Develop Mix Design and Analysis Procedures for Asphalt Mixtures Containing High-RAP Contents – TPF 5(294)

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FHWA Asphalt Binder Expert Task Group
Salt Lake City, Utah
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Outline

- Update
- Mixture Experiment
  - ALF Experiment
    - Direct Tension Cyclic Fatigue – SVECD
      - 10 Lanes
    - SCB
      - L3, L5, L7
    - Texas Overlay

Objective

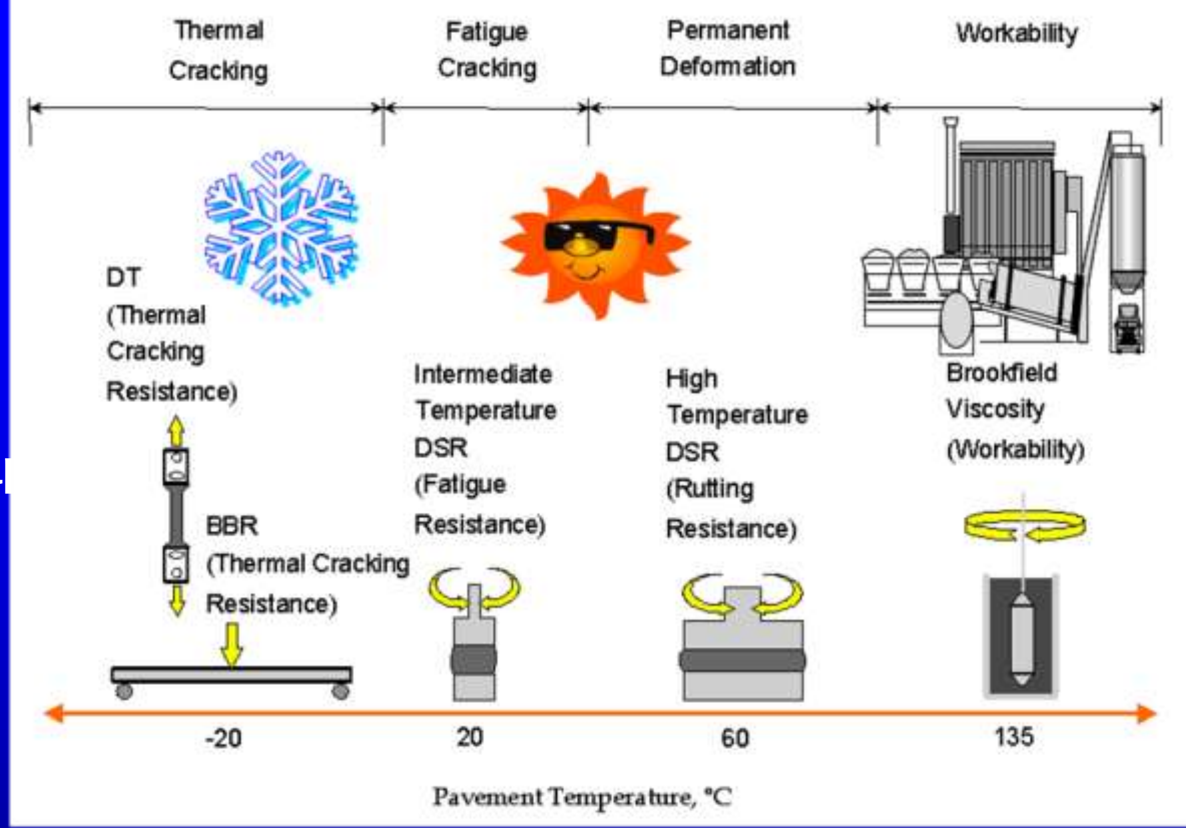
- Evaluate fatigue/fracture tests that can be conducted on plant mixtures (lab or field compacted) from participating states
  - ranking the quality of RAP and or RAP/RAS mixtures as compared to virgin mixtures.
  - Develop score card

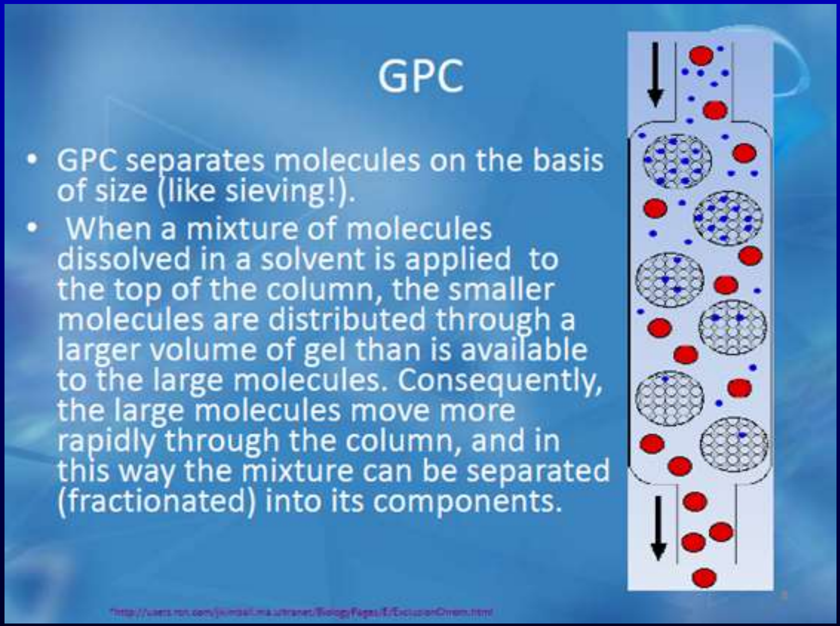
Scope

- Two field projects
  - Each field project
    - Two mixtures: Conventional, RAP and/or RAS
      - Conventional may include 15% RAP
  - Four mixtures
- Collect Mix Design / Pavement Design Record
  - JMF
  - Loose mixtures
  - Cores
    - Challenging
- Materials Characterization
  - Mixture Experiment
    - Cracking tests
  - Binder Experiment
    - Rheology and Chemisty

Binder Experiment

- Binder Rheology
  - PG grading
  - MSCR
  - GPC (Gel permeation chromatogra
  - SARA
  - Others

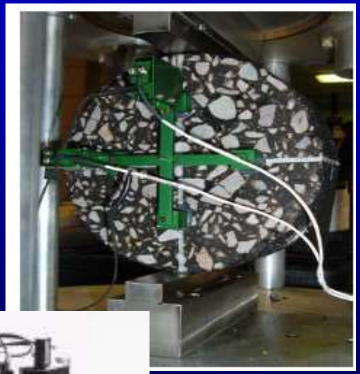


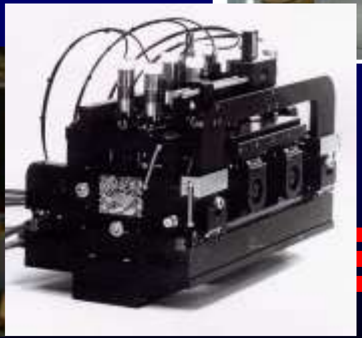


Mixture Experiment

- Specimen Types
  - Plant produced laboratory compacted (PL)
  - Plant Produced Field Compacted (PF, Cores)
    - » Challenging
  - Triplicates
- Fracture/fatigue testing
  - Semi-circular bend test, SCB
  - Overlay tester test, OT
  - Energy Ratio Test
  - Beam Fatigue Test
  - Direct Tension Cyclic Fatigue
    - » SVECD
- Per mixture and Specimen type
  - 5 tests x 3 = 15 mixes





Field Projects

U.S. Department of Transportation
Federal Highway Administration

- FHWA
  - *Advance Use of Recycled Asphalt in Flexible Pavement Infrastructure: Develop and Deploy Framework for Proper Use and Evaluation of Recycled Asphalt in Asphalt Mixtures*
  - *10 Lanes*
- FLDOT
  - SR 21 Clay County
  - Hubbard Construction
  - West Palm Beach area
  - Mix 1: Mix with 40% RAP
  - Mix 2: Mix with ~20% RAP

FDOT

Data Analysis

- Each test will be ranked
- Develop a score card

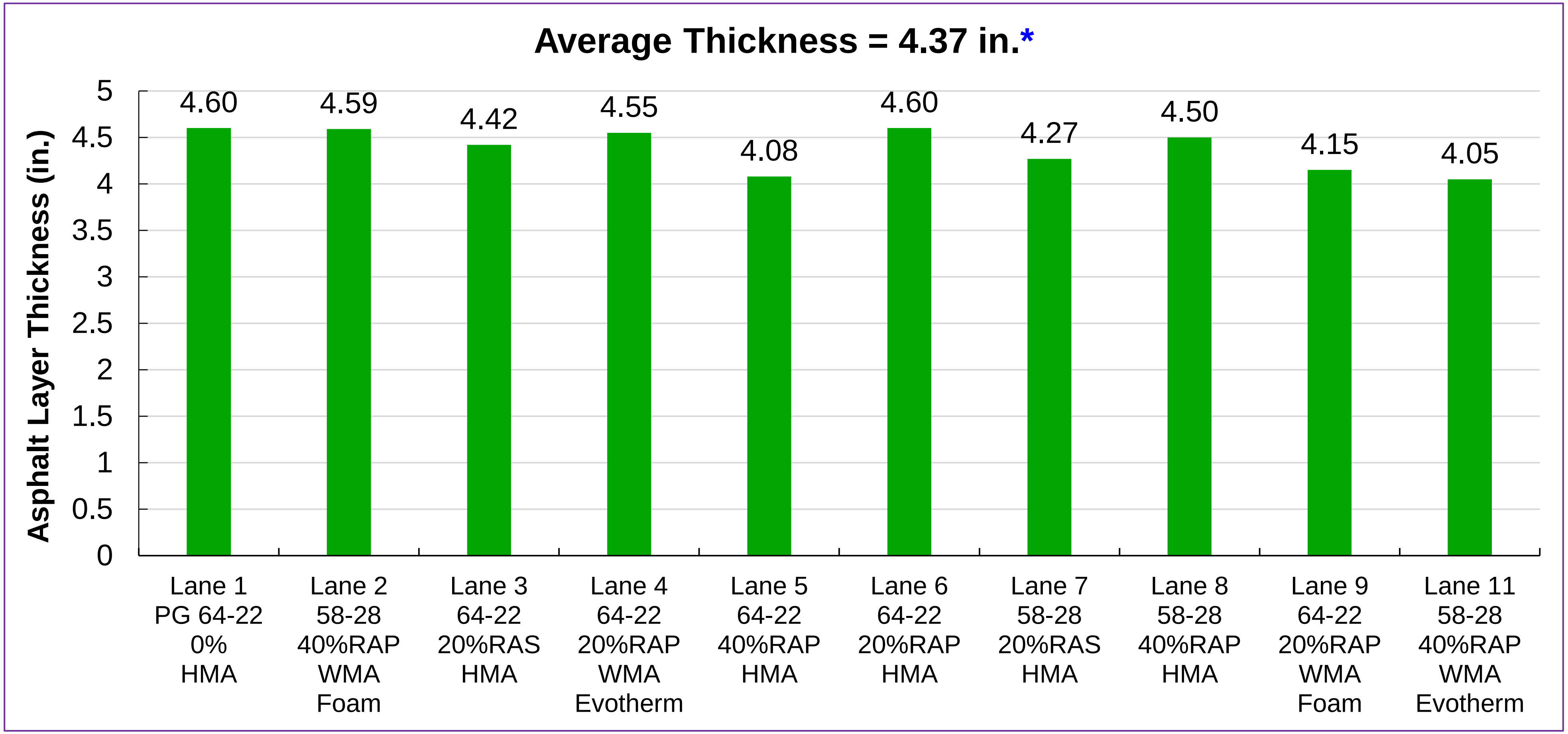
Data Analysis

- Each test will be ranked
  - Specimen preparation
  - Instrumentation
  - Standard test method
  - Testing
  - Training
  - Interpretation
  - Sensitivity to mix composition parameters
  - Routine Application
  - Correlation to field performance
  - Data Analysis
  - Repeatability

3. Testing			
1: Testing is very involved and requires substantial oversight.	2: Testing requires heavy oversight.	3: Testing requires moderate oversight.	4: Testing is very straightforward and requires little oversight.

