Performance-Related Specifications: Integration of the Asphalt Mixture Performance Tester (AMPT)

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Acknowledgements

- Office of Preconstruction, Construction, and Pavements
- Office of Infrastructure Research and Development
- Office of Technical Services
• Owner agencies short on funding
  – Need more pavement life
  – Less rehab
  – More “bang for buck”

• MAP-21 introduced performance-based administering of federal funds
  – FHWA established measures for States to set own targets
Late 1980s-Early 1990s: Strategic Highway Research Program
  - Superpave mixture design approach
  - Performance grade binders
  - But 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 prototype, conduct ruggedness and interlaboratory studies
    • Simple Performance Tester (now known as AMPT) was born!
• 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
Continuum of Performance

Planning & Pavement Design ➔ Specify ➔ Mix Design ➔ Construct & Accept ➔ Preserve & Rehab

PRS
• Asphalt distress?
• Frequency of sampling/testing?
• How to quantify/manage data?
• Cost of life loss?
• Appropriate methods to measure?
Overview of Asset Management

- Preserve assets and minimize whole life costs
- Operate in a financially sustainable manner
- Provides a framework to improve performance on a long-term basis
- A plan is now required!
Two Questions

- How can I extend pavement life?
  - Specification development/targets
  - Exceeding performance thresholds
  - Optimizing asset management plan
- How can I measure performance upfront?
  - Effect of RAP, WMA, etc., and pavement structure
  - Laboratory testing and conditioning
    - Fundamental
    - Index-based
    - Lots of tests
Continuum of Specifications

Risk

100

0

Type of Specification

Method  End-Result  QA  Performance  Warranty

Owner

Contractor
“QA specifications that describe the desired levels of key materials and construction quality characteristics that have been found to correlate with fundamental engineering properties that predict performance”
How PRS Works

1. Establish Performance Criteria
2. Identify AQCS and Target Values
3. Compare As-Built and As-Designed
4. Pay Factor

Design AQC vs. As-Constructed AQC

Value of Performance?

Model Performance

As-Designed vs. As-Constructed

Distress & IRI

Pavement Age

SOFTWARE

How PRS Works

Planning

How PRS Works

Pavement Design

Establish Performance Criteria

Identify AQCS and Target Values

Pay Factor

Compare As-Built and As-Designed

Design

Quality

Designed

Construction

PRS Works

As-Built

As-Designed

As-Constructed

Pavement Age

Value of Performance?
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
- Reliability of performance prediction models
  - Complete
- Performance volumetric relationships
  - Ongoing
- Same principles and methods between mix design and PRS
  - Ongoing
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
Reliability of Performance Prediction Models

59 asphalt mixtures, including WMA and RAP mixtures, from 55 pavement sections.
FHWA-ALF Sections

(a) FlexPAVE Prediction

Damage Area (%) vs. No. of Cycles
- Control
- CR
- TR
- SBS

(b) Field Measurement

Crack Area (%) vs. No. of Cycles
- Control
- CR-TB
- Terpolymer
- SBS-LG
Rut Depth Predictions

Before Calibration

After Calibration
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
FHWA PRS Initiative

- 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 (PEMD)
- Performance volumetric relationships used in construction
- Structural response model (stresses and strains)
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.
- Performance volumetric relationships used in construction.
- Structural response model (stresses and strains).
Performance-engineered mixture design
(balanced mixture design)

- Fundamental
  - How much distress? How much life?
  - Stresses and strains
  - Material properties (i.e., modulus)
  - Use with structural response model
  - 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 (FlexPAVE)
  - Only a few temperature/loading conditions represented
Performance-engineered mixture design
(balanced mixture design)

• **Fundamental**
  – How much distress? How much life gained/lost?
  – Stresses and strains
  – Material properties (i.e., modulus)
  – Use with structural response model
  – Many loading conditions represented

• **Index-Based**
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• **Cost-efficient way to account for relevant distress!**
AASHTOWare Pavement ME-FlexPAVE™ Compatibility

- Graphical user interfaces similar to Same climate, traffic inputs
  - Fewer unbound layer inputs needed
- AASHTO TP 107 results proven to be compatible with K1, K2, K3 fatigue coefficients
- AASHTO T 378 (|E*|) remains critical input
FlexMAT™ and FlexPAVE™ Available

