Update: AASHTO TP 107
AMPT Cyclic Fatigue

FHWA Mixture and Construction Expert Task Group
May 1, 2017
Ames, Iowa
Acknowledgements

- Y. Richard Kim, Cassie Castorena – NC St. Univ.
- Xinjun “Sean” Li – SES Group and Associates, LLC
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- FHWA Offices of Asset Management, Pavement, and Construction; Office of Infrastructure R&D
• FHWA Performance-Related Specification (PRS) initiative
• AASHTO TP 107 improvements
• Integration of AASHTO TP 107 into PRS
• Asphalt Mixture Performance Tester (AMPT) implementation
• Asphalt Technology Guidance Program
AMPT

- Temperature range from about 4° to 70°C
- Computer-controlled device
  - Software built-in for various test procedures
- Fundamental tests
  - Stress and strain modeling
  - “Bulk testing”
  - Pavement ME or FlexPAVE™
- Kits available for other tests
FHWA PRS Initiative

- Use of fundamental tests to capture variance between as-designed and as-built AWCs
- Asphalt Mixture Performance Tester (AMPT) used in performance-engineered mixture design (PEMD)
- Structural response model (stresses and strains)
- Performance volumetric relationships used in construction
Use of fundamental tests to capture variance between as-designed and as-built AQCS

- Asphalt Mixture Performance Tester (AMPT) used in performance engineered mixture design (PBMD)
- Structural response model (stresses and strains)
- Performance volumetric relationships used in construction

PERFORMANCE TESTING ONLY IN DESIGN PHASE!!!
Performance-Engineered Mixture Design

- **Fundamental**
  - How much distress? How much life?
  - Stresses and strains
  - Material properties (i.e., modulus)
  - Use with structural response model (FlexPAVE™)
  - Many temperature/loading conditions represented

- **Index-Based**
  - Go/no-go: correlation-based
  - Some engineering properties, some empirical
    - More tied to a material database
  - Not used with structural response model
  - A few temperature/loading conditions represented
Benefits of PRS

- Long term pavement performance predicted from fundamental engineering properties
- Incentives and disincentives justified through reduction or increase in pavement life
- Allow contractors to be more innovative and more competitive
Challenges with PRS

• Testing efficiency and simplicity
  – Completed/Continuous

• Standardization of test methods
  – Ongoing

• Verifying performance prediction models
  – Completed/continuous

• Performance volumetric relationships
  – Ongoing

• Same principles and methods between mix design and PRS
  – Ongoing
Testing Efficiency and Simplicity
AASHTO TP 107 Revisions

- Submitted to AASHTO SOM TS 2d
- Add failure criterion
- Simplification of language
- AMPT-specific
- Removal of spreadsheet derivation
- New strain selection guidance
- Small-specimen appendix
- Instructional videos (links available)
Standardization of Test Methods

**FULL SIZE SPECIMEN**

- Specimen Prep
  - AASHTO R 83
- Dynamic Modulus
  - AASHTO T 378
- Cyclic Fatigue
  - AASHTO TP 107
- Stress Sweep Rutting
  - AASHTO TP XXX

**SMALL SIZE SPECIMEN**

- Specimen Prep
  - AASHTO PP XXX
- Dynamic Modulus
  - AASHTO TP XXX
- Cyclic Fatigue
  - AASHTO TP XXX

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Performance-Related Specification
PASSFlex™
Field Validation of AMPT Cyclic Fatigue

- Pavement prediction software built from models (FlexMAT™ and FlexPAVE™)
- Field validation
  - 59 mixtures
  - 55 different pavement structures
- Develop laboratory-to-field transfer functions
- Volumetrics have a seat at the table!
**Description:** This tab can be used to import test data from IPC Global AMPT files directly into the template. Alternatively, the user can copy and paste data directly into the green cells within the green tabs. Note that if data is imported using this tab, the user must still enter mixture volumetric properties in the Sigmoidal Model Fit tab. This tab can also be used to clear all data that is currently in the template.

**Instructions:** Separate folders should be created for each dynamic modulus test and cyclic fatigue test. Each folder should contain the AMPT data output files for one dynamic modulus or one cyclic fatigue test.

To import dynamic modulus data for the first test replicate into the template, press the **Dynamic Modulus Specimen 1** button. A prompt will appear. Select the folder where the AMPT output files for the dynamic modulus test are stored. After selecting the appropriate folder, the data from the dynamic modulus test data will be imported into the required cells within the template. Repeat this process for the second and third replicates by pressing the **Dynamic Modulus Specimen 2** and **Dynamic Modulus Specimen 3** buttons, respectively.

