

D^R Failure Criterion for Cracking of Asphalt Concrete

Y. Richard Kim, Yizhuang Wang
NC State University

Asphalt Mixture & Construction Expert Task Group Meeting
Ames, IA
May 1, 2017

Outline

- D^R for failure criterion
- Implementation of D^R into FlexPAVE
- S_{app} for cracking index property

Dissipated Energy-Based Failure Criteria

❑ Cumulative Dissipated Energy

- Tayebali et al.
 - ✓ Power Law between Cumulative Dissipated Energy and N_f

❑ Ratio of Change in Dissipated Energy

- Carpenter et al.
 - ✓ Power law between Plateau Value and N_f

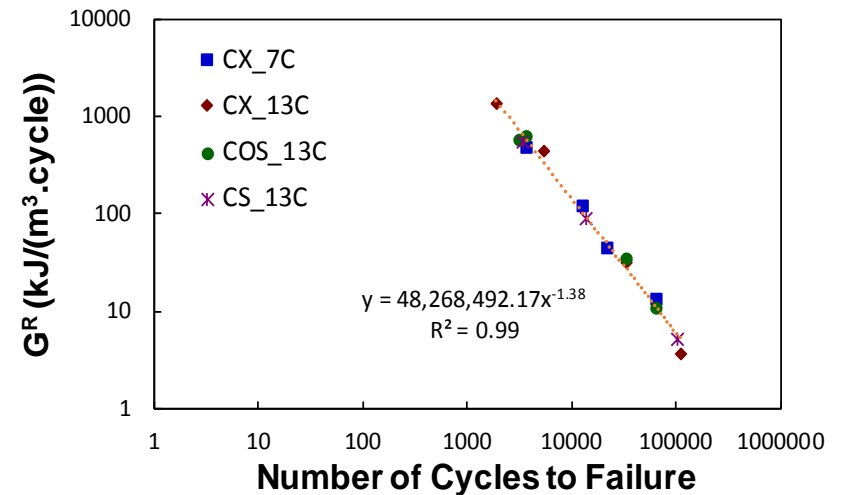
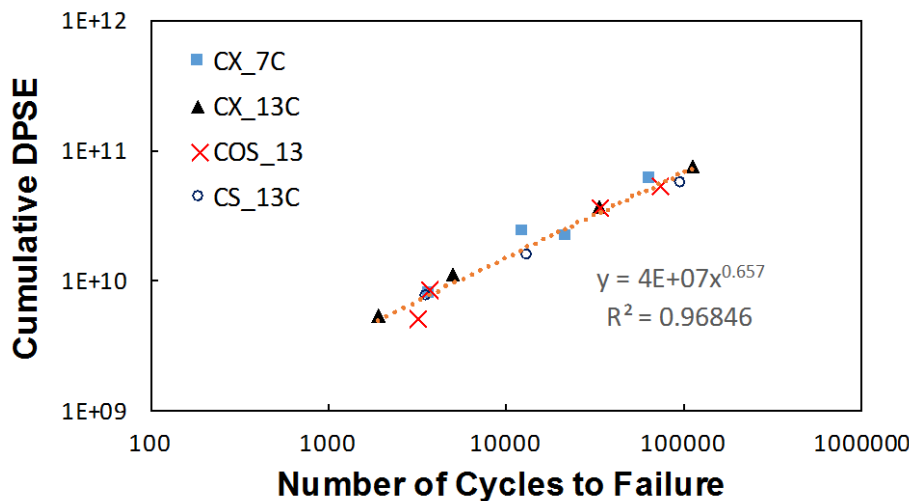
DPSE Based Failure Criteria

□ Dissipated Pseudo Strain Energy

- Remove the effect of viscoelasticity
- Fracture based criterion (Masad et al.)
- G^R failure criterion

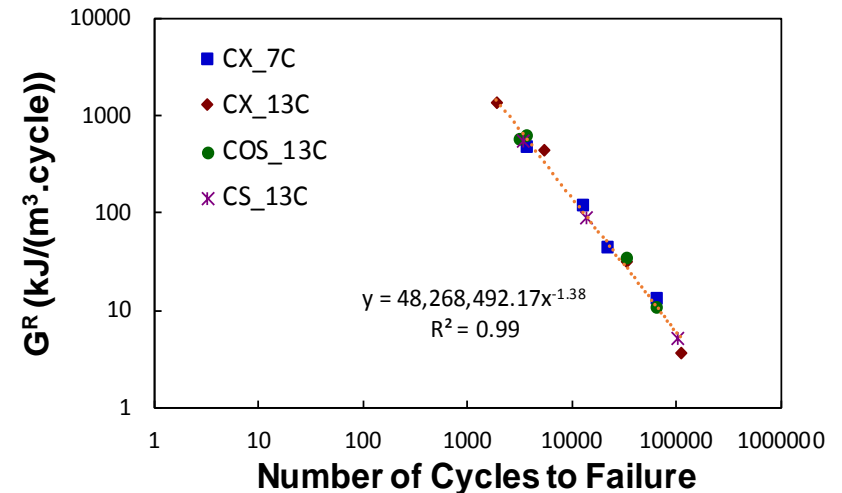
$$\int_0^{N_f} \frac{1}{2}(1-C)(\epsilon_{0,ta}^R)^2 dN = \gamma N_f^\lambda$$

$$G^R = \frac{\int_0^{N_f} \frac{1}{2}(1-C)(\epsilon_{0,ta}^R)^2 dN}{N_f^2} = \gamma N_f^\delta$$



G^R Failure Criterion

$$G^R = \frac{\int_0^{N_f} \frac{1}{2} (1-C) (\varepsilon_{0,ta}^R)^2 dN}{N_f^2} = \gamma N_f^\delta$$

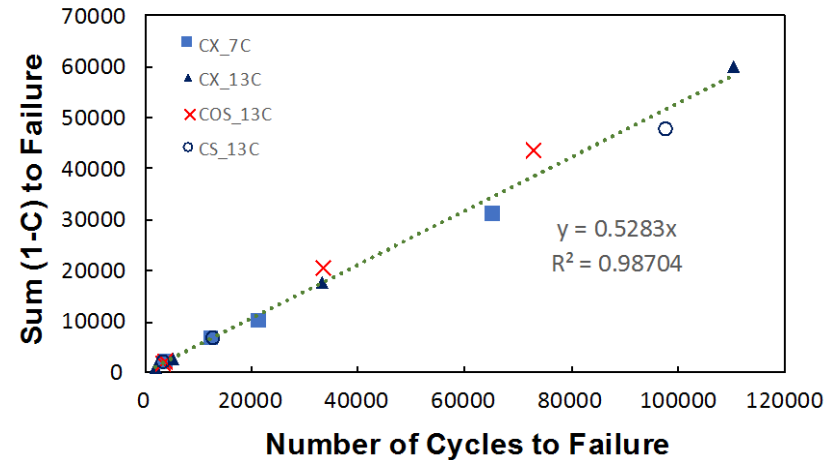


- ❑ Extrapolation in log-log scale for pavement performance prediction
- ❑ Sensitive to test variability
- ❑ At least three specimens are required

