Path towards Reliable Implementation of Rejuvenated High-Recycled HMA

Hassan A. Tabatabaee, Ph.D.
Cargill
January 2020
Cargill’s Role in Asphalt

- Cargill is a developer and producer of bio-Industrial additives and sustainable performance industrial solutions.

1. Cargill Anova™ Rheology Modifiers
2. Cargill Anova™ Rejuvenators
3. Cargill Anova™ Cold Mix Solutions
4. Cargill Anova™ Anti-strips
5. Cargill Anova™ WMA
6. Cargill Anova™ Emulsifiers
The Potential of high RAP Rejuvenation…
Introduction: Asphalt Aging

• Pavements age from the surface, downwards
• Aging is affected by rate of air permeability (porosity), climate conditions, UV, etc.
• Aged bitumen is more brittle and less durable.
  • Flaws can quickly become crack initiation points, and eventually water penetration points.
  • Excessive use of aged reclaimed asphalt pavement (RAP) can impart same properties to new pavements.
• An engineered solution is needed…

  • “Rejuvenation” is an inaccurate, but popular term.
    • Rejuvenators do not undo oxidative aging!!!
  • A good rejuvenator reverses the impact of aging on asphalt, reactivating the bitumen, to restore performance, and durability.
Re-Balancing Bitumen Fractions

Thin Layer Chromatography (TLC) using an Iatroscan
Many options for dosing:
• In virgin bitumen using antistrip pump
• Pre-blended into virgin bitumen
• Pre-treatment of RAP
• Injection into pugmill
• …

• Additive injected in-line to the bitumen line connecting bitumen tank to asphalt drum. Dosing system is similar to that utilized for liquid antistrip additives.
What is the process for producing high-RAP mixes?

1. Check and meet the fundamentals:
   - Can the plant reliably handle more RAP? (Capacity, belts, flights, dryers, etc.)
   - Do I have a way to introduce rejuvenators into my mix at the plant? (e.g. a liquid antistrip system or similar additive setups)
   - Do I have enough RAP?

2. Implementation:
   A. For implementation in “non-spec” commercial mixes: Work with rejuvenator supplier on the appropriate dosage to produce higher RAP mixes with quality consistent with normally supplied mix designs. Step up RAP QC frequency.
   B. For implementation in agency “spec” mixes: Fundamentally the same, but also requires a framework that provides transparency and reliability for all stakeholders.
High Level Typical Process Flowchart

- All Test Methods listed below are just possible examples
- It is not anticipated that all tests on every list would be necessary.
- Level of rigor should be proportionate to job type and service level.

0- Additive Basic Screening
- Performed by supplier (Quarterly Certification)
  - All test on additive itself, without bitumen
  - Safety (Flash point)
  - Stability (RTFO Mass Loss)
  - Durability (RTFO and PAV Aging viscosity ratios)
  - Manufacturing QC and batch traceability

1- Bitumen Dosing and Tests
- Performed by Supplier and/or Producer
  - Low Temp rheology and compatibility (BBR, FRAASS, ∆Tc)
  - Intermediate Temp rheology (PG/DSR)
  - Extended Aging (40hr or 60hr PAV aging)

2- Mixture Cracking and Rutting Tests
- Performed by Producer, verified by Agency
  - Optimize cracking/Durability testing (+ long term age)
  - Check rutting performance
  - Check moisture resistance

3- QC/QA Testing of RAP, Rejuvenator and HMA
- Performed by all parties
  - RAP gradation
  - RAP bitumen content
  - Control rejuvenator Certificate of Analysis
  - Performance verification tests for agency jobs
Example of Step 0: Rejuvenator Screening/Selection
(Expansion of tests listed in ASTM D4552, not standardized)

- This step insures that rejuvenator meets basic requirements for safety, thermal stability, storage stability, and compatibility to be used in Hot Mix Asphalt production.

<table>
<thead>
<tr>
<th>Rejuvenator Properties</th>
<th>Potential Limits (Internal specifications)</th>
<th>Anova 1815 Rejuvenator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneity (Storage Stability)</td>
<td>Stable, Homogenous</td>
<td>Stable, Homogenous</td>
</tr>
<tr>
<td>Density @ 25 °C, g/ml</td>
<td>Asphalt ±10% (0.90-1.10)</td>
<td>0.94</td>
</tr>
<tr>
<td>Pour point (pumpability) Temperature</td>
<td>Max 32°F (0°C)</td>
<td>-5°C</td>
</tr>
<tr>
<td>Flash Point °C, Open Cup</td>
<td>Min 240°C (as in Asphalt)</td>
<td>&gt;290°C</td>
</tr>
<tr>
<td>N-Heptane Insoluble Content</td>
<td>Max 1.0% (No Asphaltenes)</td>
<td>0.1%</td>
</tr>
<tr>
<td>RTFO Aging Viscosity Index</td>
<td>Max 3.0 (Similar to asphalt)</td>
<td>1.05</td>
</tr>
<tr>
<td>RTFO Mass Loss</td>
<td>&lt;1.0% (as in asphalt)</td>
<td>&lt;0.5%</td>
</tr>
<tr>
<td>PAV Aging Viscosity Index</td>
<td>Max 3.0 (to be verified)</td>
<td>1.10</td>
</tr>
</tbody>
</table>
So: What is the typical process for Agency high-RAP mixes?

