A Performance-Driven Laboratory Evaluation of Stone Matrix Asphalt Mixture

All images FHWA unless otherwise noted.

Mobile Asphalt Testing Trailer Program (MATT)

Long-Life Asphalt Pavements for the 21st Century

Amir Golalipour, Ph.D.
David J. Mensching, Ph.D., P.E.

Conference on Stone Matrix Asphalt
November 6, 2018 • Atlanta, GA

U.S. Department of Transportation
Federal Highway Administration
Office of Infrastructure

Office of Preconstruction, Construction, and Pavements

Outline

- Background
- Asphalt Mixture Performance Tester (AMPT)
- Mixture Performance Testing
- SMA Project
- Test Results & Discussions
- Takeaways
- Questions

Acronyms

- 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

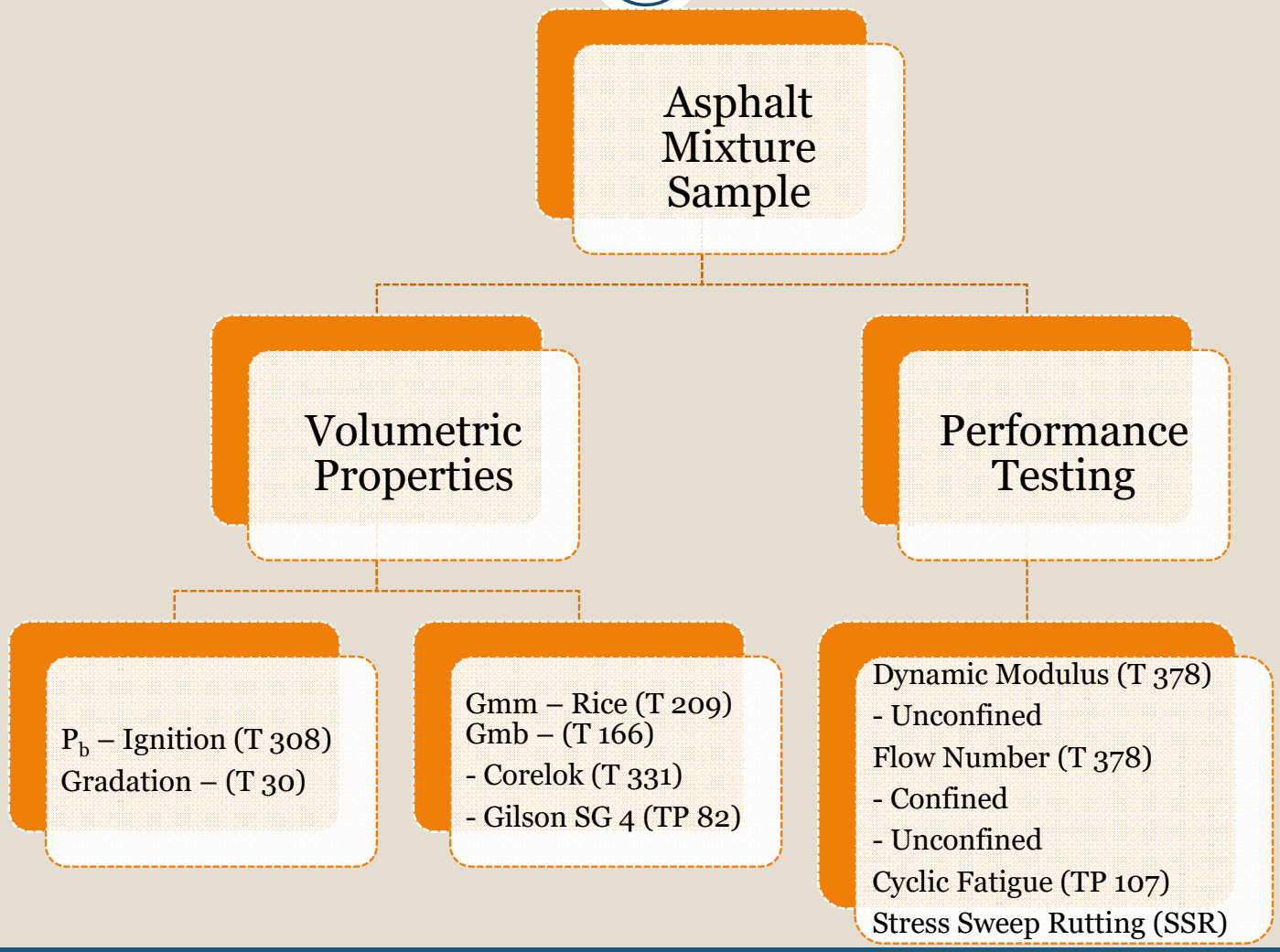
- Provide Support to National Initiatives
  - Performance-Engineered Mixture Design (PEMD)
  - Increased Pavement Density
  - Development of New QA Concepts for HMA
  - Understanding Asphalt Rubber Testing
  - Binder Performance Testing
- Provide Assistance with State-specific Issues
  - Technical Guidance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

