A Performance-Driven Laboratory Evaluation of Stone Matrix Asphalt Mixture

Mobile Asphalt Testing Trailer Program (MATT) Long-Life Asphalt Pavements for the 21st Century

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Outline

- Background
- Asphalt Mixture Performance Tester (AMPT)
- Mixture Performance Testing
- SMA Project
- Test Results & Discussions
- Takeaways
- Questions
AASHTO: American Association of State Highway and Transportation Officials
ABCD: Asphalt Binder Cracking Device
ABTL: Asphalt Binder Testing Laboratory
AIMS: Aggregate Imaging System
AMPT: Asphalt Mixture Performance Tester
BBR: Bending Beam Rheometer
CAA: Coarse Aggregate Angularity
CC: Concentric Cylinders
DSR: Dynamic Shear Rheometer
DTT: Direct Tension Tester
ETG: Expert Task Group
Gmb: Bulk Specific Gravity
GTR: Ground tire rubber
HMA: Hot mix asphalt
HQ: Headquarters
MATT: Mobile Asphalt Testing Trailer
MSCR: Multiple Stress Creep and Recovery
PAV: Pressure Aging Vessel
PEMD: Performance-Engineered Mixture Design
PG: Performance Grading
PRS: Performance Related Specification
QA: Quality Assurance
RAP/RAS: Reclaimed Asphalt Pavement/Reclaimed Asphalt Shingles
RTFO: Rolling Thin-film Oven
RV: Rotational Viscometer
SSR: Stress Sweep Rutting
TFHRC: Turner-Fairbank Highway Research Center
WMA: Warm Mix Asphalt

Note: FHWA does not endorse products or manufacturers. Trade or manufacturers’ names appear in this presentation solely for informational purposes.
Pavement & Materials Discipline

- **Program Office**
  - Office of Preconstruction, Construction, and Pavements (FHWA HQ, Washington, DC)
    - Mobile Asphalt Testing Trailer (MATT)
    - Asphalt Binder Testing Laboratory (ABTL)

- **Research and Development**
  - TFHRC (McLean, VA)

- **Technical Services**
  - Resource Center

- **Divisions**
Program Objective

- Provide Support to National Initiatives
  - Performance-Engineered Mixture Design (PEMD)
  - Increased Pavement Density
  - Development of New QA Concepts for HMA
  - Understanding Asphalt Rubber Testing
  - Binder Performance Testing

- Provide Assistance with State-specific Issues
  - Technical Guidance
  - Forensics
Field Visit Tasks

- Kickoff meeting
- Open house
- Hands-on training
- Mix design replication
- Shadow QA testing
- AMPT testing
- Binder grading
- Binder performance testing
Mixture Activities
Mixture Production Testing

Asphalt Mixture Sample

Volumetric Properties
- $P_b$ – Ignition (T 308)
- Gradation – (T 30)
- $G_{mm}$ – Rice (T 209)
- $G_{mb}$ – (T 166)
  - Corelok (T 331)
  - Gilson SG 4 (TP 82)

Performance Testing
- Dynamic Modulus (T 378)
  - Unconfined
- Flow Number (T 378)
  - Confined
- Unconfined
- Cyclic Fatigue (TP 107)
- Stress Sweep Rutting (SSR)
Asphalt Mixture Performance Tester (AMPT)
Performance Characteristics

- Asphalt Mixture Performance Tester

*Image: IPC Global*
AMPT – Addressing a Need

- **Late 1980s-Early 1990s: Strategic Highway Research Program**
  - Superpave mixture design approach
  - Performance grade binders
  - No viable performance tests for mixture

- **National Cooperative Highway Research Program**
  - 9-19: Identify simple performance tests for Superpave (rutting, fatigue)
    - Dynamic modulus, flow number, flow time
  - 9-29: Produce test methods and prototype, conduct ruggedness and interlaboratory studies
    - Simple Performance Tester (now known as AMPT) was born!
Deployment Status: AMPT

- Advancement of performance-engineered mixture design as support for TFHRC Shadow Projects
  - ME, MD, MO, NE (2017)
  - FHWA Western Federal Lands Highway Division (WFLHD), so far... (2018)
- Transition to small specimen testing and standard refinement
- Training – OK, MD, MO, VT, CT, NY since December 2016
  - Resulting in shadow projects for MD, MO
- Other States have expressed that they are moving in the direction of the AMPT due to MATT visits
AMPT

