EVALUATION OF WARM MIX ASPHALT PERFORMANCE 2007 TO PRESENT BASED ON FIELD PERFORMANCE AND LABORATORY INVESTIGATION

BY
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MTE SERVICES, INC
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WARM MIX CONCERNS—MECHANISTIC PROPERTIES

- Potential for premature rutting due to reduced binder stiffness
- If the mix does not rut does that mean that warm mix is aging in the field at a faster rate than traditional HMA?
- If WMA ages at a faster rate than HMA, is there a long term benefit to WMA?
- Does greater use of RAP in WMA ultimately yield a mix that will exhibit greater thermal and fatigue cracking potential?
- What methods are available to investigate the above concerns
WARM MIX CONCERNS-ALTERNATE CONSIDERATION

- May not be that WMA mechanistic properties are low
- Mechanistic properties for HMA may be overstated
- What tools exist to compare performance of WMA to HMA
OBJECTIVES

INVESTIGATE & COMPARE MECHANISTIC PROPERTIES OF WELL PERFORMING WMA & HMA CONTROLS TO:

1. Show why pavements are performing
2. Provide investigate testing approaches to evaluate performance of WMA
3. Focus on issues with extraction and testing of binders recovered from RAP mixes
4. This will not be a “we produced some warm mix and here are the pictures of what the road looks like” discussion
MIXES TO BE STUDIED

• Approximately 4 years old
  – Middle Aged as Warm Mixes
  – All performing well
  – If not rutted now-most likely won’t
  – What can we learn from these mixes about why they have performed

• Most use PG 58-28, one PG 64-22 reported here

• All used RAP
  – Low of 12%
  – High of 40%
MIX TESTING PERFORMED

• Hamburg Rut Testing
  – Dry at 58°C for permanent deformation
  – Wet at 50°C for moisture sensitivity

• DSR test of recovered binder
  – 4 mm plate geometry
  – Determine binder stiffness -40°C to +60°C

• Overlay Tester for fatigue failure behavior

• Testing of mixture torsion bars on DSR
  – Determine mixture complex modulus (G*) mastercurves
  – Determine mixture relaxation modulus
  – Calculate mixture fatigue characteristics
PROJECTS STUDIED

• Approximately 4 miles on Olmsted County 104
  – July 2007
  – PG 58-28 + 12% RAP in mix
  – Used surfactant solution injection technology
  – HMA mixed ≈285°F, paved at ≈270°F
  – WMA mixed <=235, paved <=220°F
## Recovered Binder Properties for Olmsted Cty, MN Warm Mix Project

<table>
<thead>
<tr>
<th>Mix Source (note 1)</th>
<th>High PG Grade</th>
<th>Low PG Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2007, PAV recovered WMA, no PAV</td>
<td>PG 58.6</td>
<td>PG -31.4 (m = -33)</td>
</tr>
<tr>
<td>Cores October 2008 (1 yr old) HMA control, as recovered no PAV. Entire lift extracted</td>
<td>PG 62.6</td>
<td>S = PG -31.5, m = -35.2</td>
</tr>
<tr>
<td>Cores October 2008 (1 yr old) WMA as recovered no PAV. Entire lift extracted</td>
<td>PG 62.0</td>
<td>S = PG -34.8, m = -36.0</td>
</tr>
<tr>
<td>Cored April 2011 ≈3.5 yr old) HMA Control as recovered no PAV. L1 =top 12 mm, L2=2nd 12 mm</td>
<td>L1 PG 72.6</td>
<td>L1 = PG -32.3, m = -34.0</td>
</tr>
<tr>
<td></td>
<td>L2 PG 70.2</td>
<td>L2 = PG -32.4, m = -34.0</td>
</tr>
<tr>
<td>Cored April 2011 ≈3.5 yr old) WMA as recovered no PAV. L1 =top 12 mm, L2=2nd 12 mm</td>
<td>L1 PG 70.1</td>
<td>L1 = PG -29.3, m = -30.1</td>
</tr>
<tr>
<td></td>
<td>L2 PG 66.0</td>
<td>L2 = PG -30.6, m = -33.9</td>
</tr>
</tbody>
</table>
Compare Olmsted Cty HMA & WMA Modulus at Year One

