WASHINGTON STATE UNIVERSITY
World Class. Face to Face.

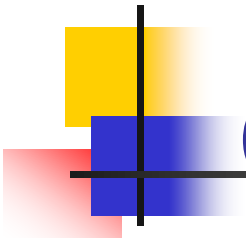
Development of a damage-based phenomenological fatigue model for asphalt pavement

Dr. Haifang Wen
Washington State University

Pavement Performance Prediction Symposium
Laramie, WY
July 16, 2009

Outline

- Introduction to fatigue model
- Experiments and data collection
- Verification of damage-based model
- Conclusions and recommendations



Outline

- Introduction to fatigue model
- Experiments and data collection
- Verification of damage-based model
- Conclusions and recommendations

Primary Pavement Distresses

- Fatigue Cracking
- Rutting
- Thermal Cracking

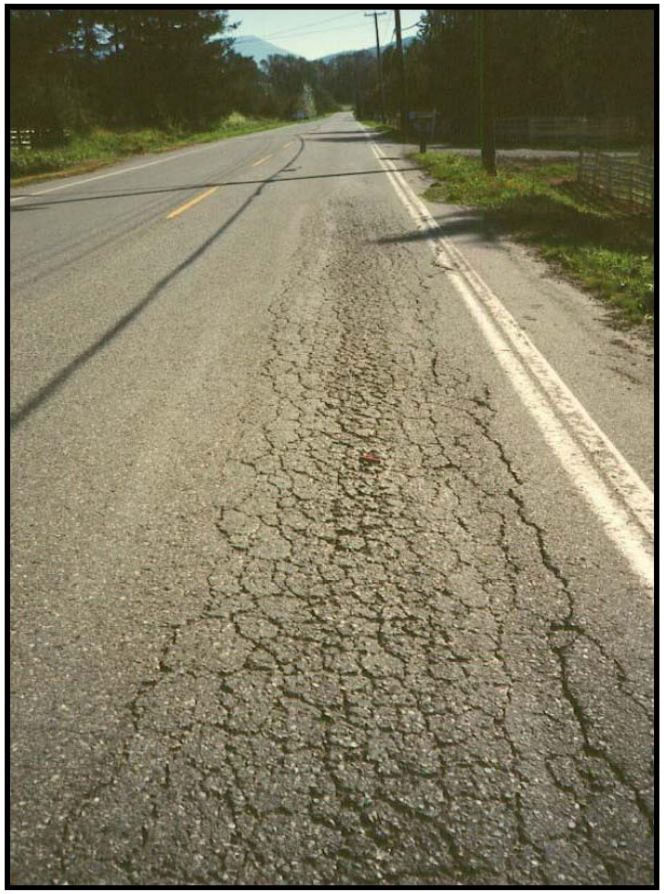
Fatigue Cracking

- Bottom-up Fatigue Cracking
- Top-down Fatigue Cracking

Bottom-up Fatigue Cracking

- Cracking initiates at the bottom of the HMA layer where the tensile stress is the highest then propagates to the surface as one or more longitudinal/transverse cracks

Bottom-up fatigue cracking



Mechanistic-empirical Design

$$N_f = Ck_1\left(\frac{1}{\varepsilon_t}\right)^{k_2}\left(\frac{1}{E}\right)^{k_3}$$