- Servo-hydraulic loading machine
- Temperature range from 4° to 70°C
- Computer-controlled device
  - Software built-in for various test procedures
- Fundamental tests
  - Stress and strain modeling
  - “Bulk testing”
  - Pavement ME
- Kits available for other tests
Performance Testing

- **AASHTO T 378 (former TP 79)**
  - Dynamic Modulus
    - Mixture Stiffness
    - Rutting
    - Fatigue Cracking
  - Flow Number
    - Rutting

- **AASHTO TP 107**
  - Cyclic Fatigue
Dynamic Modulus Test

- Mixture Stiffness
- Rutting
- Fatigue Cracking

\[ \sigma_0 \quad \epsilon_0 \]

\[ \frac{T_l}{T_p} \]

\[ |E^*| = \frac{\sigma_0}{\epsilon_0} \]

\[ \phi = \frac{T_l}{T_p} (360^\circ) \]
Flow Number Test

- Uniaxial repeated load test in which a HMA cylinder is repeatedly axially loaded and cumulative permanent deformation as a function of number of load cycles is measured
  - Lower laboratory flow numbers correspond to greater permanent deformation in field
  - Confined test provides better predictive abilities than unconfined

PG 58-22  PG 64-22
Flow Number

- Repeated Load Test – AASHTO T 378
  - 0.1 sec. load, 0.9 sec. rest
  - Unconfined (87 psi)
  - Confined (87 psi, 10 psi)
Flow Number Test Setup

Images: North Carolina State University
AMPT Cyclic Fatigue

- Fundamental, repeated loading test
  - Based in sound engineering principles, not empirical
  - Direct tension
- AASHTO TP 107-14 Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
  - $|E^*|$ Linear Viscoelastic (LVE) Test
  - $|E^*|$ Dynamic Modulus (Finger Print) Test
  - A typical mid-specimen failure
  - Predicted Nf & Failure properties
Test Procedure

- Controlled strain cyclic tension test
  - pull-pull load test
  - A constant frequency of 10 Hz
  - Temperature is based on Intermediate Grade (TP 107)
- Failure is determined by a sharp decrease in phase angle

![Graph showing phase angle vs. number of cycles]
AMPT Cyclic Fatigue Advantages

- Standard sample preparation
- AASHTOWare Pavement ME compatible
- Ruggedness, precision and bias underway
- Spreadsheet analysis & formulation available
- Predicts performance
- Material behavior across all possible loading conditions
SMA Project
Project Description

- Stone Matrix Asphalt (SMA) or gap graded mixtures
  - 12.5 mm hot mix asphalt (HMA)
  - 10-30 million equivalent single axle loads (ESALs)
  - Thickness of the SMA layer: 2 inches
  - Asphalt binder: PG 64E-22

- Design mix volumetric results

<table>
<thead>
<tr>
<th>Property</th>
<th>JMF Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Aggregate Bulk Specific Gravity (Gsb)</td>
<td>2.730</td>
</tr>
<tr>
<td>Optimum Binder Content, %</td>
<td>6.5</td>
</tr>
<tr>
<td>Maximum Specific Gravity (Gmm)</td>
<td>2.473</td>
</tr>
<tr>
<td>Design Air Voids</td>
<td>3.5</td>
</tr>
<tr>
<td>Voids in Mineral Aggregate (VMA)</td>
<td>18.2</td>
</tr>
<tr>
<td>Voids Filled with Asphalt (VFA)</td>
<td>80.9</td>
</tr>
<tr>
<td>Filler to Effective Asphalt Ratio</td>
<td>1.46</td>
</tr>
</tbody>
</table>
The gradations of the aggregates
- SMA 12.5mm mixture
**Dynamic Modulus Test**

- **|E*| Test Results**
  - PMLC4 and PMLC7 for both confined and unconfined dynamic modulus