$G^*$ Compare WMA & HMA for Olmsted Cty 104 built July 2007, cored Oct 2008

- MasterCurve Olmsted Hot mix control, 58-28 + 12% RAP L2 @ 58°C ref temp
- MasterCurve Olmsted Warm mix 58-28 + 12% RAP L2 @ 58°C ref temp

$G^*$ [Pa]

$\omega$ [rad/s]

1 YR HMA MIX

1 YR WMA MIX
COMPARE LAYER ONE COMPLEX MODULUS (G*) MASTERCURVES @ +20°C FOR
OLMSTED CTY HMA & WMA MIXES @ ~4 YEARS

- Mastercurve 04-22-11-M, 1st layer of Olmsted Cty HMA 4 years old @ 20°C reference temp
- MASTERCURVE Proj 1222, 1st layer Olmset Cty WMA 4 years old @ 20°C reference temp

\[ |G^*| (\text{Pa}) \]

\[ \text{ang. frequency (rad/s)} \]

4 YR HMA MIX

4 YR WMA MIX
COMPARE LAYER TWO COMPLEX MODULUS (G*) MASTERCURVES @ +20°C FOR OLMSTED CTY HMA & WMA MIXES @ ≈4 YEARS

-Mastercurve 04-22-11-Q, OLM 104 L2 WMA @ 20°C reference temp
-Mastercurve Proj 1222, Olmsted Cty 2nd layer HMA @ 20°C reference temp
Compare Mixture Relaxation Moduli for Olmsted Cty 104 HMA & WMA Mixes
Layer 2 PG 58-28 + 12% RAP

Mix placed in July 2007, the data presented in this plot is from cores taken in April 2011

**Model Details:**
- **Red Line:** MODEL: G(T) @ -28C Proj 1222, 04-22-11-N, L2 HMA #2o exp
- **Green Line:** MODEL: G(t) @ -28C 04-22-11-Q, OLM 104 L2 WMA, #1
- **Purple Line:** MODEL: G(t) @ -28C 04-22-11-Q, OLM 104 L2 WMA, #3o
- **Blue Line:** Reduced time = 7200 sec
Construct the July 2007, these data taken from cores of April 2011

S is a measure of internal mix fatigue damage and C is a measure of mixture cycles to fatigue failure. A C value of 0.5 is considered a failure point.
PROJECTS STUDIED

• Approximately 1 lane mile WI STH 33, La Crosse County
  – Sept 2007
  – PG 58-28 + 20% RAP, new subgrade, 1 million ESAL mix
  – Used surfactant chemistry added directly to asphalt
  – HMA mixed ≈285°F, paved at ≈270°F
  – WMA mixed 225-230°F, paved at 210-220°F
## RECOVERED BINDER PROPERTIES FROM STH 33 HMA & WMA MIXES

<table>
<thead>
<tr>
<th>Mix Source</th>
<th>High PG Grade</th>
<th>Low PG Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>WI Hwy 33 HMA at 1 year (top lift recovered)</td>
<td>PG 60.5</td>
<td>PG -35.2</td>
</tr>
<tr>
<td>WI Hwy 33 WMA at 1 year (top lift recovered)</td>
<td>PG 58.9</td>
<td>PG -36.3</td>
</tr>
<tr>
<td>WI Hwy 33 HMA at 3 years (top lift recovered)</td>
<td>PG 68.0</td>
<td>PG -31.4</td>
</tr>
<tr>
<td>WI Hwy 33 WMA at 3 years (top lift recovered)</td>
<td>PG 65.5</td>
<td>PG -32.6</td>
</tr>
<tr>
<td>WI Hwy 33 HMA at 3.5 years (data from top two 12 mm mix layers)</td>
<td>PG 70 to 67.5</td>
<td>PG -29.8 to -30.2</td>
</tr>
<tr>
<td>WI Hwy 33 WMA at 3.5 years (data from top two 12 mm mix layers)</td>
<td>PG 70.1 to 67.5</td>
<td>PG -31.0 to -30.0</td>
</tr>
</tbody>
</table>
Torsion Bar |G*| Results At 20°C Ref Temp 3 Year Mix Top 12 mm for STH 33