D^R Failure Criterion

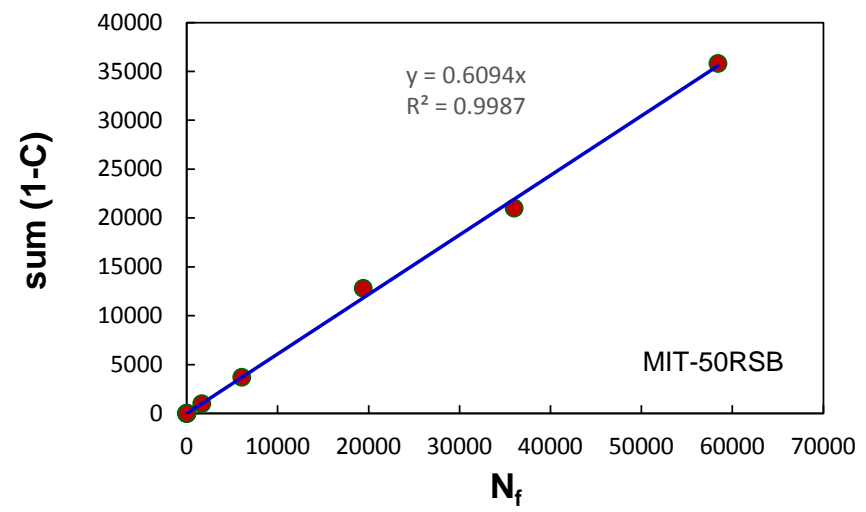
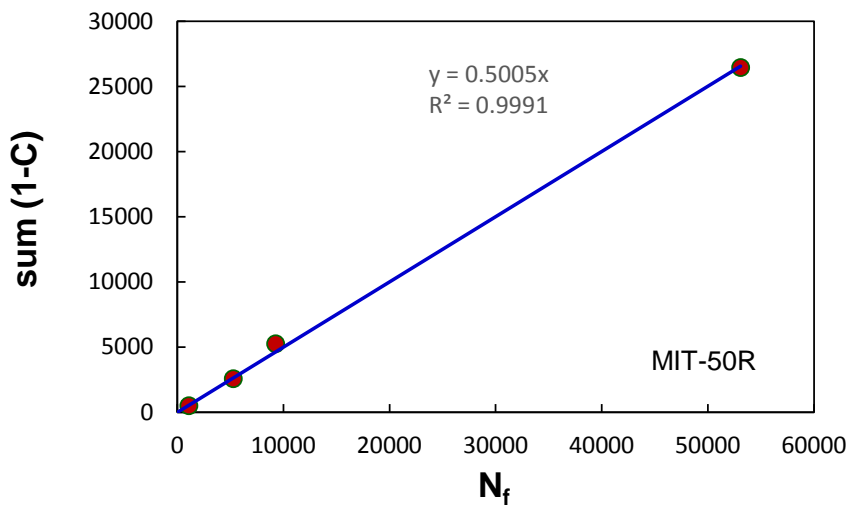
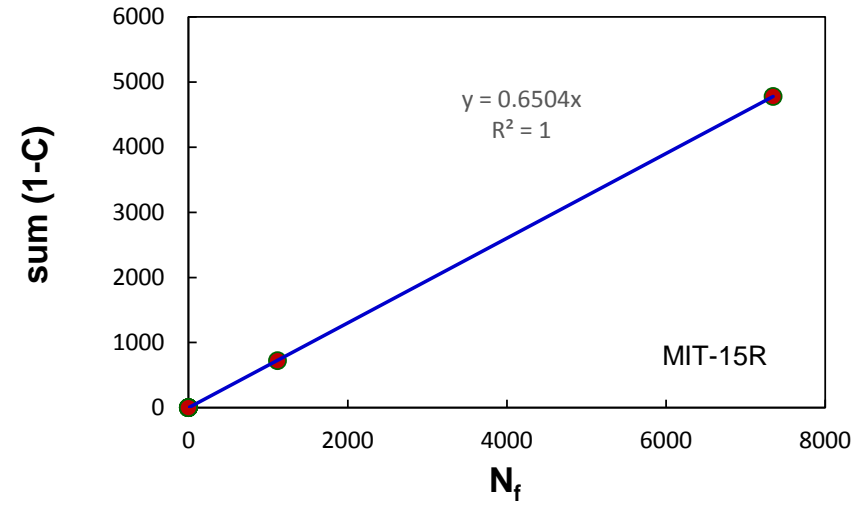
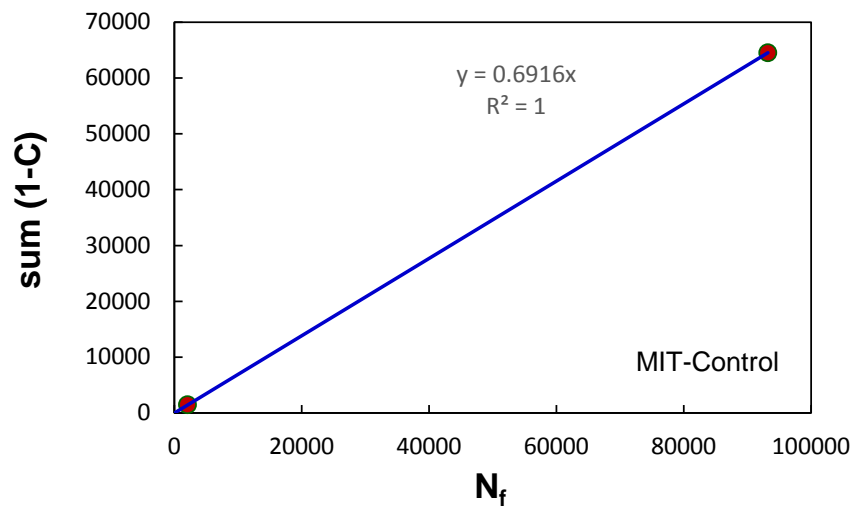
- D^R = Average reduction in pseudo stiffness up to failure

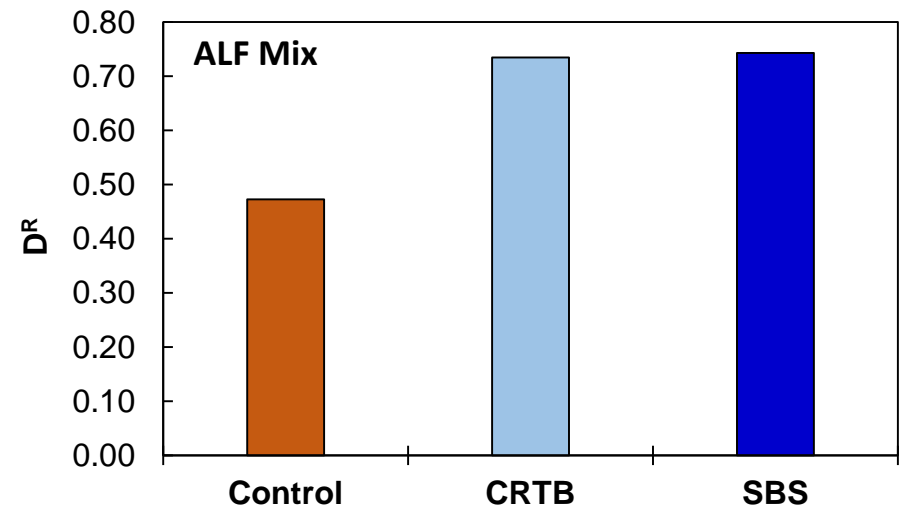
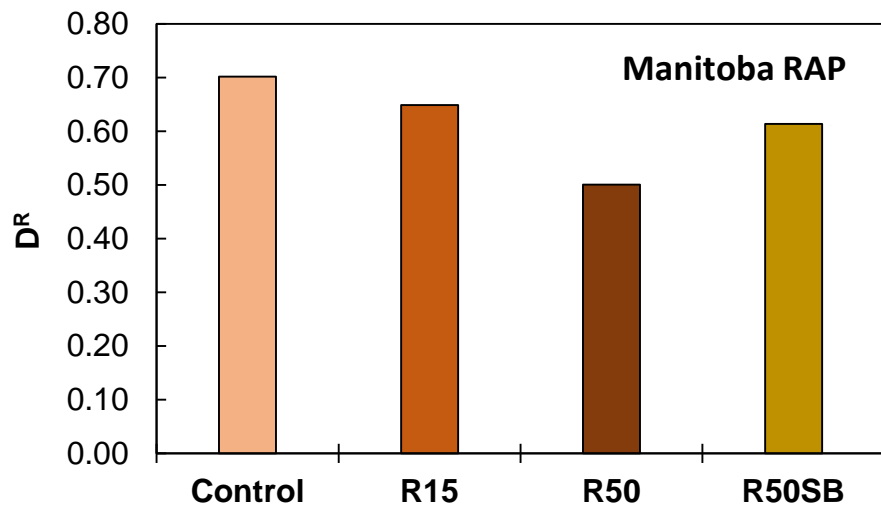
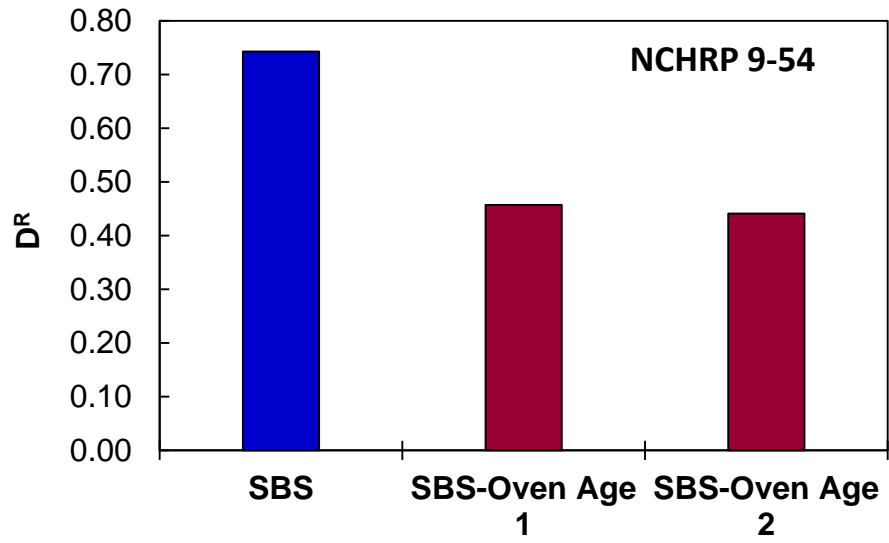
$$D^R = \frac{\int_0^{N_f} (1-C) dN}{N_f} = \frac{\text{sum}(1-C)}{N_f}$$