<table>
<thead>
<tr>
<th>Temperature, °C</th>
<th>Frequency, Hz</th>
<th>PMLC4-Unconfined</th>
<th>PMLC4-Confined</th>
<th>PMLC7-Unconfined</th>
<th>PMLC7-Confined</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>10</td>
<td>12101</td>
<td>3.9%</td>
<td>12362</td>
<td>2.1%</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>8878</td>
<td>3.9%</td>
<td>8993</td>
<td>0.9%</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>5956</td>
<td>3.7%</td>
<td>6116</td>
<td>1.6%</td>
</tr>
<tr>
<td>20</td>
<td>10</td>
<td>5068</td>
<td>3.1%</td>
<td>5764</td>
<td>1.9%</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
<td>2813</td>
<td>3.4%</td>
<td>3326</td>
<td>2.5%</td>
</tr>
<tr>
<td>20</td>
<td>0.1</td>
<td>1414</td>
<td>5.2%</td>
<td>1773</td>
<td>5.1%</td>
</tr>
<tr>
<td>45</td>
<td>10</td>
<td>880</td>
<td>10.9%</td>
<td>1339</td>
<td>1.4%</td>
</tr>
<tr>
<td>45</td>
<td>1</td>
<td>370</td>
<td>11.9%</td>
<td>622</td>
<td>1.1%</td>
</tr>
<tr>
<td>45</td>
<td>0.1</td>
<td>183</td>
<td>10.1%</td>
<td>342</td>
<td>7.9%</td>
</tr>
<tr>
<td>45</td>
<td>0.01</td>
<td>113</td>
<td>5.3%</td>
<td>210</td>
<td>13.0%</td>
</tr>
</tbody>
</table>
• MasterSolver spreadsheet application
  ○ Reference temperature: 20 °C
## Flow Number Test

### Test Details
- The tests are terminated at either 10,000 load cycles or at the accumulation of 50,000 microstrain.
- Flow number conducted at adjusted high PG temperature is 54.1 °C based on the project weather station, for which the corresponding (50% reliability, 20 mm below the pavement surface and not adjusted for traffic).
- Francken Model used for analysis.
- Minimum Average Flow Number Requirements:

  Table X2.4 from AASHTO T 378, Appendix X2

<table>
<thead>
<tr>
<th>Traffic Level, million ESAL’s</th>
<th>HMA Minimum Average Flow Number</th>
<th>WMA Minimum Average Flow Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>3 to 10</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>10 to &lt; 30</td>
<td>190</td>
<td>105</td>
</tr>
<tr>
<td>&gt;30</td>
<td>740</td>
<td>415</td>
</tr>
</tbody>
</table>

\[ E_p = A(N^B) + C [e^{D\times N-1}] \]
Flow Number Results – PMLC4

- Flow number calculated

<table>
<thead>
<tr>
<th>PMLC4 Unconfined</th>
<th>Flow Number</th>
<th>μstrain @ flow point</th>
<th>Permanent Strain Rate at flow number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate 1</td>
<td>120</td>
<td>18778</td>
<td>91.2</td>
</tr>
<tr>
<td>Replicate 2</td>
<td>217</td>
<td>24089</td>
<td>61.9</td>
</tr>
<tr>
<td>Replicate 3</td>
<td>152</td>
<td>19993</td>
<td>79.8</td>
</tr>
<tr>
<td>Average</td>
<td>163</td>
<td>20953</td>
<td>77.6</td>
</tr>
<tr>
<td>StDev</td>
<td>49</td>
<td>2783</td>
<td>15</td>
</tr>
<tr>
<td>CV%</td>
<td>30</td>
<td>13</td>
<td>19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PMLC4 Confined</th>
<th>Flow Number</th>
<th>μstrain @ flow point</th>
<th>Permanent Strain Rate at flow number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate 1</td>
<td>1503</td>
<td>27503</td>
<td>9.1</td>
</tr>
<tr>
<td>Replicate 2</td>
<td>1071</td>
<td>26061</td>
<td>11.9</td>
</tr>
<tr>
<td>Replicate 3</td>
<td>1436</td>
<td>22908</td>
<td>8.2</td>
</tr>
<tr>
<td>Average</td>
<td>1337</td>
<td>25491</td>
<td>9.7</td>
</tr>
<tr>
<td>StDev</td>
<td>233</td>
<td>2350</td>
<td>2</td>
</tr>
<tr>
<td>CV%</td>
<td>17</td>
<td>9</td>
<td>20</td>
</tr>
</tbody>
</table>
## Flow Number Results – PMLC7