RESULTS OBTAINED FROM DSR TORSION BAR TESTING OF TOP 12 mm 2010 CORES
Torsion Bar $|G^*| \text{ Results At } 20^\circ\text{C Ref Temp 3 Year Mix 2}\text{nd} \ 12 \text{ mm for STH 33}$
Compare Mixture Relaxation Moduli for WI Hwy 33 HMA & WMA Mixes L2 PG 58-28 + 20% RAP

Model: G(t) @ -28C 04-22-11-T, Hwy 33 L2, HMA run #1

Model: G(t) @ -28C 04-22-11-W, Hwy 33 L2 WMA run #1

Reduced Time = 7200 sec
C Versus S Comparison for Layer 2 of WMA & HMA Sections on WI HWY 33 in La Crosse County (PG 58-28 +20% RAP)

S is a measure of internal mix fatigue damage and C is a measure of mixture cycles to fatigue failure. A C value of 0.5 is considered a failure point.

Proj 1222, 04-22-11-W, Hwy 33 L2 WMA, 20° Time Sweep, 600 kPa, AR3-0002o
Proj 1222, 04-22-11-T, Hwy 33 L2 HMA, 20° Time Sweep, 600 kPa, AR3-0002o
Proj 1222, 04-22-11-W, Hwy 33 L2 WMA, 20° Time Sweep, 900 kPa, AR3-0002o
Proj 1222, 04-22-11-W, Hwy 33 L2 WMA, 20° Time Sweep, 900 kPa, Run #1
PROJECTS STUDIED

• Test section on I-90 La Crosse County, WI 2009
  – June 2009
  – PG 64-22 virgin mix
  – Used surfactant chemistry added directly to asphalt
  – HMA mixed \( \approx 285^\circ F \), paved at \( \approx 270^\circ F \)
  – WMA mixed \( \leq 235^\circ F \), paved \( \leq 220^\circ F \)
Comparision of $E^*$ Stiffness between Replicates at 40°C for HMA & WMA Mixes Placed on I-90 in June 2009

- Blue line: Warm mix - Average of the three
- Red line: Hot mix - Average of the three

Frequency (Hz) vs. $E^*$ (MPa)
Mix Type, I-90, 30 million ESAL virgin mix using PG 64-22 | PG Grade of recovered binder at time of construction in 2009
---|---
HMA | PG 69.4-30.4
WMA | PG 62.2-33.0
PROJECTS STUDIED

• **CONTROLLED OUTDOOR AGING OF FIELD PRODUCED WARM MIX**
  - County Highway in September 2008
  - PG 58-28 + 25%, 35% and 45% RAP in different locations
  - Used surfactant chemistry added directly to asphalt
  - HMA mixed ≈285°F, paved at ≈270°F
  - WMA mixed <=235, paved <=220°F
  - Large quantity of 35% RAP mix returned to lab, compacted into test specimens and put outside to condition for 2+ years
  - Samples periodically removed from aging table, tested for mix characteristics and binder properties.
PLT 5 WARM MIX TIME STUDY PG 58-28 + 0.65% EVOTHERM 3G
TESTED IN HAMBURG DRY AT 58.3°C, 158# LOAD
PLANT MIX CONDITIONED OUTSIDE FROM 9/19/08 TO ONGOING

RUT CYCLES AT 58.3°C & 158 LBS (703 N)

RUT DEPTH IN mm
RUT TEST PLANT 5 WMA HAMBURG RUT TESTING 12, 20 & 24 MO AGED OUTSIDE--TESTED @ 58°C

RUT PASSES AT 58°C AND 158 LBS (702 N)