FHWA ALF Overview

- Materials and structures.



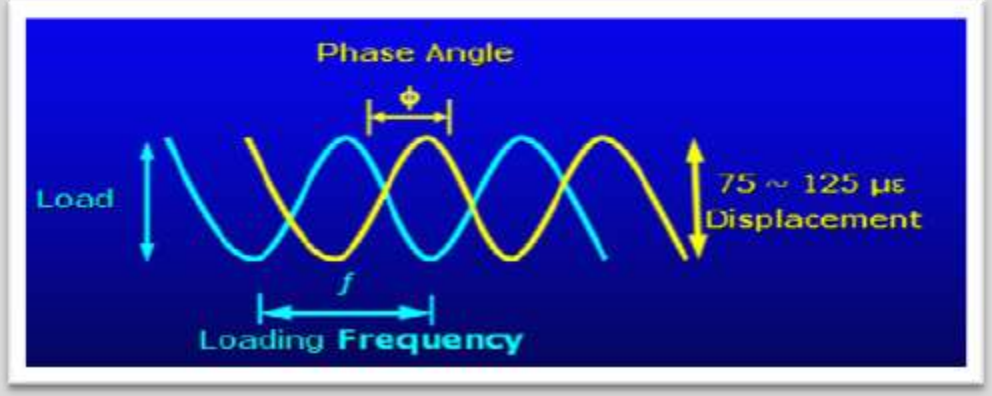
*Data from presentation by Dr. Nelson Gibson at 2014 ETG Fall meeting.

Fracture/fatigue testing

- Direct Tension Cyclic Fatigue – SVECD
- AASHTO TP 79-15: Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
  - Stiffness
- AASHTO TP 107-14: Standard Method of Test for Determining the Damage Characteristic Curve of Asphalt Mixtures from Direct Tension Cyclic Fatigue Tests
  - Damage characteristic curve (C vs. S)




Dynamic Modulus Test

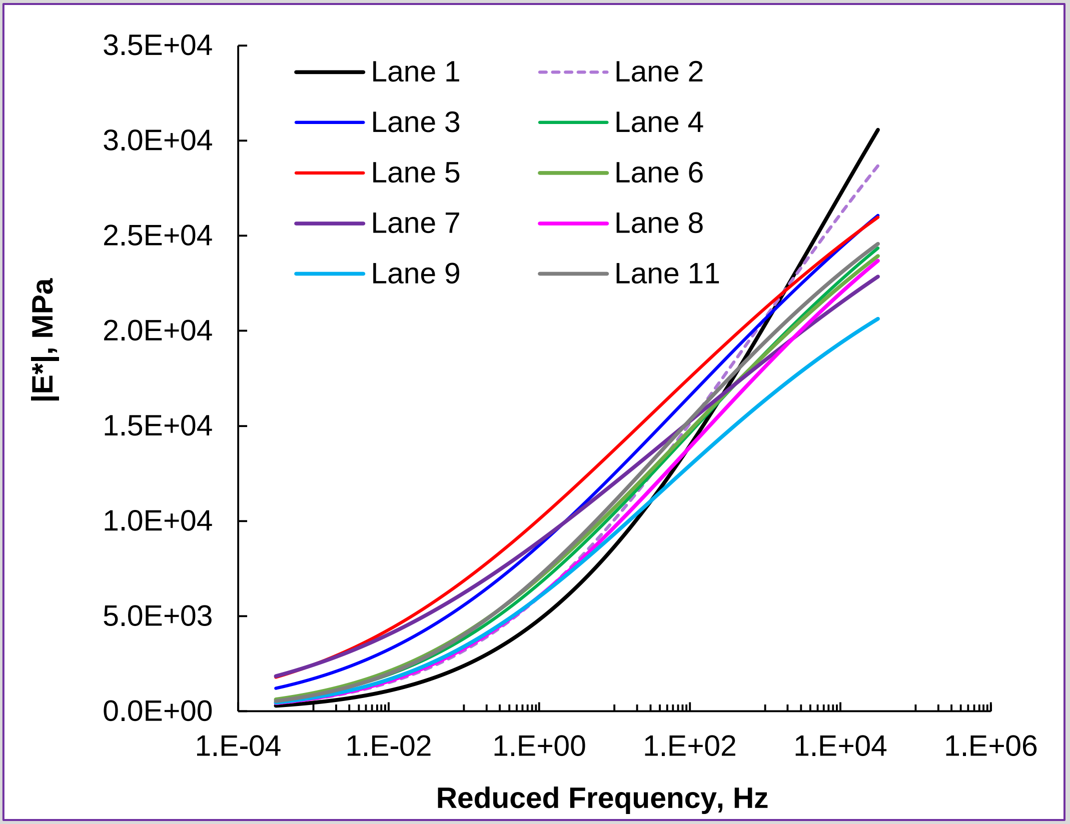


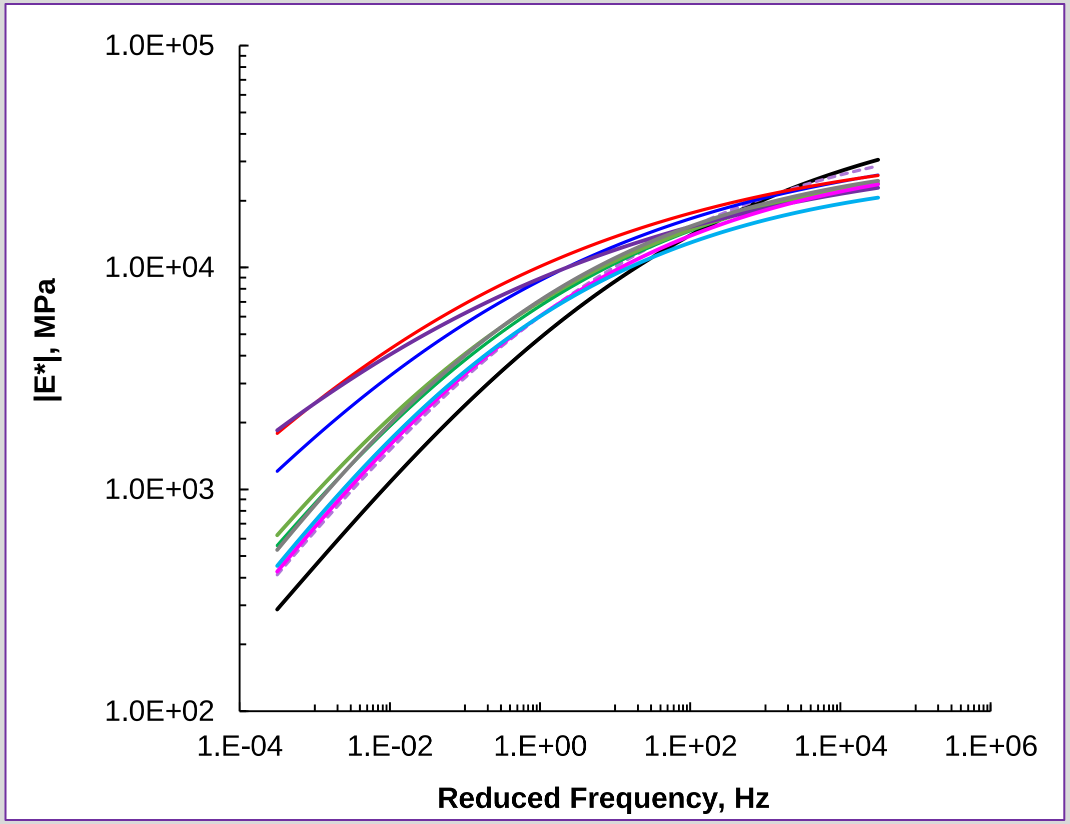
- 150 mm X 170 mm
- Air void: 7.0 ± 0.5%
- 3 replicates