Design Methods:

Option 1: Performance-modified Volumetric Design: AC content based on voids, determine rejuvenator content to meet performance

Option 2: “Full” Balanced Mix Design (BMD): Determine AC and rejuvenator directly based on performance test instead of voids.

Designing a high performance HMA with rejuvenation is a 3+1 step process:

- Step 0: Rejuvenator characterization and Quality Control (performed by Rejuvenator supplier)
- Step 1: Initial dosage determination based on rheology (performed by Rejuvenator Supplier, based on HMA Producer’s Volumetric mix design)
- Step 2: Performance-modified mix design (HMA Producer, supported by Rejuvenator Supplier)
- Step 3: Robust QC/QA protocol to be followed for all material. (All Parties Involved)
## Examples of Current BMD Systems adopted by agencies

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Durability Test</strong></td>
<td>Overlay Tester</td>
<td>DCT</td>
<td>DCT + IFIT</td>
<td>IFIT</td>
<td>IDEAL-CT, Contabro</td>
</tr>
<tr>
<td><strong>Rutting Test</strong></td>
<td>APA</td>
<td>Hamburg</td>
<td>Hamburg</td>
<td>Hamburg</td>
<td>APA</td>
</tr>
<tr>
<td><strong>Binder Specification</strong></td>
<td>None</td>
<td>Extracted pass PG XX-22, ΔTc &gt; 5</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td><strong>High-RAM Approval Process</strong></td>
<td>Mix Design Approval</td>
<td>Mix Design approval and trial</td>
<td>Mix Design approval and trial</td>
<td>Meet Spec Limits</td>
<td>Meet Spec Limits</td>
</tr>
<tr>
<td><strong>State of Implementation</strong></td>
<td>Active as of 2018</td>
<td>Active as of 2018</td>
<td>Active as of 2018</td>
<td>Active as of 2019</td>
<td>Trial spec as of 2019</td>
</tr>
</tbody>
</table>
Balanced Mix Design for Minnesota: MnDOT Approved Mix for I-94 Freeway

Approval Process

1. Lab samples were prepared based on rejuvenator supplier dosage recommendations and HMA producer’s mix design.
2. Laboratory performance tests were conducted to determine reasonable equivalence to control.
3. Binder extraction tests were conducted on lab samples to determine reasonable equivalence to control.

<table>
<thead>
<tr>
<th>Description</th>
<th>Extract AC %</th>
<th>HT PG</th>
<th>LT S PG</th>
<th>LT m PG</th>
<th>ΔTc</th>
<th>DCT -20°C (J/m²)</th>
<th>HWT at 50°C n=5K</th>
</tr>
</thead>
<tbody>
<tr>
<td>25%RAP Control</td>
<td>5.19%</td>
<td>65.1</td>
<td>-29.6</td>
<td>-24.3</td>
<td>-5.2</td>
<td>502.8</td>
<td>7.95mm</td>
</tr>
<tr>
<td>45%RAP Rejuvenator</td>
<td>4.51%</td>
<td>66.5</td>
<td>-28.7</td>
<td>-27.2</td>
<td>-1.5</td>
<td>495.0</td>
<td>2.35mm</td>
</tr>
</tbody>
</table>

45% RAP + Anova™ Rejuvenator vs. Control: 25% RAP

“Performance-modified” Volumetric Mix Design:
- AC% optimized by VMD, standard densities
- Performance checked with DCT and Hamburg
Balanced Mix Design for City of Chicago: Chicago DOT Approved Mix

55% FRAP, 5% RAS, Surface Course

1. Lab samples were prepared based on supplier’s dosage recommendations and HMA producer’s mix design.
2. Laboratory performance tests were conducted to determine reasonable equivalence to control.
3. Binder extraction tests were conducted on lab samples to confirm reasonable equivalence to control.
4. After lab approval a plant trial was carried out verifying design performance.
5. Mixture has been approved and in use since 2017.
## But do we have enough tests?

<table>
<thead>
<tr>
<th>test</th>
<th>DCT</th>
<th>IDEAL-CT</th>
<th>IFIT / SCB</th>
<th>Overlay Tester</th>
<th>Beam Fatigue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disc Compact Tension</td>
<td>Indirect Tensile Asphalt Cracking Test</td>
<td>Illinois Flexibility Index Test / Semi-circular Bend</td>
<td>a.k.a. Texas Overlay Tester</td>
<td>4-point Beam Fatigue</td>
<td></td>
</tr>
<tr>
<td>Low Temp PG + 10</td>
<td>25°C or room</td>
<td>Generally 25°C or room</td>
<td>25°C (or 15°C)</td>
<td>Varies 4-25°C</td>
<td></td>
</tr>
<tr>
<td>Cut and notched sample</td>
<td>Sample only compacted to height</td>
<td>Cut and notched sample</td>
<td>Cut sample</td>
<td>Cut sample after Slab compaction</td>
<td></td>
</tr>
</tbody>
</table>
Objective: Answer critical questions needed for Implementation of Hi-RAM BMD