- **FlexMAT™** – Excel spreadsheet
  - Analyzes cyclic fatigue, $|E^*|$, and SSR data
  - Import files directly
  - Output → FlexPAVE™

- **FlexPAVE™** – performance prediction tool
  - PEMD through acceptance
  - Simulate as-design and as-built performance
**FlexMAT™**

**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.
Predicts Performance!
Performance criteria determines pavement life! Compare as-design life to the as-built pavement life in PASSFleX™ to assign pay factors!
Material Behavior Across All Loading Conditions

- Time-temperature superposition
  - Major benefit
  - Reduces testing time/specimens
  - Enables robustness of models

- Fundamental properties required to describe behavior across wide-range of conditions

- Allows for direct incorporation of pavement structure into predictions
Material Behavior Across All Loading Conditions

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THIS IS THE KEY DIFFERENCE BETWEEN OTHER AVAILABLE METHODS!
FHWA Shadow PRS Program
Objectives of Shadow PRS

- How would project have been accepted, (and contractor paid), if PRS were used
- Understand ways that PRS may impact normal testing and acceptance operations
DOT determines project(s)

Develop sampling plan with FHWA, NC St., ARA
- 10 plant-produced samples
- Proficiency sample (1 project only)
- Mix design replication sample

Training before AMPT testing begins

Volumetric testing as normally done

AMPT testing whenever DOT has time
• Maryland SHA – Underway (10 projects)
• Maine DOT – Underway
• Missouri DOT – Underway (3 projects)
• Ontario MOT – Underway
• Western Federal Lands – 1st Project Complete

• Marketing of success stories
AMPT Users Group

- National/International
  - TRB Annual Meeting
  - Discussion of issues, best practices, future efforts
  - 164 members
    - 28 DOTs represented
- Regional
  - User-Producer Groups
  - State Asphalt Paving Assoc. meetings
Asphalt Technology Guidance Program (ATGP)

Office of Asset Management, Pavements, & Construction

Long-Life Asphalt Pavement for the 21st Century
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
Thank you!

• Questions?
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• Contact information (AMPT and PRS)
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  – 202.366.1286
  – david.mensching@dot.gov
Asset Management Plans

- Pavement inventory and conditions (NHS)
- Objectives and measures
- Performance gap identification
- Lifecycle planning and risk management analysis
- Financial plan
- Investment strategies

- Short term performance measures key to invest funds effectively and meet long-term goals!
- Performance prediction leads to smart planning!
Asphalt Pavement Performance

- Low temperatures or fast loading rate
  - Thermal cracking
- Intermediate temperatures and loading rates
  - Fatigue cracking
  - Durability cracking
  - Thermal fatigue
- High temperatures and slow loading rates
  - Rutting
  - Increased oxidative aging
- Insufficient structure
  - Rutting
  - Fatigue cracking
- All influence ride quality
PRS Framework

Sampling of Mixtures/Data from Paving Project → Performance Tests in AMPT → FlexMAT™ Excel-Based Data Analysis → FlexPAVE™ Pavement Performance Analysis → Prediction of Life

Performance Monitoring & Feedback → Incentives/Disincentives → Application of Pay Factors in PASSFlex™ → Prediction of Life
Testing Efficiency and Simplicity

Large Specimen

|E*| Tests

Fatigue Tests

Small Specimen

|E*| Tests

Fatigue Tests
### Testing Efficiency and Simplicity (2)

<table>
<thead>
<tr>
<th></th>
<th>Large Specimen</th>
<th>Small Specimen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel Putty</td>
<td>Devcon 10110</td>
<td>Devcon 10240</td>
</tr>
<tr>
<td>Working Time</td>
<td>10 – 20 min.</td>
<td>5 min.</td>
</tr>
<tr>
<td>Functional Cure</td>
<td>16 hours</td>
<td>1 hour</td>
</tr>
<tr>
<td>Amount of Putty (per specimen)</td>
<td>100 g</td>
<td>3 g</td>
</tr>
</tbody>
</table>

![Images of test setups]
AASHTO TP 107 Revisions

- Add failure criterion
- Simplification of language
- AMPT-specific
- Removal of spreadsheet derivation
- New strain selection guidance
- Small-specimen appendix
- Instructional videos (links available)
Same Principles and Methods in Design and PRS