Frequency (HZ)	**25, 10, 5, 1, 0.5, 0.1**
Temp. (°C)	**4.4, 25, 37.8**

- Target on-specimen strain: 50-75 $\mu\varepsilon$

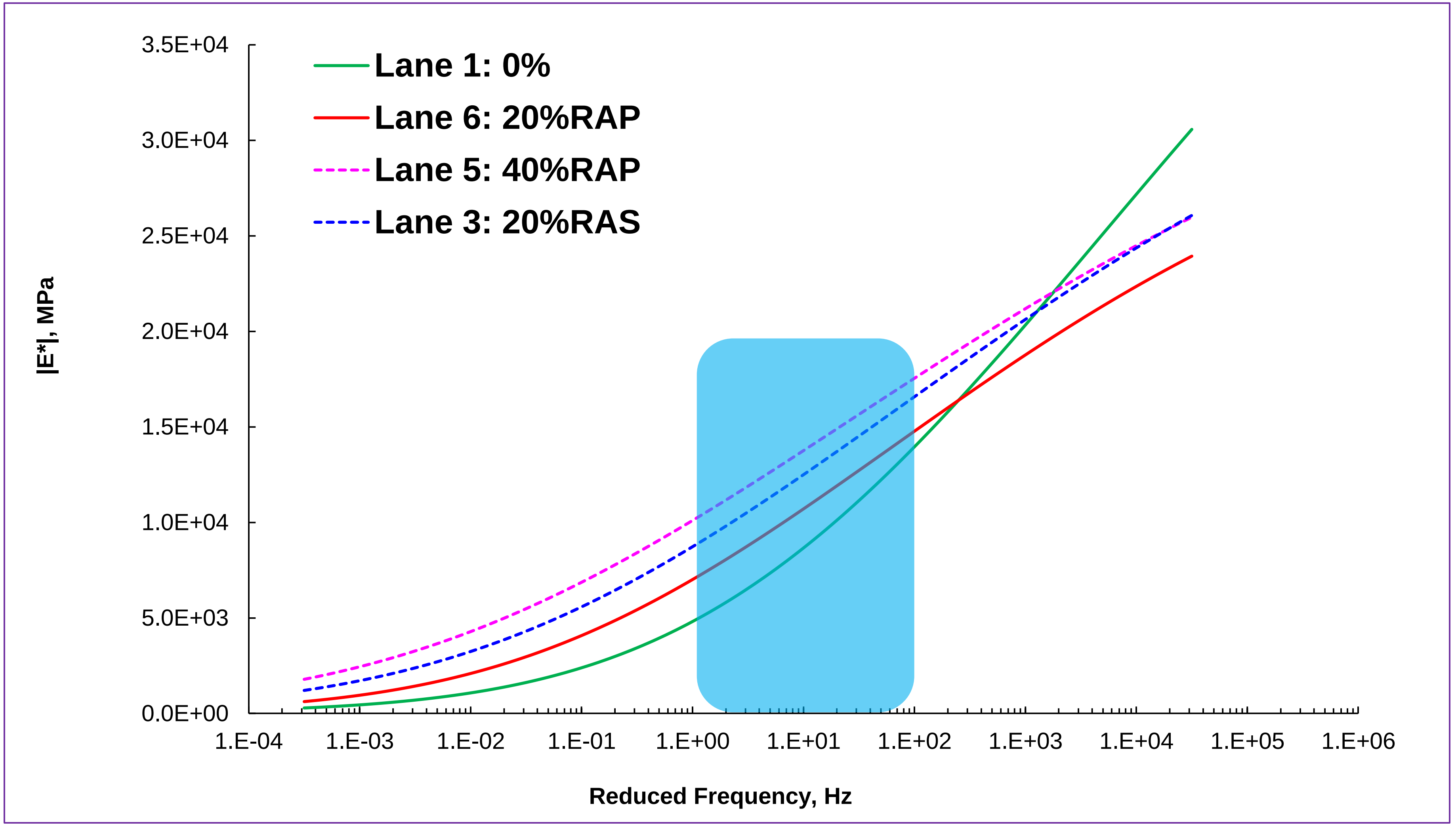
Dynamic Modulus Test Results





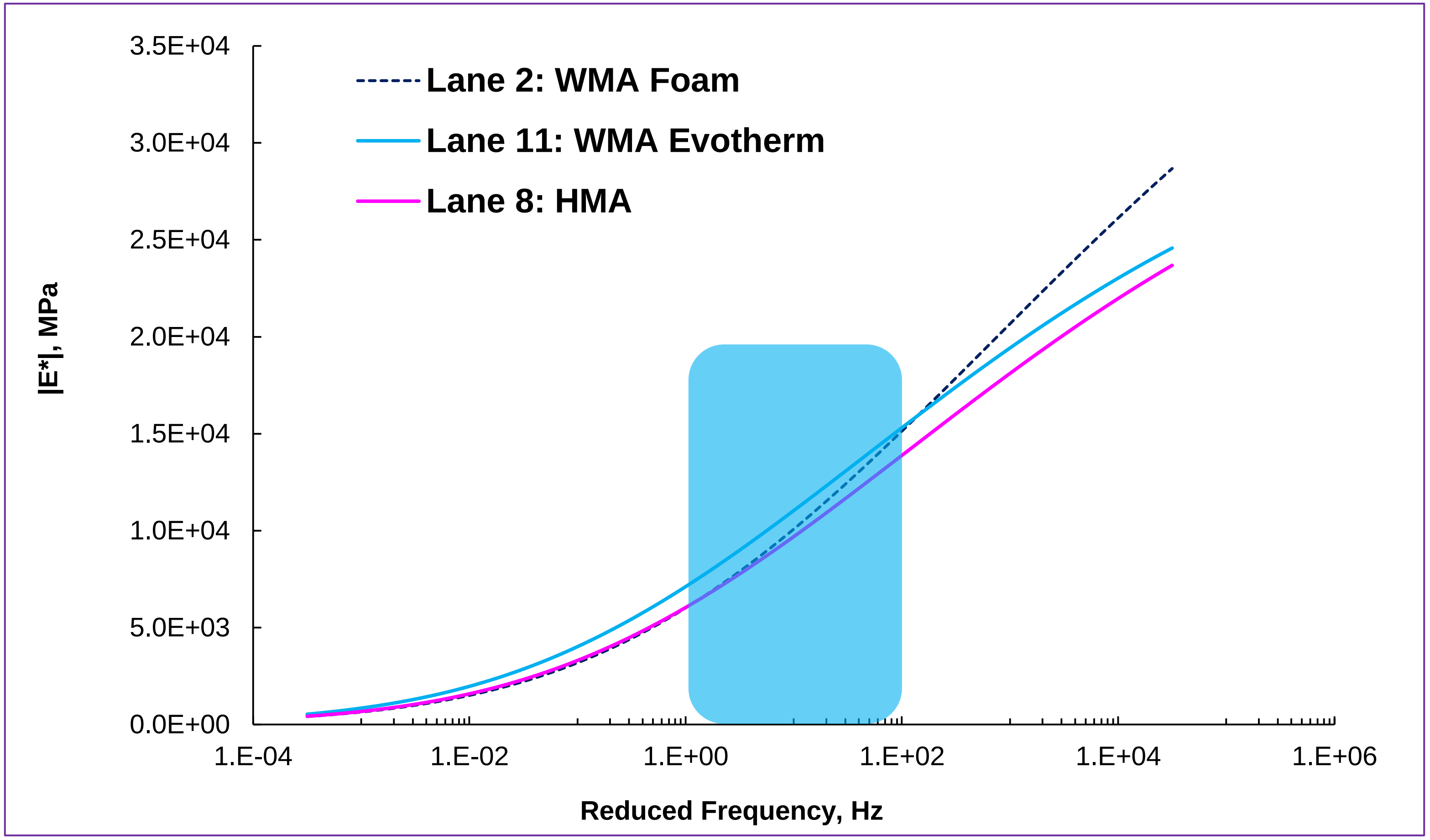
Dynamic Modulus Test Results

- Effect of RAP/RAS content (PG 64-22, HMA)



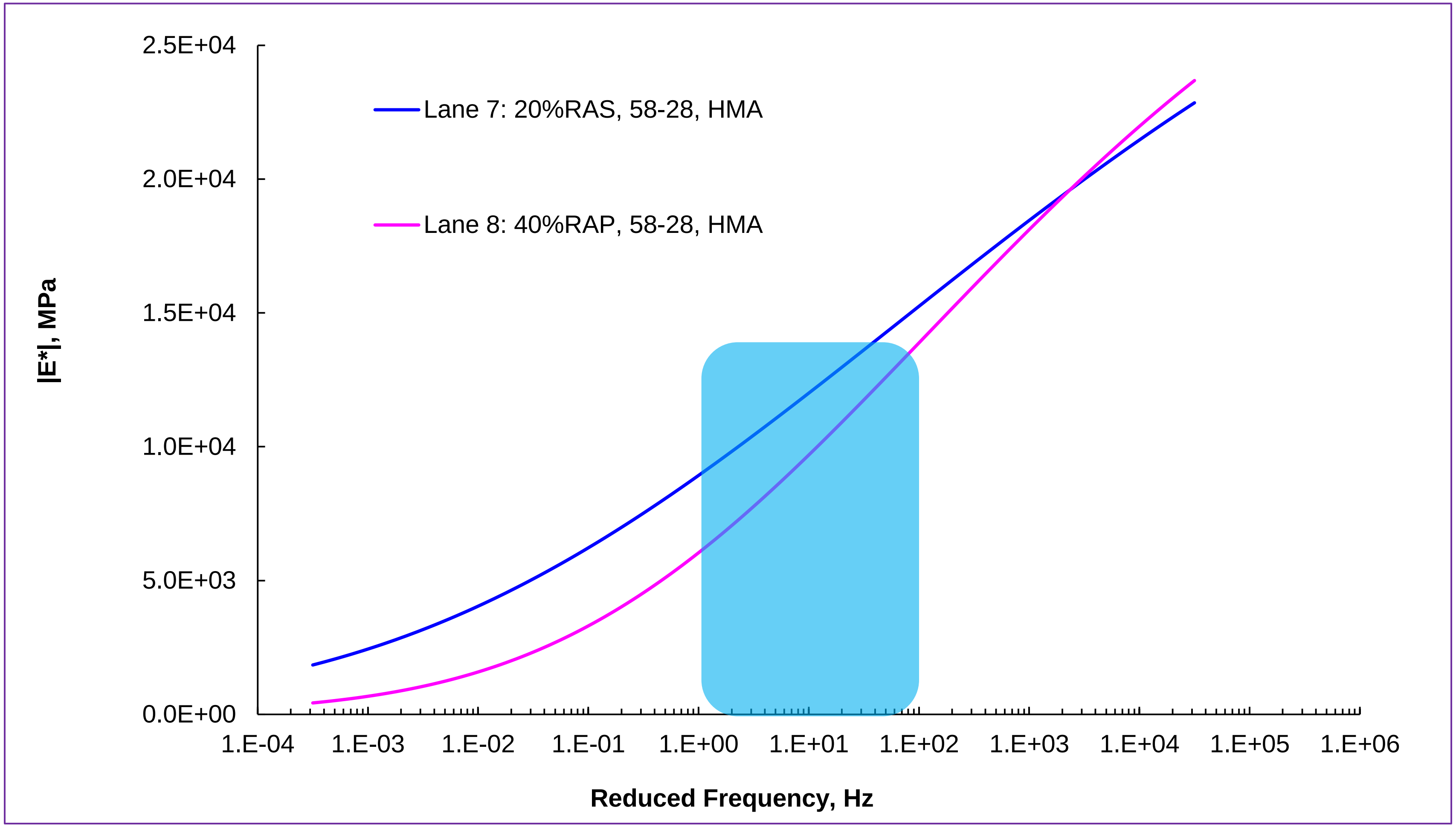
Dynamic Modulus Test Results

- Effect of WMA technologies (PG 58-28, 40%RAP)