- 5 main mixes with varying RAP content, Rejuvenator content, Virgin Binder types (good and bad ΔTc)
- Cold climate and warm climate comparisons
- All mixtures to be tested using DCT, Overlay, IFIT, IDEAL-CT, Hamburg, APA, Contabro, and TSR.
- Cracking tests after short term and long term aging.
- Outcomes:
  - Establish equivalency levels, and long term aging impacts across all test types.
  - Potential QC/QA methods
NCAT + MnROAD + Cargill Partnership

NCAT Trial (Auburn, AL with VDOT)
- 45% RAP + Anova™ Rejuvenator
- Control: 30% RAP
- Balanced Mix Design
  - AC% optimized by IDEAL-CT and APA
  - Air voids allowed to vary (higher density)

MnROAD Trial (Minneapolis, MN with MNDOT)
- 45% RAP + Anova™ Rejuvenator
- Control: 25% RAP
- “Performance-modified” Volumetric Mix Design
  - AC% optimized by VMD, standard densities
  - Performance checked with DCT and Hamburg

<table>
<thead>
<tr>
<th>Description</th>
<th>HT PG</th>
<th>LT m PG</th>
<th>ΔTc</th>
<th>IFIT FI</th>
<th>DCT -12°C (J/m²)</th>
<th>IDEAL-CT</th>
<th>Overlay NJDOT</th>
<th>APA at 64°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% RAP Control</td>
<td>76.7</td>
<td>-14.6</td>
<td>-9.2</td>
<td>6.1</td>
<td>520</td>
<td>124</td>
<td>296</td>
<td>2.51mm</td>
</tr>
<tr>
<td>45% RAP Rejuvenator</td>
<td>75.9</td>
<td>-22.0</td>
<td>-2.0</td>
<td>8.0</td>
<td>565</td>
<td>100</td>
<td>325</td>
<td>2.55mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Extract AC %</th>
<th>HT PG</th>
<th>LT S PG</th>
<th>LT m PG</th>
<th>ΔTc</th>
<th>DCT -20°C (J/m²)</th>
<th>HWT at 50°C n=5K</th>
</tr>
</thead>
<tbody>
<tr>
<td>25% RAP Control</td>
<td>5.19%</td>
<td>65.1</td>
<td>-29.6</td>
<td>-24.3</td>
<td>-5.2</td>
<td>502.8</td>
<td>7.95mm</td>
</tr>
<tr>
<td>45% RAP Rejuvenator</td>
<td>4.51%</td>
<td>66.5</td>
<td>-28.7</td>
<td>-27.2</td>
<td>-1.5</td>
<td>495.0</td>
<td>2.35mm</td>
</tr>
</tbody>
</table>
Meeting VDOT BMD required higher AC content at low RAP and use of a Rejuvenator at high RAP.

With adoption of BMD, some VMD specification become superfluous and can be loosened.
## Construction (Sep. 6, 2018)

<table>
<thead>
<tr>
<th>Section</th>
<th>Production Temp.</th>
<th>Compaction Temp.</th>
<th>In-place Density</th>
<th>QC Air Voids</th>
</tr>
</thead>
<tbody>
<tr>
<td>N3A (30%RAP)</td>
<td>310°F</td>
<td>290°F</td>
<td>96.2%</td>
<td>2.7%</td>
</tr>
<tr>
<td>N3B (45%RAP+Rej)</td>
<td>315°F</td>
<td>275°F</td>
<td>96.8%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

### Performance As of 4/2019

<table>
<thead>
<tr>
<th></th>
<th>N3A</th>
<th>N3B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean IRI (in/mi)</td>
<td>94.7</td>
<td>61.4</td>
</tr>
<tr>
<td>Laser Rut (mm)</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Mean Texture Depth (mm)</td>
<td>0.38</td>
<td>0.37</td>
</tr>
<tr>
<td>Cracking (%)</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>
Conclusions and Summary

• Implementation of high RAP + Rejuvenators in “non-spec” commercial mixes can be highly practical and feasible today:
  – Work with rejuvenator supplier on the appropriate dosage to produce higher RAP mixes with quality consistent with normally supplied mix designs.
  – Step up RAP QC frequency.
• Implementation of high RAP + Rejuvenator in agency “spec” mixes requires a framework that provides transparency and reliability for all stakeholders.
• Designing a high performance HMA with rejuvenation is a 4-step process:
  – Step 0: Rejuvenator characterization and quality control (supported by supplier)
  – Step 1: Bitumen Design: Initial dosage determination based on rheology
  – Step 2: Balanced Mix Design (BMD) using performance-related tests to optimize and select design parameters.
  – Step 3: Robust QC/QA protocol to be followed for all material.