Team members

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Their efforts on the projects and presentation are greatly appreciated.
FHWA MATT Program

- Mobile Asphalt Testing Trailer (MATT)
- AASHTO Accredited
- Superpave™ Technology
  - Test
  - Evaluate
  - Refine
  - Improve
  - Implement
FHWA MATT’s Involvement

- Address National Pavement Issues
  - Interaction with Transportation Partners
    - FHWA Division Offices and Resource Center
    - State DOTs and Industry
    - ETG’s and TWG’s
  - Technical Support on National Initiatives
    - Hot Mix Asphalt (HMA)
    - Warm Mix Asphalt (WMA)
    - Reclaimed Asphalt Pavement (RAP)
    - Reclaimed Asphalt Shingles (RAS)
    - Ground Tire Rubber (GTR)
  - Pavement ME™ (Previously Mechanistic-Empirical Pavement Design Guide)
Outline

• Challenges of GTR Modified Binder testing
  – Aging (Conditioning)
  – Rotational Viscosity testing
  – DSR testing

• Effect of GTR Modification on Asphalt Binder
  – Master Curve
  – Performance Grade M332
  – Viscosity
  – Low Temperature properties and performance

• Summary of Findings
Challenges

• National discussions of GTR modified binder testing
  – Aging: RTFO & Long Term conditioning
  – Adequate temperature equilibrium time
  – DSR testing: Different gap sizes, Concentric Cylinder testing
• **Project Location:**
  - Pennsylvania

• **Plant produced WMA mixtures containing Ground Tire Rubber (GTR)**

• **Binders**
  - **Base:** PG 64-22 + Evotherm 3G (0.5% Wt. of Binder)
  - **GTR modified (Full Reaction)**
    
    \[ \text{PG 64-22} + 0.5\% \text{ Evotherm} + 15.9\% \text{ GTR} \]
• GTR
  – MEI 20-80: the ambient temperature grinding process.

<table>
<thead>
<tr>
<th>Sieve Size (mm)</th>
<th>Percent Passing (%)</th>
<th>PennDOT Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.36 (No. 8)</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>1.18 (No. 16)</td>
<td>100</td>
<td>90-100</td>
</tr>
<tr>
<td>0.6 (No. 30)</td>
<td>74.3</td>
<td>25-100</td>
</tr>
<tr>
<td>0.3 (No. 50)</td>
<td>16.1</td>
<td>0-45</td>
</tr>
<tr>
<td>0.15 (No. 100)</td>
<td>1.2</td>
<td>-</td>
</tr>
<tr>
<td>0.075 (No. 200)</td>
<td>0.0</td>
<td>0-5</td>
</tr>
</tbody>
</table>
Short-term Conditioning

• Difficult to prepare RTFO-aged specimens
  – Material creeps out of RTFO bottles
  – Dripping on the heating elements
    Bottles were not fully coated

• Difficult to prepare GTR specimens for DTT and ABCD
Changes to the procedure

• Modification to current procedure
  – Heating the glasses after pouring binder in them
    Tilting the RTFO oven by $+1^\circ$ from the horizontal (upwards by 6.5mm thick in the vertical direction): $\pm 1^\circ$ tolerance in AASHTO T 240
  – Material didn’t creep out of bottles and mass loss was determined.
  – Questionable conditioning due to material pooling toward bottom of bottle.
Rotational Viscosity Results

Original binder at 175°C

- Viscosity keeps changing throughout the test due to temperature fluctuations.
- Constant binder stirring/agitation using paddle mixer, sample temperature stabilized.
Example Video
Recommendation

- Compared to the conventional asphalt binders, the GTR materials should be handled appropriately with careful attention to reheating, conditioning, and testing.

- GTR evaluation should include gradation (particle sizes), distribution, and procedures to prevent settlement/segregation.

- Trimming is not a trivial when testing GTR samples in parallel plate geometries.
Project Description - 2014

• Project Location:
  – New Jersey

• Plant produced WMA mixtures containing GTR and RAP:
  – Portable blending plant for GTR modification (wet process)

• Fabrication of Specimens
  ✓ Pre-blend Samples
  ✓ 163 °C for 1.5 hours. (Stirring)
Materials - Binders

• Binder
  – Base: PG 64-22 + Evotherm 3G (0.5% Wt. of Binder)
  – PMLC 1 (Reaction for 24 hours)
    PG 64-22 + 0.5 % Evotherm + 20 % GTR
  – PMLC 2 (Reaction for 24 hours)
    PG 64-22 + 0.5 % Evotherm + 20 % GTR
  – PMLC 3 (Reaction for 48 hours)
    PG 64-22 + 0.5 % Evotherm + 20 % GTR
• DSR
  – 25 mm Parallel Plate
  – 1 mm vs. 2 mm Gap Setting