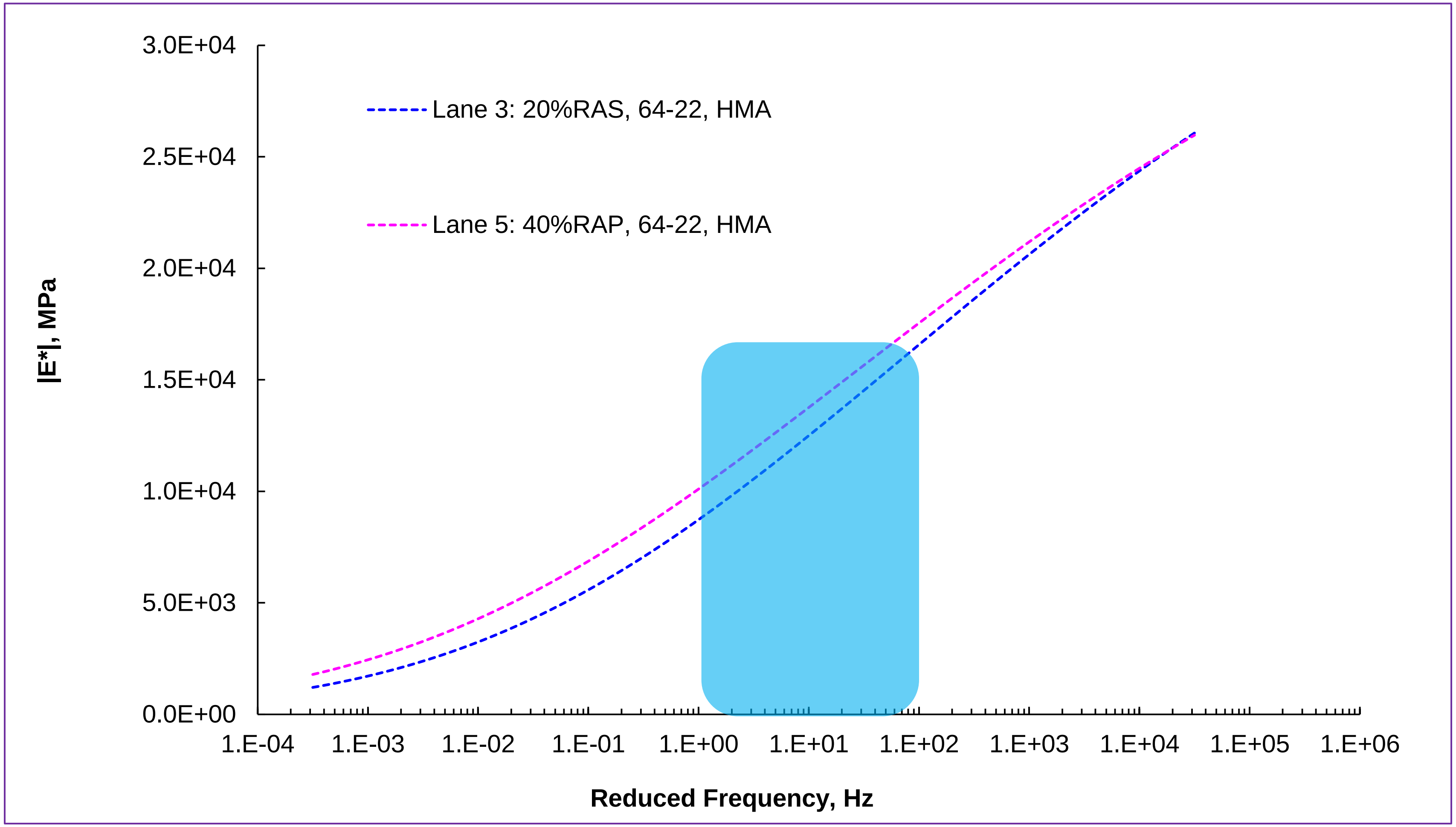
Dynamic Modulus Test Results

- Binder PG58-28



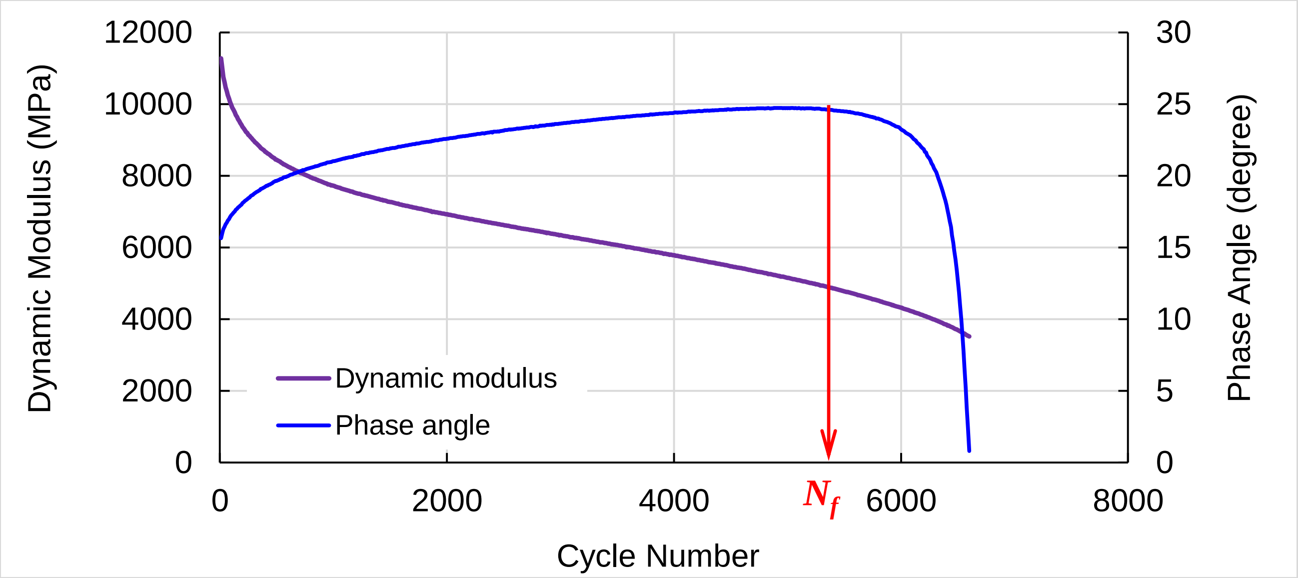
Dynamic Modulus Test Results

- Binder PG 64-22



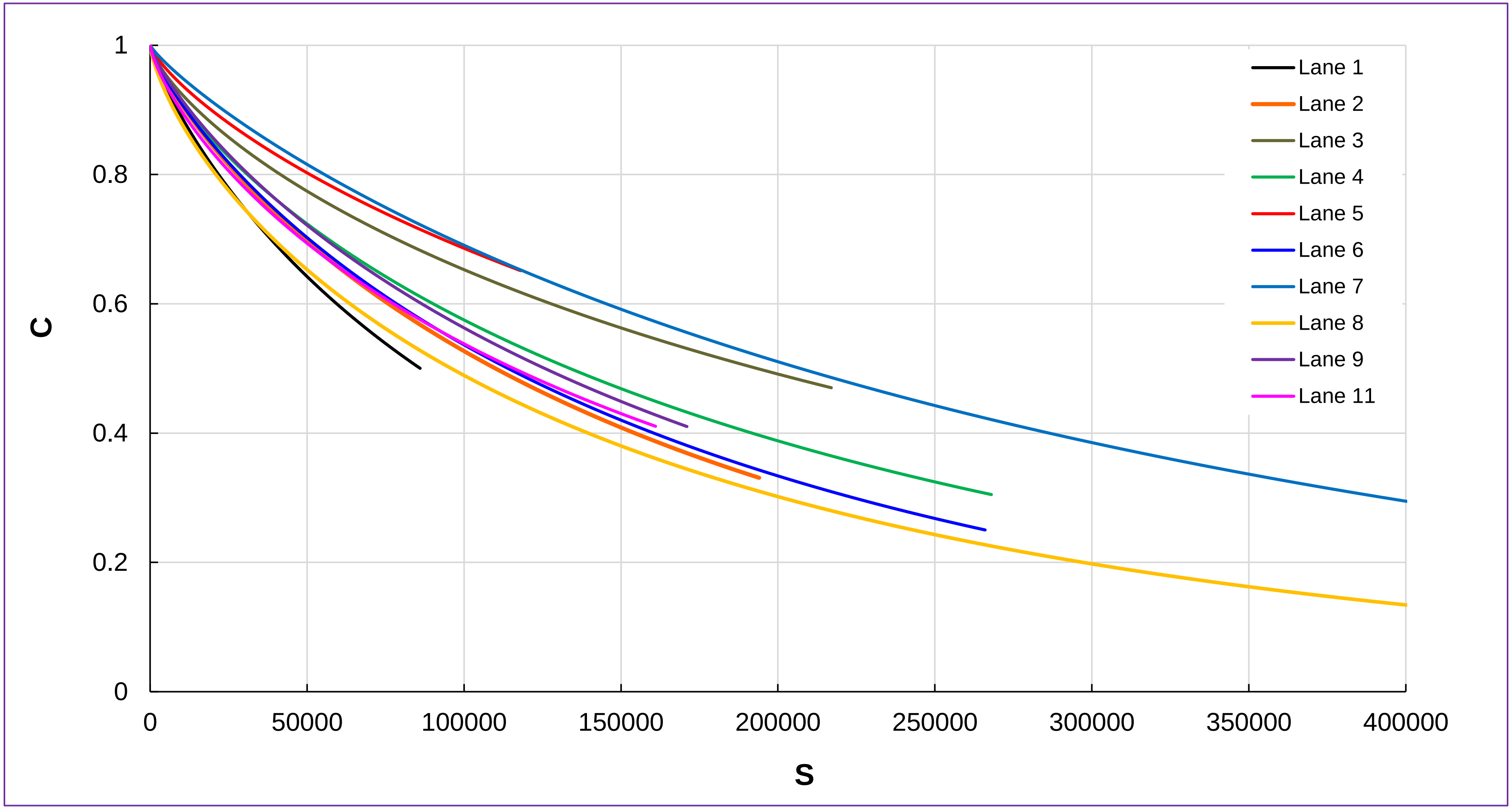
Direct Tension Cyclic fatigue Test

- Test Condition
- Temperature: 18°C
- Frequency: 10 Hz
- Initial on-specimen strain level: 190-260 $\mu\varepsilon$
- Failure determined by phase angle drop



Direct Tension Cyclic fatigue Test

➢C(S) Damage characteristic curves



Direct Tension Cyclic fatigue Test

Strain-Based SVECD Fatigue Simulation

- For a given strain level input, perform S-VECD fatigue simulation* and produce the cyclic history of normalized pseudo stiffness *C* for each mix.
  - Temperature: 20°C**
  - Frequency: 10 Hz
  - Failure criterion: C_f = 0.25
- Plot fatigue life versus strain level in a log-log space for each mix.

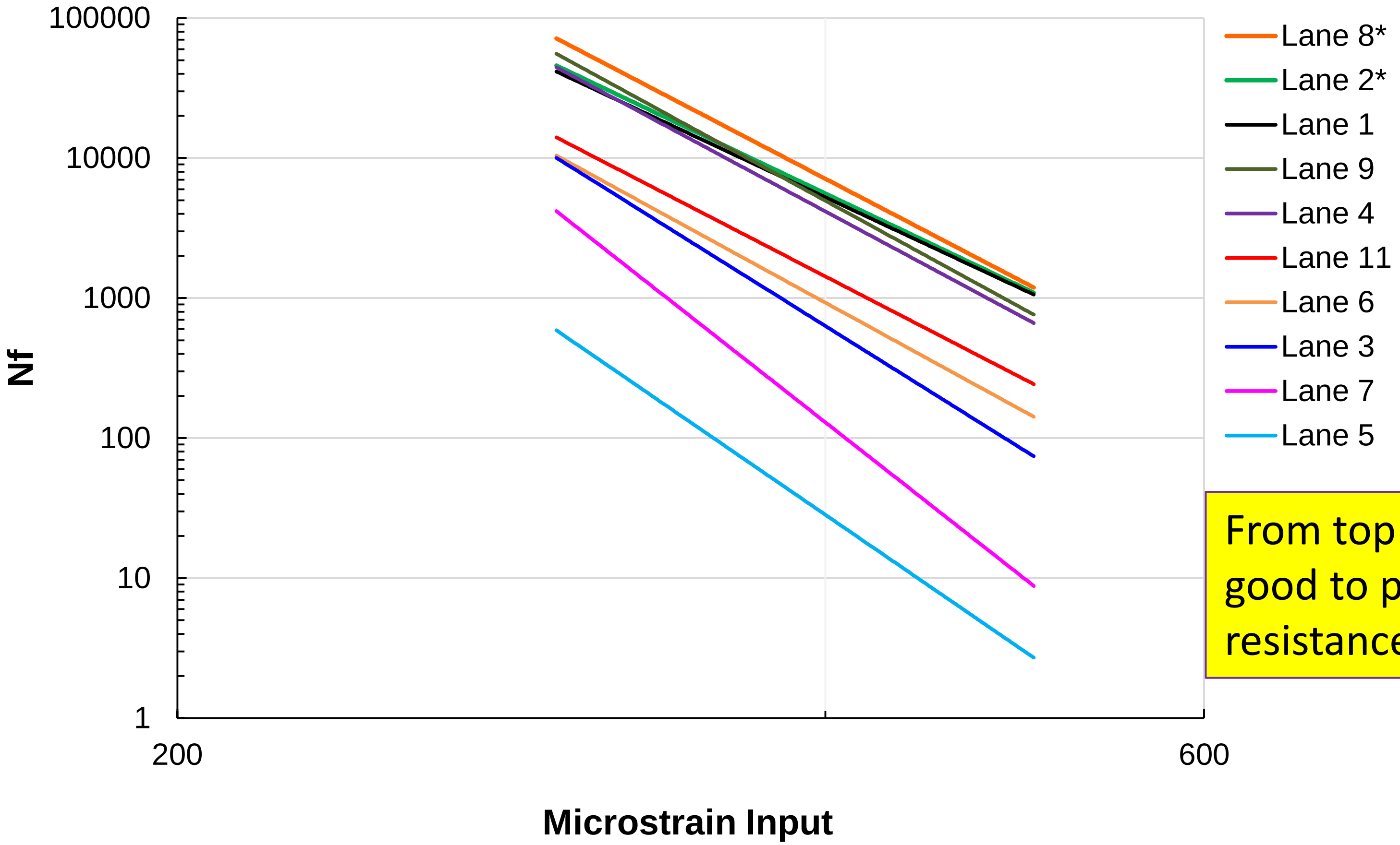
*Hou, T., Underwood, B.S., and Kim, Y.R., *Fatigue Performance Prediction of North Carolina Mixtures Using the Simplified Viscoelastic Continuum Damage Model*. Journal of the Association of Asphalt Paving Technologists 79, 2010.

