Outline

- Update
- Mixture Experiment
  - ALF Experiment
    - 10 test lanes
    - SCB
    - Texas Overlay
- Structural performance vs. mixture performance

Project Status Update

U.S. Department of Transportation
Federal Highway Administration

- FHWA ALF test lanes
  - Mixture Experiment
    - S-VECD (Simplified Viscoelastic Continuum Damage): Completed
    - **SCB (Semi-Circular Bend): Completed**
    - **Texas Overlay: Completed**
    - Florida IDT: On-going
    - Beam Fatigue: On-going
  - Asphalt binder characterization: On-going
    - Extraction
    - PG grading, LAS, MSCR
    - HP-GPC, SARA
- In acquisition
  - Florida DOT
  - Colorado DOT

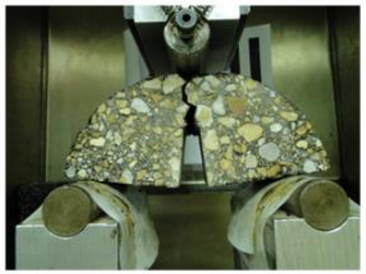
FDOT

CO CDOT

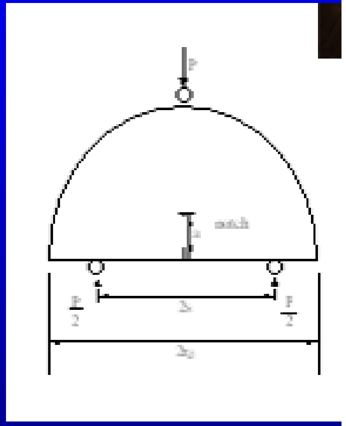
FHWA ALF Test Lanes Overview

Lane #	Asphalt Mixture Description				
	Binder Content (%)	% RBR		Virgin Binder PG	Warm-Mix Technology
		RAP	RAS		
L1	5.08	--	--	64-22	--
L2	5.07	40	--	58-28	Water foam
L3	4.98	--	20	64-22	--
L4	4.95	20	--	64-22	Evotherm
L5	4.60	40	--	64-22	--
L6	4.91	20	--	64-22	--
L7	4.91	--	20	58-28	--
L8	4.95	40	--	58-28	--
L9	4.98	20	--	64-22	Water foam
L11	4.89	40	--	58-28	Evotherm

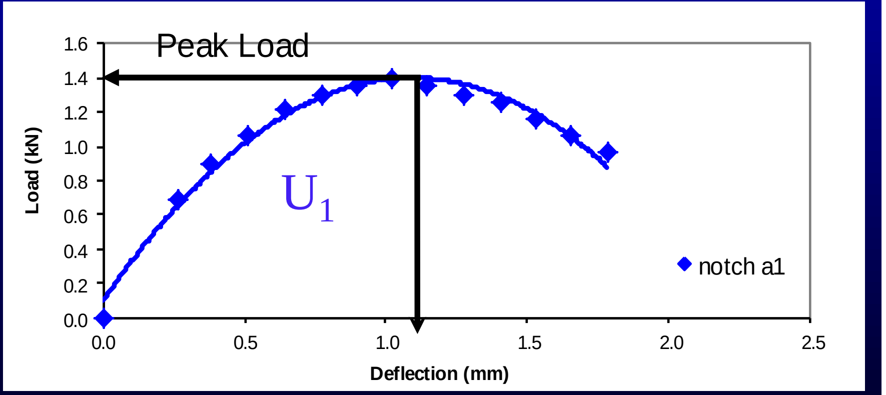
Semi Circular Bend (SCB) Test



- LADOTD TR 30/ASTM D8044
- 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

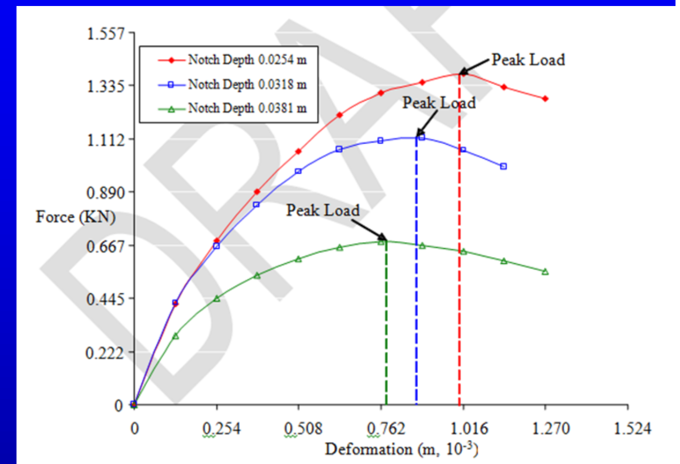


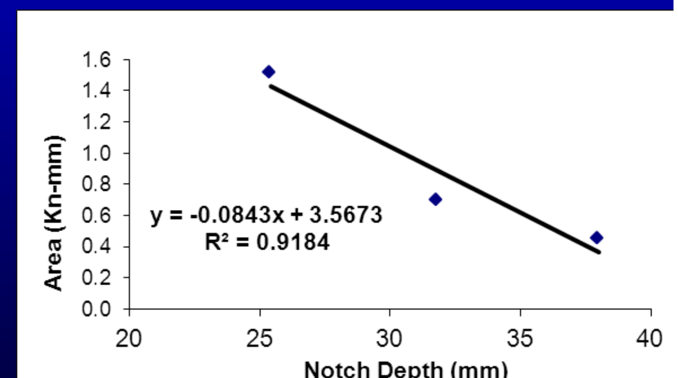
- Record Load and Vertical Deformation
- Compute Critical Strain Energy: Jc

SCB Test – Analysis

J_c=

- 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





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

Jc= critical strain energy release rate (kJ/m²);
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 .