To import cyclic fatigue data for the first fatigue test, press the **Fatigue Specimen 1**. A prompt will appear. Select the folder where the AMPT output for the cyclic fatigue test are stored. After selecting the appropriate folder, the data from the cyclic fatigue test data will be imported into the required cells within the template. Repeat this process for the remaining cyclic fatigue tests by pressing the **Fatigue Specimen 2**, **Fatigue Specimen 3**, and **Fatigue Specimen 4** buttons. Note that it is not necessary to press all of the buttons if you have fewer than three dynamic modulus and/or four cyclic fatigue tests.

Press the **Clear Template** button to remove all data that is currently in the template. Note that the **Clear Template** button should only be used if the user wants to revert to the blank template.
FlexMAT™ (2)

**Descriptive Text:**
- Fits the sigmoidal and temperature-shifting models to the storage modulus data obtained from the dynamic modulus test results.
- **Instructions:**
  1. Enter the percentage of voids in Mineral Aggregate (VMA) and percentage of Voids Filled with Asphalt (VFA) of the dynamic modulus test specimens into the green cells within the maximum limiting modulus table.
  2. If the buttons within the Import Data tab were not used to import the test data, copy and paste the data corresponding to the fields included in the Measured Data table into the green cells from the summary dynamic modulus test file. Each block of test data should correspond to a single replicate and temperature of testing. Include data for each test specimen. Do not average data prior to entry into the spreadsheet.
  3. Review the load standard error, average deformation drift, average deformation standard error, deformation uniformity, and phase uniformity cells within the Measured Data table. The cells will appear yellow where the data quality requirements of AASHTO TP 79 and AASHTO PP 81 are not met, which may indicate an invalid test.

**Maximum Limiting Modulus**

| VMA (%) | 16 |
| VFA (%) | 73 |
| Max E' (kPa) | 2.298E+07 |

**Shift Factor**

| a1 | 0.0008 |
| a2 | -0.1738 |
| a3 | 3.372 |
| \( T_{ad} \) | 21.1 |

**Sigmoidal Function**

\[
\log \left( \frac{E'(a, T)}{E'(a_0)} \right) = -k \cdot \left( T - T_{ad} \right) - a_2 \cdot T + a_3
\]

**Fit Time-Temperature Shift Factor and Sigmoidal Model**

**Measured Data**

| Frequency (Hz) | 25 | 10 | 5 | 1 | 0.5 | 0.1 |
| Dynamic modulus (kPa) | 5898 | 6185 | 7265 | 5961 | 4433 | 2389 |
| Phase angle (Degrees) | 55.4 | 11.1 | 6.45 | 22.11 | 23.03 | 27.40 |
| Average temperature (°C) | 18.9 | 18.9 | 18.9 | 18.9 | 18.9 | 18.9 |
| Average micro-strain | 65 | 62 | 61 | 61 | 61 | 61 |
| Load standard error (%) | 5.7 | 2.9 | 1.7 | 0.6 | 0.5 | 0.7 |
| Average deformation drift (%) | -78.1 | -35.6 | -57.6 | -13.7 | -13.5 | -17.4 |
| Average deformation standard error (%) | 8.6 | 9.0 | 15.4 | 15.4 | 15.4 | 15.4 |
| Deformation uniformity (%) | 17.9 | 17.1 | 15.4 | 15.2 | 14.1 | 12.5 |
| Phase uniformity (Deg mm) | 0.2 | 0.2 | 0.3 | 0.7 | 0.8 | 1.0 |

**Sigmoidal**

| Reduced Frequency | 1.0E+01 |
| E' Measured (kPa) | 1.0E+00 |
| E' Predicted (kPa) | 1.0E+01 |
| Sq Error | 1.0E-01 |

**Reduced Frequency**

| 1.0E+01 |
| E' Measured (kPa) | 1.0E+00 |
| E' Predicted (kPa) | 1.0E+01 |
| Sq Error | 1.0E-01 |
FlexMAT™ (3)

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Model</th>
<th>Coefficients</th>
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</thead>
<tbody>
<tr>
<td>$G^2 = y \cdot N_r^2$</td>
<td>$D^R = \frac{1}{N_r} \int (1 - CyN) N_i$</td>
<td>$C_{11} = 3.174E-03$</td>
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<tr>
<td>$C_{12} = 4.239E-01$</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample 1</th>
<th>C vs. S Data</th>
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Description: Determines the failure criteria parameters, calculates the damage capacity, and optimizes the damage characteristic curve model coefficients.

