Evaluating Impact of Warm Mix Asphalt Production

How Lower Temperatures Improves Asphalt Binder & Mix Performance
Agenda

- Sustainability & Durability
- WMA Economics and CO$_2$ reduction
- Binder Aging
- Binder Service life
- Long-term binder performance
  - Binder blend comparison
- Field Mix Evaluation
Acknowledgements

- Dennis Muncy, Binder Formulations Chemist at Ingevity, whose binder work is the basis of this presentation
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- Lincoln Beard, Rebekah Way and Bill Criqui, Ingevity, who generated the binder and mix samples and performance data
TODAY’S TECHNOLOGICAL IMPERATIVES

- SUSTAINABILITY

- Reducing waste and re-usability
- Asphalt Institute Foundation
  - Improved Durability
- Europe
  - Zero Odors
  - Higher Recycled Content (RAP, Plastics)
  - Circular Economy
- Greater Asphalt Pavement Sustainability
GREATER SUSTAINABILITY

Positive
Economic and Technological Advancement

Negative
Environmental and Societal Impacts
For a given load & axle configuration, velocity spectrum, under the expected range of climate conditions, the layers of a well-designed, well-constructed pavement will show superior service life using more durable (low rutting, crack- & moisture-resistant) bitumen and mix formulations.
GREATER SUSTAINABILITY

Positive
Economic and Technological Advancement

Negative
Environmental and Societal Impacts

Asphalt Industry Is Good at
Materials Selection and Mixture Design
Production/Construction, Preservation, Maintenance, Rehabilitation, End-of-Life

Needs for Greater Sustainability
Durability, Longer Life
Lower Environmental Impact (Less Emissions, Less Fuel, More Recycling)
Need Alternative Delivery Systems (versus adversarial low bid)
Economic Benefit of Chemical WMA

Mix Component

$100.00
$1.20

$-0.35
$-0.35

$-0.60
$-0.40

$-0.35
$-0.05

$-0.05

$97.05
$-2.00

$90.00
$92.00
$94.00
$96.00
$98.00
$100.00
$102.00

HMA
ADDITIVE
FUEL CONSUMPTION
NO LIME
LESS AC ADSORBED
10% HIGHER RAP
BETTER COMPACTION
DENSITY BONUS
EXTENDED SEASON
LONGER SERVICE LIFE
WMA

Increase
Decrease
Total
https://www.epa.gov/sites/production/files/2015

\[ \text{EF}_{\text{lime}} = 0.75 \text{ metric tons CO}_2/\text{metric ton of lime produced} \]
WARM MIX BENEFITS: Mass Loss Reduction with Temperature Decrease

![Graph showing the relationship between RTFO Aging Temperature (°F) and % Mass Loss, with a highlighted sweet spot.](image)
2 Types of Binder Aging

Short-Term “Spurt” Aging

- Time and Temperature
- Micron film thickness

In-Service Aging

- Aging varies with environmental conditions:
  - Temperature
  - Hrs of sunlight
  - Moisture exposure
Lab Tools Used to Simulate Aging

Short-term Aging
Rolling Thin Film Oven

AASHTO T240
Time – 85 min
Temperature 325 F (163 C)

In-service Aging
Pressure Aging Vessel

AASHTO R28
Time  20 Hrs
Temperature 100 C
Air pressure 305 psi
Screening neat asphalts

< 50 F reduced mass loss approx. 40%

Asphalt Binder Mass Loss

- PG 64-22 A
- PG 64-22 B
- PG 58-28 A

Warm mix sweet spot
Impact of Binder Aging Rate

Rate of Std RTFO stiffness change is 10 times greater than PAV aging rate

50 F lower RTFO reduces RTFO binder aging rate ~30%
Binder Service Life

Short Term Aging + Long Term (In-Service) Aging

In-service Aging
- Environment (Mother nature)
- Increase density – lower aging/improved durability

Short-term aging → Controllable?
Binder Service Life

Impact of Basic Short-Term Production Controls
- Mix design/Aggregate structure
- Binder grade
- AC content
- Volumetric properties such as In-place density, etc.

Impact of Short-term aging ➔ is this controllable?
- Reduce Production and Paving Temperatures
- Why cook off the “Goodies”
- What’s the impact of lower production temperatures?
Characterizing Binder Life

PG Grading System
- 1 PAV cycle (2 – 6 yrs service life depending on depth  Smith et al., TRB, 2018)
- Is this enough?