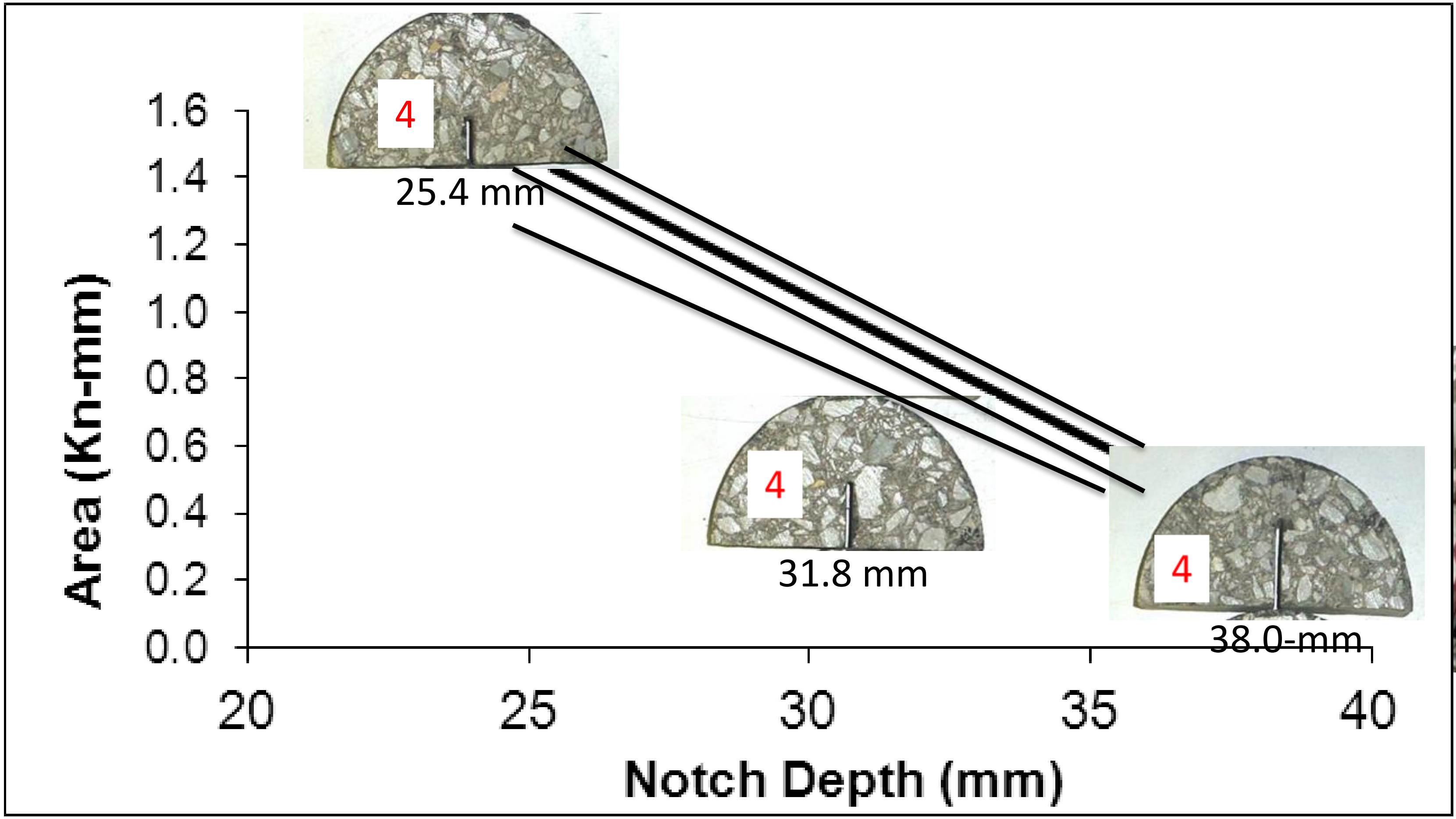
SCB at Intermediate Temperature

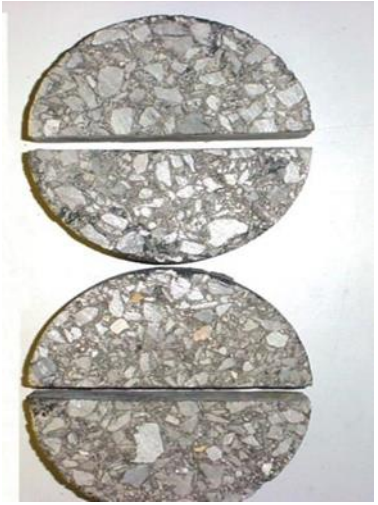
- **Specimen Preparation QC Sheet**

	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												

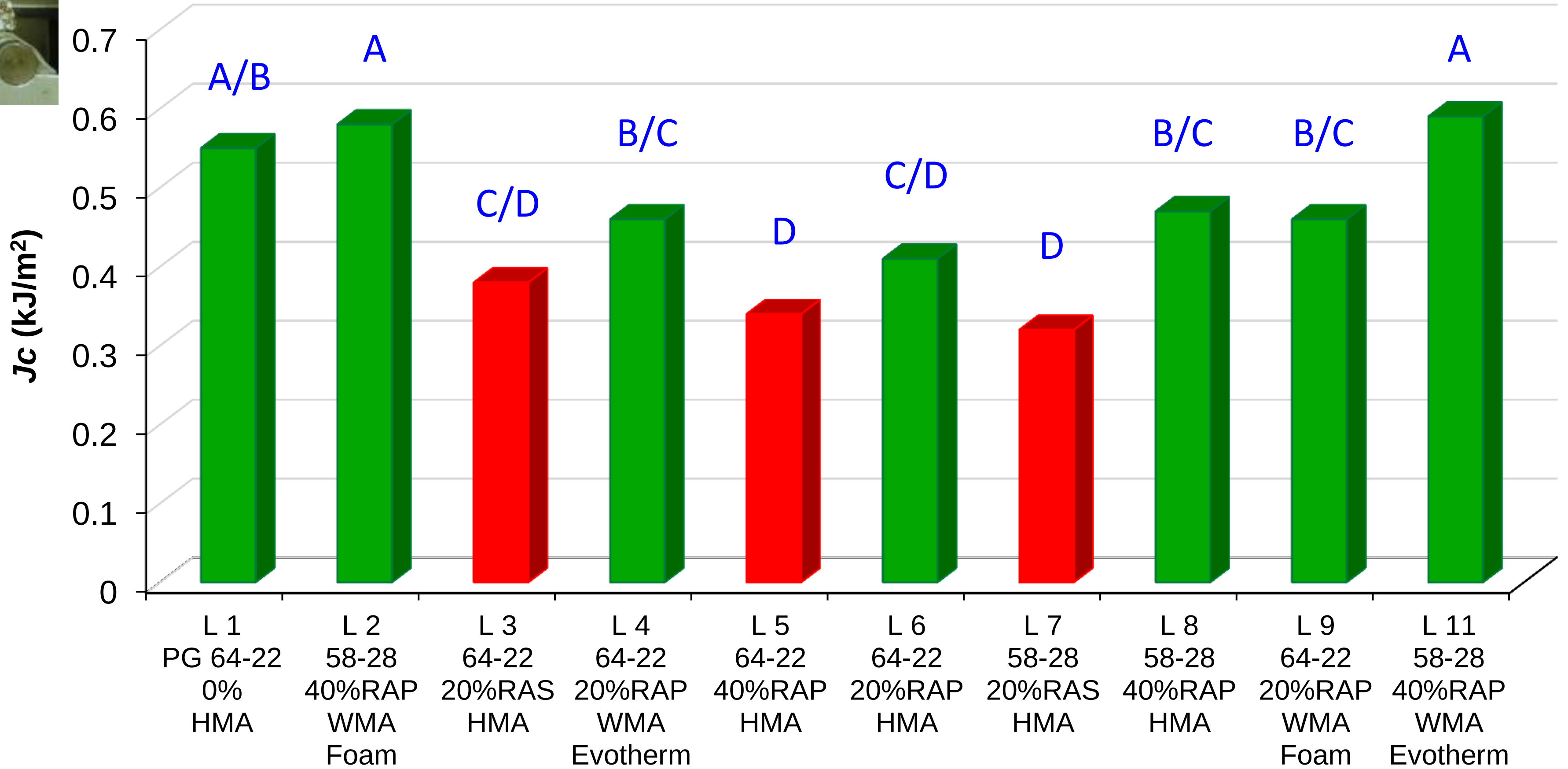
SCB at Intermediate Temperature

- **Data Analysis**





SCB Test Results, J_c

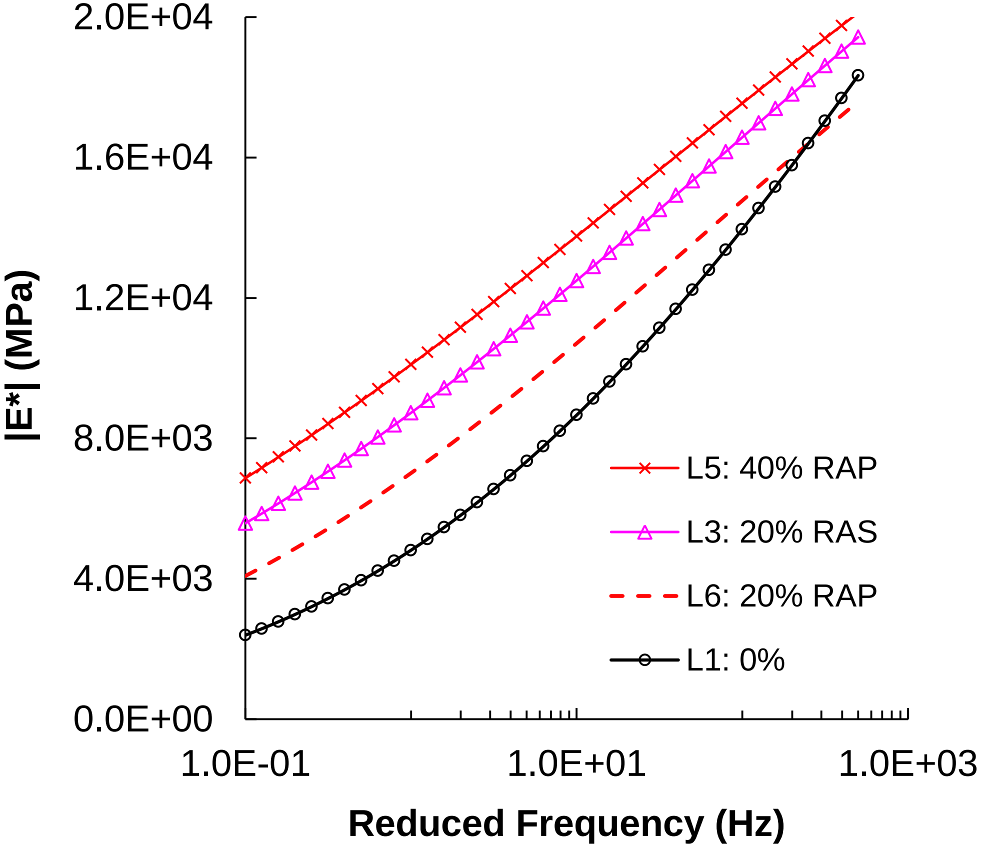


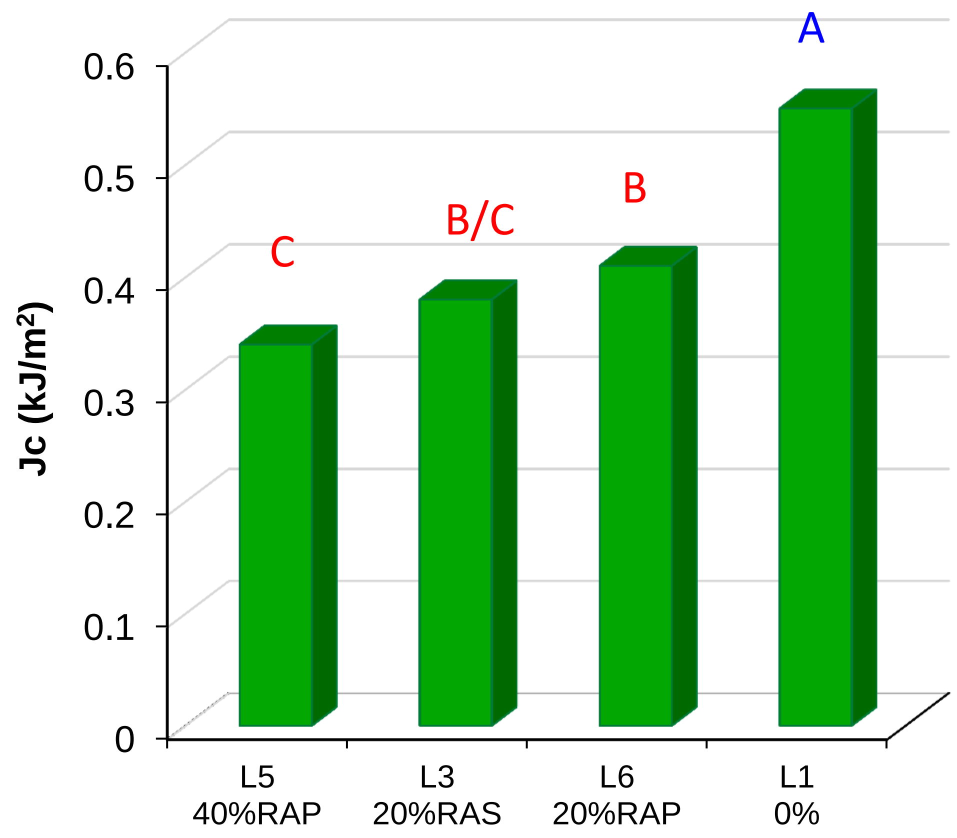
CoV=14.5%.

ANOVA GLM with least square difference multiple comparison test

SCB Test Results, J_c *and* |*E**|

➢ Sensitivity to RAP, RAS Content (PG 64-22, HMA)



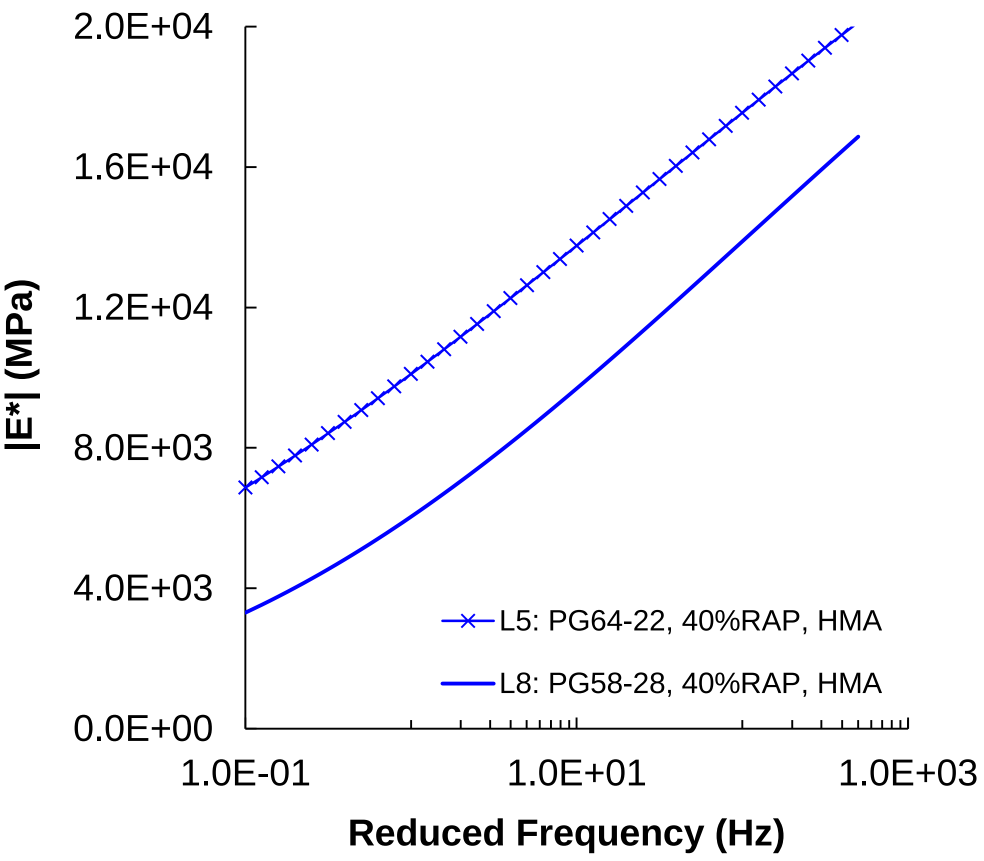


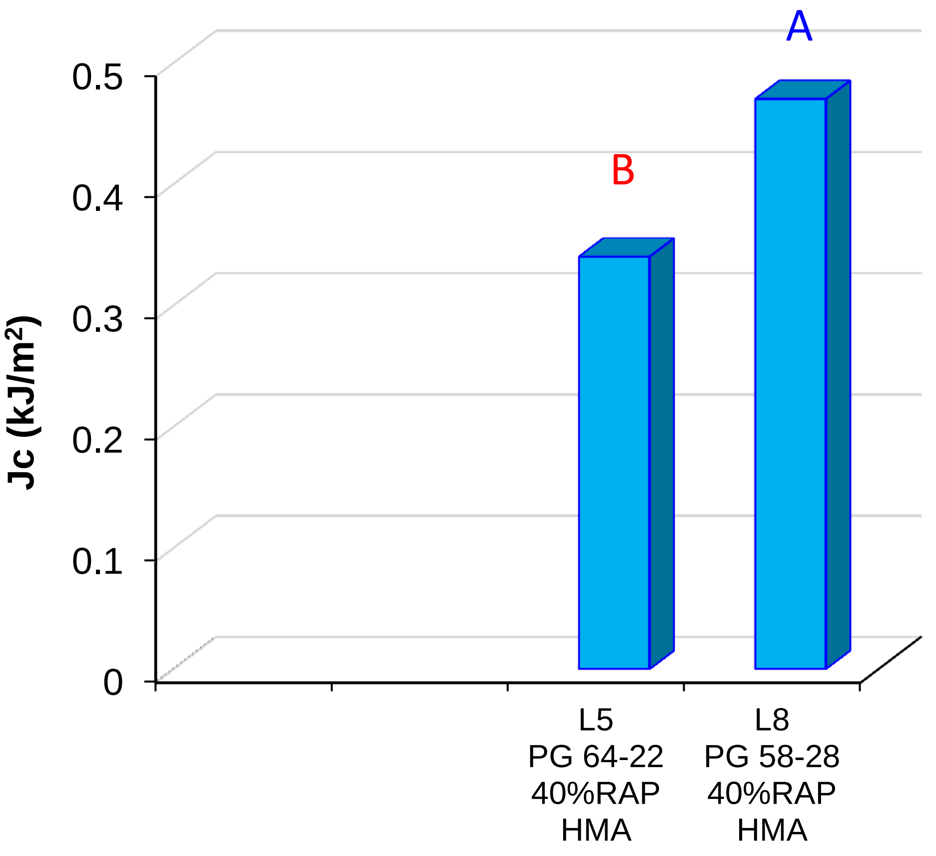
Stiffness: L5 > L3 > L6 > L1.