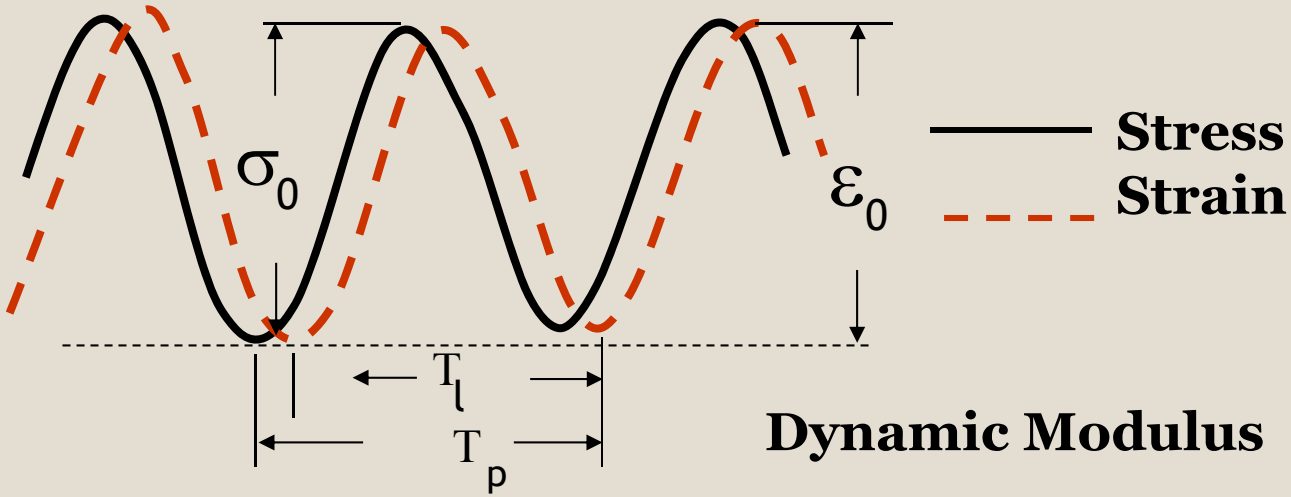
- Servo-hydraulic loading machine
- Temperature range from 4° to 70°C
- Computer-controlled device
  - Software built-in for various test procedures
- Fundamental tests
  - Stress and strain modeling
  - “Bulk testing”
  - Pavement ME
- Kits available for other tests