- **Flow number calculated**

<table>
<thead>
<tr>
<th>PMLC7 Unconfined</th>
<th>Flow Number</th>
<th>μstrain @ flow point</th>
<th>Permanent Strain Rate at flow number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate 1</td>
<td>460</td>
<td>26774</td>
<td>31.0</td>
</tr>
<tr>
<td>Replicate 2</td>
<td>579</td>
<td>25751</td>
<td>22.7</td>
</tr>
<tr>
<td>Replicate 3</td>
<td>459</td>
<td>27638</td>
<td>31.7</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>499</strong></td>
<td><strong>26721</strong></td>
<td><strong>28.5</strong></td>
</tr>
<tr>
<td><strong>StDev</strong></td>
<td><strong>69</strong></td>
<td><strong>945</strong></td>
<td><strong>5</strong></td>
</tr>
<tr>
<td><strong>CV%</strong></td>
<td><strong>14</strong></td>
<td><strong>4</strong></td>
<td><strong>17</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PMLC7 Confined</th>
<th>Flow Number</th>
<th>μstrain @ flow point</th>
<th>Permanent Strain Rate at flow number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replicate 1</td>
<td>10000</td>
<td>23059</td>
<td>0.11</td>
</tr>
<tr>
<td>Replicate 2</td>
<td>10000</td>
<td>23842</td>
<td>0.37</td>
</tr>
<tr>
<td>Replicate 3</td>
<td>10000</td>
<td>25802</td>
<td>0.66</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>10000</strong></td>
<td><strong>24234</strong></td>
<td><strong>0.4</strong></td>
</tr>
<tr>
<td><strong>StDev</strong></td>
<td><strong>0</strong></td>
<td><strong>1413</strong></td>
<td><strong>0</strong></td>
</tr>
<tr>
<td><strong>CV%</strong></td>
<td><strong>0</strong></td>
<td><strong>6</strong></td>
<td><strong>73</strong></td>
</tr>
</tbody>
</table>
Cyclic Fatigue Test - Analysis Process

- Simplified Viscoelastic Continuum Damage (S-VECD) Model
- ALPHA-Fatigue proprietary software
  - Damage Characteristic Curve (C vs. S curve)
  - Number of Cycles to Failure (Nf)
  - Failure Properties
Cyclic Fatigue Results

- **Simplified Viscoelastic Continuum Damage (S-VECD) model**
  - \((C \text{ versus } S)\) that relates the amount of damage \((S)\) in a specimen to the material integrity or pseudo stiffness \((C)\)
  - \(GR\), characterizes the overall rate of damage accumulation during the test

![Graph of C versus S](image)

![Graph of GR versus Nf](image)
Summary of Findings

- AMPT Performance Testing
  - Dynamic modulus charts showed changes in stiffness of the mixture during production.
  - Based on the flow number criteria in AASHTO T 378, the SMA mixture has acceptable rutting resistance for the design traffic level.
  - The AMPT cyclic fatigue testing indicated a difference in the fatigue properties for during production.

- The present project succeeded in identifying and confirming the performance of SMA asphalt mixtures using AMPT equipment and tests.
AMPT Implementation

- Transportation Pooled Fund Study (TPF(5)-178)
  - Purchase, installation of 29 AMPTs
  - NHI Course (over 80 trainees)
  - Interlaboratory study on effect of air voids
  - National workshop
  - Equipment specification, and others
- Test standard development, improvement, and revision
- Instructional videos, TechBriefs
- MATT projects/training
- User groups at TRB and regional meetings
AMPT Users Groups

• National/International
  - TRB annual meeting
  - Discussion of issues, best practices, future efforts
  - 195 members, 28 DOTs present

• Regional
  - User-producer groups
  - State asphalt paving association meetings
If you have upcoming projects for which you would like MATT technical assistance, contact:

- Amir Golalipour, amir.golalipour.ctr@dot.gov, 202.366.3982
- Dave Mensching, david.mensching@dot.gov, 202.493.3232

https://www.fhwa.dot.gov/pavement/asphalt/trailer/
Thank You – Questions?

- Trailer is parked outside! Come in for a tour!
- We’re here to assist! Please stop by anytime for more discussion.