Crack resistance: L5 < L3 < L6 < L1.

SCB Test Results, J_c and $|E^*|$

➢ Sensitivity to Asphalt Binder Grade





SCB Test Results, J_c and |E*|

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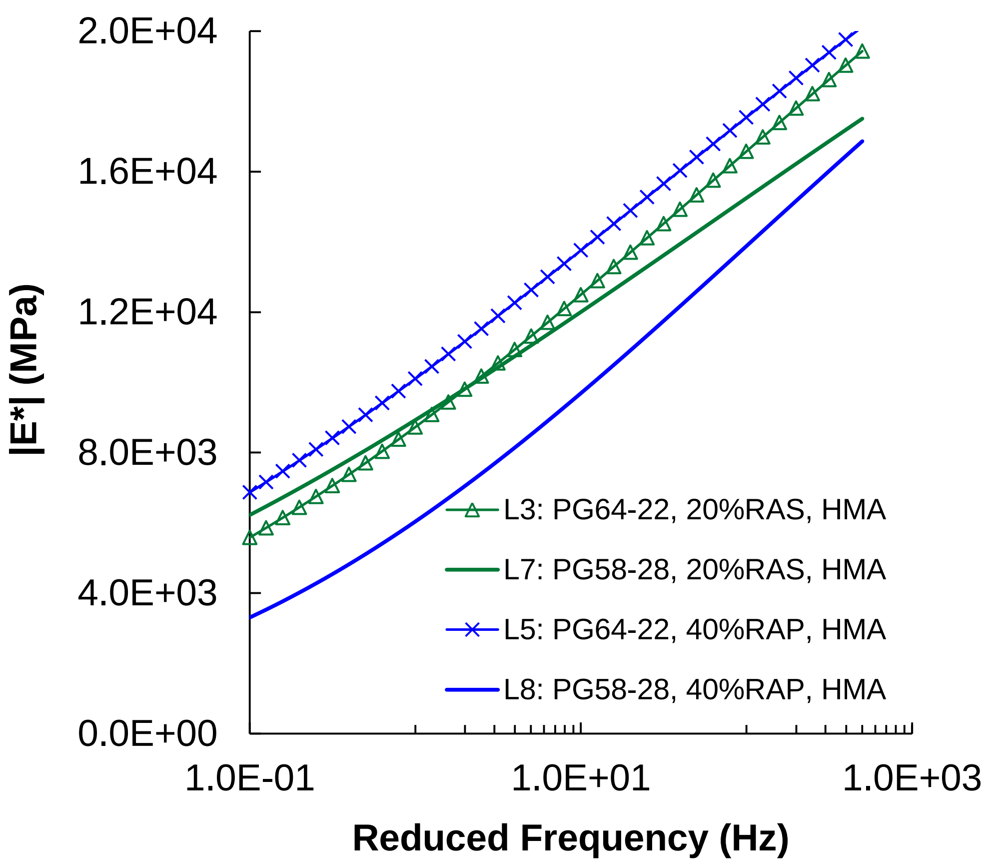
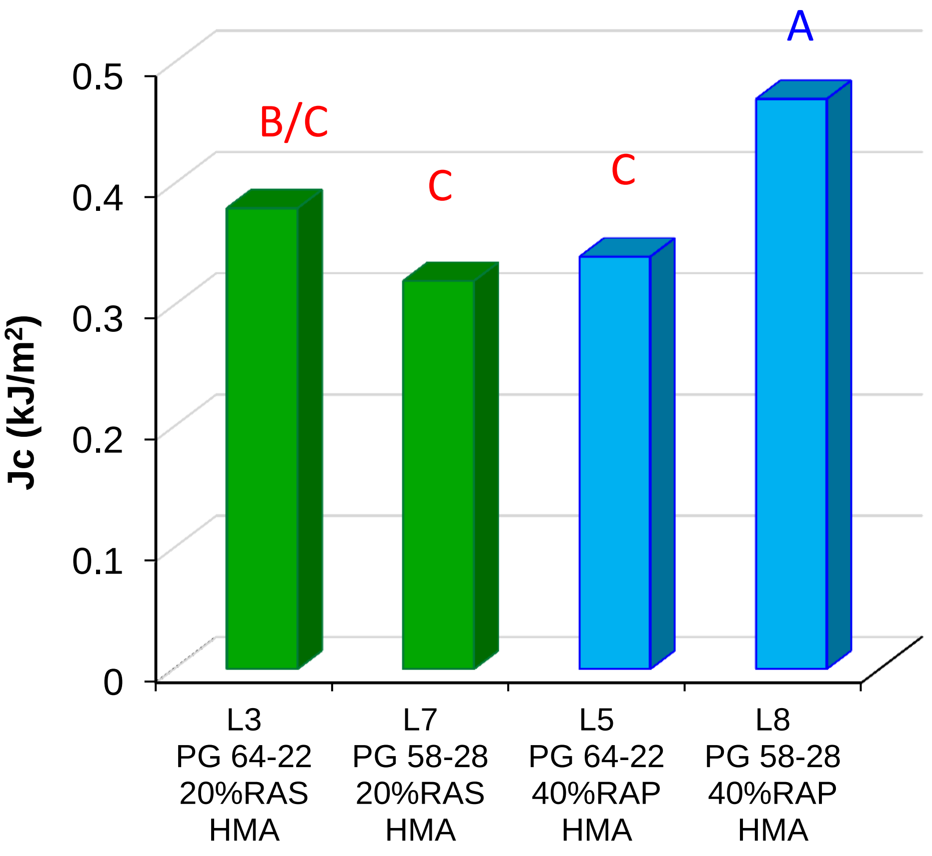
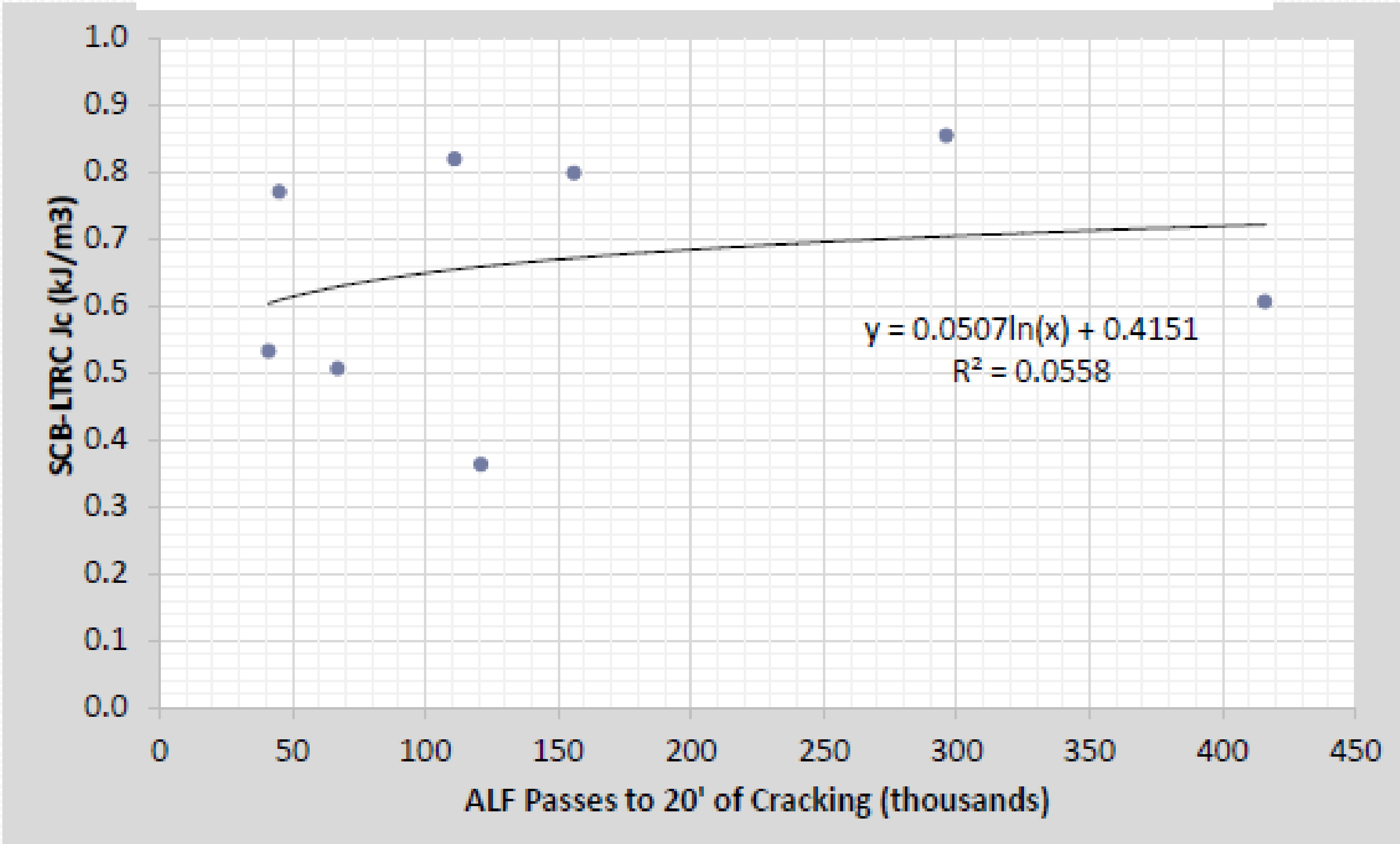