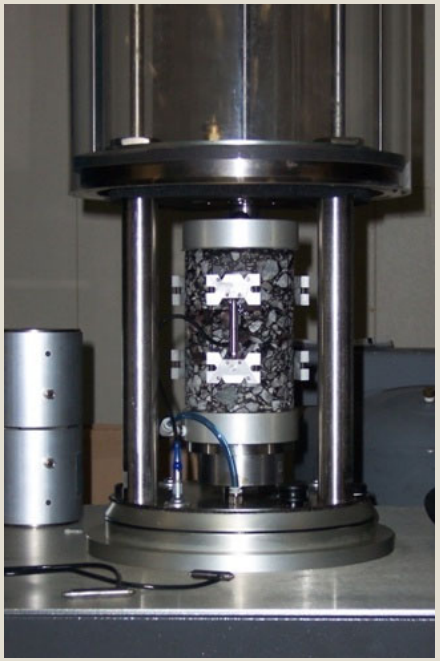
Performance Testing

- 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





Dynamic Modulus

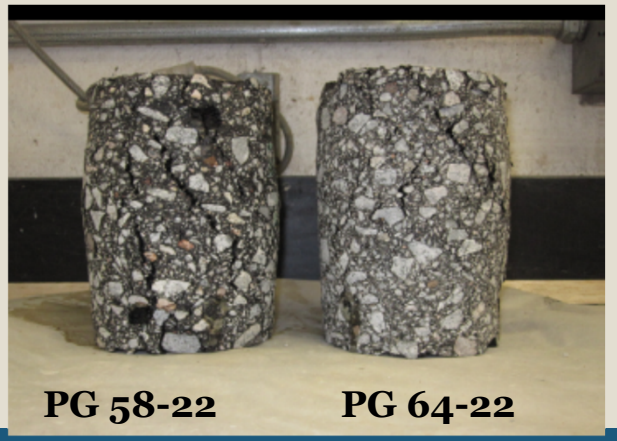
$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