**The ALF full scale sections were tested under controlled temperature of 20°C, according to *Li, X. and Nelson, G., Comparison of Asphalt Mixture Performance Tester Fatigue Characteristics with Full Scale Pavement Cracking for Recycled and Warm Mix Asphalts. Transportation Research Board, doi: 10.3141/2576-11.*

Direct Tension Cyclic fatigue Test

Strain-Based SVECD Fatigue Simulation

- Ranking is indicated by the legend below



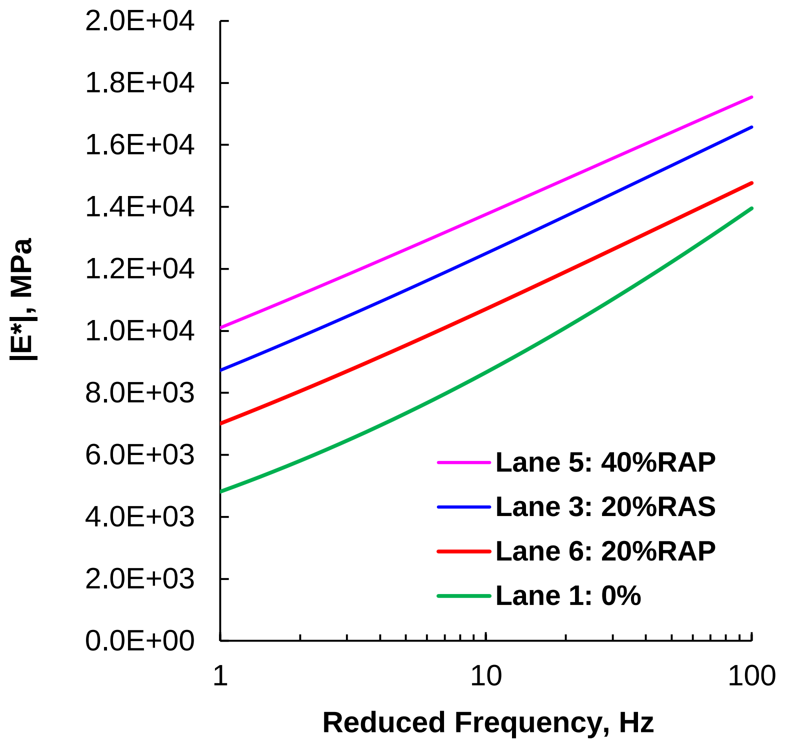
From top to bottom: good to poor fatigue resistance.

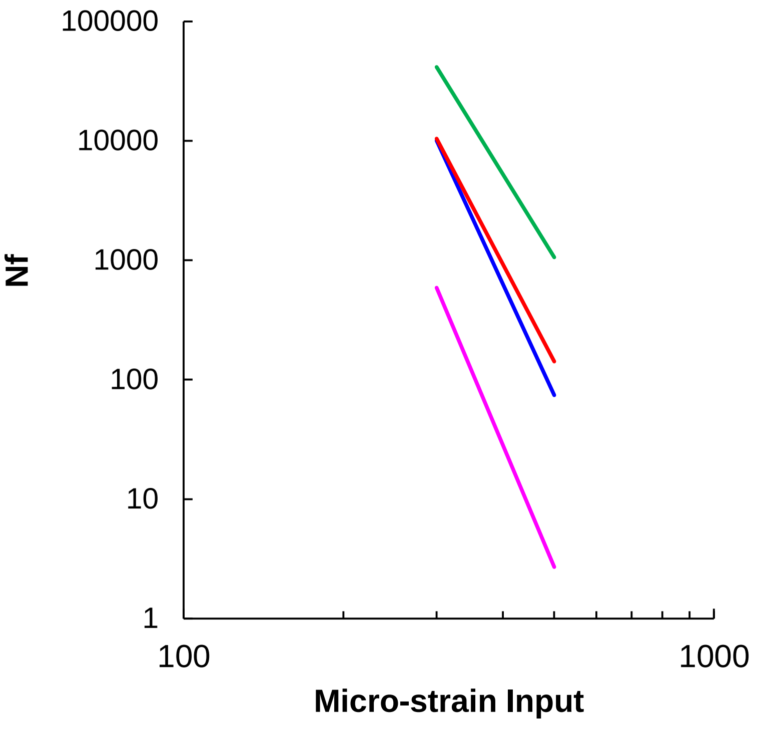
*The ALF data for Lane 2 and 8 are not available yet.

Direct Tension Cyclic fatigue Test

Strain-Based SVECD Fatigue Simulation

- Effect of RAP/RAS content (PG 64-22, HMA)





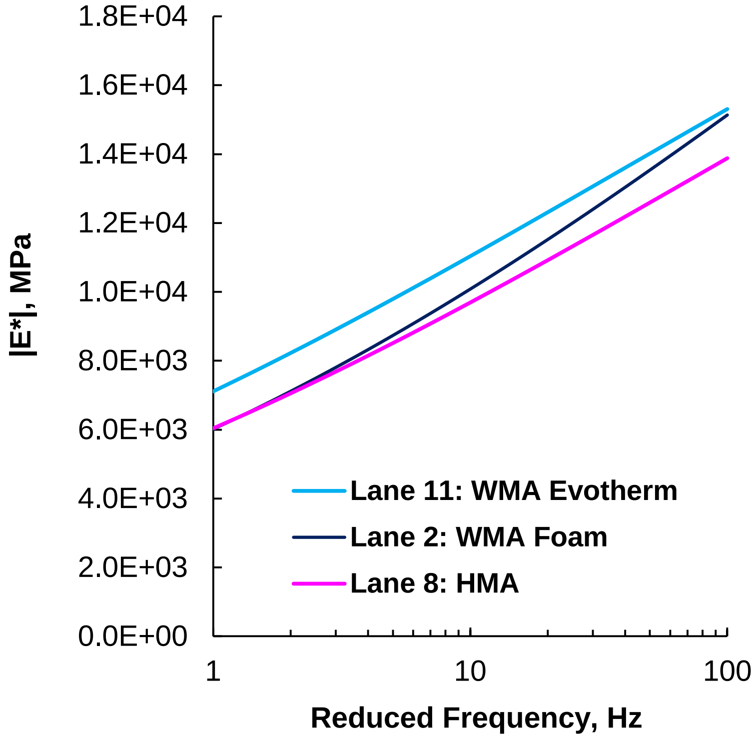
Stiffness: L5 > L3 > L6 > L1.

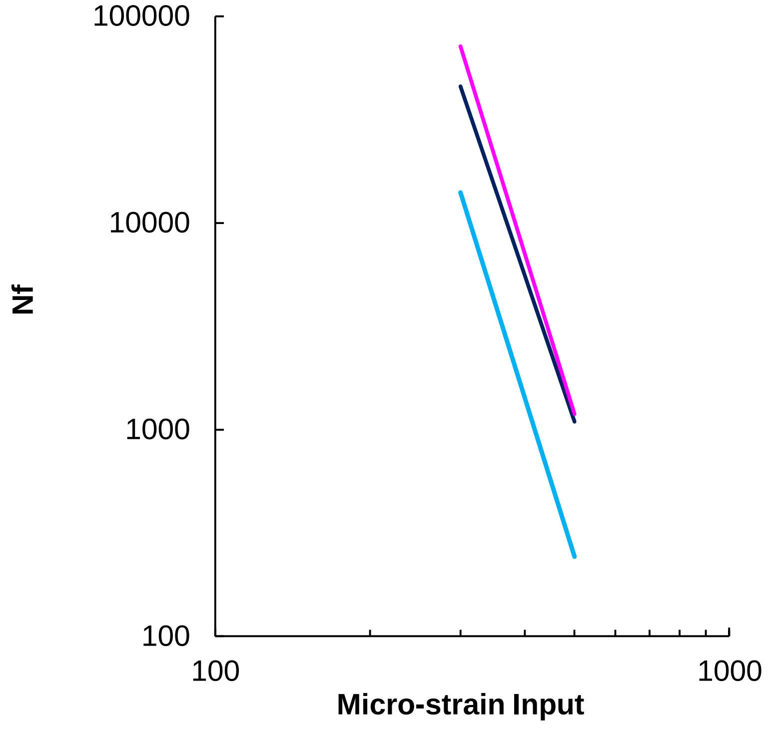
Fatigue resistance reduces with RAP/RAS content: L1 > L6 > L3 > L5.

Direct Tension Cyclic fatigue Test

Strain-Based SVECD Fatigue Simulation

- Effect of WMA technologies (PG 58-28, 40%RAP)





