.0°C

5. Evaluate Hamburg
   • Base Binder (Plan) = PG 52-40, also SPV air voids result in higher total binder content.
   • Modify binder to PG 58-40 to improve Hamburg results.

6. Cracking Resistance
   • 5 Days Aging at 85°C – Compacted Mixture
   • Mixture: SCB @ 25°C, DCT @ -24°C, Fracture Energy > 400 J/m²
Lab Blends for Initial Formulation

- 19.0mm: 60% PG 58-40 + 40% RAP from STH 77
- 12.5mm: 70% PG 58-40 + 30% RAP from STH 77
Results – Recovered Binder $\Delta T_c$

WisDOT Requirement: $\Delta T_c \geq -5 ^\circ C$
Mix Performance Results

Hamburg at 50°C

Rut Depth (mm)

WisDOT Maximum

- 12.5 mm
- 19mm

Rut Depth at 5000 passes.
Mix Performance Results

SCB @ 25°C

Possible Minimum Limit

<table>
<thead>
<tr>
<th>Jc (kJ/m²)</th>
<th>Mix Design</th>
<th>Test Strip</th>
<th>Production 1</th>
<th>Production 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.5 mm</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>19 mm</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Mix Performance Results

DCT @ -24°C

Fracture Energy (J/m²)

- 12.5 mm
- 19 mm

Mix Design | Test Strip | Production 1 | Production 2
Points for Discussion

1. SCB Test Temperature Selection
   - Constant or based on climate?

2. Alternative Long Term Aging Methods
   - Loose mix aging at 12 to 24 hrs.

3. Comparison to the Control
   - Focus on recovered binder properties and cracking tests.
• IT PG of asphalt used in the study ranges from 25°C to 34°C.
• Recommends $J_c > 0.5$ kJ/m$^2$ for PG 76 and lower.
• Limit established based on relation to field performance.
WisDOT Pilot Project Results
15°C vs. 25°C

<table>
<thead>
<tr>
<th>Material</th>
<th>15°C</th>
<th>25°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0mm Prod. 1</td>
<td>0.51</td>
<td>-</td>
</tr>
<tr>
<td>19.0mm Prod. 2</td>
<td>0.42</td>
<td>-</td>
</tr>
<tr>
<td>12.5mm Prod. 1</td>
<td>0.54</td>
<td>-</td>
</tr>
<tr>
<td>12.5mm Prod. 2</td>
<td>0.56</td>
<td>-</td>
</tr>
</tbody>
</table>
SCB Temperature Selection

- When test temperature was adjusted to 15°C for WisDOT mixes, Jc values were consistent with LSU recommendations.

- **Recommendation**
  - Select SCB test temperature based on climate using LTTP Bind and calculation for intermediate temperature PG.

- For Wisconsin
  - Northern half is a PG 58-34: SCB temp = 16°C
  - Southern half is a PG 58-28: SCB temp = 19°C
Mixture Long Term Aging

• Issues with AASHTO R30 (5 days @ 85°C)
  – Aging gradient with depth in sample.
  – Sample dimensions change due to creep.
  – Time requirements, particularly when applied to a construction project.

• Proposed alternative:
  – Loose mix aging at 135°C for 12 to 24 hours.
  – Based on AAPT paper by Braham (2009) and further work by Phil Blankenship at AI.
Loose Mix Aging at 135°C

Effect of Aging Time on DCT

Binder Evaluation for High RAM Mixes

Direct Measurement – 4mm PP

Effect of Aging

PG Grading

Evaluation of Loose Mix Aging
Binder Properties

- Production Samples were aged for 5 days at 85°C. All binders extracted with toluene and recovered with Roto Vap.
- Low temperature properties estimated using 4mm DSR.
- 12 hour loose mix aging correlates well with 5 day aging procedure.
Evaluation of Loose Mix Aging Mixture Cracking Performance

• Performance is similar for 5 day aged production samples and 12 hr loose mix aged samples.
• Effect of 24 hour aging not as severe for mixture performance, particularly in DCT test.
Laboratory vs. Field Aging, (Reinke, 2015 ETG)

12 Hr. Loose Mix @ 135°C

As binder becomes more m-controlled (neg. Tc), this aging protocol under-represents 8 years field aging in Minnesota.
Laboratory vs. Field Aging (Reinke, 2015 ETG)

24 Hr. Loose Mix @ 135°C

Aging protocol over-predicts 8 years field aging in Minnesota. Over prediction becomes worse as Tc becomes more negative.
Mixture Long Term Aging

• Loose mix aging at reduced times is a viable alternative to compacted sample aging.
• Mixture fracture tests, particularly the DCT showed less sensitivity to aging than recovered binder properties.