SCB Test Results, J_c vs. ALF Test Lanes N_f

NCAT



FHWA Asphalt Binder Expert Task Group Meeting
April 25 – 27, 2016

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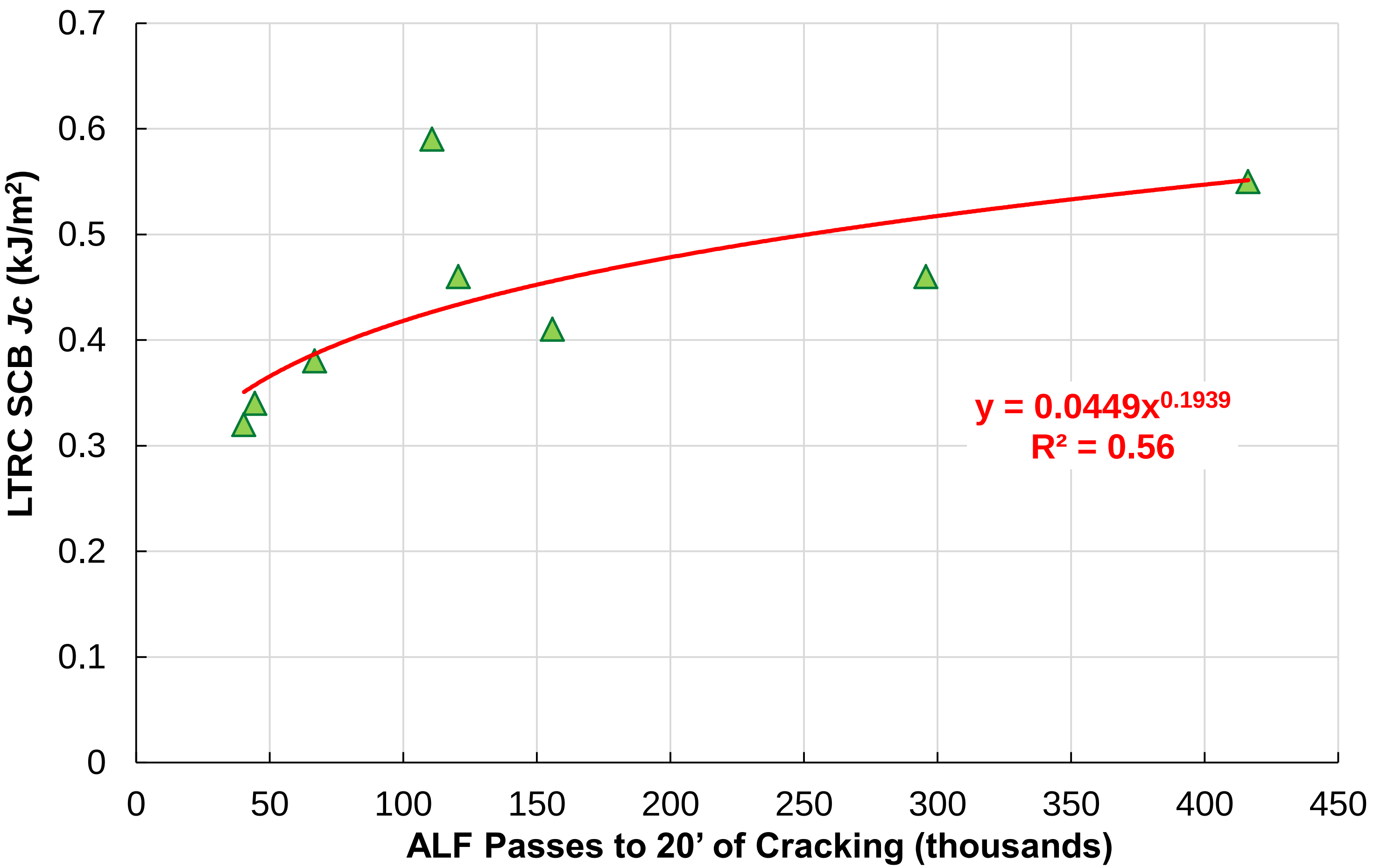
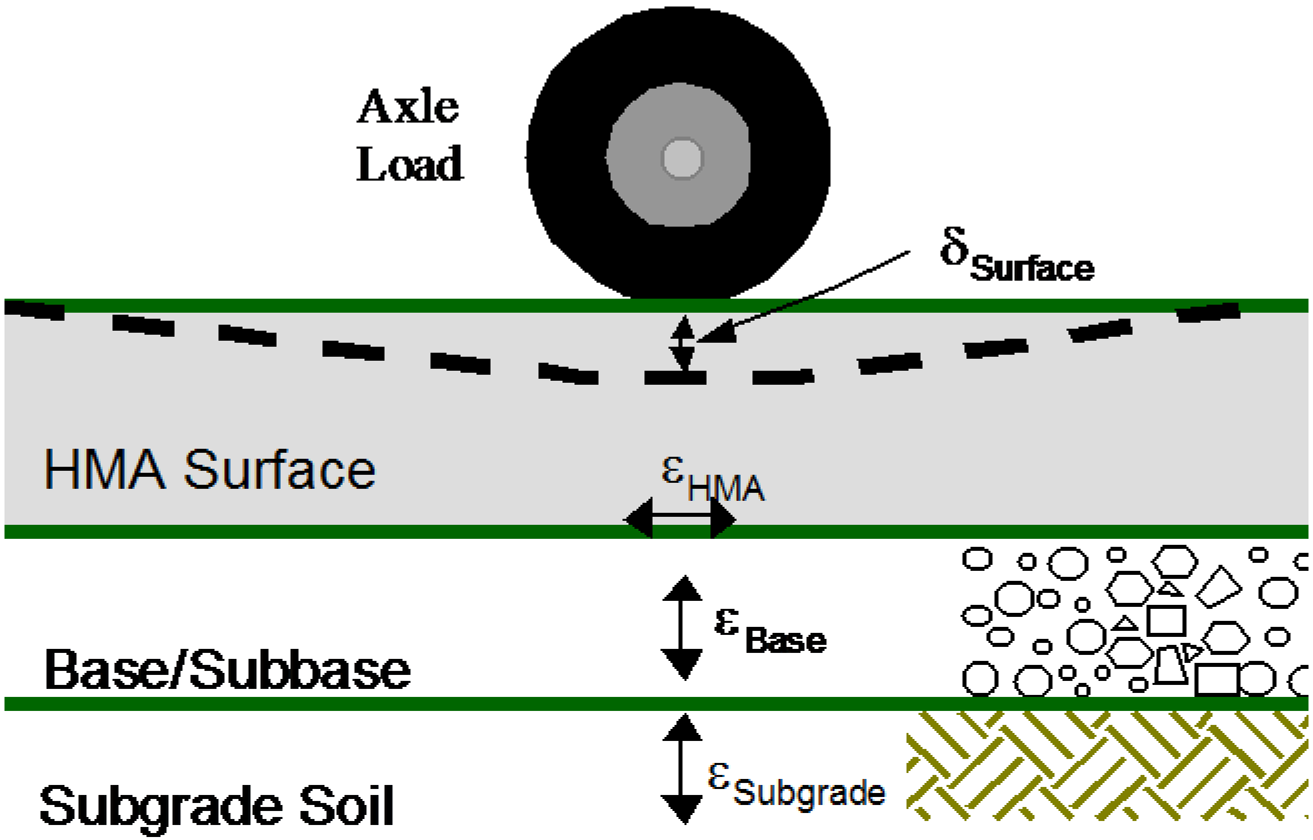
National Center for Asphalt Technology NCAT at AUBURN UNIVERSITY

SCB Test Results, J_c vs. ALF Test Lanes N_f

LTRC



Pavement Responses Under Load



$\delta_{Surface}$ = Surface deflection

ε_{HMA} = Tensile strain at the bottom of HMA surface layer

ε_{Base} = Vertical strain in the base/ subbase layer

$\varepsilon_{Subgrade}$ = Vertical strain at the top of subgrade soil

Structural layout of ALF Test Lanes

ALF Lanes	AC Layer Thickness (cm)	Aggregate Base Modulus (MPa)	Subgrade Modulus (MPa)
L 1	11.7	115.1	71.2
L 2	11.7	109.6	81.3
L 3	11.2	103.4	54.5
L 4	11.6	83.4	72.4
L 5	10.4	96.5	49.0
L 6	11.7	82.7	103.4
L 7	10.8	83.4	126.2
L 8	11.4	85.5	61.4
L 9	10.5	111.0	57.9
L 11	10.3	90.3	57.2

NOTE: Aggregate base layer thickness = 56 cm for all lanes.

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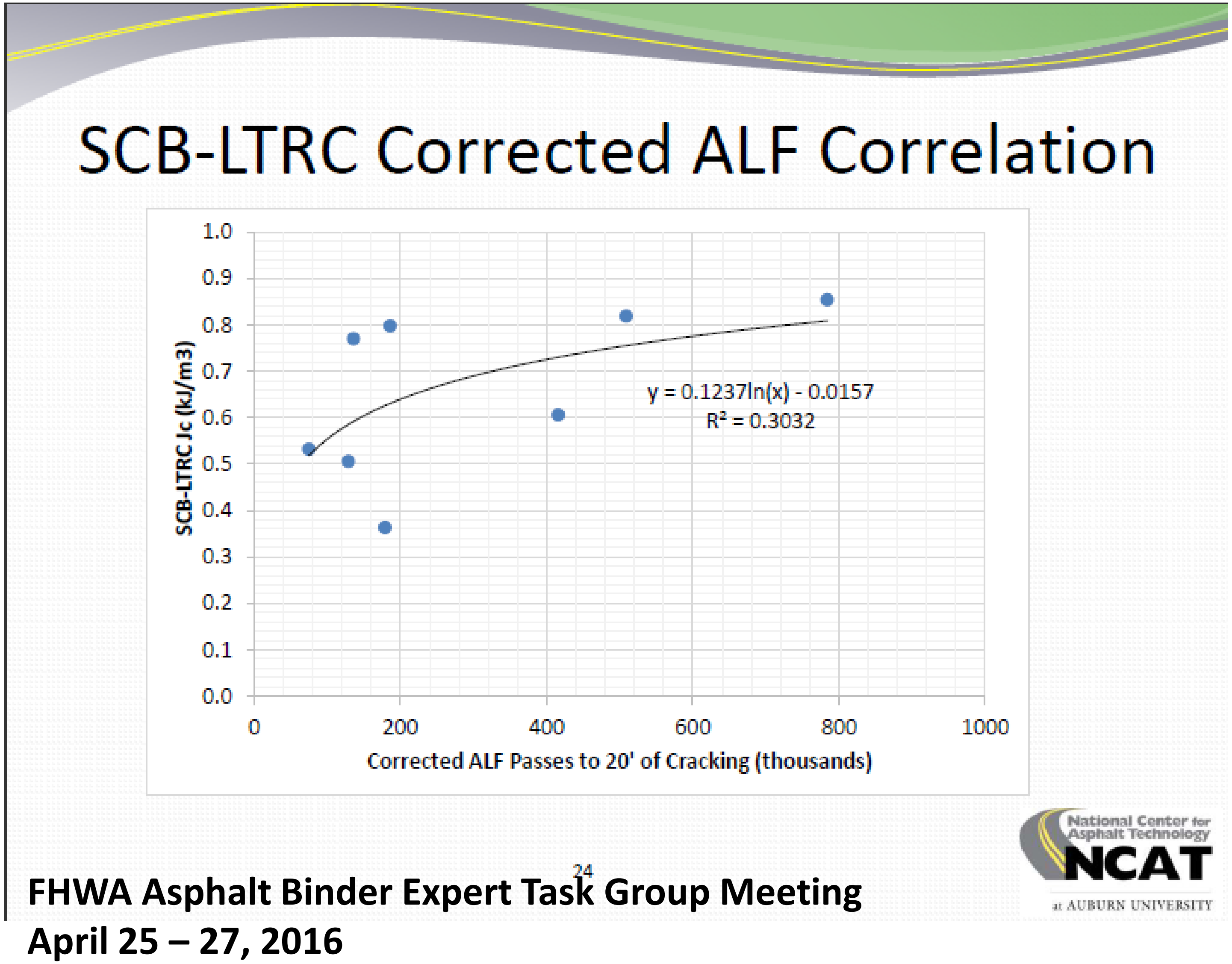
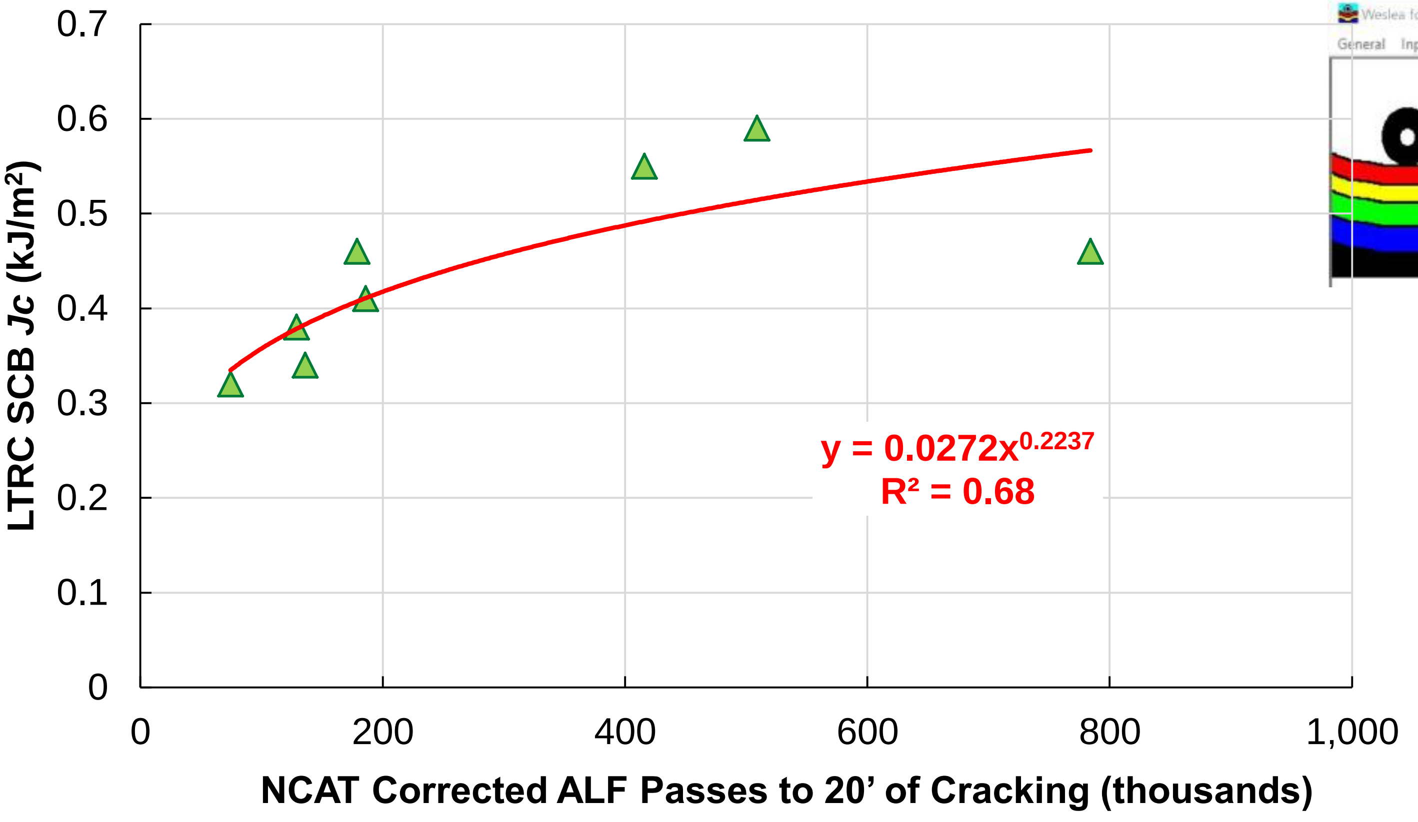
SCB Test Results, J_c *vs. ALF Test Lanes* N_f *Corrected*