Time to Failure Criteria
Short Term Engineering Controls
- Vary RTFO Temps

In Service - Multiple PAV Cycles
- Extend PAV cycles to a failure criteria
## Binder Failure Performance Comparison

### Materials and Tests

<table>
<thead>
<tr>
<th>Binder Blend</th>
<th>RTFO Temp</th>
<th>PAV Conditioning, Hrs</th>
<th>PG Tc low</th>
<th>Delta Tc</th>
<th>Glover-Rowe Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 64-22</td>
<td>350 F (Std +25 F)</td>
<td>60</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PG 64-22</td>
<td>325F (Std)</td>
<td>60</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PG 64-22, 10% RAP ABR, 0.5% WMA</td>
<td>275 F (std – 50 F)</td>
<td>60</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>PG 64-22, 25% RAP ABR, 0.5% WMA</td>
<td>275 F (std – 50 F)</td>
<td>60</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Binder Performance after Extended Aging

20 Hr PAV = 2 – 6 yrs service life

WMA blends contained a EVOTHERM P25

Standard RTFO, 325 F
Warm Mix RTFO, 275 F  (50 F < Std)

• PG 64-22, RTFO 350 F, out of spec after 20 Hr PAV
• PG 64-22 w/ 10% RAP, RTFO 275 F, maintained -22 grade after 60 Hrs PAV

Standard PG Testing Ends Here
Binder Performance after Extended Aging

\[ \Delta T_c = T_{\text{cont}}^S - T_{\text{cont}}^\dagger \]

Standard RTFO, 325 F
Warm Mix RTFO, 275 F
(50 F < Std)

- Binder blends with EVOTHERM P25 show consistent Delta Tc

Standard PG Testing Ends Here
Binder Performance after Extended Aging

20 Hr PAV = 2 – 6 yrs service life

GRP < 180 kPa No Block Cracking
180 < GRP < 450 kPa Cracking Initiation Zone
GRP > 600 kPa Block Cracking

- Binder at 350 F (25F > std Temp) showed reduced PAV Hrs to GRP
- Binder blends w/ WM additive showed increased PAV Hrs to common GRP
Summary of Binder Testing

WMA Production temperatures in RTFO

- Reduce binder mass loss
  - Less binder waste
  - Less CO$_2$ produced
  - Less environmental impact

- Improved binder low temperature performance & fatigue cracking performance

- WMA temperatures can compensate for RAP binder stiffness & extend binder service life
Mixture Testing

HMA VS WMA MIX PERFORMANCE EVALUATION
Field Mix Evaluation 1

Mix Type
9.5 mm Mix
- PG 64-22S
- 40% RAP
- 0.3% MWA (EVOTHERM J1)
- 2.0% Rejuvenator (EVOFLEX CA-7)

Production Variable
- HMA 305 F
- WMA 275 F

Testing
- Hamburg Wheel Tracker – AASHTO T 324-17
- IDEAL CT – ASTM D8225
- Cantabro - AASHTO TP 108-14
HWT and IDEAL CT
Cantabro Testing

![Graph 1: Mean Loss (%) vs. Prod Date & Product Temp, F](image1)

![Graph 2: Mean Loss (%) vs. Product Temp, F](image2)

- Each error bar is constructed using 1 standard deviation from the mean.
Field Mix Evaluation 2

Mix Type
9.5 mm Mix
- PG 58-28
- 40% RAP
- 0.3% MWA (EVOTHERM J1)

Production Variable
- HMA 305 F
- WMA 275 F

Testing
- Hamburg Wheel Tracker – AASHTO T 324-17
- IDEAL CT – ASTM D8225
HWT and IDEAL CT

**Graph:**
- **Title:** Rut, mm @ 20k Pass vs. CT Index, Avg
- **Axes:**
  - Y-axis: Rut, mm @ 20k Pass
  - X-axis: CT Index, Avg
- **Legend:**
  - Prod Temp, F: 275
  - Prod Temp, F: 305
- **Data Points:**
  - Row 1:
    - CT Index, Avg: 103.300
    - Rut, mm @ 20k Pass: 3.050
    - Prod Temp, F: 275
  - Row 2:
    - CT Index, Avg: 76.300
    - Rut, mm @ 20k Pass: 2.470
    - Prod Temp, F: 305
- **Legend Colors:**
  - Red circle for 305
  - Green circle for 275

**Color Key:**
- Unacceptable: Red
- Dense Graded: Green
- SuperPave: Blue
- SMA: Brown

**Legend Phrases:**
- Rut, mm @ 20k Pass
- CT Index, Avg
- Prod Temp, F
Use Warm Mix and Lower Production Temperatures!

Don’t Cook off the “Goodies”

Questions?