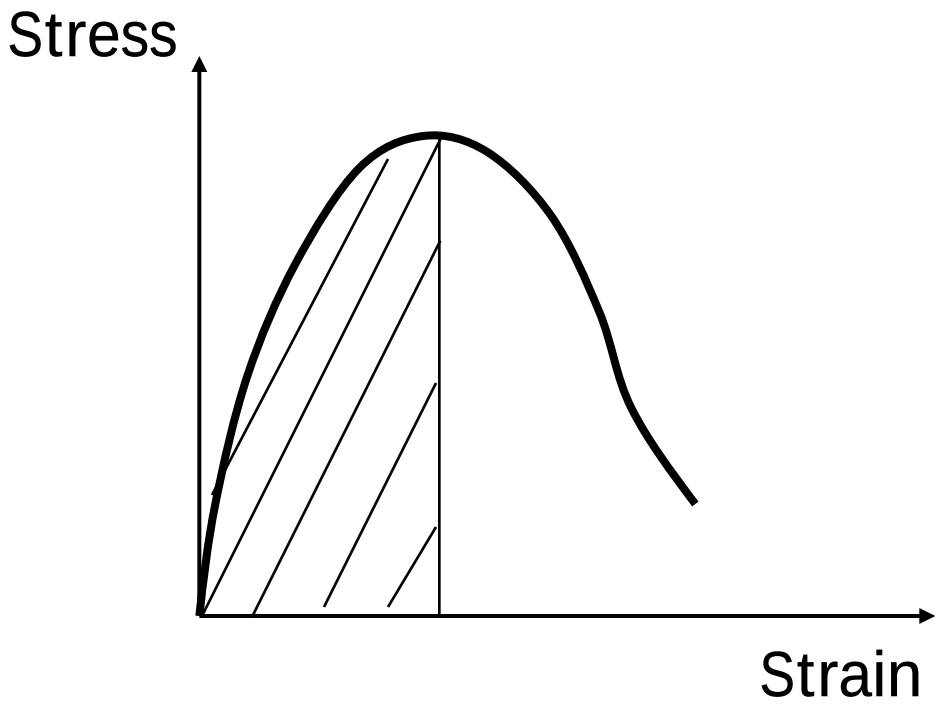
$$k_1 = \frac{1}{0.000398 + \frac{0.003602}{1 + e^{11.02 - 3.49h_{ac}}}}$$

- N_f=fatigue life in lab
- E=dynamic modulus of HMA
- ε_t=strain at bottom of HMA
- K_1, k_2, k_3=regression coeff.
- C=shift factor from lab to field