Phase Angle

$$\phi = \frac{T_l}{T_p}(360^\circ)$$

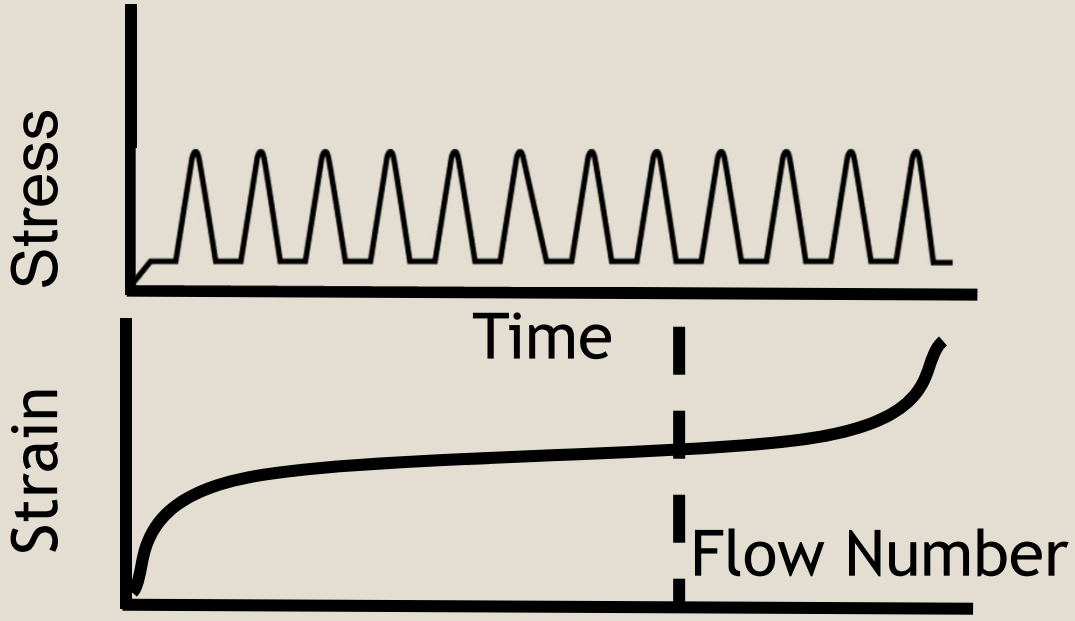
Flow Number Test

- 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

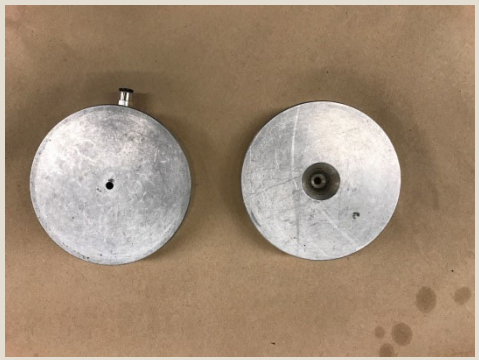


Flow Number

- 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



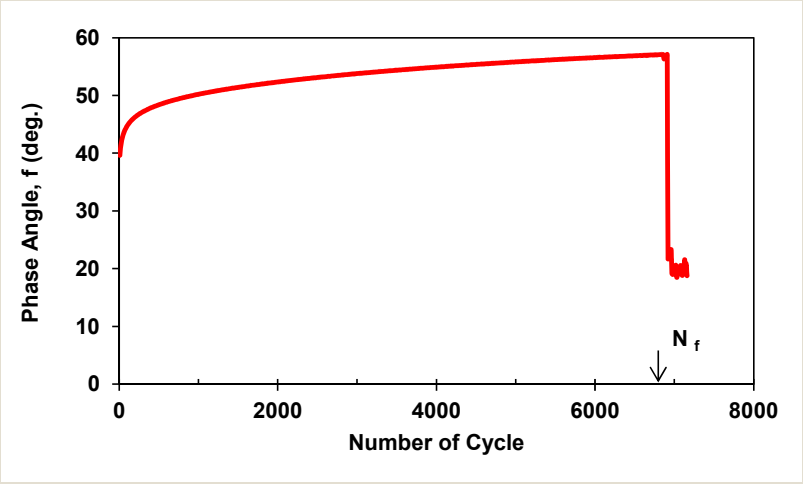
Images: North Carolina State University

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