NCAT



SCB Test Results, J_c *vs. ALF Test Lanes* N_f *Corrected LTRC*



Structural fatigue Performance vs. Mixture Characterization

- depends on mixture’s crack resistance, structural layout, stiffness of all layers, traffic loading, and environmental conditions.
- Prediction of allowable number of load repletion to fatigue cracking
  - Incorporate mixture cracking parameter

Compute N_f ASSHTO Pavement ME

- Obtain the fatigue life for structures
  - ❖Fatigue model in AASHTOWare Pavement ME Design

$$N_f = k_{f1} C C_H \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{k_{f2}\beta_{f2}} \left(\frac{1}{|E^*|}\right)^{k_{f3}\beta_{f3}} \quad \text{with} \begin{cases} C = 10^{4.84\left(\frac{V_{be}}{V_a+V_{be}}-0.69\right)} \\ C_H = \dfrac{1}{0.000398+\dfrac{0.003602}{1+e^{11.02-3.49H_{AC}}}} \end{cases}$$

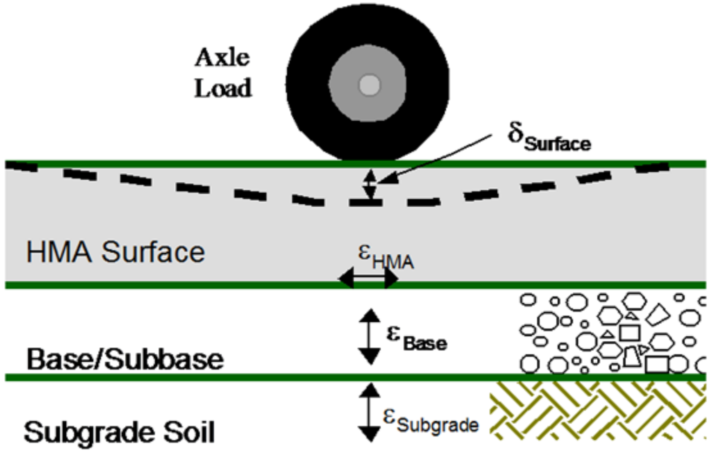
where,

N_f	=	allowable number of load repetitions to fatigue cracking;
ε_t	=	tensile strain at the bottom of asphalt layers beneath the wheel;
$\lvert E^*\rvert$	=	dynamic modulus of the asphalt mixture at loading frequency of 2.5 Hz and temperature of 20°C, psi;
C_H	=	thickness correction term for fatigue cracking;
$k_{f,1\text{-}3}$	=	global field calibration coefficients, k_{f1} = 0.007566, k_{f2} = 3.9492, and k_{f3} = 1.281;
$\beta_{f,1\text{-}3}$	=	local calibration factors (set to 1.0 for global calibration);
V_{be}	=	effective binder content by volume, %;
V_a	=	air void content, %; and
H_{AC}	=	total thickness of asphalt layers, in.

Compute N_f ASSHTO Pavement ME

Strain Response

- ALF pavement structures:
  - Asphalt mixture:
    - laboratory |E*| test
  - Aggregate base & subgrade:
    - modulus
  - Thicknesses of Layers



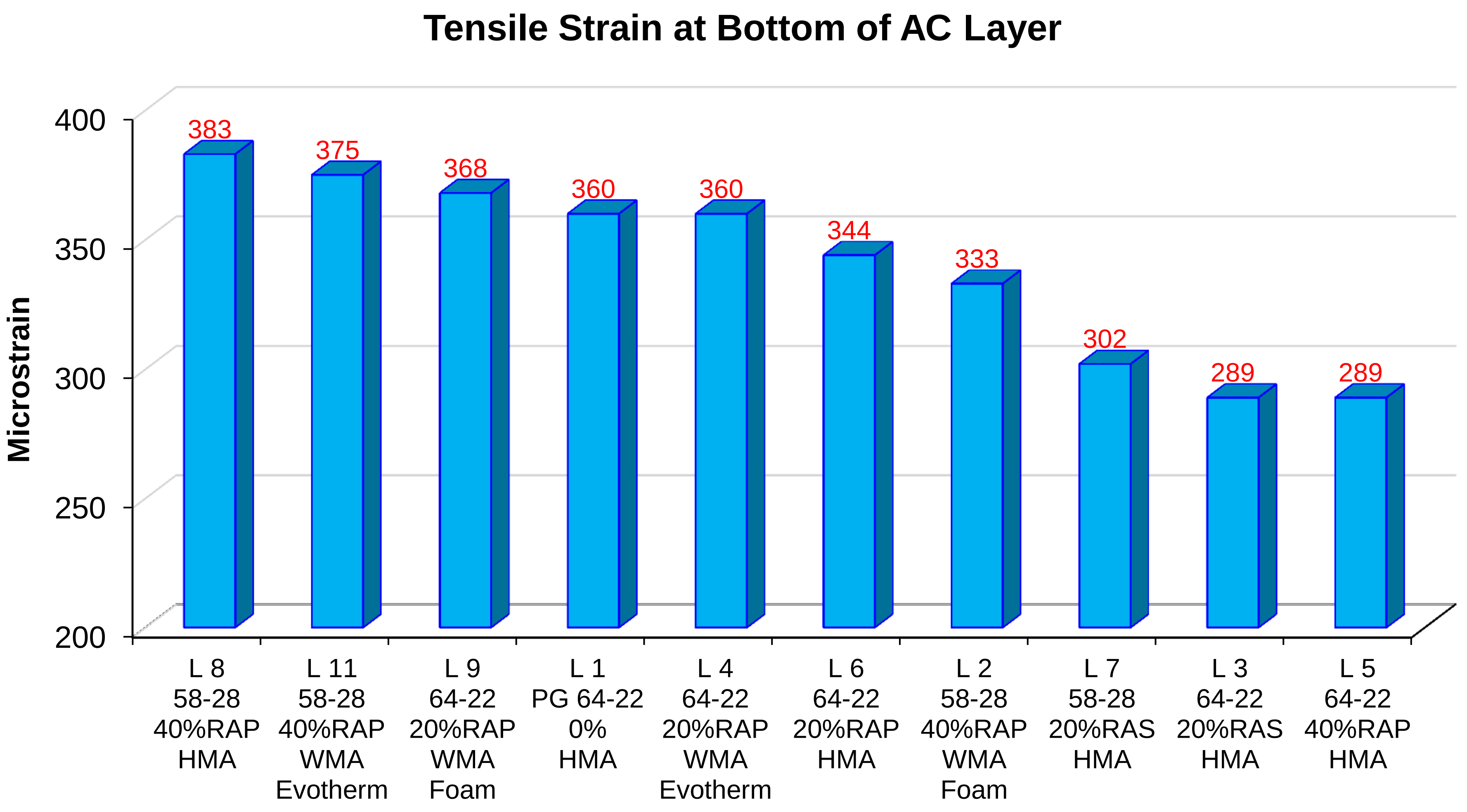
Strain Response

- LVECD
  - Layered ViscoElastic pavement analysis for Critical Distresses
  - Developed at North Carolina State University[1]
  - Technical aspects
    - Asphalt mixture: linear viscoelastic
    - Base & subgrade: linear elastic
    - Interface: fully bounded
    - Consider moving loading impacts via fast Fourier transform techniques.

NOTE: [1]Eslaminia, M., S. Thirunavukkarasu, M. N. Guddati, and Y. R. Kim. Accelerated Pavement Performance Modeling Using Layered Viscoelastic Analysis. *Proc., 7th RILEM International Conference on Cracking in Pavements*, Delft, 2012, pp. 497-506.

Tensile strain responses

Layered Viscoelastic Pavement Analysis for Critical Distresses



NOTE: At the bottom of asphalt layer, the loading frequency = 2.5 Hz.

Mixture property and ALF Test Lanes fatigue life

ALF Lanes	Mixture Property				ALF Lane Fatigue Life	
	V_a (%)	V_{be} (%)	SCB *Jc* (kJ/m^2)	|E*| @ 20°C, 2.5Hz (psi)	Measured passes to 1st crack	Predicted by AASHTO ME Eq.
L1	4.3	11.8	0.55	975,462	368,254	2,627,003
L3	3.3	11.3	0.38	1,561,815	42,399	5,341,760
L4	4.4	11.2	0.46	1,258,140	88,740	1,607,996
L5	5.2	10.7	0.34	1,753,802	36,946	1,529,784
L6	3.6	11.2	0.41	1,302,897	122,363	2,785,564
L7	4.1	11.3	0.32	1,540,264	23,005	3,035,187
L8	4.9	11.5	0.47	1,152,218	47,679	1,170,212
L9	3.7	11.4	0.46	1,129,115	270,058	2,581,196
L11	4.9	11.7	0.59	1,332,941	81,044	1,111,697

$$N_f = k_{f1} C C_H \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{k_{f2}\beta_{f2}} \left(\frac{1}{|E*|}\right)^{k_{f3}\beta_{f3}}$$

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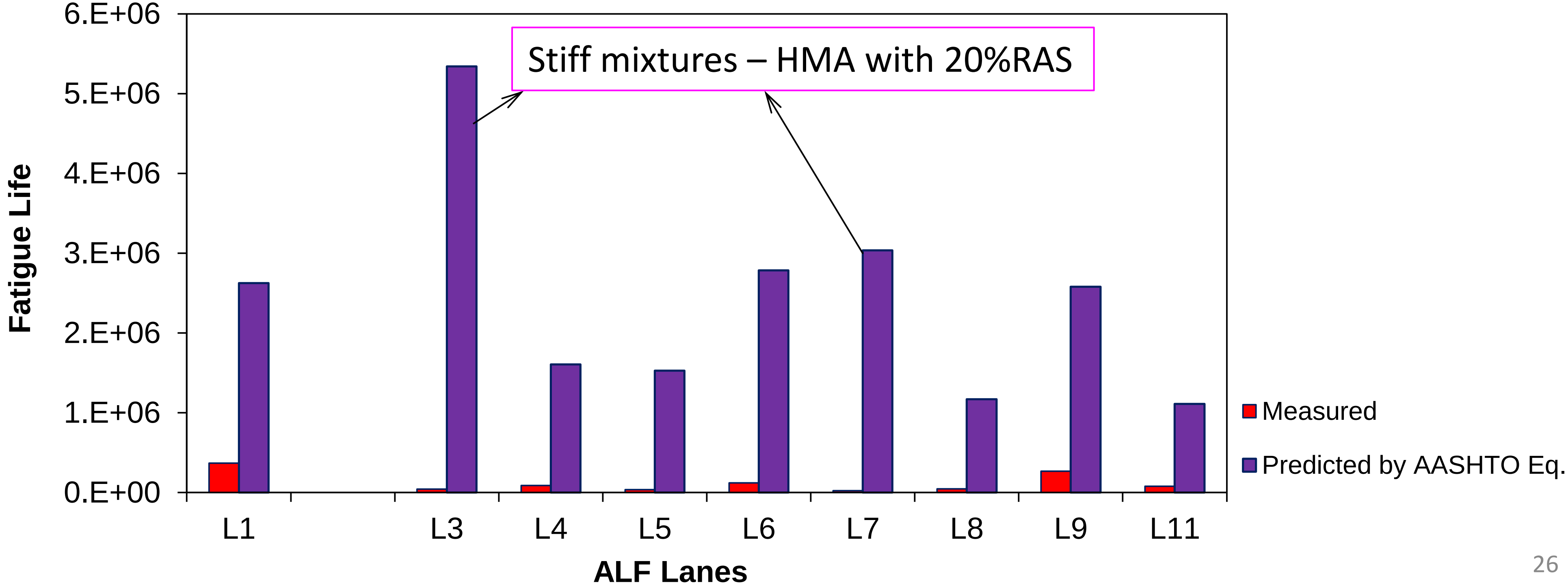
$$N_f = k_{f1} C C_H \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{k_{f2}\beta_{f2}} \left(\frac{1}{|E^*|}\right)^{k_{f3}\beta_{f3}}$$

Limitations: AASHTO Pavement ME

- Primarily controlled by mixture's stiffness
- Lack of a material parameter representing mixture's fatigue crack resistance

$$N_f = k_{f1} C C_H \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{k_{f2}\beta_{f2}} \left(\frac{1}{|E^*|}\right)^{k_{f3}\beta_{f3}}$$