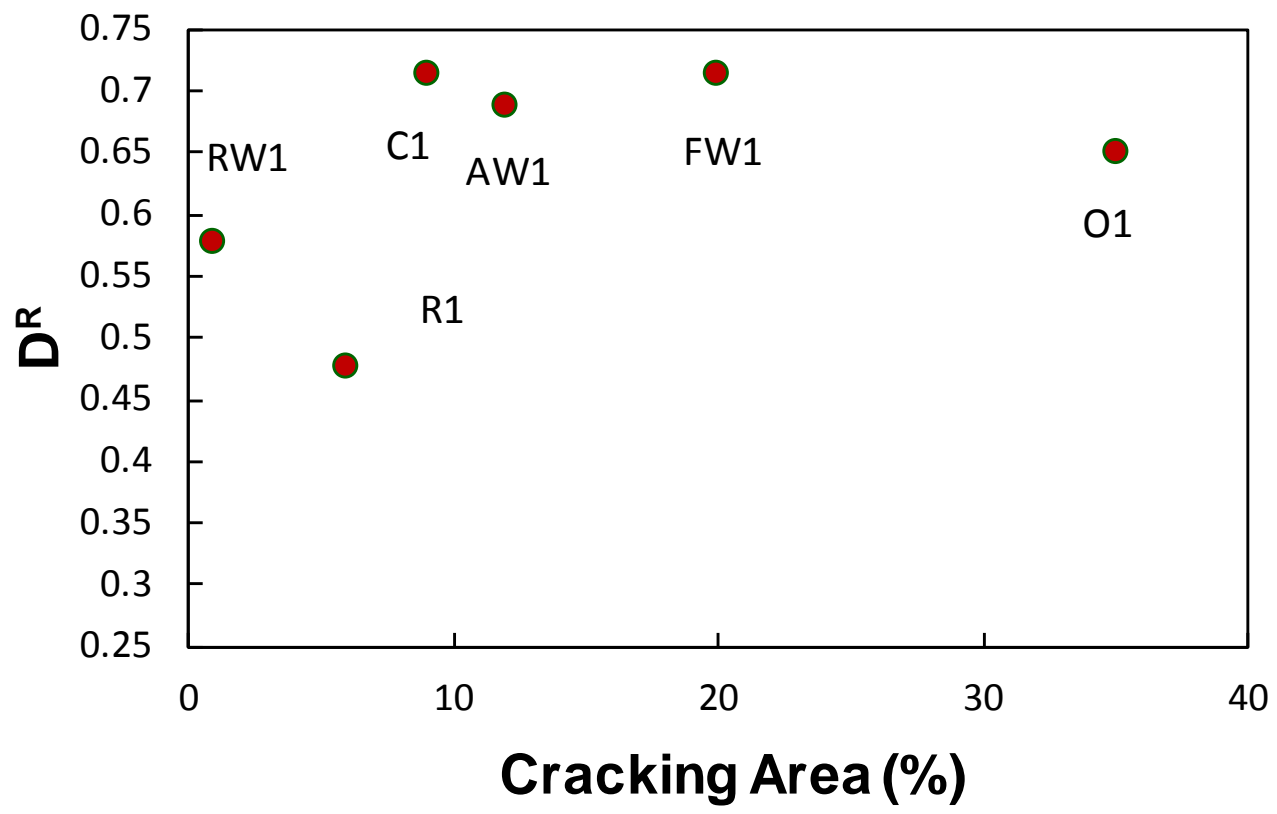
- $(1-C)$, loss of integrity, indicates the damage potential in each cycle.
- Independent of mode of loading, temperature, loading amplitude
- Linear relationship in arithmetic scale; therefore, less sensitive when extrapolated
- The linear relationship passes through the origin. Theoretically only one specimen is required. Three are recommended.

D^R for PRS Mixtures





D^R for NCAT Sections



DR in FlexPAVE 1.0

FlexPAVE 1.0 Program : Untitled Project

File Analysis Tools Help

Project

- General Information
- Design Structure**
- Climate Data
- Traffic Data
- Outputs and Analysis Options
- Results

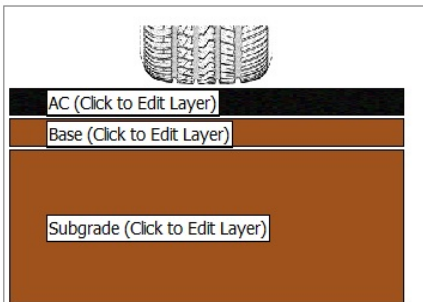
General Information x Design Structure x

Structure General Information

Structure Name Flexible 3-Layer Pavement

Pavement/Lane Width (m) 3.65

Add Layer Remove Layer Move Layer



AC (Click to Edit Layer)

Base (Click to Edit Layer)

Subgrade (Click to Edit Layer)

Layer Properties

Layer AC

Thickness (cm) 10 Infinite Layer

Material Type Asphalt Concrete more..

GR Based Criterion DR Based Criterion

Specific Gravity (optional) 2.5 Expansion Co. (1/C) 0.00005

Strength/Modulus

Poisson's Ratio	0.3000	Alpha	Fatigue	4	Beta	Rutting	p1	Rutting
Einf (KPa)	9.7300e+04	a		0.0017	0.8026	0.8026	0.6069	
Ref. Temp. (C)	5	b		0.5449	Epsilon0	0.0052	p2	0.0719
Shift Factor a1	6.9619e-04	Initial C		0.8000	NI	0.8024	d1	0.0396
Shift Factor a2	-0.1620	Gamma		1000000	TR(C)	61	d2	1.6831
Shift Factor a3	0.7928	Delta		-1.3500				