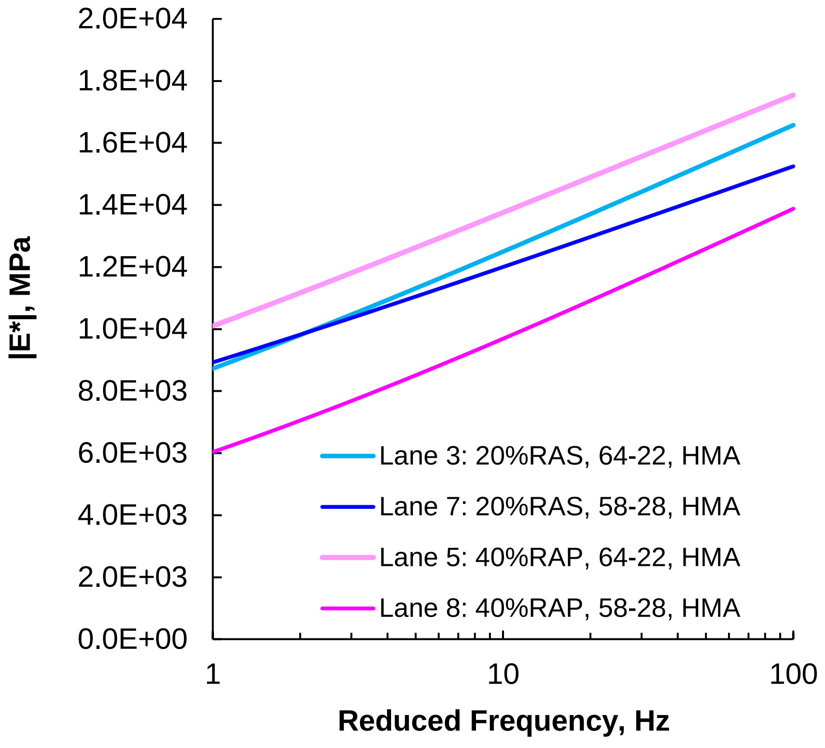
Stiffness: L11 > L2 > L8

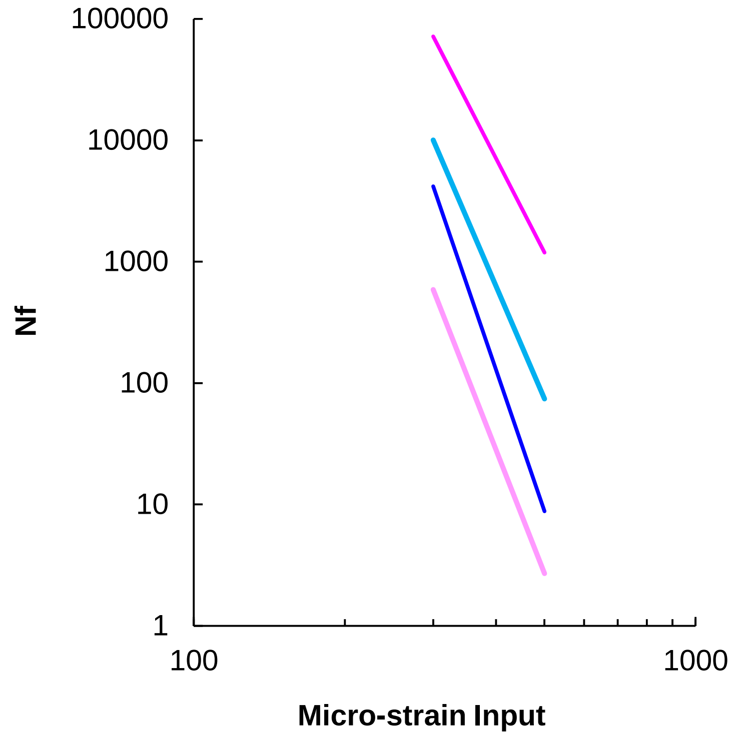
Fatigue resistance: L 8 & L 2 > L11

Direct Tension Cyclic fatigue Test

Strain-Based SVECD Fatigue Simulation

- Effect of soft binder





Direct Tension Cyclic fatigue Test

SVECD Ranking Based on alpha

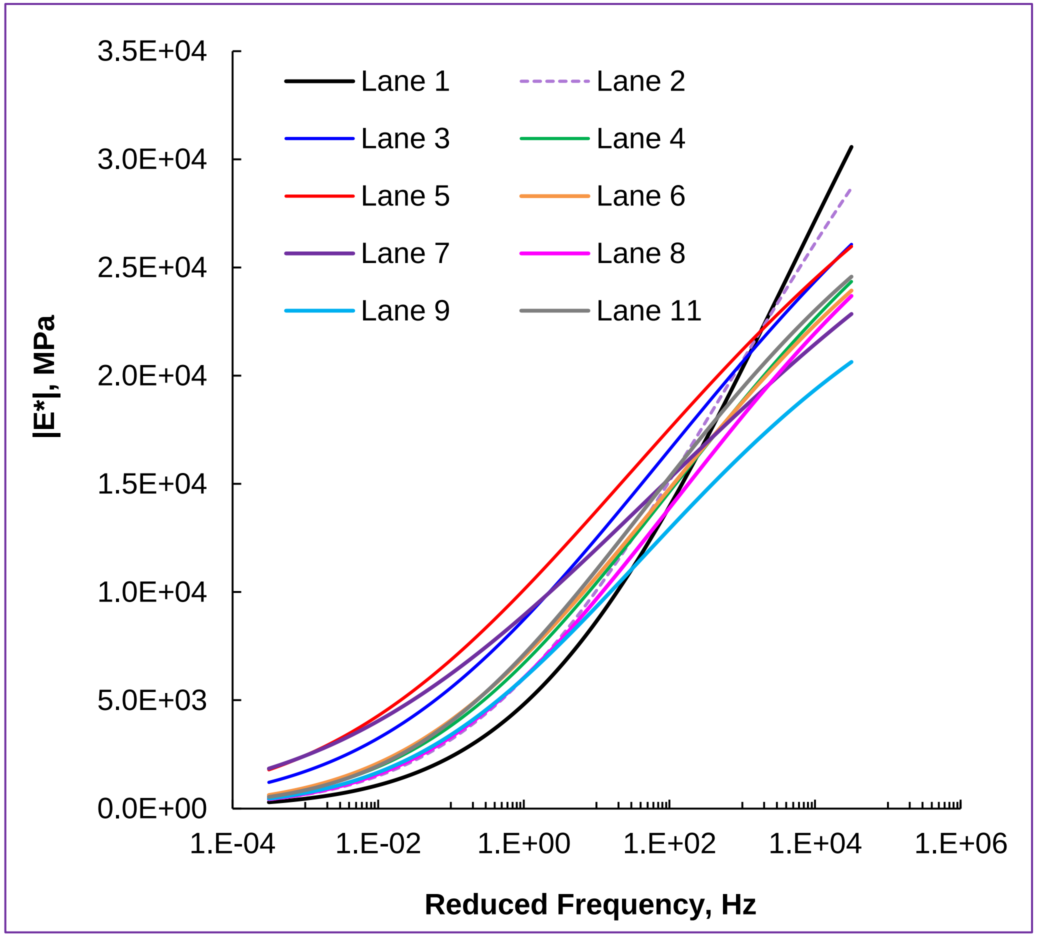
- Damage evolution rate – α
  - Pseudo strain energy density: $W^R = f(\varepsilon^R, S)$
  - Damage evolution law
    - ✓ $$\frac{dS}{dt} = \left(-\frac{\partial W^R}{\partial S} \right)^{\alpha} \quad \text{with} \quad \alpha = \frac{1}{n} + 1$$
    - ✓ where *n* = maximum log-log slope of relaxation modulus
  - Larger α -values indicate faster damage evolution

Direct Tension Cyclic fatigue Test

SVECD Ranking Based on alpha

- Ranking based on damage evolution rate

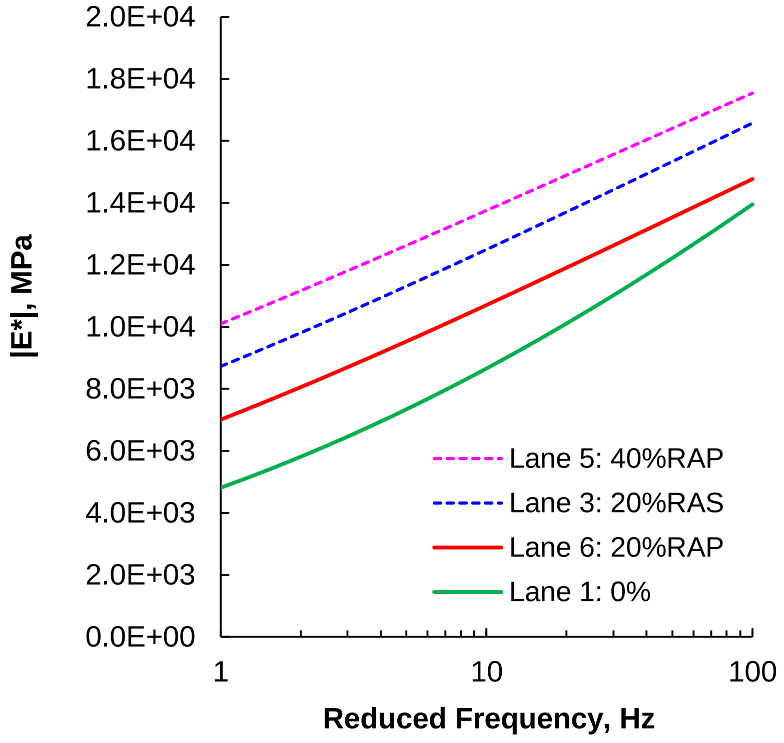
Ranking		SVECD using α
Best Three	1	***L1***
	2	***L2***
	3	***L11***
Middle Four	4	***L8***
	5	***L4***
	6	***L9***
	7	***L6***
Worst Three	8	***L3***
	9	***L5***
	10	***L7***

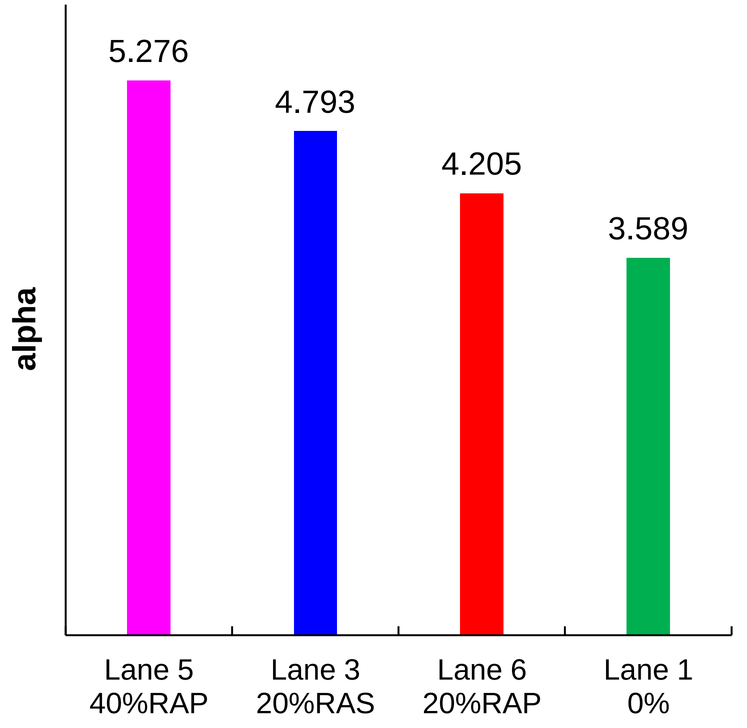


Direct Tension Cyclic fatigue Test

SVECD Ranking Based on alpha

- Effect of RAP/RAS content (PG 64-22, HMA)





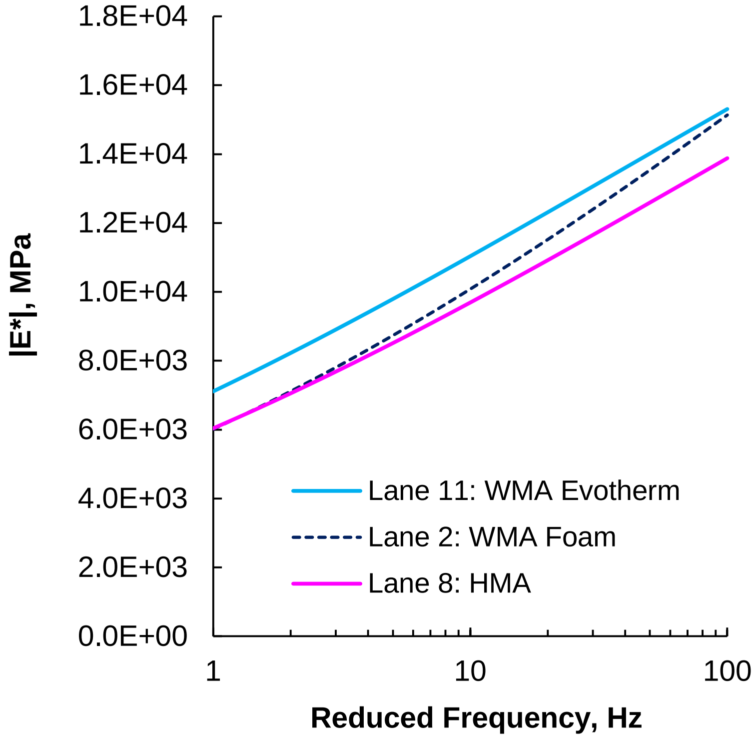
Stiffness: L5 > L3 > L6 > L1.

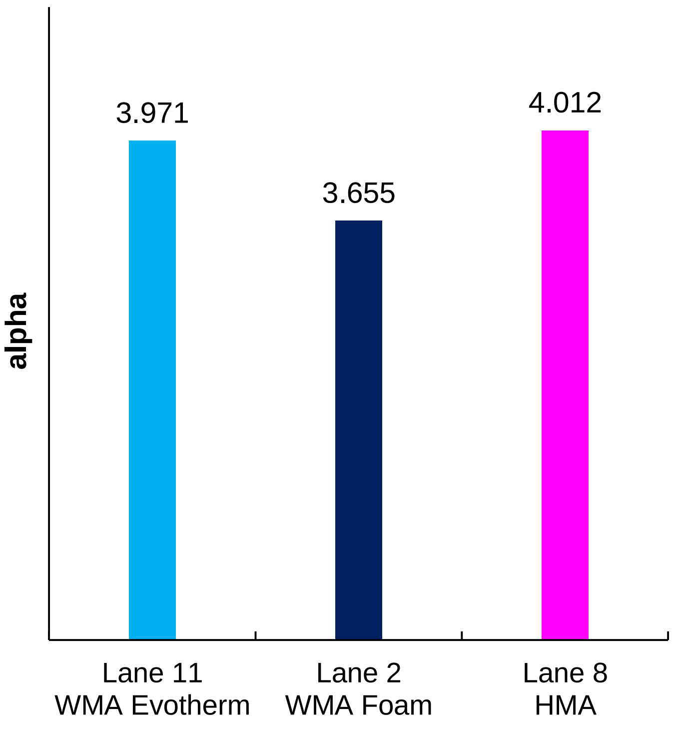
Fatigue resistance reduces with RAP/RAS content: L1 > L6 > L3 > L5.