Solution: AASHTO Pavement ME
Jc-based fatigue model

- Incorporate parameter representing mixture’s crack resistance

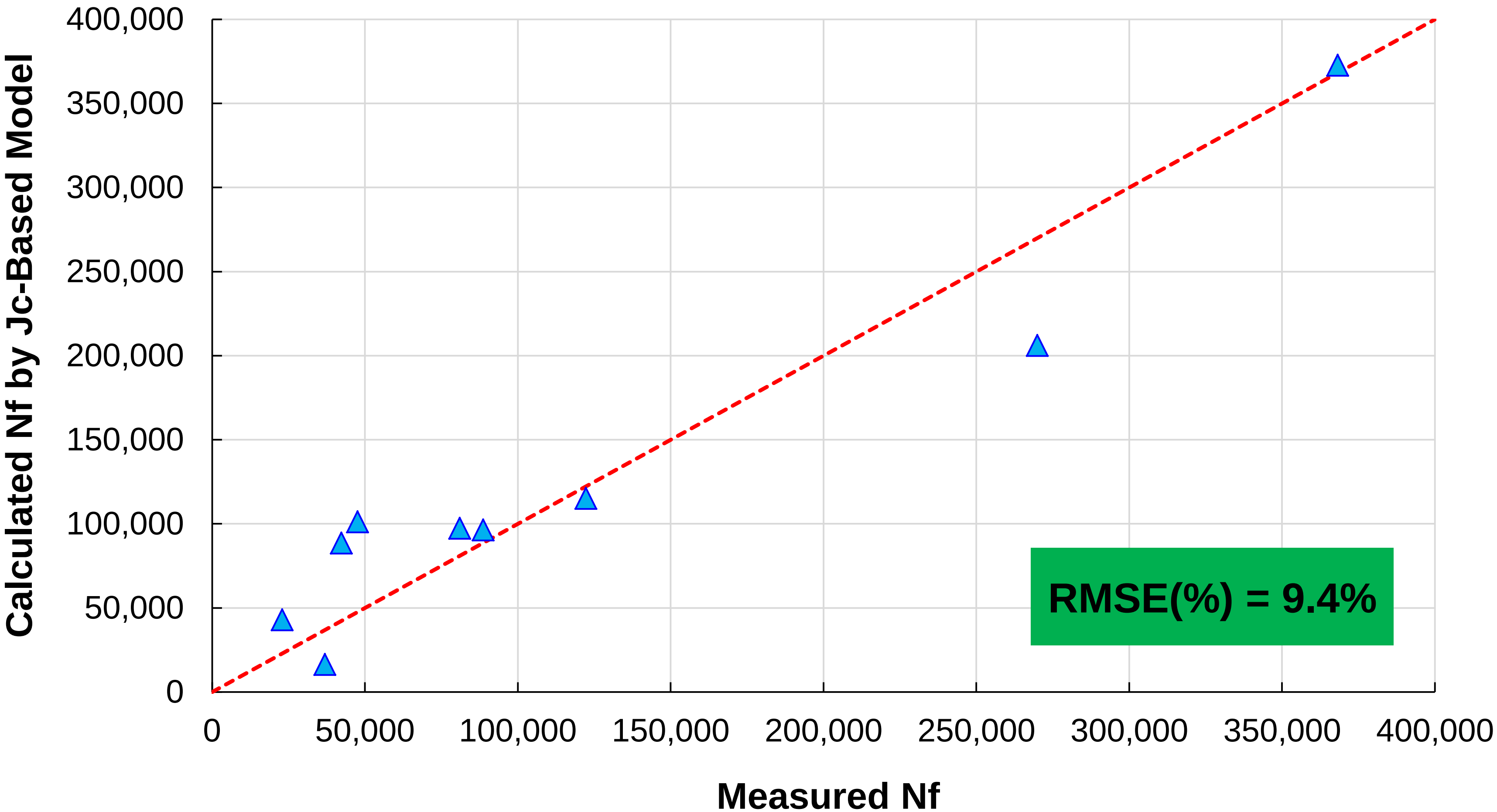
$$N_f = k_{f1} C C_H \beta_{f1} \left(\frac{1}{\varepsilon_t}\right)^{k_{f2}\beta_{f2}} \left(\frac{1}{|E^*|}\right)^{k'_{f3}\beta_{f3}} (J_c)^{k_{f4}\beta_{f4}}$$

where,

J_c	=	critical strain energy release rate obtained from SCB test at intermediate temperature, kJ/m^2;
k_{f4}	=	global calibration coefficient for the J_c parameter;
β_{f4}	=	local calibration factor (set to 1.0); and
k'_{f3}	=	adjusted global calibration factor for dynamic modulus with incorporation of J_c.

Measured vs. Predicted N_f

Jc-based fatigue model

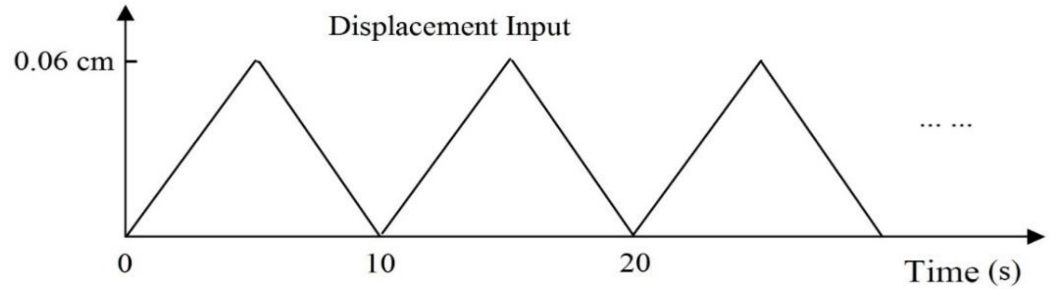


NOTE: Measured Nf = number of ALF passes to 1st surface crack.

Texas Overlay

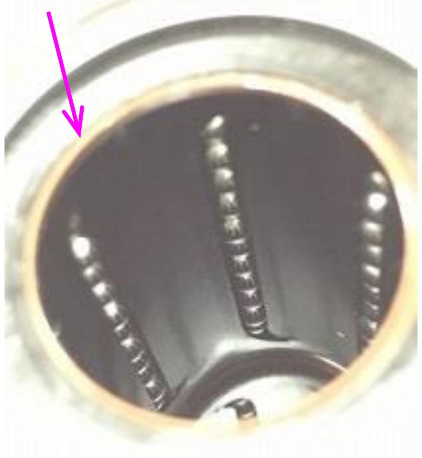
TXDOT Designation: Tex-248-F (2014)

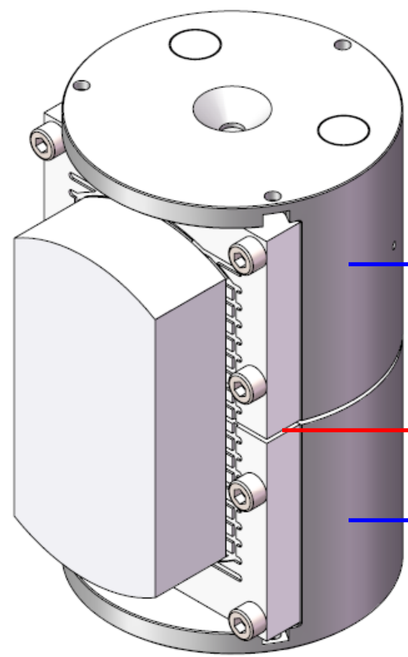
- Load
  - Displacement controlled
  - triangular shape
  - Amplitude: 0.06 cm
  - 1 cycle = 10 seconds



- Temperature 25°C
  - Test jig manufactured by IPC Global

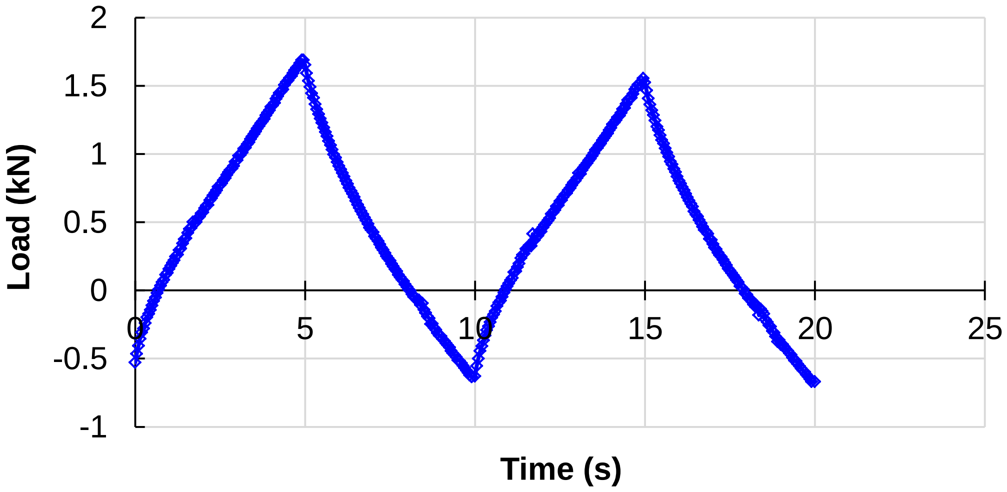
Use ball bearing to reduce friction





Texas Overlay

- Concerns
  - Load does not start from zero

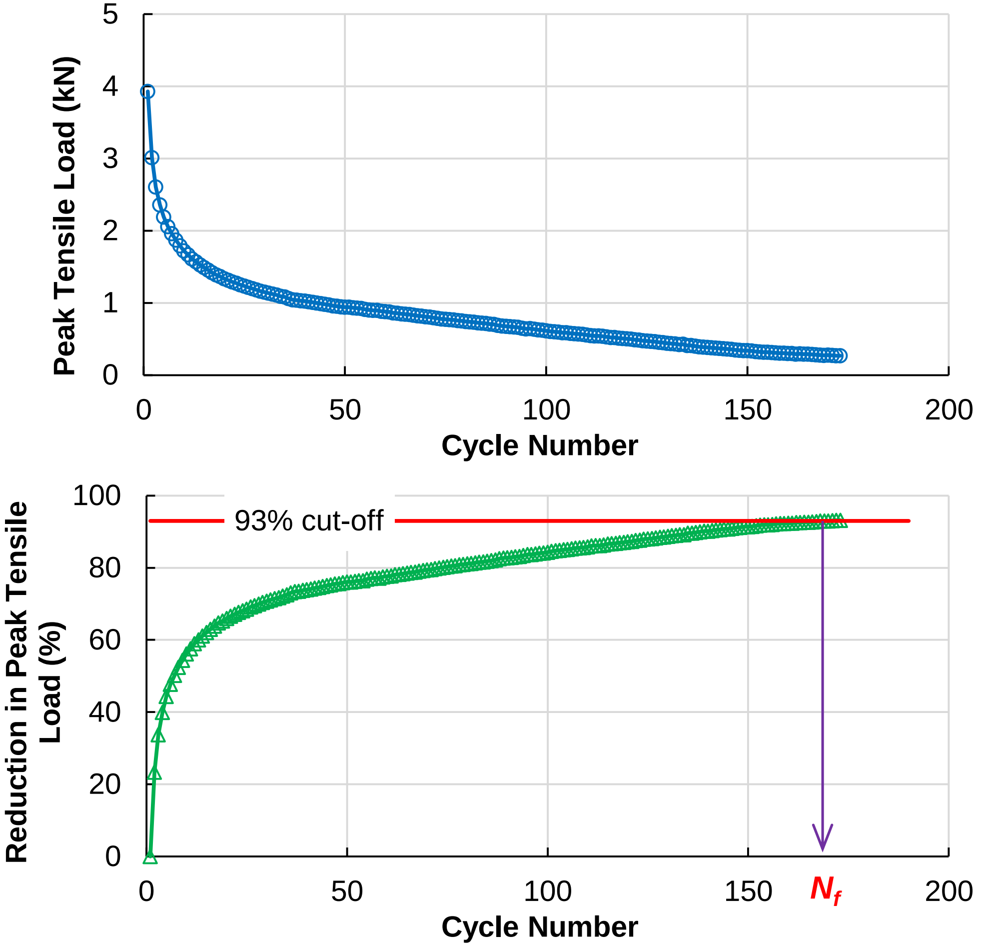


- Resolution
  - Test template modified by IPC Global
    - Current version – UTS036 V1.01 (released Aug 18, 2016)
  - Use ball bearing in jig