Import Damage Data Import Rutting Data

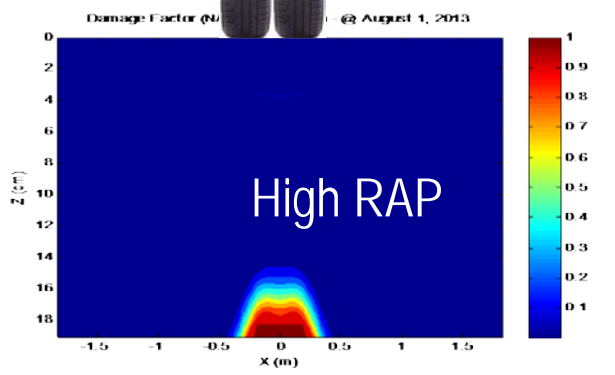
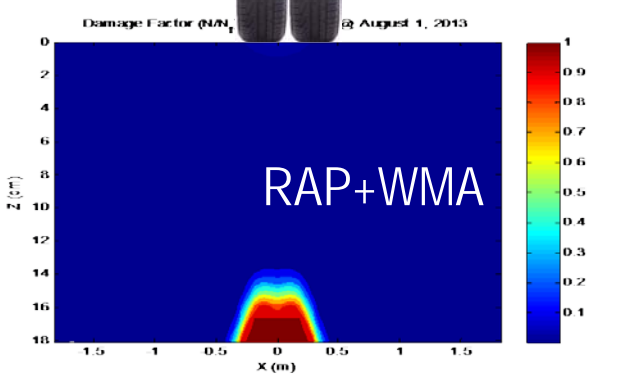
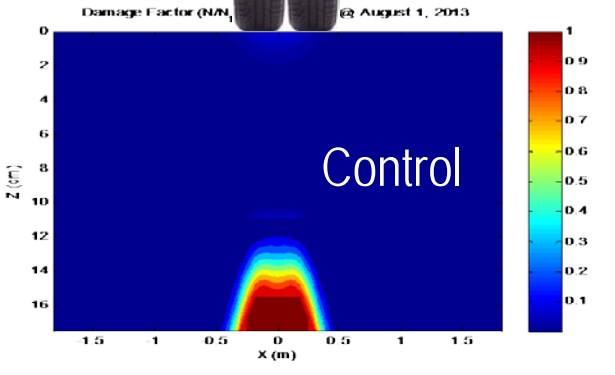
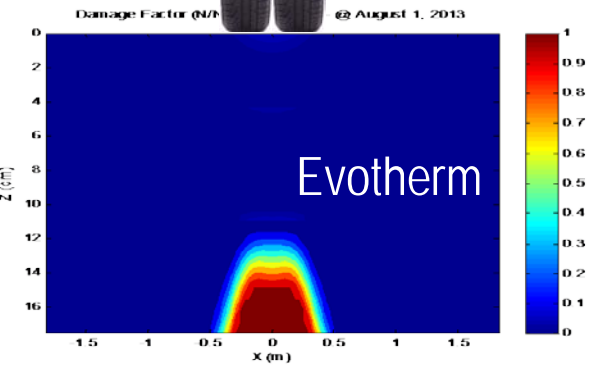
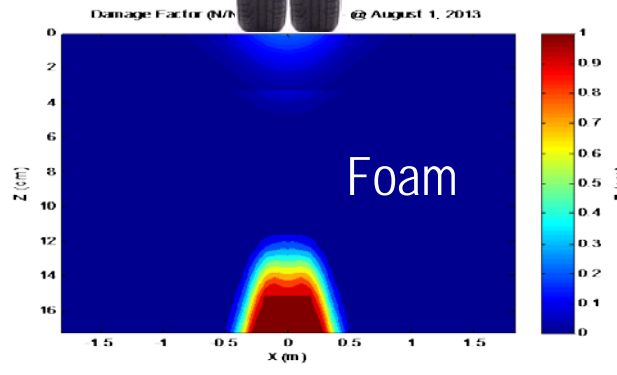
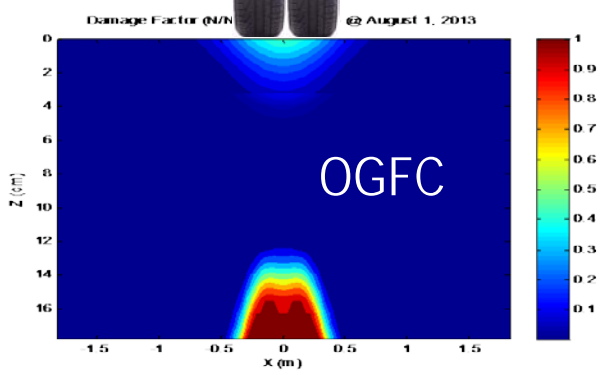
	Ti (sec)	Ei (KPa)
1	2.0000e+16	757.4885
2	2.0000e+15	97.6079
3	2.0000e+14	267.7187
4	2.0000e+13	366.0952
5	2.0000e+12	686.5036
6	2.0000e+11	1.2298e+03
7	2.0000e+10	2.2287e+03
8	2.0000e+09	4.0690e+03

Import Prony Series Data Help...

Errors and Warnings

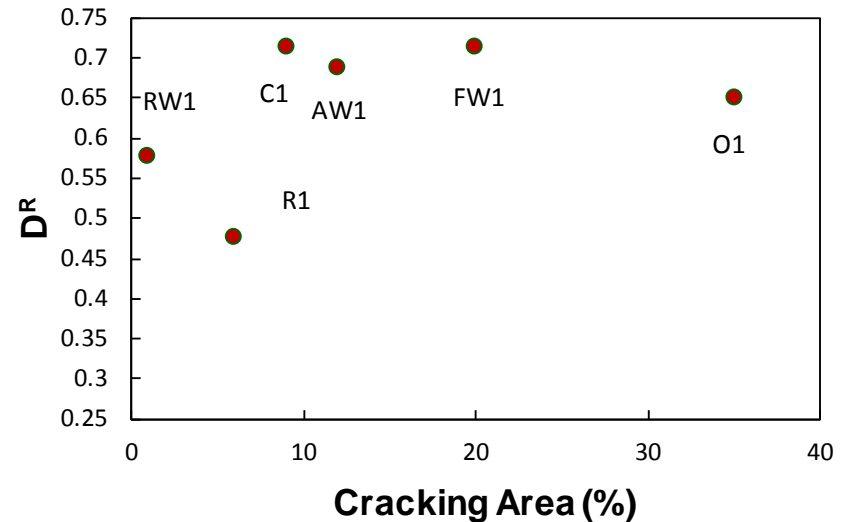
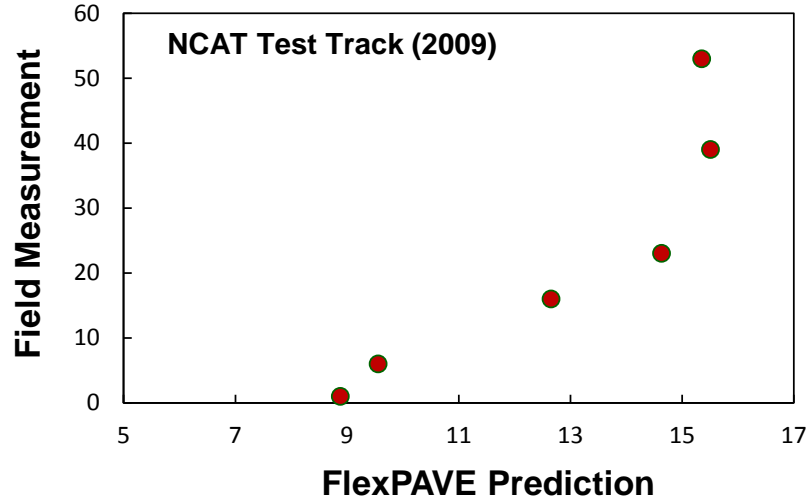
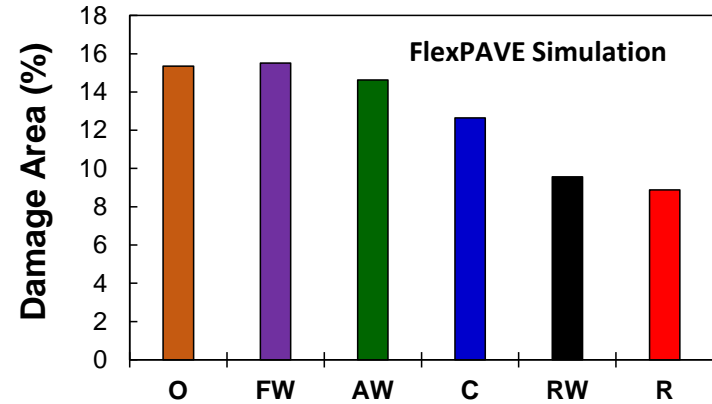
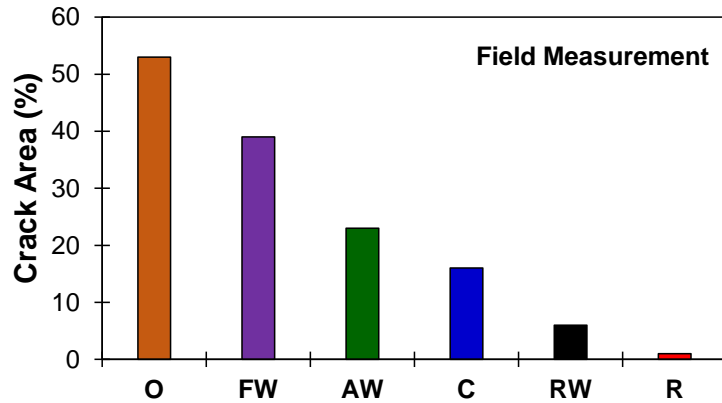
FlexPAVE Simulation