*** These values are not absolute:
  – Testing geometry and particle size effects
  – RTFO issues
PG Results: 1 vs. 2 mm gap

PMLC 1 – Original binder

- Same PG grade
- Some noticeable differences in phase angle
- Similar results overall
PG Results: 1 vs. 2 mm gap

*PMLC 1 – RTFO binder*

- Same PG grade
- Lower $G^*/\sin\delta$ and phase angle for 1mm
- Similar results overall
MSCR Results: 1 vs. 2 mm gap

PMLC1 – RTFO binder

- 2mm gap size -> higher $J_{nr}$ and lower percent recovery values.
- Differences may vary based on the stress level or test temperature
- Similar M 332 grade
• DSR PG Testing
  – Differences observed between the two gap sizes with parallel plate geometry.
  – Increasing the gap resulted in an increase of the phase angle values.
  – Testing with a 2mm gap size resulted in a more viscous-like response.
  – The difference in phase angle between the two gap sizes increased with increasing test temperature.
GTR Modification Effect

• Critical Properties

  – Rheological behavior (Master Curve)
  – Rutting resistance (MSCR)
  – Low temperature performance
Master Curve

Reference Temp: 21.1 C

- Effect on low and high temperature behavior.
- Improvement in temperature susceptibility.
- Different shape for phase angle.
MSCR

RTFO binders

- GTR modification improved base binder rutting resistance at wide range of high temperatures.
- GTR modified binders’ exhibit higher recovery values.
### Low Temperature Properties

**PAV binders**

<table>
<thead>
<tr>
<th>Binder ID</th>
<th>AASHTO M320</th>
<th>Critical Low Cracking Temperature (°C)</th>
<th>ABCD Cracking Temperature</th>
<th>ABCD Cont. Low Temperature Grade</th>
<th>ABCD Cont. PG Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M320 T1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M320 T2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>M320 T1 Continuous</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG Grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG 64-22 base binder</td>
<td>PG 64-28</td>
<td>PG 66.1-29.1</td>
<td>-26.8</td>
<td>-32.6</td>
<td>-26.3</td>
</tr>
<tr>
<td></td>
<td>PG 64-22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC 1</td>
<td>PG 88-28</td>
<td>PG 91-29.9</td>
<td>-28.7</td>
<td>-41.2</td>
<td>-33</td>
</tr>
<tr>
<td></td>
<td>PG 88-28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC 2</td>
<td>PG 88-28</td>
<td>PG 92.2-29.5</td>
<td>-29</td>
<td>-41.9</td>
<td>-33.6</td>
</tr>
<tr>
<td></td>
<td>PG 88-28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PMLC 3</td>
<td>PG 88-28</td>
<td>PG 91.3-29.8</td>
<td>-29.3</td>
<td>-41.9</td>
<td>-33.6</td>
</tr>
<tr>
<td></td>
<td>PG 88-28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Base binder measured the lowest cracking temperature (warmer) when compared to GTR modified binders.
- GTR modification can improve low temperature performance of asphalt binder.
- Compared to the M 320 Table 2 test method, the ABCD test method resulted in a colder cracking temperature.
Summary of Findings II

- GTR modification has an effect on viscoelastic behavior of base asphalt binder.

- Phase angle master curve of asphalt binder altered by GTR modification.

- Introducing GTR to asphalt binder not only improving rutting resistance, it may also have positive effect on low temperature performance and properties.

- Elasticity of base binder improved by using GTR as an modifier.
• Project Location:
  – Arizona

• Open Graded Friction Course (OGFC) mixtures:
  – Three different Terminal blended Asphalt Rubbers
  – Hybrid Binders: GTR + SBS
    ✓ PG70-22 TR+ (contains 8 % of GTR)
    ✓ PG70-22 TR+ SBS (8 % GTR + 2 % SBS; solubility limit of 97%)
    ✓ PG70-22 TR+ S92 (8 % GTR + 2 % SBS; solubility limit of 92%)
• Topics investigated in this project
  – Solubility
  – DSR testing: gap size effect
  – Long term conditioning
Solubility – AASHTO T 44

- UW-Madison MARC have proposed changes to the standard
  - Use of toluene as the solvent
  - The addition of an analytical filter: To increase the filter area and reduce the potential for the fiberglass filter to become clogged during testing