• **Recommendation**
  – Adopt 12 hrs. loose mix aging at 135°C as an alternative method for AASHTO R30.
  – Continue research on relating properties of field mixes to distress.
## WisDOT High RAM SPV Sample Conditioning Protocol

<table>
<thead>
<tr>
<th>Step</th>
<th>Test Procedure</th>
<th>Conditioning</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1)</td>
<td>Mix Design/Volumetrics</td>
<td>2 hrs $\pm$ 5 min @ Compaction Temp</td>
<td>AASHTO R30, Section 7.1</td>
</tr>
<tr>
<td>2)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Hamburg</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>lab-mixed</td>
<td>4 hrs $\pm$ 5 min @ 135 $\pm$ 3C</td>
<td>AASHTO R30, Section 7.2</td>
</tr>
<tr>
<td></td>
<td>plant produced</td>
<td>min. reheat time to reach Compaction Temp</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>DCT and SCB</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>lab-mixed</td>
<td>Step 1 PLUS 12 hrs $\pm$ 30 min @ 135 $\pm$ 3C</td>
<td>WisDOT-Modified AASHTO R30, SPV Section 7.2</td>
</tr>
<tr>
<td></td>
<td>plant produced</td>
<td>12 hrs $\pm$ 30 min @ 135 $\pm$ 3C</td>
<td></td>
</tr>
</tbody>
</table>

12 hour loose mix aging protocol selected as an accelerated aging method based on comparison with 5 day compacted sample aging at 85°C
Comparison to Control Mix

• At a minimum our expectation was that the high RAM mix would perform as well as conventional mixes placed in WI.

• Primary distress in WI is cracking, comparison will focus on
  – Recovered binder grading
  – SCB and DCT testing
  – Sensitivity to aging
## Comparison of Mix Designs

<table>
<thead>
<tr>
<th>Property</th>
<th>Control Mix – 12.5mm</th>
<th>High RAM 12.5mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Binder Replacement</td>
<td>24.5%</td>
<td>36.7%</td>
</tr>
<tr>
<td>Design Air Void</td>
<td>4.0%</td>
<td>3.5%</td>
</tr>
<tr>
<td>VMA</td>
<td>15.1%</td>
<td>14.9%</td>
</tr>
<tr>
<td>Vbe</td>
<td>11.1%</td>
<td>11.4%</td>
</tr>
<tr>
<td>Dust to Binder Ratio</td>
<td>0.90</td>
<td>1.0</td>
</tr>
<tr>
<td>Asphalt Binder Grade</td>
<td>PG 58-34</td>
<td>PG 58-40</td>
</tr>
<tr>
<td>MSCR Jnr 3.2 kPa @ 58°C</td>
<td>3.0</td>
<td>1.1</td>
</tr>
<tr>
<td>MSCR %R 3.2 kPa @ 58°C</td>
<td>0</td>
<td>43.5%</td>
</tr>
</tbody>
</table>
Binder Properties

Binder recovered from mixes subjected to loose mix aging at 135°C

- High RAM mix is softer after 12 hours loose mix aging, mixes behave the same at 24 hour aging.
DCT Results @ -24C

Load vs. CMOD(fit) – 12 hr Loose Mix Aging

<table>
<thead>
<tr>
<th>Mix</th>
<th>Gf: 12 Hr Loose Mix Aging (J/m²)</th>
<th>Gf: 24 Hour Loose Mix Aging (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High RAM</td>
<td>634.3</td>
<td>587.5</td>
</tr>
<tr>
<td>Control</td>
<td>296.1</td>
<td>360.4</td>
</tr>
<tr>
<td>High RAM</td>
<td>70.8</td>
<td>127.9</td>
</tr>
<tr>
<td>Control</td>
<td>20.4</td>
<td>5.0</td>
</tr>
</tbody>
</table>
SCB Results at 15°C

12 Hour Loose Mix Aging

\[ y = -0.0269x + 1.3703 \]
\[ R^2 = 0.97367 \]

\[ y = -0.0258x + 1.2532 \]
\[ R^2 = 0.99419 \]

Jc High RAM Mix = 0.48 kJ/m²
Jc Control Mix = 0.45 kJ/m²
SCB Results at 15°C
24 hour Loose Mix Aging

\[ y = -0.0323x + 1.4891 \quad R^2 = 0.99664 \]
\[ y = -0.0232x + 1.11 \quad R^2 = 0.99922 \]

Strain Energy (kJ)
Notch Depth (mm)

Jc High RAM Mix = 0.58 kJ/m²
Jc Control Mix = 0.40 kJ/m²
Analysis method presented by UIUC was applied to the existing SCB test data set.

Main differences between SCB procedures are test temperature (15°C vs. 25°C), loading rate (0.5 mm/min vs. 50 mm/min) and notch depth (25mm vs. 15mm).
Flexibility Index – Effects of Mix Design and Aging

- Flexibility Index discriminates between mixtures and the effects of aging.
- For 12.5mm mix, high RAM performs better than control for both aging conditions. Possibly due to presence of polymer and use of bio oil.
- Subsequent work at MTE has implemented the formal UIUC draft AASHTO procedure.
STH 77 Observations After 1 Yr.

- High RAM Section was 4 miles long.
- Control is 9 miles.
- Overall pavement is performing well.

- Very few transverse cracks.
- Small crack width
- No difference in performance between sections.
Summary

• Goal to meet or exceed the performance properties of the control mix was achieved.

• Contributing factors to performance improvements for high RAM mix.
  – Higher effective binder content/lower air voids.
  – Benefits of modification from polymer and bio-derived oil.

• Effect of aging on mixture cracking tests needs further investigation.
Next Steps

• WisDOT High RAM Committee will review performance testing provision after 2015 construction season.

• Continue standardization and evaluation of the SCB test.  *ASTM WK 48574*

• Continue investigation of post-peak behavior in SCB evaluation (UIUC method).

• Fall 2015 – Survey and coring of STH 77 to capture field performance after 1 year in service.
Thank You

Andrew Hanz, Ph.D.
Technical Director
MTE Services Inc.
608-779-6352 (office)
608-780-2509 (mobile)
andrew.hanz@mteservices.com