NCAT Test Track



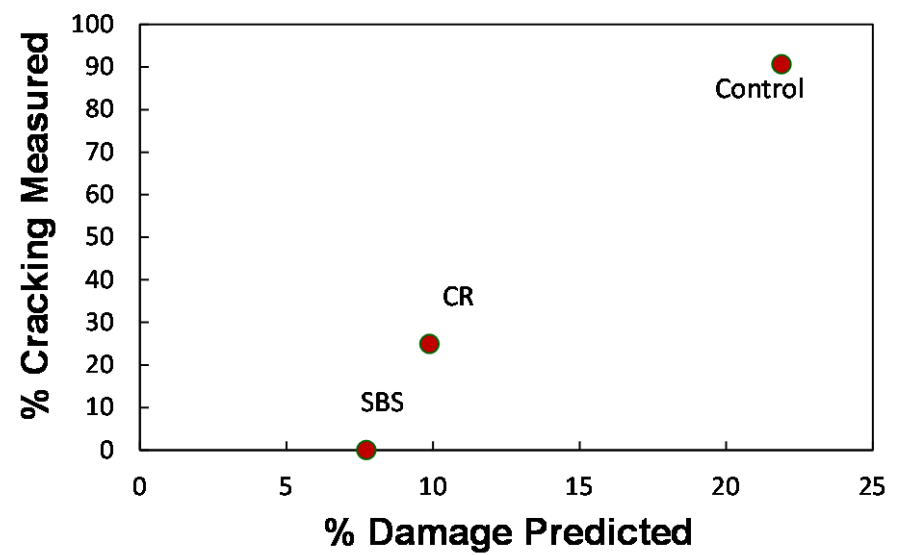
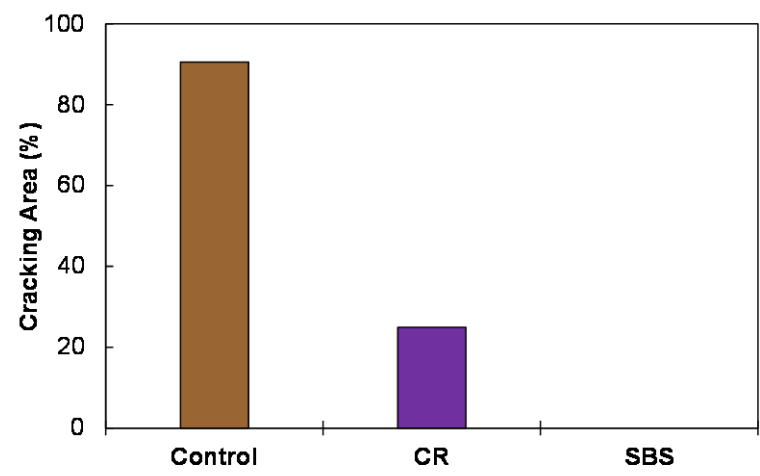
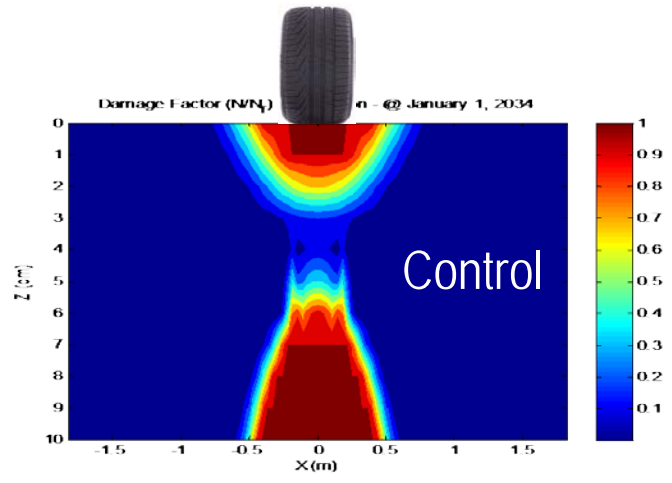
FlexPAVE Simulation

NCAT Test Track



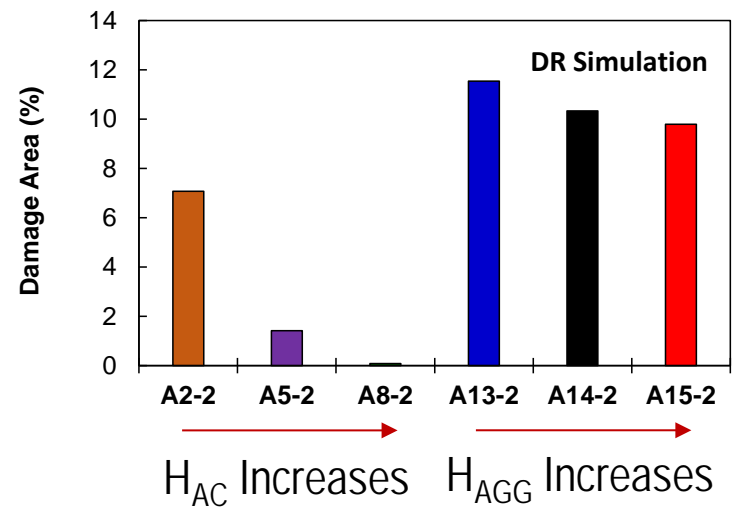
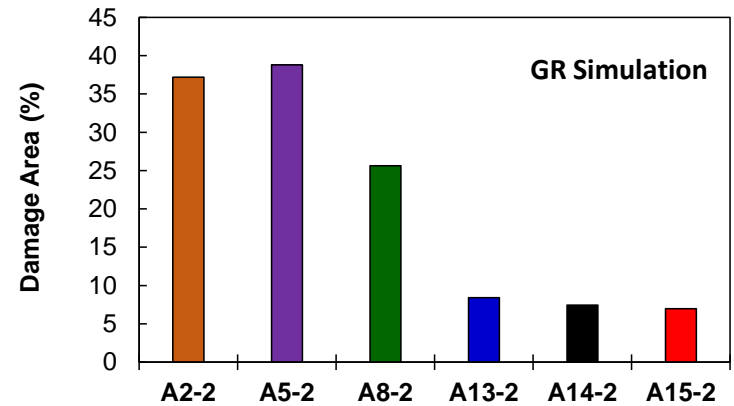
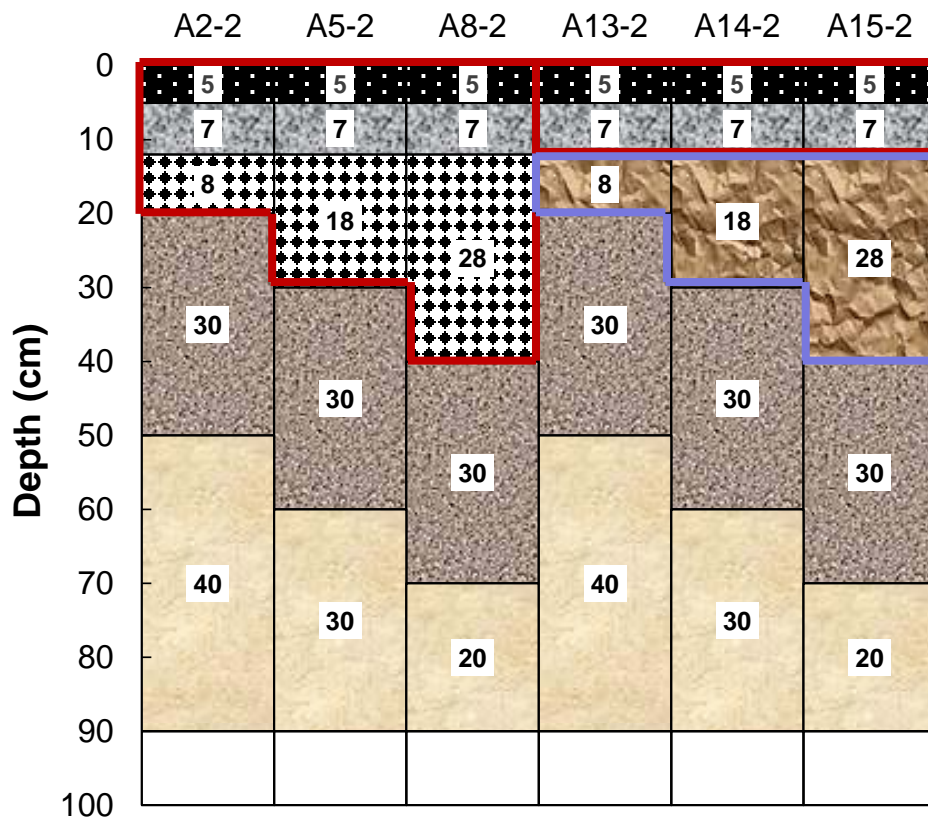
FlexPAVE Simulation