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

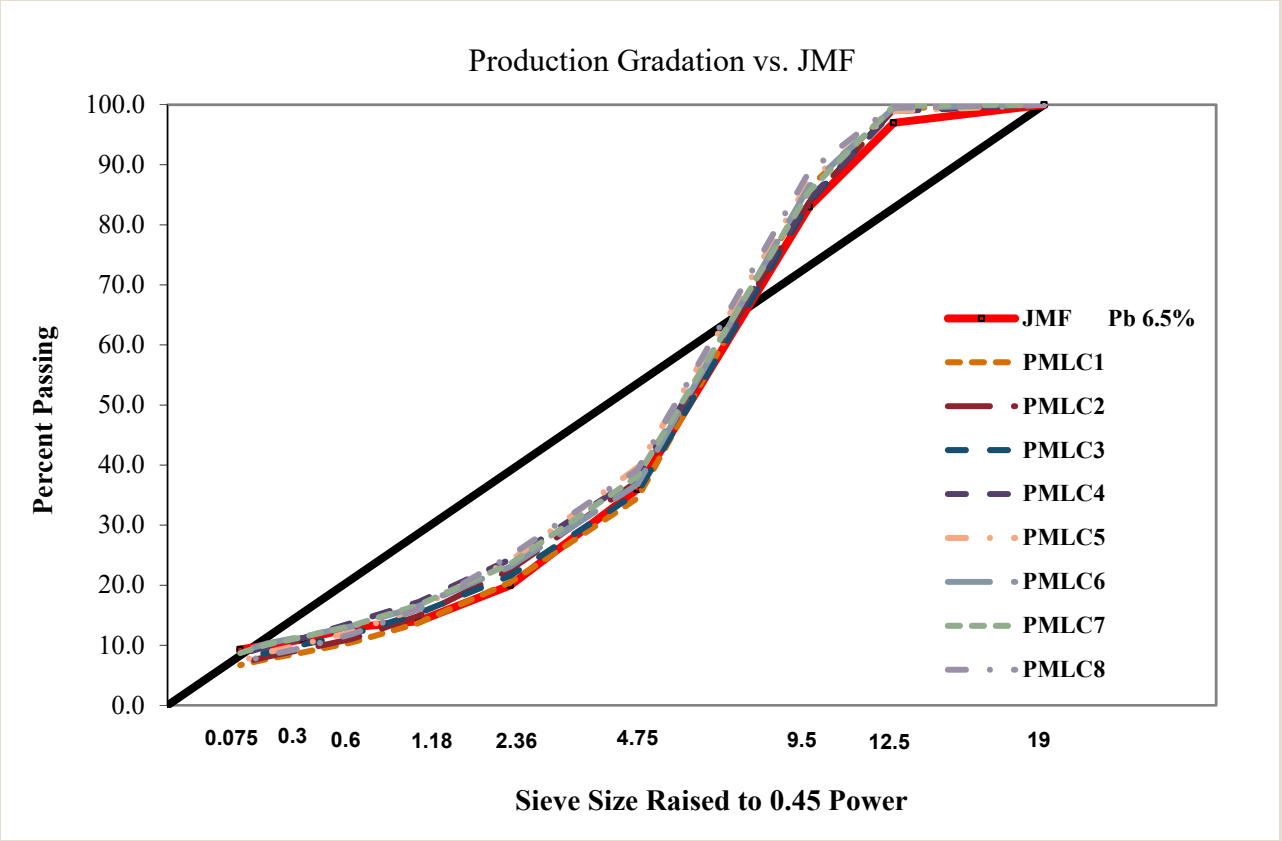
Project Description

- 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

Property	JMF Value
Combined Aggregate Bulk Specific Gravity (G_{sb})	2.730
Optimum Binder Content, %	6.5
Maximum Specific Gravity (G_{mm})	2.473
Design Air Voids	3.5
Voids in Mineral Aggregate (VMA)	18.2
Voids Filled with Asphalt (VFA)	80.9
Filler to Effective Asphalt Ratio	1.46