Direct Tension Cyclic fatigue Test

SVECD Ranking Based on alpha

- Effect of WMA technologies (PG 58-28, 40%RAP)



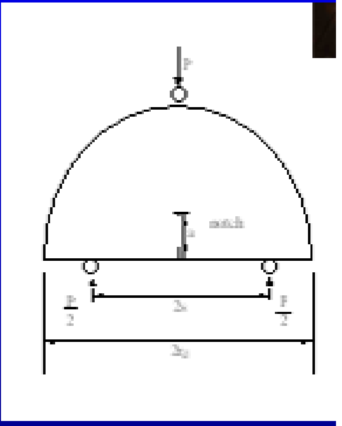


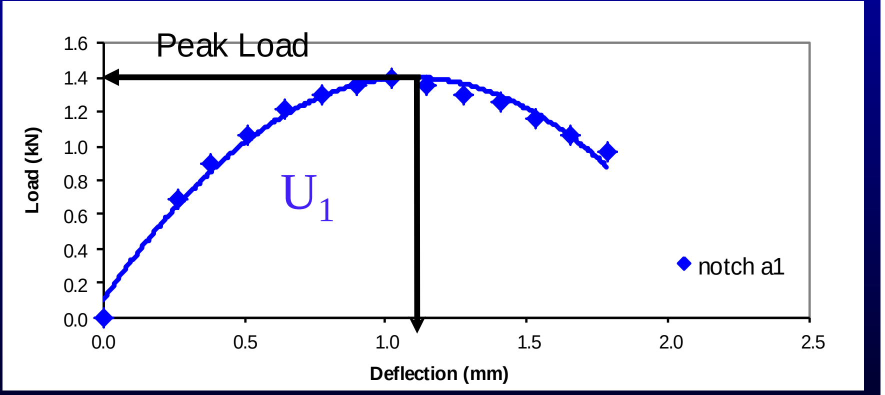
Stiffness: L11 > L2 > L8

Fatigue resistance: L8 < L11 < L2.
WMA better than HMA.

Semi Circular Bend (SCB) Test

- LADOTD TR 30/Proposed ASTM WK48574
- Temperature: 25°C
- Half-circular Specimen
  - Laboratory prepared
  - Field core
  - 150mm diameter X 57mm thickness
  - simply-supported and loaded at mid-point
- Notch controls path of crack propagation
  - 25.4-, 31.8-, and 38.0-mm
- LTA: 5 days, 85°C
- Loading type
  - Monotonic
  - 0.5 mm/min
  - To failure
- Record Load and Vertical Deformation
- Compute Critical Strain Energy: Jc

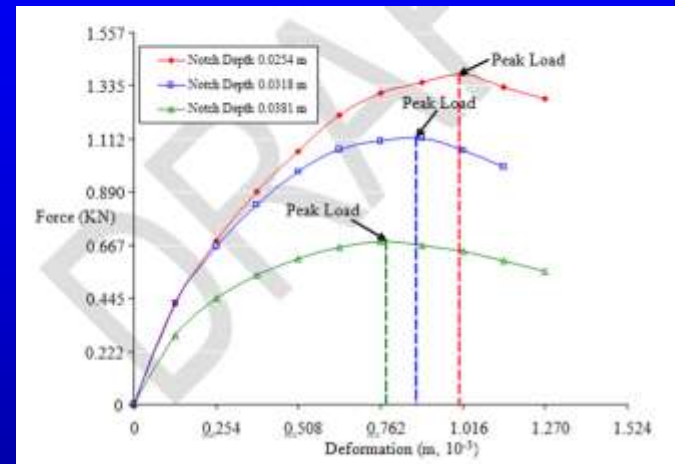


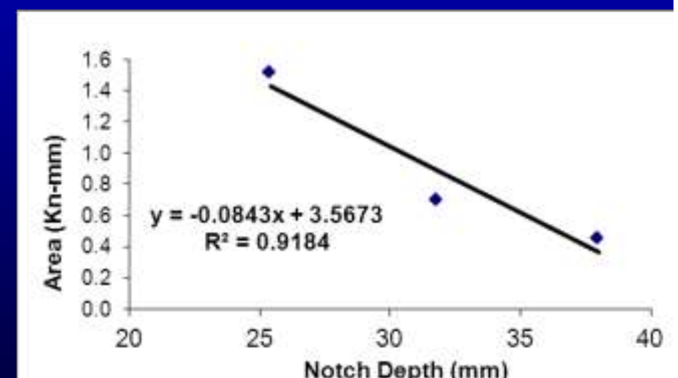


J_c=

SCB Test – Analysis

- Apply load to specimen in displacement control
  - 0.5 mm/min (slow rate);
- Collect force and displacement
  - sampling rate of 10 Hz;
- Plot force versus displacement
- Compute U: area under the curve up to peak load
  - For each notch depth
- Plot notch depth versus the corresponding U
- Determine slope of the line (notch depth vs U graph)
- Compute Jc: slope of line sample thickness





$$J_c = -\left(\frac{1}{b}\right)\frac{du}{da}$$

Jc= critical strain energy release rate (kJ/m^2);
b = sample thickness (m);
a = notch depth (m);
U = strain energy to failure (kilo-Joule, kJ); and
dU/da = change of strain energy with notch depth, KJ/m .

SCB @ Intermediate Temperature

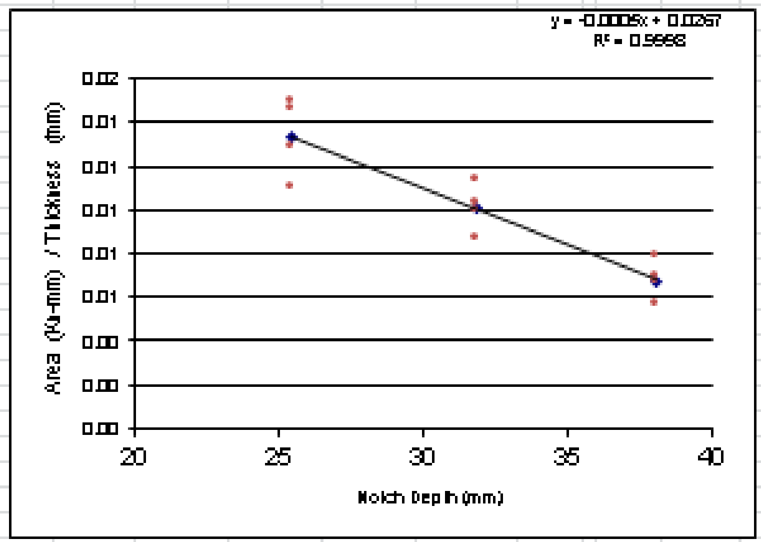
- **Fracture Energy COV ~ 15%**

Barriere Mix #PB 192 - Level A Incidental Wearing - LDOTD Form.

A	B	C	D	E	F	G	I	J	K
				Integration					
		Peak	Peak	Area	Thick	Area		Area (Kn-mm)	
	25.4	Load	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	Test52	1.574	0.803	0.882	60.3	0.015			
√	Test53	1.626	0.744	0.771	60.1	0.013			
√	Test54	1.483	0.632	0.668	60.3	0.011			
√	Test55	1.669	0.866	0.901	60.3	0.015	0.013	0.002	13.4
		Peak	Peak	Area	Thick	Area		Area (Kn-mm)	
	31.8	Load	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	Test56	1.386	0.627	0.625	60.2	0.010			
√	Test57	1.326	0.541	0.523	60.4	###			
√	Test58	1.323	0.640	0.602	60.1	0.010			
√	Test59	1.480	0.643	0.675	59.6	0.011	0.010	0.001	10.9
		Peak	Peak	Area	Thick	Area		Area (Kn-mm)	
	38.0	Load	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	Test60	1.094	0.566	0.405	60.4	0.007			
√	Test61	0.965	0.503	0.341	60.4	###			
√	Test62	0.918	0.747	0.475	60.4	###			
√	Test63	0.900	0.752	0.416	60.3	0.007	0.007	0.001	13.4

Notch Depth	Area / Thick
25.4	0.01
31.8	0.01
38.0	0.01
Es	**-0.0005**
J1c	**0.52**
R^2	**1.00**

12.6



SCB @ Intermediate Temperature

- **Fracture Energy COV ~ 15%**

				Integration					
		Peak	Peak	Area	Thick	Area	Area (Kn-mm)		
	25.4	Load (Kn)	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	7a	1.680	0.962	0.897	57.0	0.016			
√	7b	1.751	0.869	0.894	57.0	0.016			
√	8a	1.520	1.061	0.980	57.0	0.017			
√	8b	1.502	0.949	0.804	57.0	0.014	0.016	0.001	8.020
		Peak	Peak	Area	Thick	Area	Area (Kn-mm)		
	31.8	Load (Kn)	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	9a	1.211	0.756	0.569	57.0	0.010			
√	9b	1.055	0.763	0.488	57.0	0.009			
√	10a	1.212	0.716	0.534	57.0	0.009			
√	10b	1.240	0.789	0.622	57.0	0.011	0.010	0.001	10.177
		Peak	Peak	Area	Thick	Area	Area (Kn-mm)		
	38.0	Load (Kn)	Disp	(Kn-mm)	(mm)	Thick	Avg	Stdev	COV
√	11a	0.888	0.630	0.358	57.0	0.006			
√	11b	0.987	0.750	0.478	57.0	0.008			
√	12a	0.978	0.703	0.429	57.0	0.008			
√	12b	0.862	0.597	0.331	57.0	0.006	0.007	0.001	16.784

Dr. Erv Dukatz ASTM work item :WK48574 Ruggedness testing between four laboratories has shown the Jc for split samples to have a within laboratory COV of 9.9%

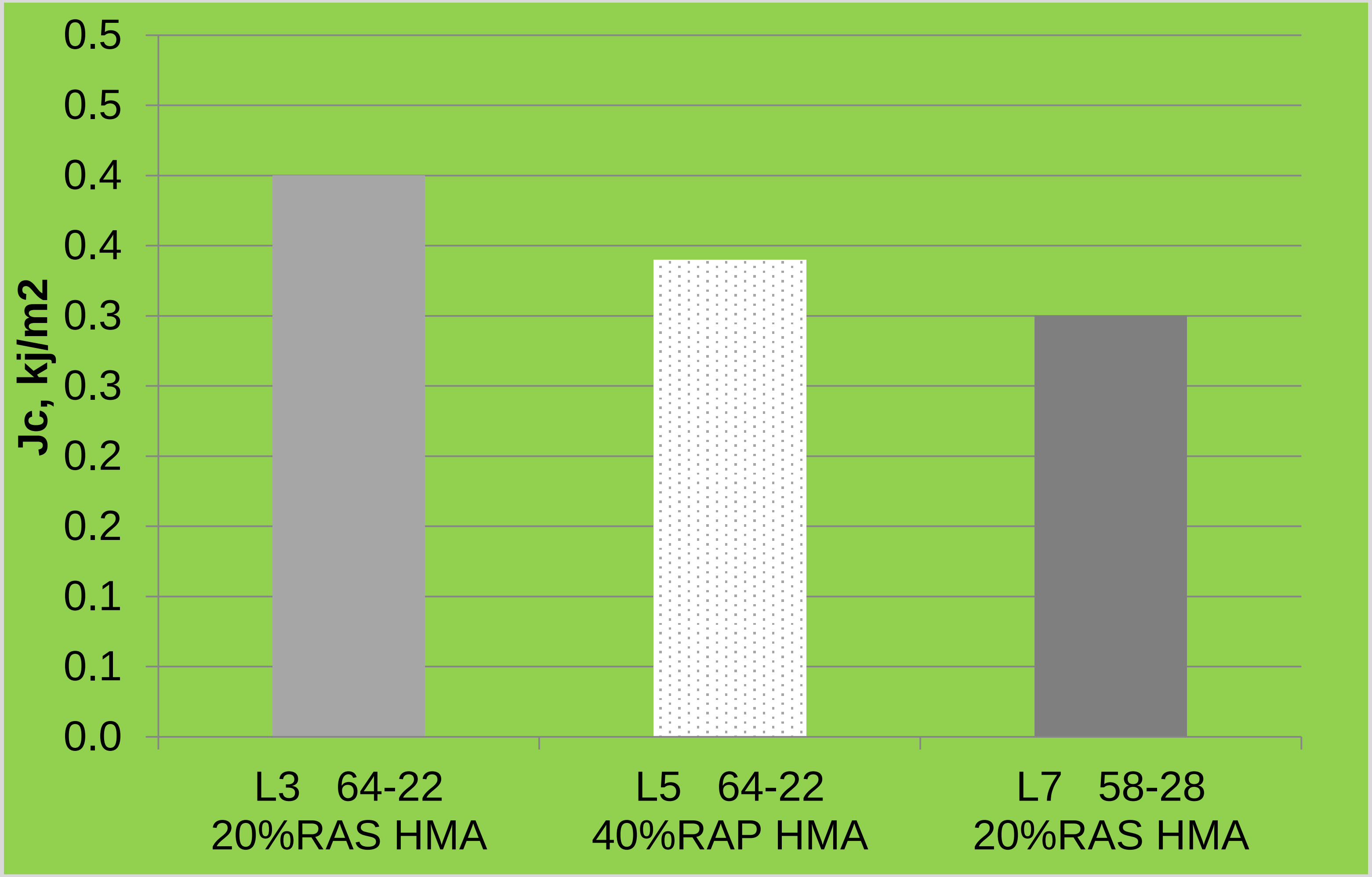
SCB @ Intermediate Temperature

- **Specimen Preparation QC Sheet**

	A	B	C	D	E	F	G	H	I	J	K	L
6					Target Notch -	25.4						
7	Notch Depth (mm)		Deviation from Target (mm)	Notch Width, 3.0 mm		Thickness (mm)		Diameter (mm)		Left center	Right center	middle height
8	1.0	25.5	0.1	1.0	2.7	1.0	57.4	1.0	149.3	73.5	73.3	72.9
9	2.0	25.6	0.2	2.0	2.8	2.0	57.4	2.0	149.2	74.5	73.8	72.8
10	3.0	24.0	1.4	3.0	2.8	3.0	57.3	3.0	149.3	74.1	73.7	
11	AVG	25.0	0.4	AVG	2.8	AVG	57.4	AVG	149.3			
12												