- Analytical Filters used in this study
  - Celite
  - Diatomaceous Earth (DE)
Solubility

- Use of toluene as the solvent
- The addition of an analytical filter
- Some differences in solubility
Solubility

Analysis of Variance

<table>
<thead>
<tr>
<th>Solubility Test Variation</th>
<th>PG 70-22 TR+</th>
<th>70-22 TR+ (S 92)</th>
<th>PG 70-22 (SBS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toluene</td>
<td>Not significant</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>Toluene + Celite 505</td>
<td>2.47 % lower</td>
<td>Not significant</td>
<td>0.52 % lower</td>
</tr>
<tr>
<td>Toluene + Diatomaceous Earth</td>
<td>1.16 % lower</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
</tbody>
</table>

– Compared to Standard Method, AASHTO T 44.
– Not a statistically significant difference using toluene compared to trichloroethylene.
– The differences in solubility when using an analytical filter aid were 0.5 to 2.5 percent: significant considering solubility is normally specified to the nearest 0.1 percent!
### DSR PG Results: 1 vs. 2 mm gap

**PG 70-22 TR+ (S 92) – Original binder at 76 °C**

<table>
<thead>
<tr>
<th>Item</th>
<th>1 mm gap Complex Modulus, (kPa)</th>
<th>1 mm gap Phase Angle, (°)</th>
<th>2 mm gap Complex Modulus, (kPa)</th>
<th>2 mm gap Phase Angle, (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate 1</td>
<td>1.52</td>
<td>58.6</td>
<td>1.34</td>
<td>63.3</td>
</tr>
<tr>
<td>Replicate 2</td>
<td>1.59</td>
<td>60.2</td>
<td>1.34</td>
<td>63.3</td>
</tr>
<tr>
<td>Replicate 3</td>
<td>NA</td>
<td>NA</td>
<td>1.32</td>
<td>63.8</td>
</tr>
<tr>
<td>Average</td>
<td>1.55</td>
<td>59.4</td>
<td>1.33</td>
<td>63.5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.05</td>
<td>1.17</td>
<td>0.01</td>
<td>0.26</td>
</tr>
</tbody>
</table>

- For gap sizes of 1 to 2 mm: if there is an interaction of the particles with the testing plates ->
  ↑ gap : ↓ variability, ↓ the complex modulus, ↑ the phase angle.
- Lower G*/sinδ and phase angle for 1mm
- Similar results overall
DSR PG Results: 1 vs. 2 mm gap

*Statistical Analysis – Effect of 1mm increase in gap*

<table>
<thead>
<tr>
<th>Binder</th>
<th>Original Complex Modulus</th>
<th>RTFOT Complex Modulus</th>
<th>Original Phase Angle</th>
<th>RTFOT Phase Angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 70-22 TR+</td>
<td>Increases 0.04 kPa</td>
<td>Increases 0.07 kPa</td>
<td>Increases 0.63°</td>
<td>Zero difference</td>
</tr>
<tr>
<td></td>
<td>Not significant</td>
<td>Significant</td>
<td>Not significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>PG 70-22 TR+ (S 92)</td>
<td>Decreases 0.22 kPa</td>
<td>Increases 0.22 kPa</td>
<td>Increases 4.05°</td>
<td>Increases 1.90°</td>
</tr>
<tr>
<td></td>
<td>Significant</td>
<td>Significant</td>
<td>Significant</td>
<td>Not significant</td>
</tr>
<tr>
<td>PG 70-22 (SBS)</td>
<td>Increases 0.03 kPa</td>
<td>Increases 0.07 kPa</td>
<td>Decreases 0.03°</td>
<td>Decreases 0.11°</td>
</tr>
<tr>
<td></td>
<td>Not significant</td>
<td>Significant</td>
<td>Not significant</td>
<td>Not Significant</td>
</tr>
</tbody>
</table>

– Only PG 70-22 TR+ (S 92) original binder show effects consistent with particle interaction.