Mix Gradation

- The gradations of the aggregates
  - SMA 12.5mm mixture



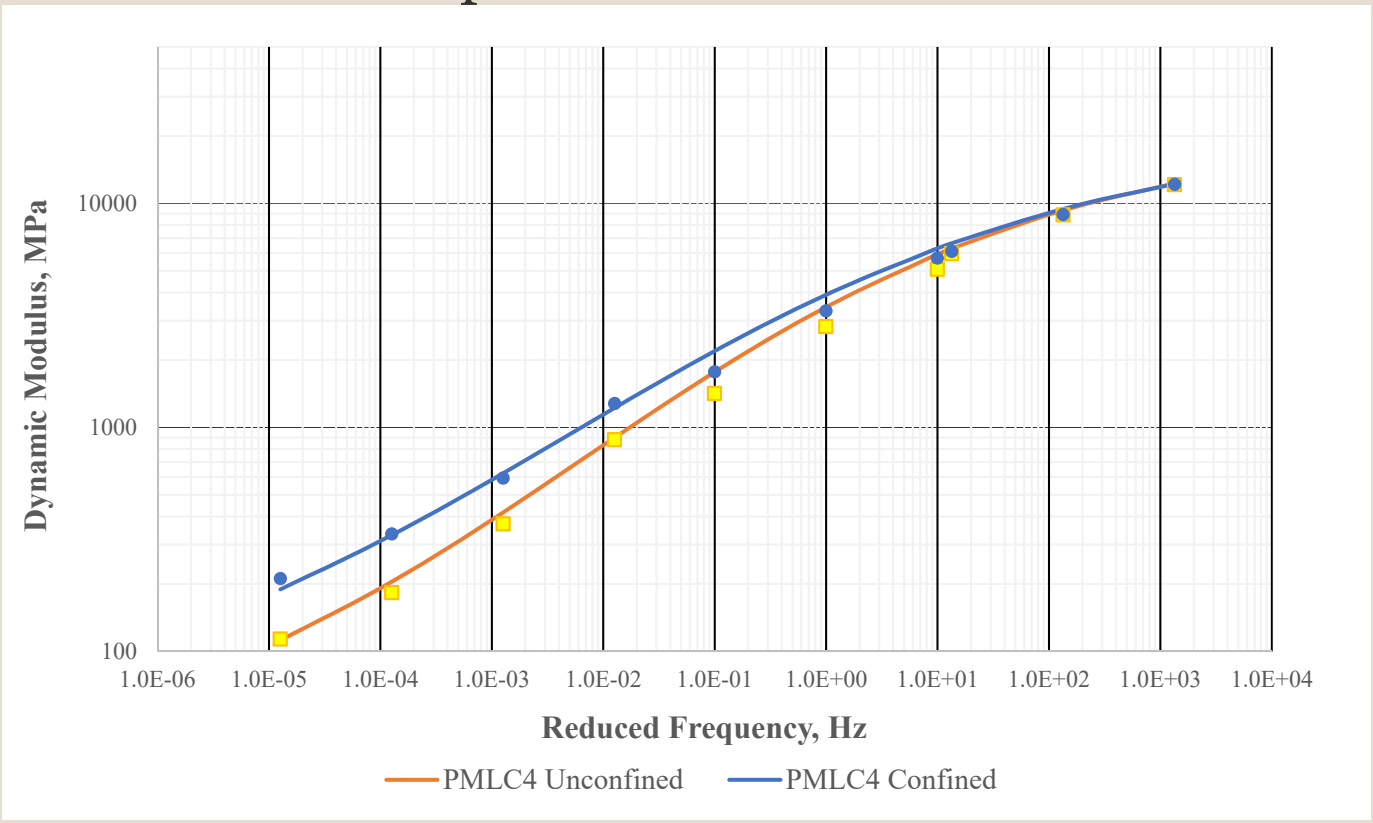
Dynamic Modulus Test

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

Temperature, °C	Frequency, Hz	PMLC4-Unconfined		PMLC4-Confined		PMLC7-Unconfined		PMLC7-Confined	
		Avg. |E*|	|E*| COV	Avg. |E*|	|E*| COV	Avg. |E*|	|E*| COV	Avg. |E*|	|E*| COV
4	10	12101	3.9%	12362	2.1%	12341	8.9%	12048	7.0%
4	1	8878	3.9%	8993	0.9%	8892	7.9%	8607	8.8%
4	0.1	5956	3.7%	6116	1.6%	5905	7.9%	5711	10.4%
20	10	5068	3.1%	5764	1.9%	5312	6.2%	5619	1.8%
20	1	2813	3.4%	3326	2.5%	2970	8.4%	3242	3.9%
20	0.1	1414	5.2%	1773	5.1%	1512	10.6%	1718	6.8%
45	10	880	10.9%	1339	1.4%	948	10.9%	1334	4.0%
45	1	370	11.9%	622	1.1%	411	12.8%	759	4.8%
45	0.1	183	10.1%	342	7.9%	205	11.1%	512	11.8%
45	0.01	113	5.3%	210	13.0%	148	24.5%	405	17.3%

E* Master Curve

- 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

$$E_p = A(N^B) + C\,[e^{D*N} - 1]$$

  - Minimum Average Flow Number Requirements: Table X2.4 from AASHTO T 378, Appendix X2

Traffic Level, million ESAL's	HMA Minimum Average Flow Number	WMA Minimum Average Flow Number
<3	---	---
3 to 10	50	30
10 to < 30	190	105
>30	740	415

Flow Number Results – PMLC4

- Flow number calculated

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

PMLC4 Confined	Flow Number	µstrain @ flow point	Permanent Strain Rate at flow number
Replicate 1	1503	27503	9.1
Replicate 2	1071	26061	11.9
Replicate 3	1436	22908	8.2
Average	1337	25491	9.7
StDev	233	2350	2
CV%	17	9	20