- Testing is conducted at mix design phase
- Run predictions to establish as-design pavement life
- Same principles present
  - Prediction using cyclic fatigue and shift models
  - Pay factors assigned on a life difference
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
- PRS shadow implementation (TFHRC-led)
- PRS workshops (2017, 2018, 2019)
- MATT projects/training
- User Groups at TRB and regional meetings
AMPT Overview
Dynamic Modulus Test

- Mixture Stiffness
- Rutting
- Fatigue Cracking

\[ |E^*| = \frac{\sigma_0}{\varepsilon_0} \]

\[ \phi = \frac{T_l}{T_p} (360) \]
Dynamic Modulus Master Curve

E*max=3,376,744 psi
E*min=4,259 psi

R² = 0.9978
Se/Sy = 0.038

Reduced Frequency, Hz

U.S. Department of Transportation
Federal Highway Administration
Stress Sweep Rutting (SSR) Test

**High Temperature: 0.4s pulse, 3.6s rest**

- 0.4s x 200 cycles for each loading block

**20°C: 0.4s pulse, 1.6s rest**

- 0.4s x 200 cycles for each loading block

**Graphs:***

- **SSR: T_H**
  - Permanent Strain vs. Number of Cycles
  - Peaks at 100 psi, 70 psi, 130 psi

- **SSR: 20°C**
  - Permanent Strain vs. Number of Cycles
  - Peaks at T_L 70 psi, 100 psi, 130 psi
SSR Test

• Draft procedure ready for consideration by AASHTO
• FlexMAT™-Rutting available
  – Single tab spreadsheet
• Confined testing (10 psi)
• 1 day to complete all replicates
• Model predicts permanent deformation at all loading conditions!
AMPT Cyclic Fatigue

- 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 all possible loading conditions!
Pavement prediction software built from models

Field validation
  – 59 mixtures
  – 55 different pavement structures

Develop laboratory-to-field transfer functions

Volumetrics have a seat at the table!
Ruggedness, Precision, and Bias

- AASHTO T 378 $|E^*|$ – Complete!
- AASHTO TP 107 – Ruggedness and precision and bias underway
- Small-specimen cyclic fatigue – Ruggedness and precision and bias underway
- Small-specimen $|E^*|$ – coming soon
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
Standard Sample Preparation

• Cylindrical specimens
  – AASHTO R 83 for full-size
  – Draft procedure ready for small-size

• Equipment required
  – Superpave gyratory compactor and molds
  – Core drill (bits depend on specimen size)
  – Wet saw
  – Water bath or other device (for Gmb)
  – Engineering square, piano wire
PRS Software

PASSPave™

PASSFlex
PASSRigid
FlexPAVE
FlexMAT
AMPT + Performance Prediction

- Predicted Rutting
- Predicted Cracking

✓ Structure ✓ Traffic ✓ Climate

U.S. Department of Transportation
Federal Highway Administration
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?

U.S. Department of Transportation
Federal Highway Administration
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 all possible loading/temperature conditions!
FlexPAVE™ Simulations

FHWA-ALF Sections
Two Major Tasks for DOT

• Accept ‘shadow’ mixtures based on the performance engineered mix design (PEMD) approach
• Collect volumetric-based acceptance quality characteristics (AQC) during construction (PASSFlex™)
  – These would be used to determine hypothetical contractor pay
Material Testing

• Proficiency Testing
  – Ensure repeatable results with separate laboratory AMPT
  – Only done on first shadow project

• PEMD Testing
  – Baseline for the as-designed condition
  – Needed in design phase of each project

• Production Testing with AMPT (Shadow only)
  – Establish PVR

• Production Testing with Volumetrics
What Will a DOT Get Out of Shadow Project Participation?

- Understanding concept of PRS
  - Understanding pavement fatigue and rutting using fundamental test procedures
  - Pavement performance as function of AQC
  - Construction Acceptance
- AMPT training
  - ARA, NCSU, & FHWA will work with State Agency to determine the best solution for training. The FHWA-MATT provides opportunities for DOTs to look over the shoulder of its personnel when testing for performance.
- PRS Software training and analysis support
- Potential for FHWA project funding support
- Potential for Mobile Asphalt Testing Trailer support
Program Objectives

- Advance Performance
- Advance Quality Assurance
- Advance Innovation

Courtesy of Anton Paar