SCB Test Results

- Completed L3, L5, L7



Correlation to field performance ALF vs , S-VCED and SCB

Ranking		ALF
Best Three	1	L1
	2	L9
	3	L6
Middle Two	4	L4
	5	L11
Worst Three	6	L3
	7	L5
	8	L7

Correlation to field performance ALF vs , S-VCED and SCB

Ranking		ALF	S-VECD simulation Cf = 0.25	S-VECD Alpha
Best Three	1	L1	L1	L1
	2	L9	L9	L11
	3	L6	L4	L$
Middle Two	4	L4	L11	L9
	5	L11	L6	L6
Worst Three	6	L3	L3	L3
	7	L5	L7	L5
	8	L7	L5	L7

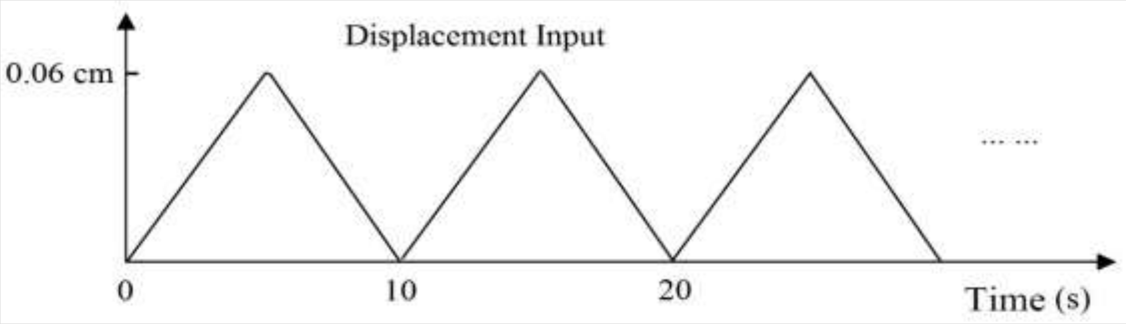
Correlation to field performance ALF vs , S-VCED and SCB

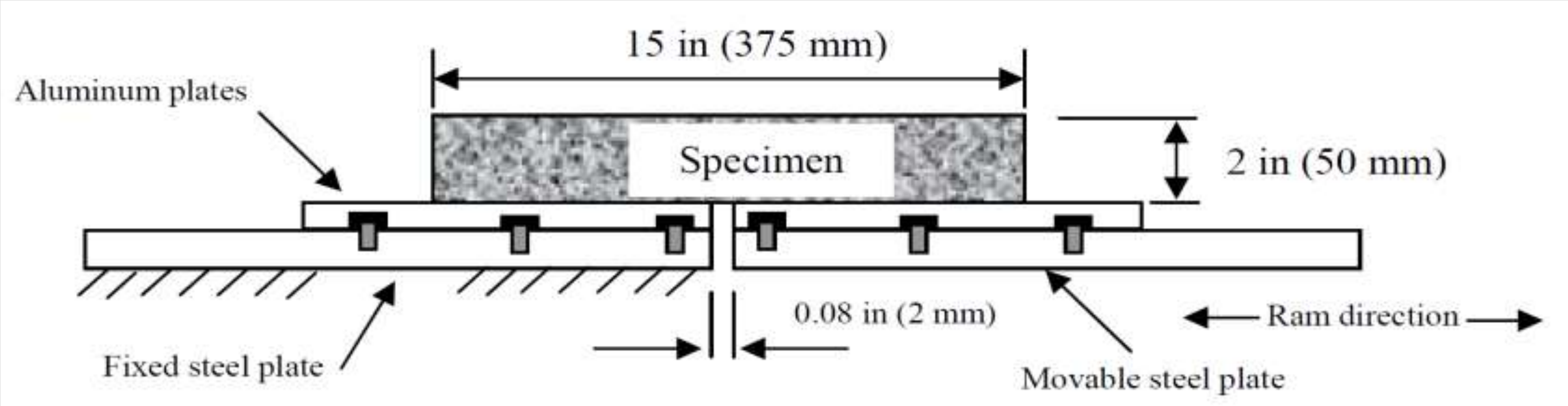
Ranking		ALF	S-VECD simulation Cf = 0.25	S-VECD Alpha	SCB
Best Three	1	**L1**	**L1**	L1	
	2	**L9**	**L9**	L11	
	3	**L6**	**L4**	L$	
Middle Two	4	**L4**	**L11**	L9	
	5	**L11**	**L6**	L6	
Worst Three	6	**L3**	**L3**	L3	**L3**
	7	**L5**	**L7**	L5	**L5**
	8	**L7**	**L5**	L7	**L7**

Texas Overlay

Test method: Tex-248-F

- AMPT

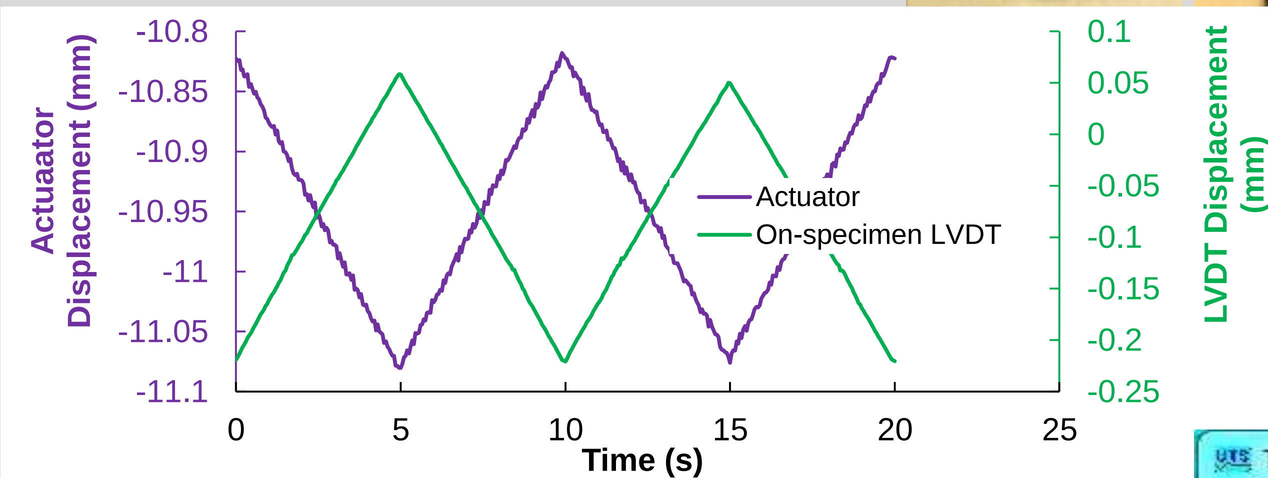


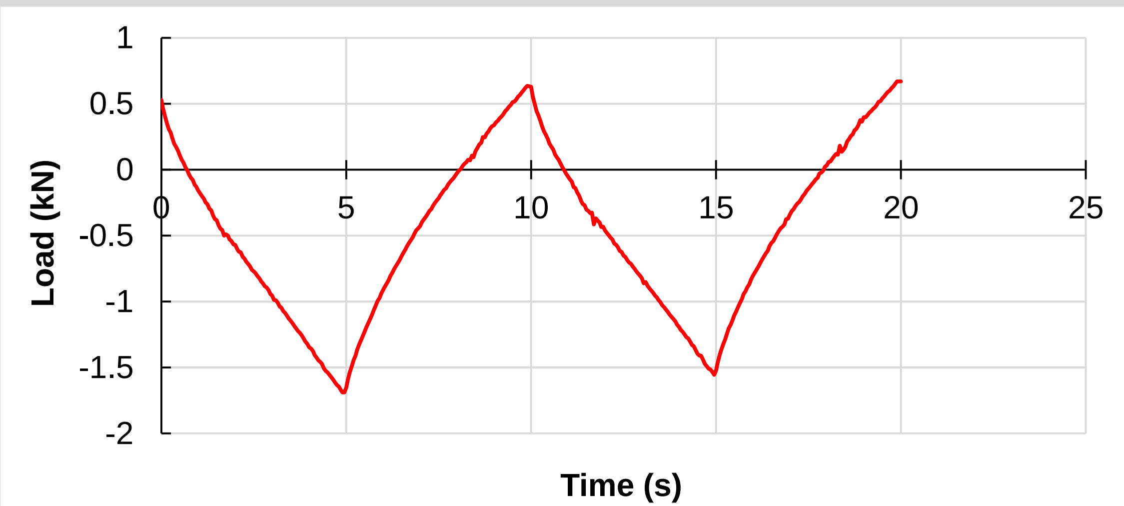


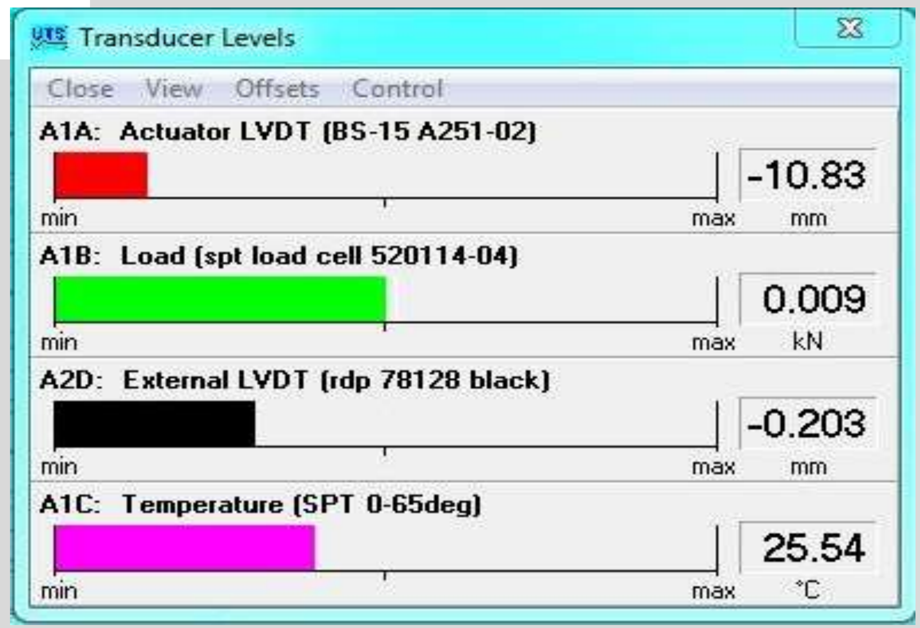
Texas Overlay

Test method: Tex-248-F

- AMPT







THANK YOU


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Photo: Jim Zietz, Office of Public Affairs