Texas Overlay

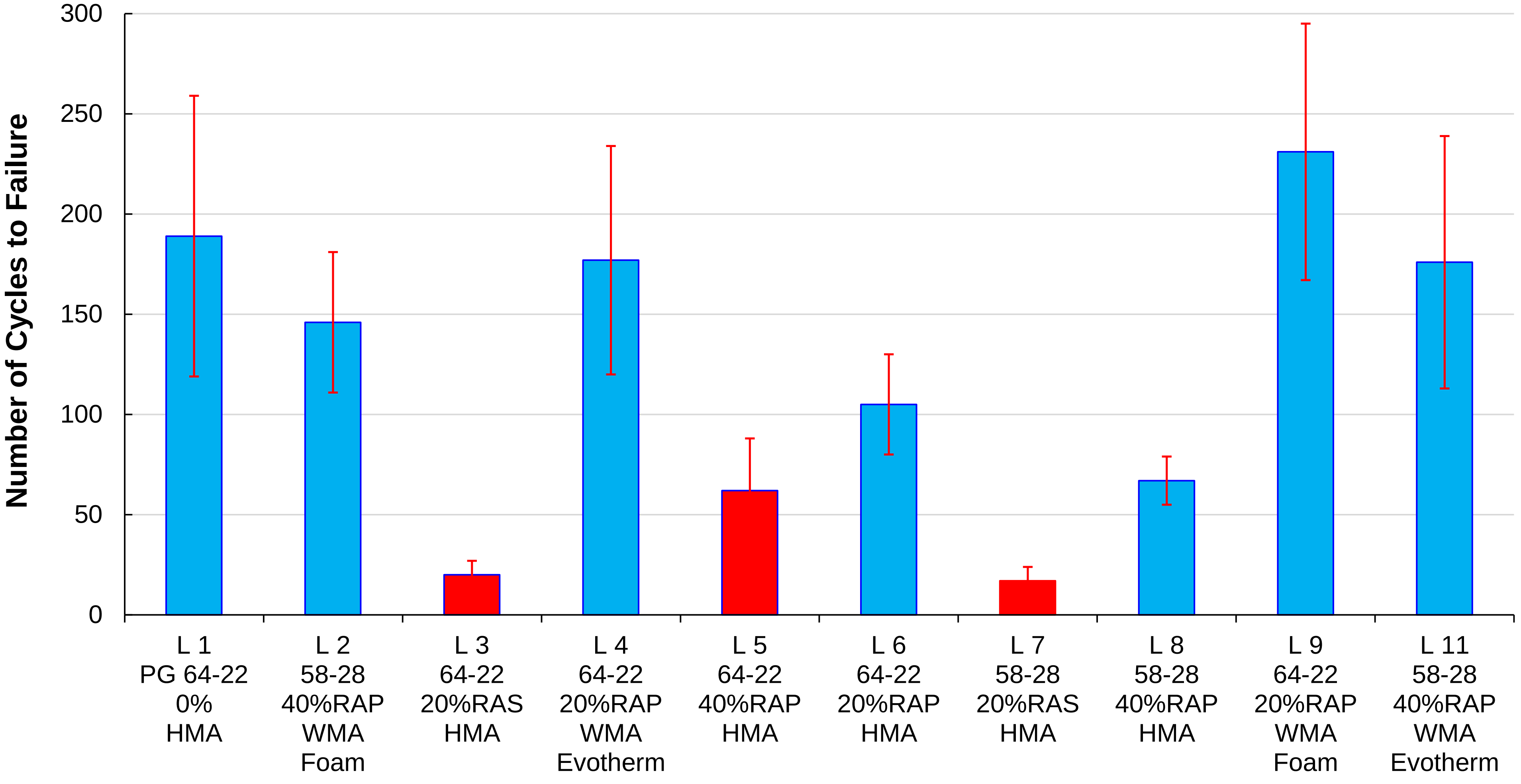
Analysis

- Peak load in each cycle
- Plot peak tensile load versus cycle number
- Determine max. load
- Plot reduction of max. Load vs Cycle number
- Nf is defined as the cycle number at 93% percent decline in load



Overlay Test Results, N_f

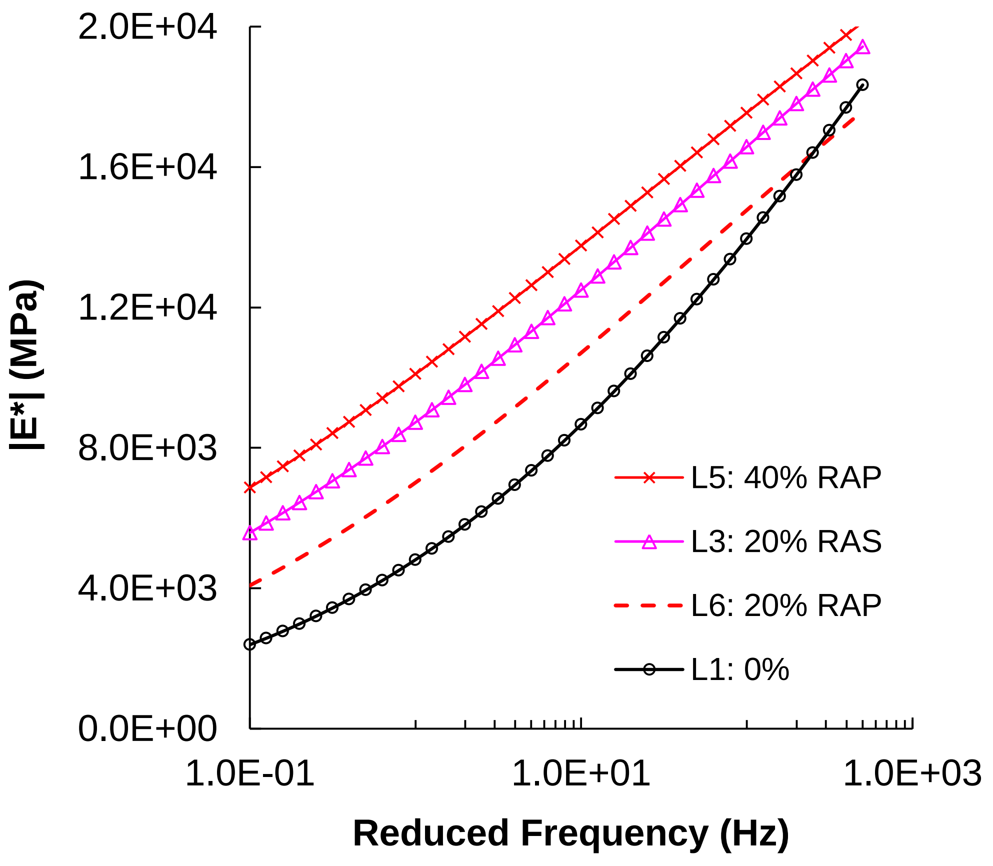
FHWA ALF Mixtures

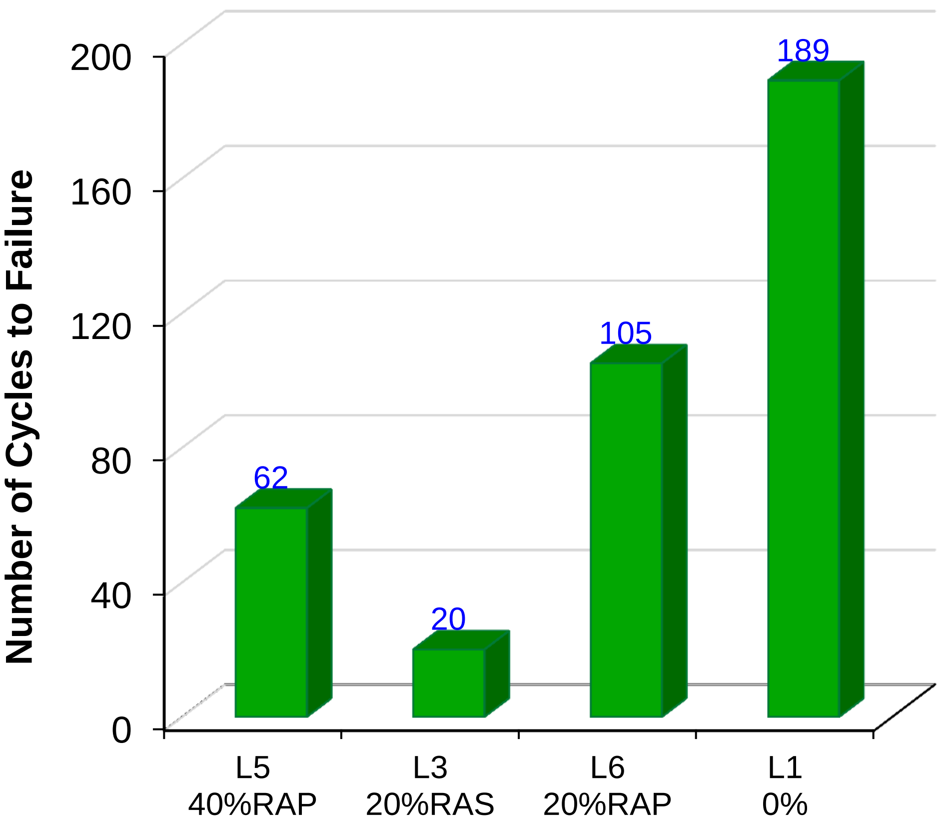


NOTE: A total of 3-5 replicates were tested for each mixture. CoV ranges from 18.1% to 42.4% with an average of 31.6%.

Overlay Test Results, N_f and |E*|

- **Sensitivity to RAP/RAS content** (PG 64-22, HMA)





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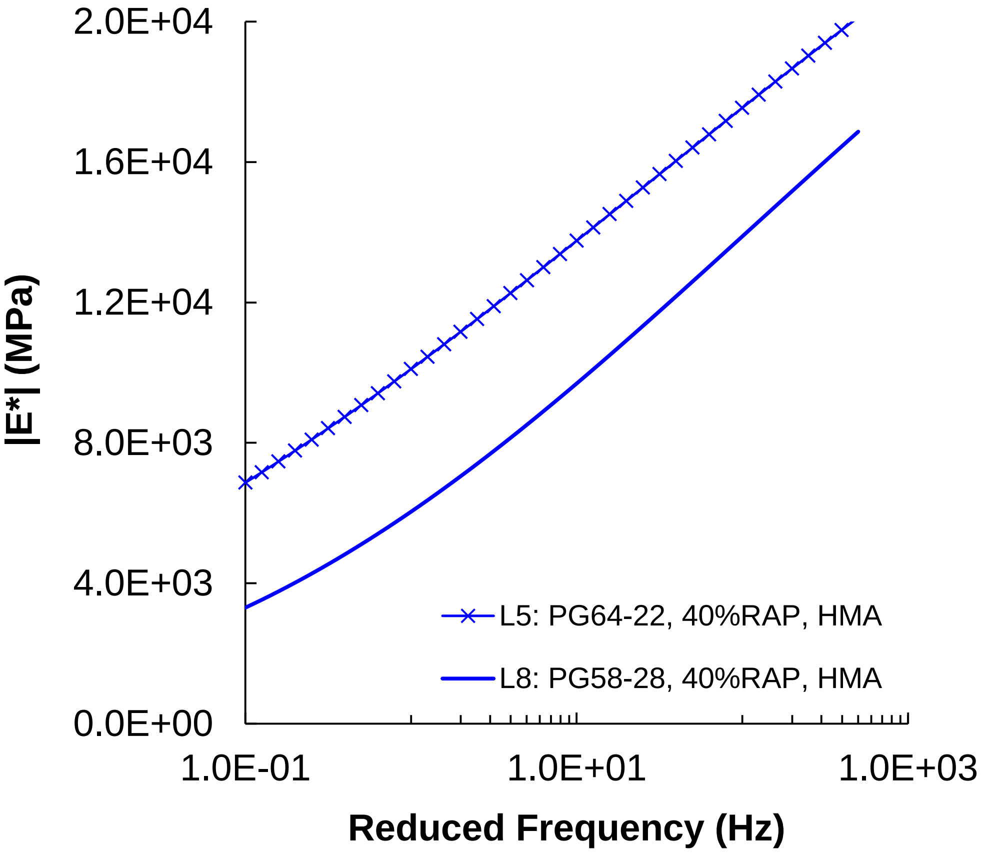
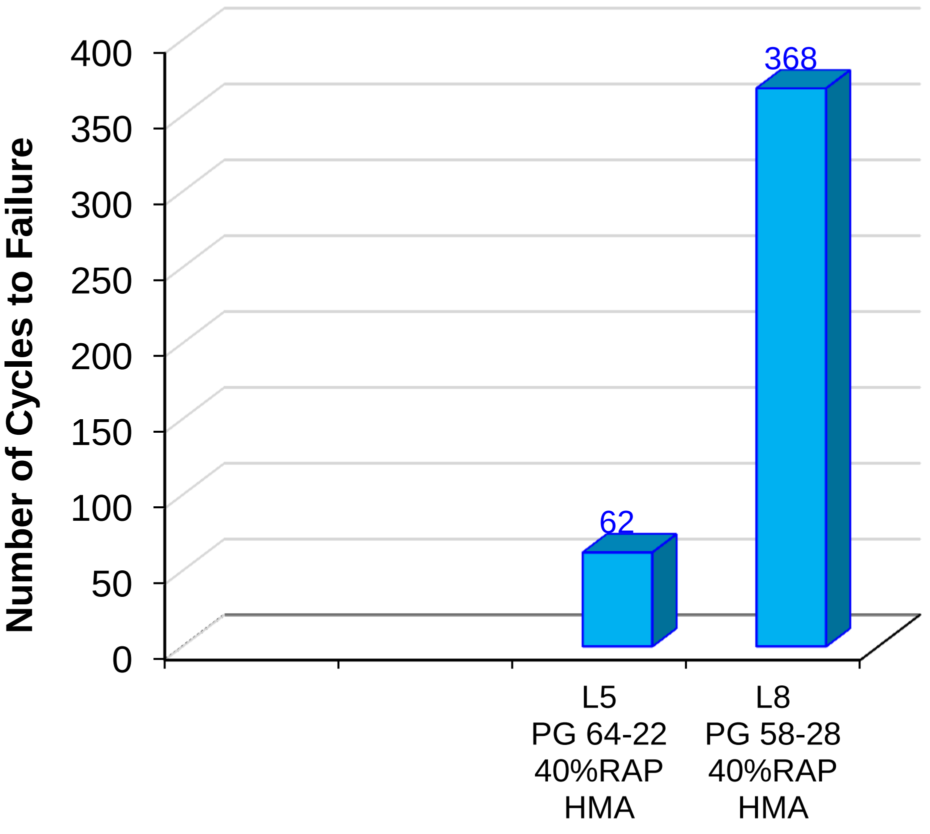
Crack resistance: L3 < L5 < L6 < L1.