FHWA ALF

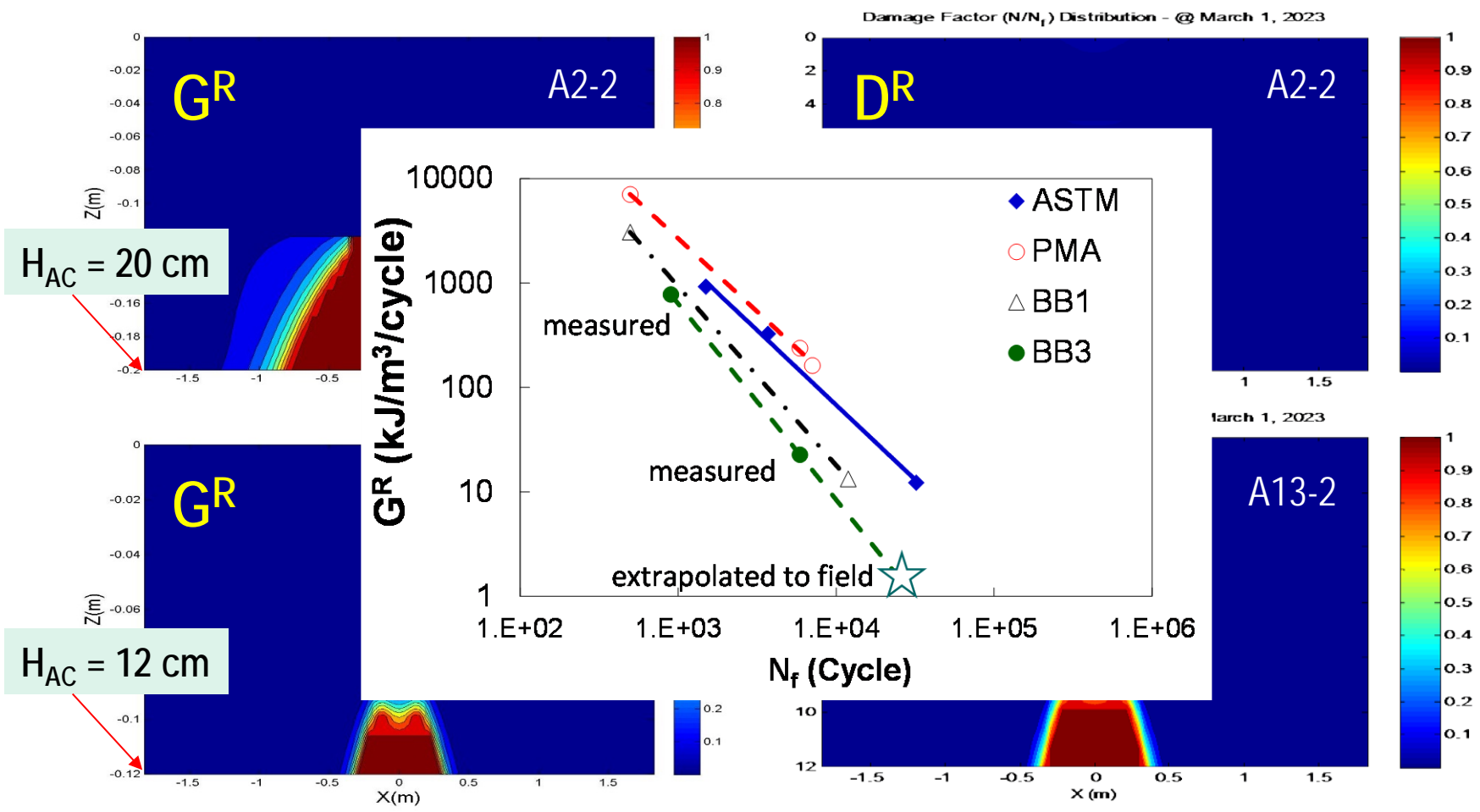


FlexPAVE Simulation

KEC Test Road



Effect of Extrapolation



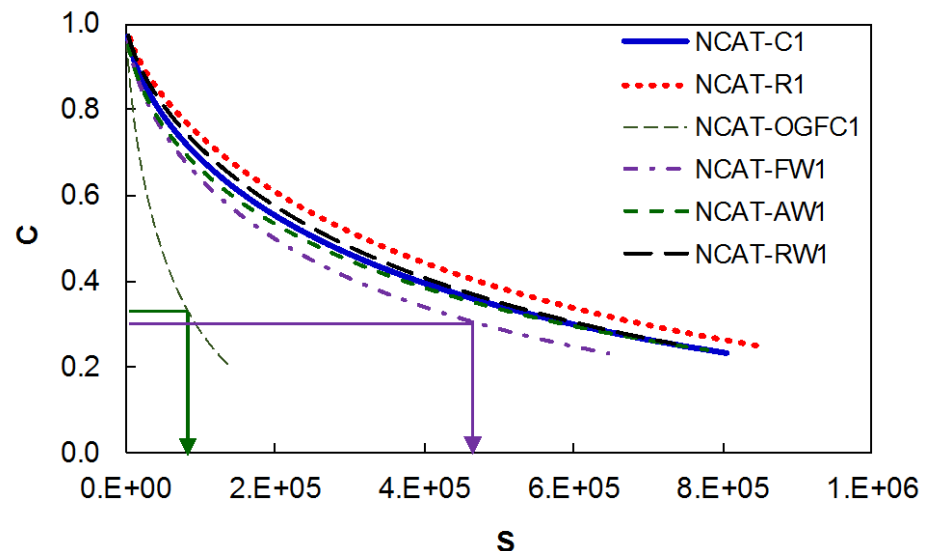
S_{app} as Cracking Index Property

- Determined from measurements from the TP 107 test procedure at the reference temperature
- Apparent Damage Capacity: the amount of damage the material can tolerate until the material stiffness reaches the average stiffness value