- average RUT DEPTH @ 24 mo
- AVERAGE RUT TEST 20 mo
- AVERAGE RUT DEPTH @ 12 mo
Comparision of Stiffness at Increasing Aging Times at 40°C

Frequency (Hz)

E* (MPa)

- Unaged (pills 1-4 to 1-6)
- 1 month aged
- 4 month aged
- 9 month aged
- 12 month aged
- 24 month aged

24 mo
% Strain vs. Time Comparison (flow comparison at 52°C) 69 kPa confining pressure

- 9, 12, 24 month 800 kPa
- 12 month 600 kPa
- 9 month 600 kPa
- 24 month 600 kPa
- 9 month 400 kPa
- 12 month 400 kPa
- 24 month 400 kPa

# of cycles (1 cycle/sec)

0.0 1.0 2.0 3.0 4.0 5.0

% Strain

0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000

9, 12, 24 month 800 kPa
12 month 600 KPa
9 month 600 KPa
24 month 600 KPa
9 month 400 KPa
12 month 400 KPa
24 month 400 KPa

MTE
Mathy Technology and Engineering Services
Compare G* Results for 2 year field core and 24 month outdoor conditioned sample.
RELAXATION MODULUS, G(t) in Pa

REDUCED TIME, sec's

MODEL: G(t) @ -28C Plt 5 Warm Mix, aged 2 year outdoor, Rec AC, 4mm
ARES all isotherms

MODEL: G(t) -28C Plt 5 WMA, CTH X, 2 yr Core 5, 35% RAP, 11-19-10-R,
ARES -28

REDUCED TIME = 7200 SECONDS
<table>
<thead>
<tr>
<th>AGE</th>
<th>PG GRADE RECOVERED AC</th>
<th>PG GRADE PAV OF REC AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZERO DAY</td>
<td>65.1-33.4</td>
<td>65.1-30.4</td>
</tr>
<tr>
<td>ZERO DAY</td>
<td>66.2-33.0</td>
<td>66.2-29.9</td>
</tr>
<tr>
<td>2 WEEK</td>
<td>68.1-32.1</td>
<td>68.1-29.4</td>
</tr>
<tr>
<td>7 MONTH</td>
<td>68.8-32.1</td>
<td>No PAV performed</td>
</tr>
<tr>
<td>9 MONTH</td>
<td>69.5-31.9</td>
<td>No PAV performed</td>
</tr>
<tr>
<td>12 MONTH</td>
<td>69.5-31.6</td>
<td>69.5-28</td>
</tr>
<tr>
<td>14 MONTH</td>
<td>70.1-31.1</td>
<td>70.1-28.4</td>
</tr>
<tr>
<td>24 MONTH</td>
<td>72.9-30.3</td>
<td>72.9-28.8</td>
</tr>
</tbody>
</table>
Compare Mastercurves Plant 5 Field Core with 25%, 35%, 45% RAP, Top 12 mm Layer Temp-Freq Sweep at 20°C reference temp

ALL FIELD CORES 2 YEARS OLD
Compare MASTERCURVEs Plant 5 Field Cores 2 year old with 25%, 35%, 45% RAP
20°C reference temp
Compare MasterCurve Plt 5 WMA, CTH X, 2 YR OLD FIELD CORE, 25%, 35%, 45% RAP REC AC @ +20°C
CONCLUSIONS

1. WMA & HMA recovered binders from mixes containing RAP have similar PG properties after 3 – 4 years

2. Mixture mechanistic test properties do not necessarily support these findings
   ✓ Similar binder properties of recovered WMA & HMA mixes does not necessarily mean these mixes have the same properties

3. Complex shear modulus, repeated creep, relaxation modulus tests, and VECD fatigue tests can be performed on a DSR using torsion bar samples that will provide comparative characteristics of field produced mixes without the need for binder recovery
QUESTIONS
COMMENTS

CONTACT INFORMATION
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