Overlay Test Results, N_f and |E*|

- Sensitivity to Binder Grade





Overlay Test Results, N_f and |E*|

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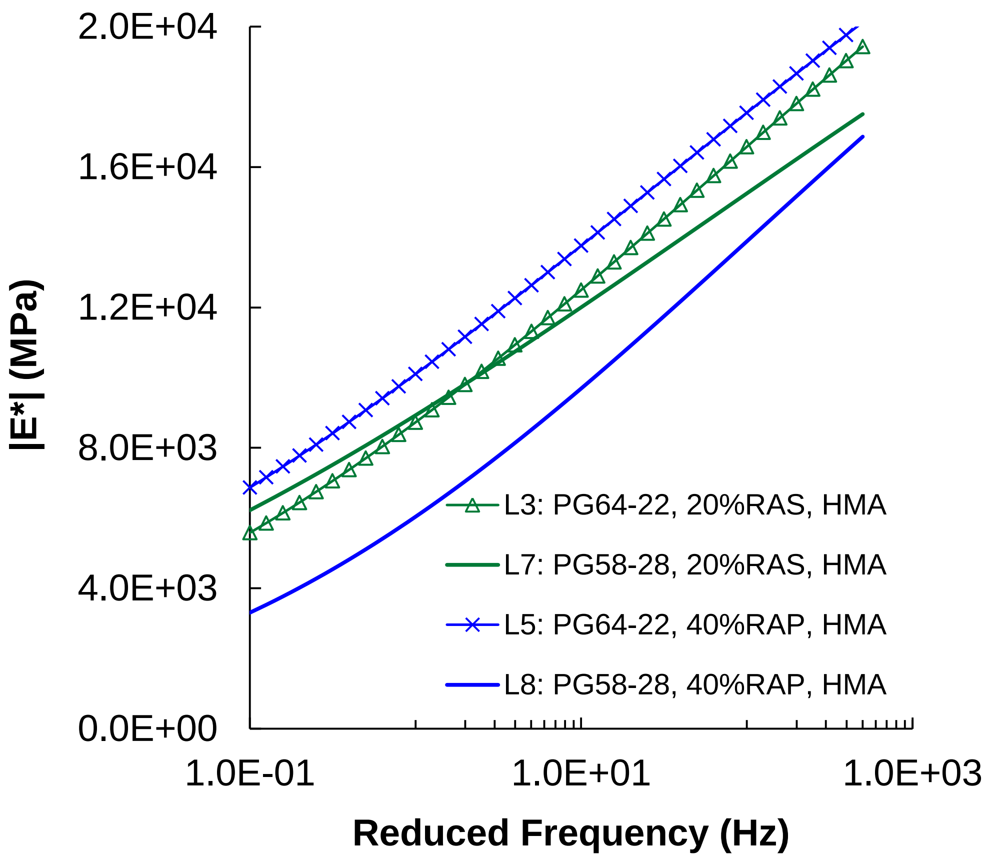
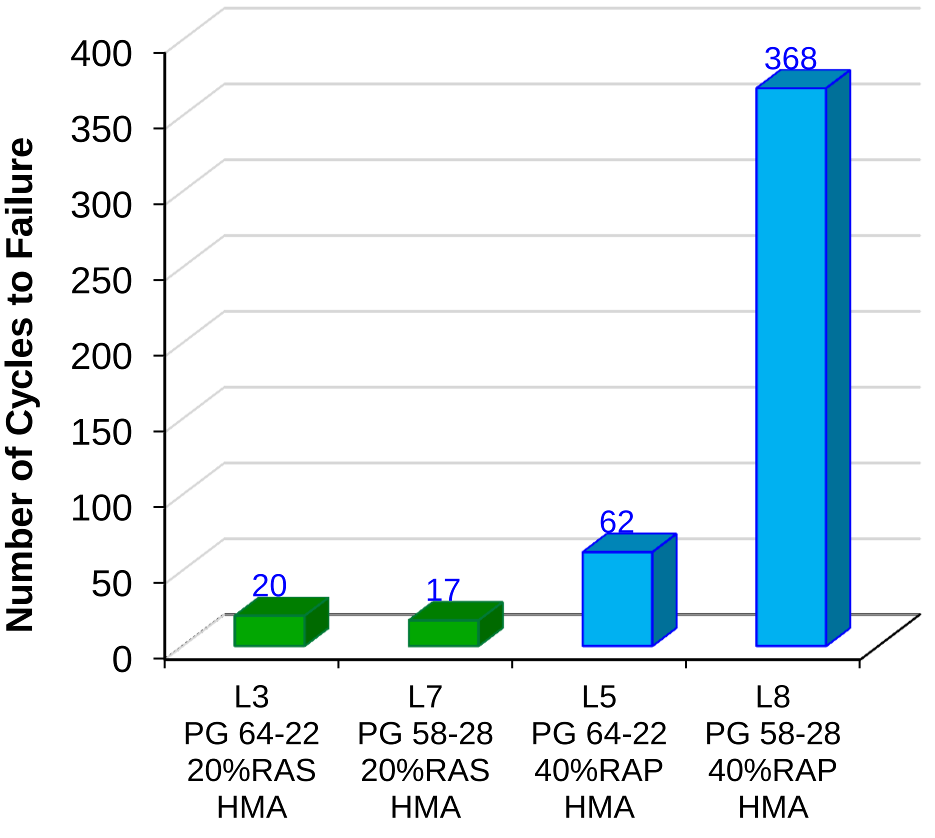
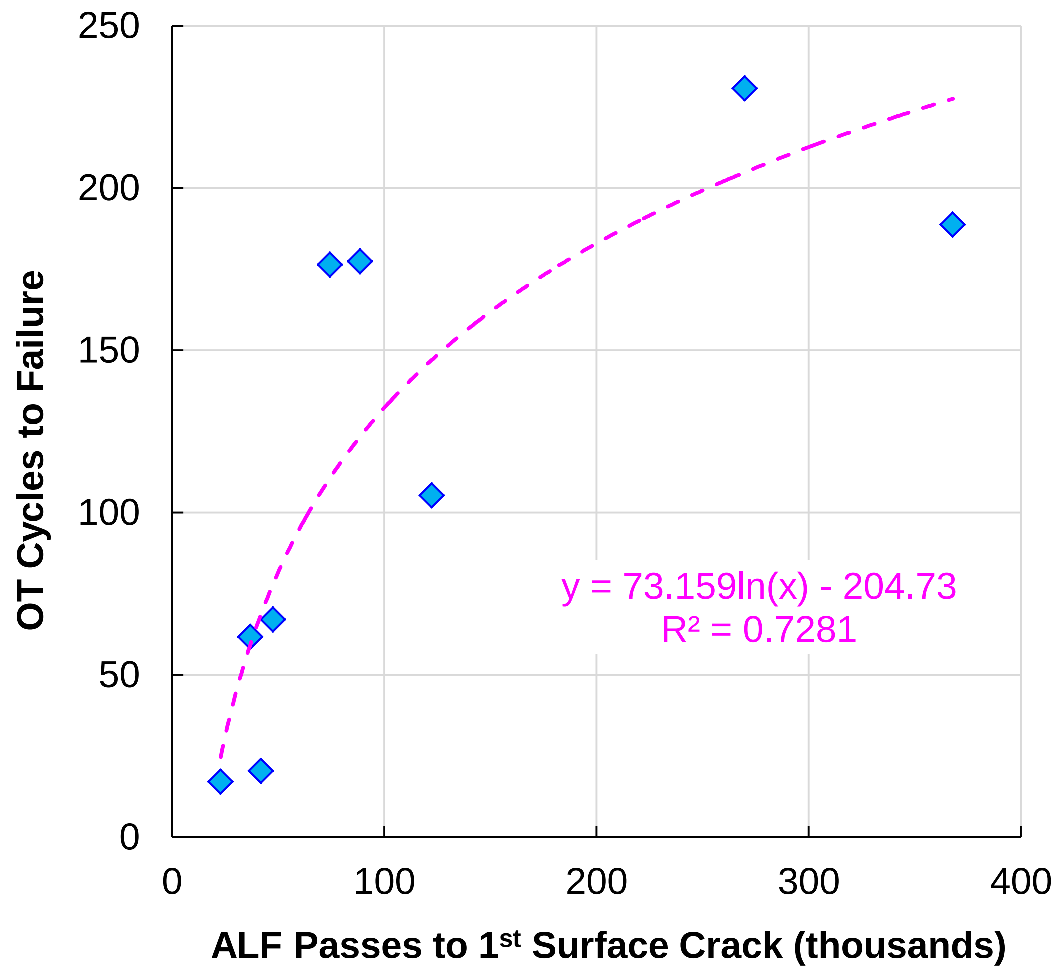




Cracking: ALF Test Lane vs. Mixture Performance

Overlay Test Results, N_f

Ranking		Structure	Mixture
		ALF	$N_{f, OT}$
Best Three	1	***L1***	***L9***
	2	***L9***	***L1***
	3	***L6***	***L4***
Middle Three	4	***L4***	***L11***
	5	***L11***	***L6***
	6	***L8***	***L8***
Worst Three	6	***L3***	***L5***
	7	***L5***	***L3***
	8	***L7***	***L7***



Summary

- SCB test at intermediate temperature
  - Variability
    - Average COV ~ 15%
  - Mixture from the FHWA test lanes
  - Sensitive to RAP/RAS content
    - Increased %RBR SCB Jc
  - Sensitive to binder grade
    - More pronounced effect on mixtures with %RBR from RAP than RAS
  - Structural performance to mixture characterization
    - Good correlation, R^2=0.68
  - Pavement ME fatigue crack prediction
    - Mixture stiffness
    - Inconsistence ranking/magnitude
  - Proposed fatigue predictive equation with SCB J_c
    - Good correlation to measured N_f from ALF test lanes
    - More field data

Summary

- Overlay Test
  - Variability
    - Average COV 31.6%
  - Sensitive to RAP/RAS content
    - Decreased number of cycles to failure
  - Sensitive to binder grade
    - More pronounced effect on mixtures with %RBR from RAP than RAS
  - Structural performance to mixture characterization
    - Good correlation, R^2=0.73


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Photo: Jim Zietz, Office of Public Affairs

THANK YOU