Flow Number Results – PMLC7

- Flow number calculated

PMLC7 Unconfined	Flow Number	µstrain @ flow point	Permanent Strain Rate at flow number
Replicate 1	460	26774	31.0
Replicate 2	579	25751	22.7
Replicate 3	459	27638	31.7
Average	499	26721	28.5
StDev	69	945	5
CV%	14	4	17

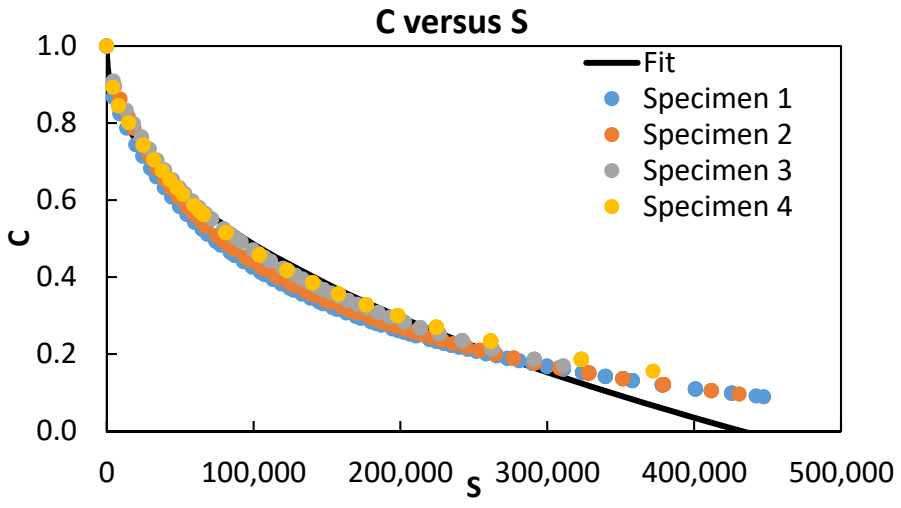
PMLC7 Confined	Flow Number	µstrain @ flow point	Permanent Strain Rate at flow number
Replicate 1	10000	23059	0.11
Replicate 2	10000	23842	0.37
Replicate 3	10000	25802	0.66
Average	10000	24234	0.4
StDev	0	1413	0
CV%	0	6	73

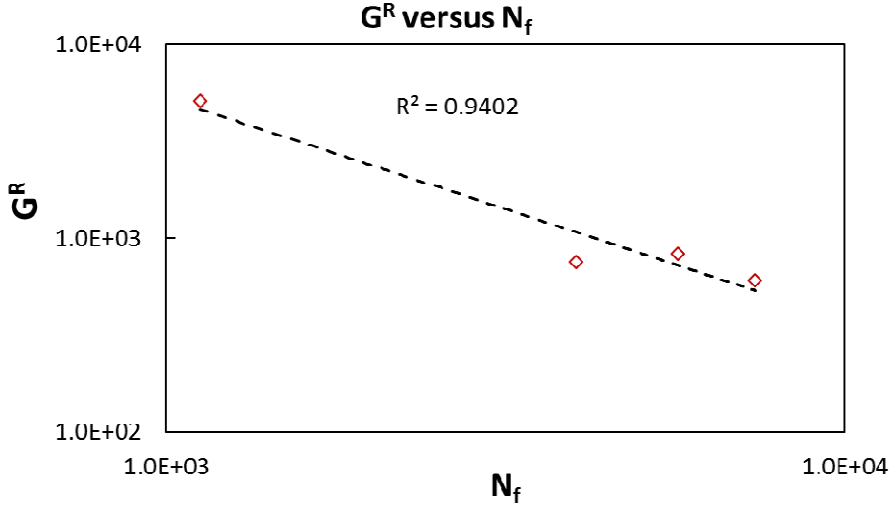
Cyclic Fatigue Test- Analysis Process

- 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 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





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

Technical Assistance

- 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.