– When used to test binders modified with GTR, this gap may be too small to accommodate the rubber particles. Maybe using Concentric Cylinder as an alternative ?!
Long Term Conditioning

Low Temperature Cracking – PAV conditioning at 110 °C

<table>
<thead>
<tr>
<th>Asphalt Binder</th>
<th>PAV Cond Time, (hr)</th>
<th>AASHTO M 320 Table 1, (°C)</th>
<th>AASHTO M 320 Table 2, (°C)</th>
<th>ABCD, (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 70-22 TR+</td>
<td>20</td>
<td>-28.8</td>
<td>-29.5</td>
<td>-26.6</td>
</tr>
<tr>
<td>PG 70-22 TR+</td>
<td>40</td>
<td>-24.5</td>
<td>-24.8</td>
<td>-26.3</td>
</tr>
<tr>
<td>PG 70-22 TR+ (S 92)</td>
<td>20</td>
<td>-32.0</td>
<td>-31.8</td>
<td>-32.3</td>
</tr>
<tr>
<td>PG 70-22 TR+ (S 92)</td>
<td>40</td>
<td>-26.0</td>
<td>-26.7</td>
<td>-31.0</td>
</tr>
<tr>
<td>PG 70-22 (SBS)</td>
<td>20</td>
<td>-30.9</td>
<td>-29.7</td>
<td>-30.5</td>
</tr>
<tr>
<td>PG 70-22 (SBS)</td>
<td>40</td>
<td>-23.0</td>
<td>-27.8</td>
<td>-29.4</td>
</tr>
</tbody>
</table>

- Reasonable agreement between the three measurements for 20 hrs PAV conditioning.
- The ABCD is less sensitive than the other two tests to conditioning time.
- Doubling PAV time:
  - 0.9 °C ↑ of cracking temp (ABCD)
  - 6.1 °C ↑ of cracking temp (Table 1)
  - 3.9 °C ↑ of cracking temp (Table 2)
Long Term Conditioning

Intermediate grade & $\Delta T_c$

- The low temperature grade becomes much more m-value controlled for 40 hrs vs. 20 hrs PAV conditioning.
- The $\Delta T_c$ parameter dropped lower than -5.0 °C for the PG 70-22 TR+ (S 92) and the PG 70-22 (SBS) after 40 hrs PAV conditioning.
- These changes indicate that the in-service aging will likely be greater for the PG 70-22 TR+ (S 92) and PG 70-22 (SBS).

<table>
<thead>
<tr>
<th>Asphalt Binder</th>
<th>PAV Conditioning Time, (hr)</th>
<th>AASHTO M 320 Table 1 Intermediate Temperature Continuous Grade, (°C)</th>
<th>AASHTO M 320 Table 1 $\Delta T_c$, (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PG 70-22 TR+</td>
<td>20</td>
<td>20.7</td>
<td>0.4</td>
</tr>
<tr>
<td>PG 70-22 TR+</td>
<td>40</td>
<td>24.1</td>
<td>-2.7</td>
</tr>
<tr>
<td>PG 70-22 TR+ (S 92)</td>
<td>20</td>
<td>13.1</td>
<td>-3.1</td>
</tr>
<tr>
<td>PG 70-22 TR+ (S 92)</td>
<td>40</td>
<td>17.4</td>
<td>-6.9</td>
</tr>
<tr>
<td>PG 70-22 (SBS)</td>
<td>20</td>
<td>15.1</td>
<td>-1.6</td>
</tr>
<tr>
<td>PG 70-22 (SBS)</td>
<td>40</td>
<td>19.9</td>
<td>-8.4</td>
</tr>
</tbody>
</table>
Long Term Conditioning

Master Curve - PG 70-22 TR+ (S 92)

More conditioning causes the master curves to become flatter with R increasing and \( \omega_c \) decreasing.
After 40 h of PAV conditioning, all binders have Glover-Rowe parameters above the recommended limit for the onset of cracking.

The slope for these binders is about 5 kPa per hr of PAV conditioning over the first 20 hrs increasing to about 16 kPa per hr for 40 hrs PAV conditioning.
Summary of Findings

- **Solubility:** Toluene was found to be an acceptable alternative to Trichloroethylene as a solvent for solubility testing.

- **DSR testing:** Results indicate that particle interaction with the plates likely occurs when testing the PG 70-22 TR+ (S 92) using the parallel plate geometry.

- For extended PAV conditioning, binders becoming highly m-value controlled.

- **40 hr PAV** conditioning may better differentiate between different materials.
FHWA Field Support
Mobile Asphalt Testing Trailer (MATT)

- Mobile Asphalt Pavement Materials Lab
  - Site Visits
  - Field Data/Testing/Evaluation
  - Use/Demo Emerging Test Devices
  - POC: Matthew Corrigan
Thank You!!

FHWA’s Mobile Asphalt Testing Trailer
Office of Asset Management, Pavement, and Construction

www.fhwa.dot.gov/pavement/asphalt