$$C = 1 - C_{11} S^{C_{12}}$$

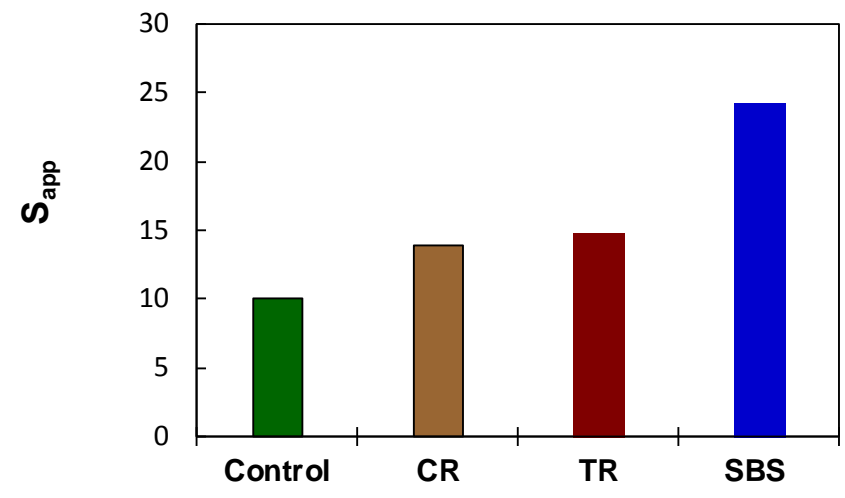
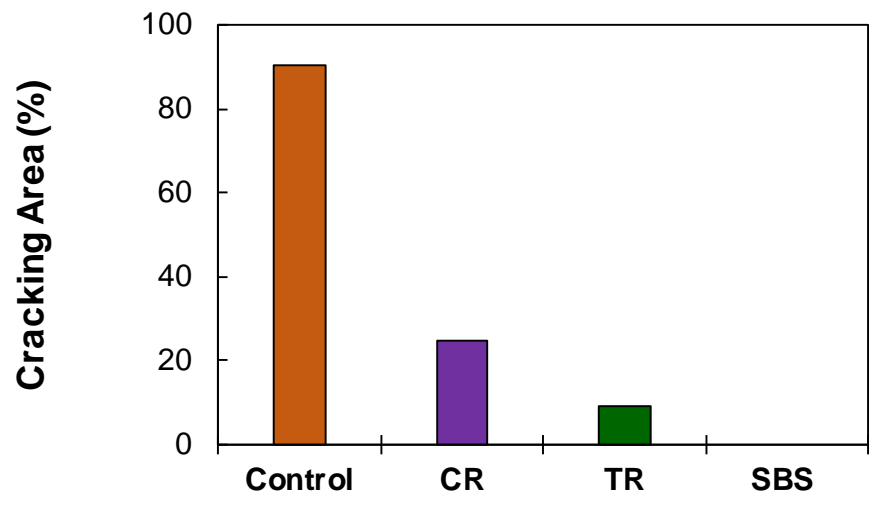
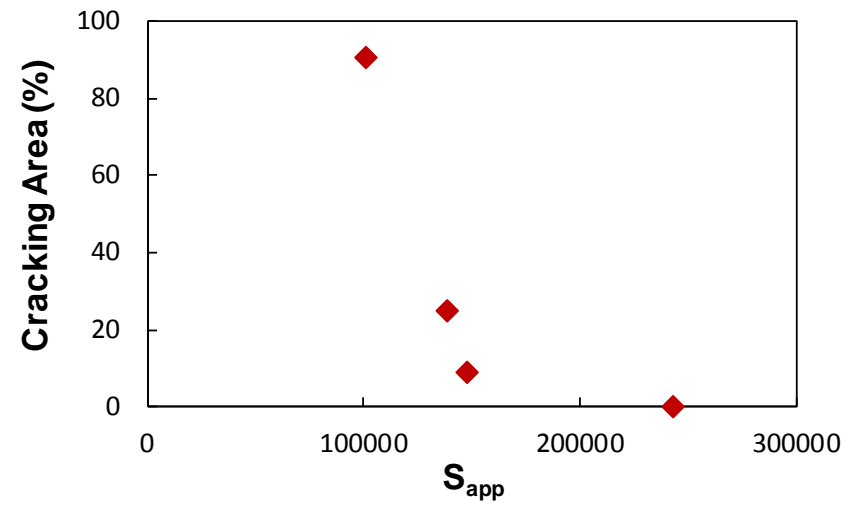
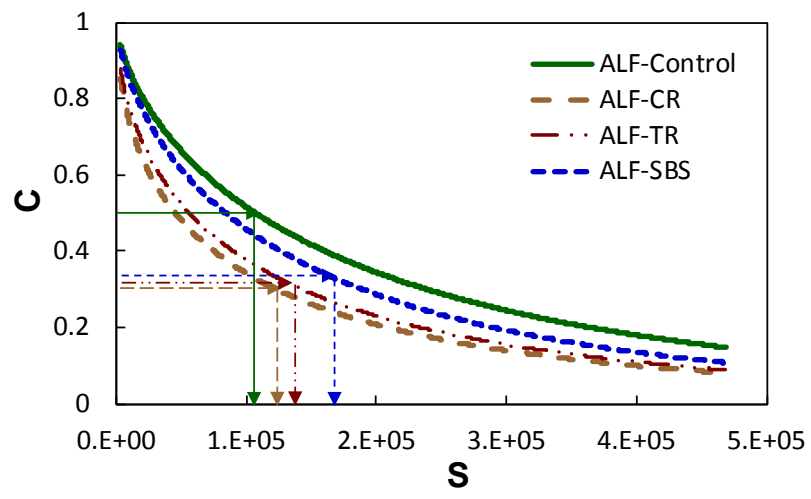
$$S_{app} = \frac{1}{10000} \times \left(\frac{1}{C_{11}} \times D^R \right)^{\frac{1}{C_{12}}}$$

$$S_{app} = \frac{\left(\frac{C_{12}}{a_T^{\alpha+1}} D^R \right)^{\frac{1}{C_{12}}}}{10,000}$$

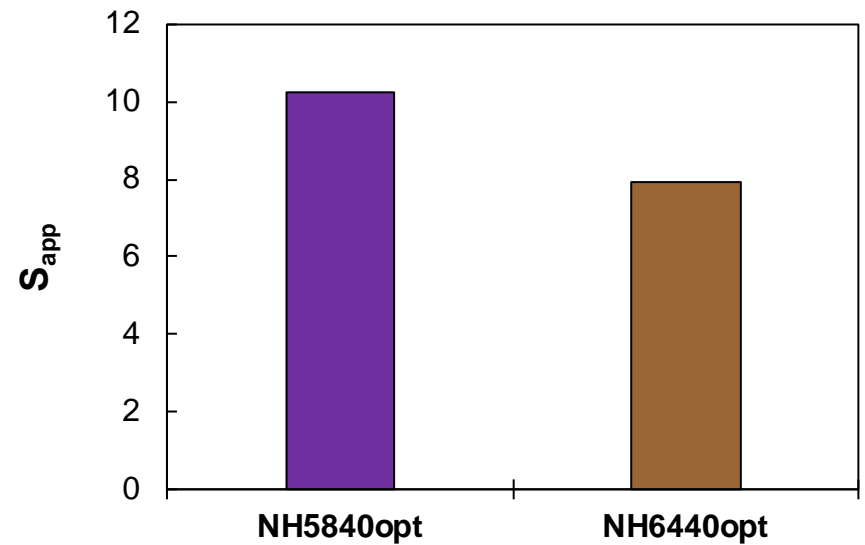
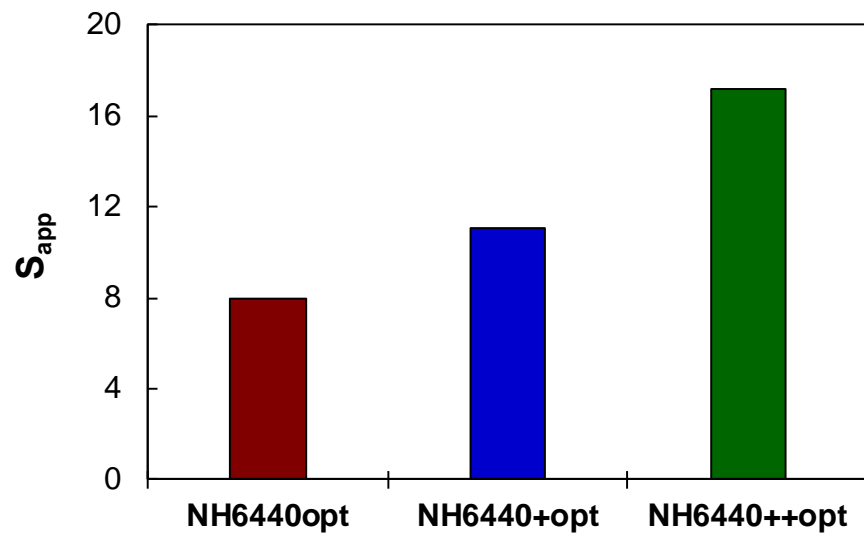


- $S_{app} > 8$ is the preliminary critical value.