Instructions: No data action or entry is required. The quality of the damage characteristic curve model fit and repeatability of fatigue test results can be observed in the C vs. S graph. The C vs. S curves fit in good agreement. The failure criteria parameters are calculated automatically. The $G^2$ versus $N_r$ and Cumulative (1-C) versus $N_r$ graphs can also be used to further assess sample-to-sample variability. The relationship between Cumulative (1-C) and $N_r$ should be linear. Thus, the repeatability of the fatigue tests can be assessed by the $R^2$ values reported in the $G^2$ versus $N_r$ and $C$ graphs and outliers can be identified by visually observing deviations from the trend line of the other data points in these plots.
FlexPAVE™ (3)
Challenges with PRS

- Testing efficiency and simplicity
  - Completed/Continuous
- Standardization of test methods
  - Ongoing
- Verifying performance prediction models
  - Completed/Continuous
- **Performance volumetric relationships (PVR)**
  - Ongoing
- Same principles and methods between mix design and PRS
  - Ongoing
Performance Volumetric Relationships (PVR)

- Predict as-built performance
  - Without performance testing
- Database developed at TFHRC
- Expansion underway in shadow projects
  - Will use plant-produced variations
- Agency and contractor guidance for planning purposes
Initial PVR Database

Relative not absolute distress

Applicable for a particular structure and traffic
BUT we can generate a catalog with FlexPAVE™

Anchor point is standard Superpave
- Minimum VMA for NMAS
- 4% Design Air Voids
- 7% Air Voids In-Place Density
AMPT Cyclic Fatigue Summary

• Fundamental, repeated loading test
• Direct tension (pull-pull)
• Small-specimen testing available (AASHTO TP xxx)
• AASHTO TP 107 – revisions out for ballot!
• Material behavior across wide range of loading conditions!
AMPT Cyclic Fatigue Process

**Preparation**
- Cylindrical specimen
  - 100 mm x 130 mm
- Small-specimen: 38 mm x 110 mm
- End plate gluing, clamp system being explored
  - 2-3 days for mix

**Testing**
- Dynamic modulus fingerprint for specimen variability
- Pull-pull fatigue test
- Strain level based on TFHRC database
- Test temperature based on location of interest
- Load until crack forms
  - 1-2 days for mix

**Analysis**
- AMPT automatically captures data for analysis
- Calculate damage via FlexMAT™ or FlexPAVE™
- Assign mixture rankings or use FlexPAVE™
  - 1-2 hours for mix

About one week per mixture...worth it when considering the cost of premature failure?
Advantages of AMPT Cyclic Fatigue

- Standard sample preparation
- AASHTOWare Pavement ME compatible
- Ruggedness, precision and bias underway
- FlexMAT™ & FlexPAVE™ available
- Predicts performance!
- **Material behavior across wide range of loading/temperature conditions!**
• 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
• PRS shadow implementation (TFHRC-led)
• Mobile Asphalt Testing Trailer (MATT) projects/training
• User Groups at TRB and regional meetings
AMPT Users Group

- National/International
  - TRB Annual Meeting
  - Discussion of issues, best practices, future efforts
  - 70 attendees, 10 DOTs present
- Regional
  - User-Producer Groups
  - State Asphalt Paving Assoc. meetings
AMPT Users Group

• National/International
  – TRB Annual Meeting
    Discussion of issues and next meetings

NEXT AMPT USERS GROUP MEETING
JULY 25 AT 1 PM EASTERN

• Regional
  – User-Producer Groups
  – State Asphalt Paving Assoc. meetings
Shadow PRS Status

- Maine DOT – SHRP2 R07
- Western Federal Lands – SHRP2 R07
- Missouri DOT – 2 projects (3 total mixtures)
- North Carolina DOT – SHRP2 R07
- MATT support
- Marketing of success stories
- **SEEKING ADDITIONAL SHADOW PROJECTS WITH DOTs**
Asphalt Technology Guidance Program (ATGP)

Long-Life Asphalt Pavement for the 21st Century
Program Objectives

- Advance Performance
- Advance Quality Assurance
- Advance Innovation
Program Focus Areas

• Provide Support to National Initiatives
  – Increased Pavement Density
  – Increased RAP/RAS Usage
  – Understanding GTR Testing
  – Mixture Performance Testing and the AMPT
  – Stone Matrix Asphalt
  – Binder Performance Testing
  – Long-Term Aging
Program Focus Areas (2)

- Equipment Development & Refinement
  - Asphalt Mixture Performance Tester (AMPT)
    - Standardization of Equipment, Test Methods
  - Binder Performance Testing
- Development of New QA Concepts for HMA
  - Performance-Based/Related and Risk-Based Acceptance
- Advanced Rapid Test Tools
  - AIMS, CoreLok, CoreDry, Small-Scale Geometry
Solutions to Agency Needs

• Project-Specific Workplans
  – Material Characterization
    • High RAP/RAS, GTR, SMA, PRS...
  – Mix Design Replication and Testing
  – Mix Production Testing
  – Performance Prediction
  – Training and Demonstration
• Questions?
• Contact information (AMPT and PRS)
  – David Mensching
  – 202.366.1286
  – david.mensching@dot.gov
• Contact information (PRS and Shadow)
  – Richard Duval
  – 202.493.3365
  – Richard.duval@dot.gov

Thank you!