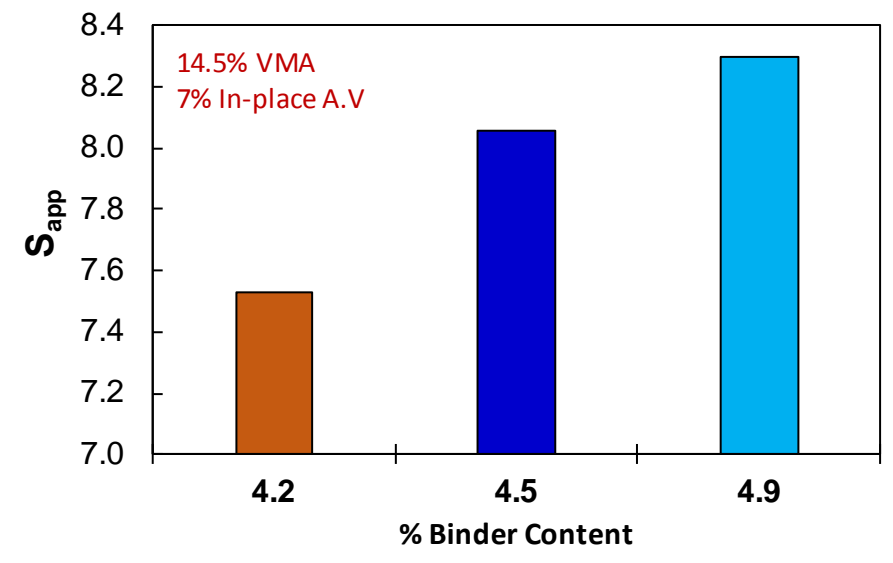
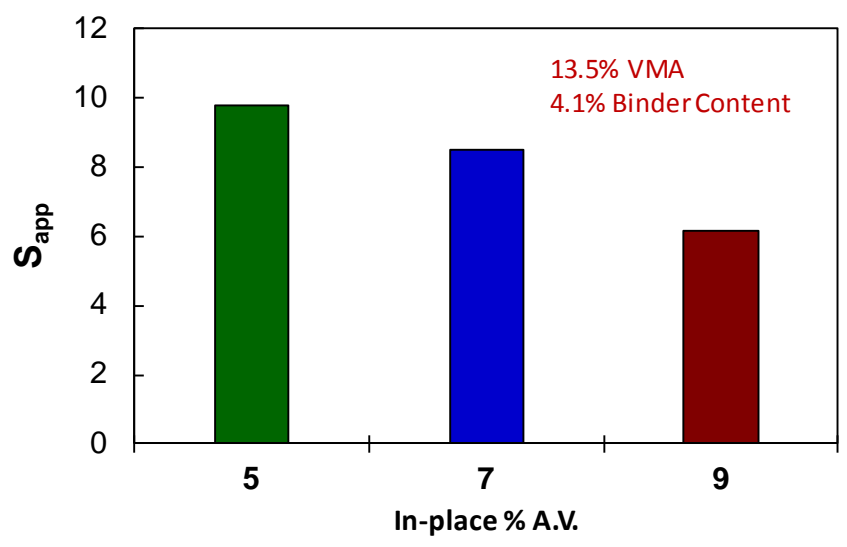
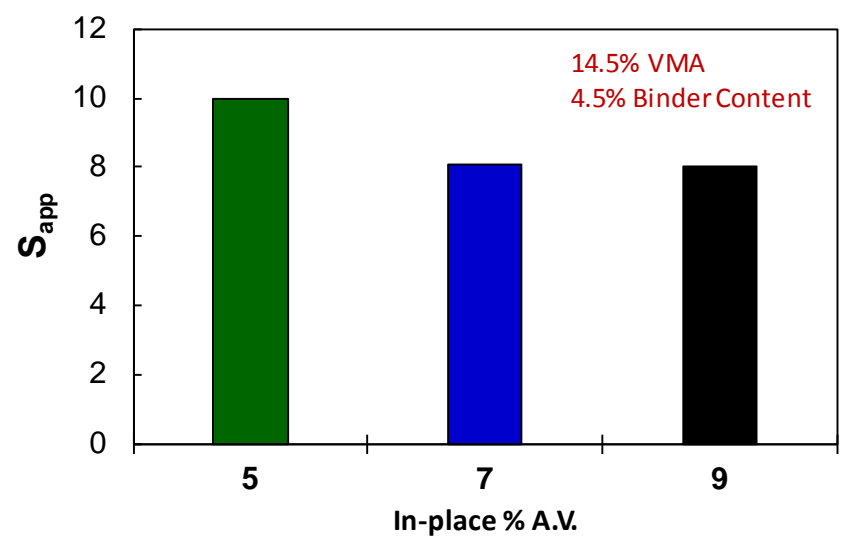
S_{app} for ALF Mixtures



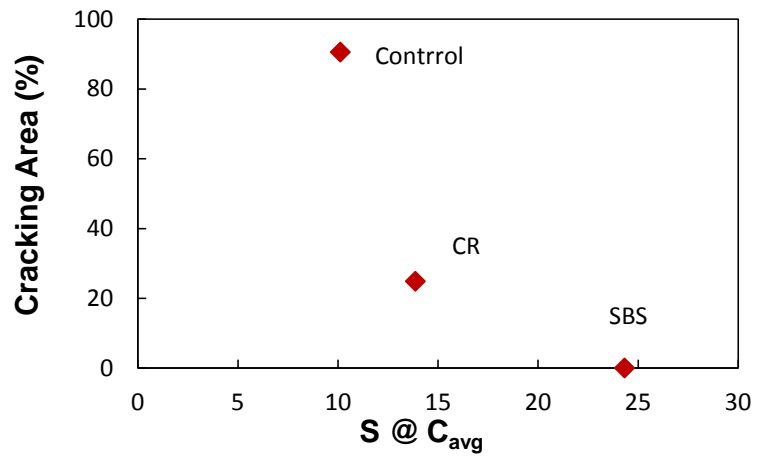
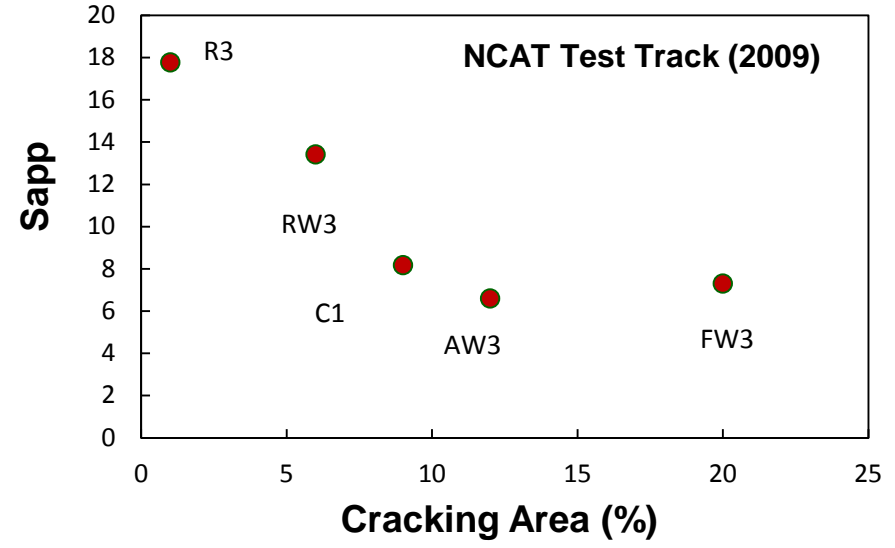
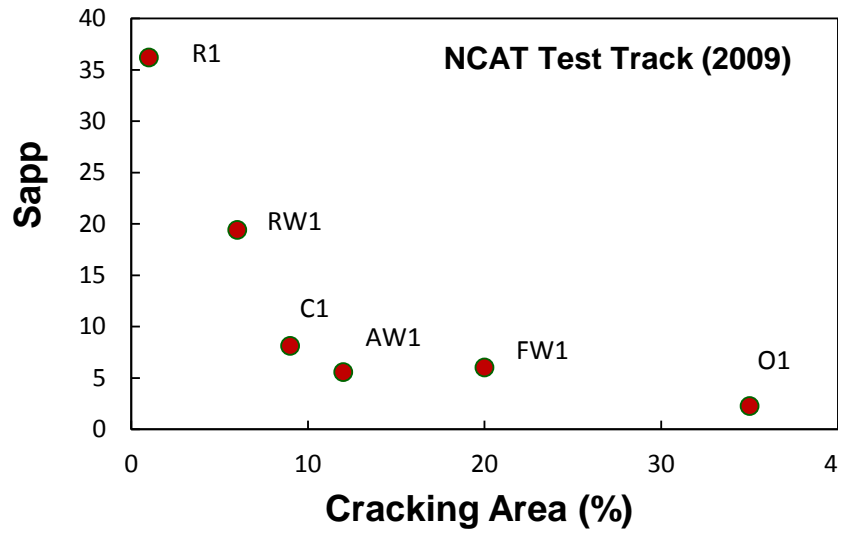
S_{app} for RAP Mixtures



S_{app} As a Function of Volumetrics



Field Validation



Proposed Change in TP 107

- ❑ Three tests recommended
- ❑ Fatigue testing at one strain level
 - Closed-form solution is available for the prediction of N_f under different strain levels
- ❑ Inclusion of D^R and S_{app} in the specification

Questions?