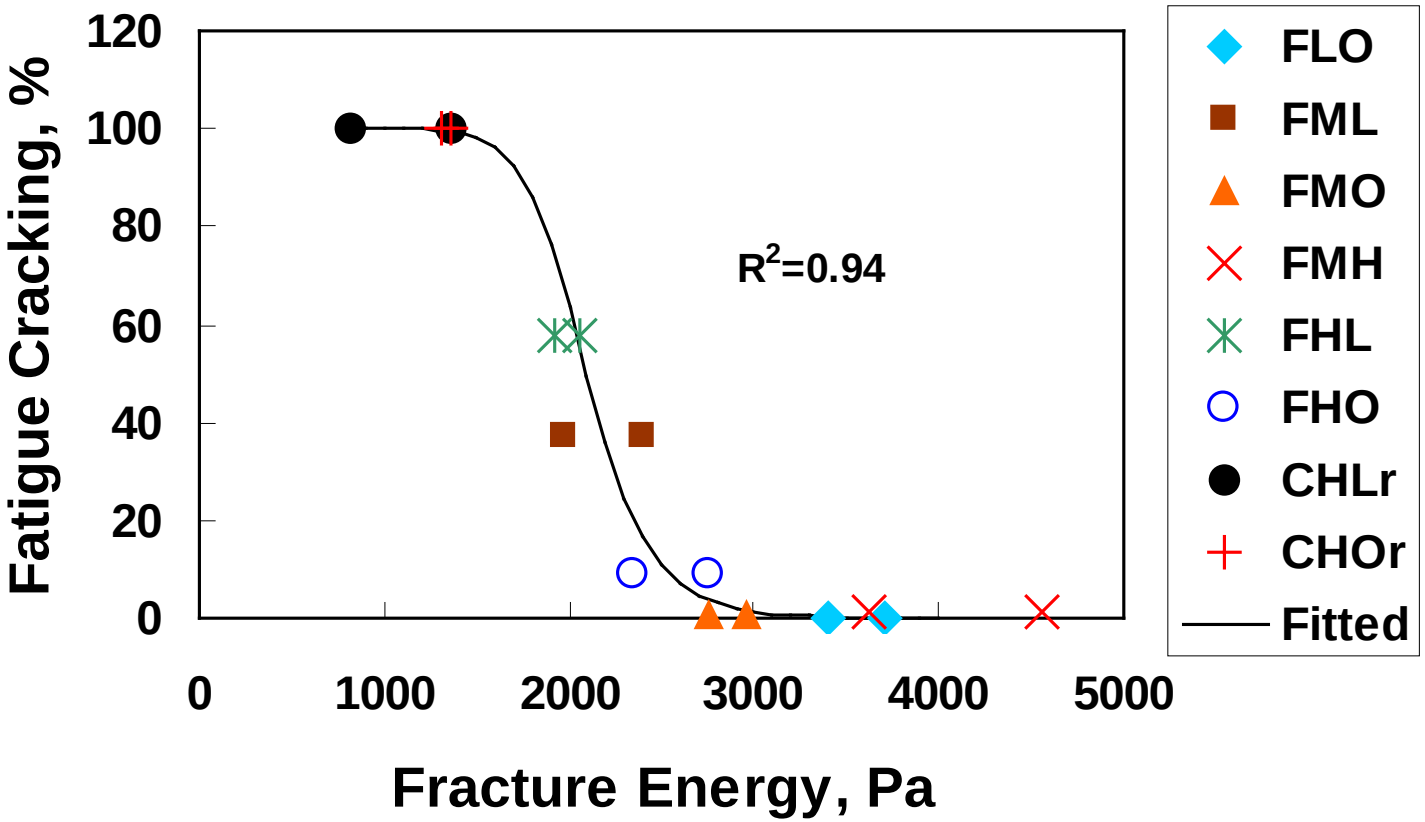
Concern on E* for fatigue

- E* is not a damage property, while fatigue is due to damage
- High modulus materials not necessarily fatigue resistant, e.g. paper clip vs. rubber band,
- Or vice versa, e.g. glass vs. steel

Fracture Energy from IDT Strength Test



Fracture Energy vs. Performance
(Field Cores/5 million ESALs) (Wen & Kim)



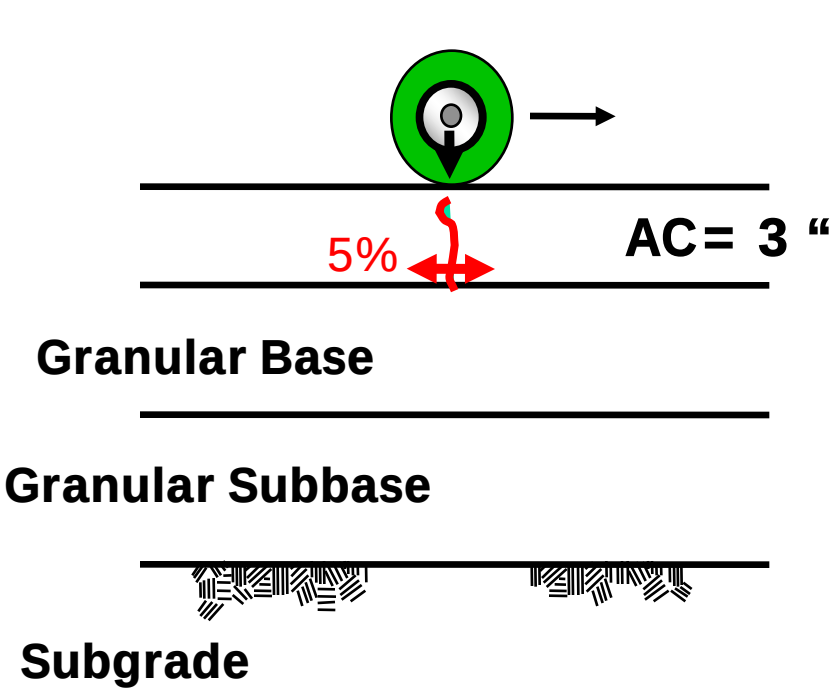
Damage-based model

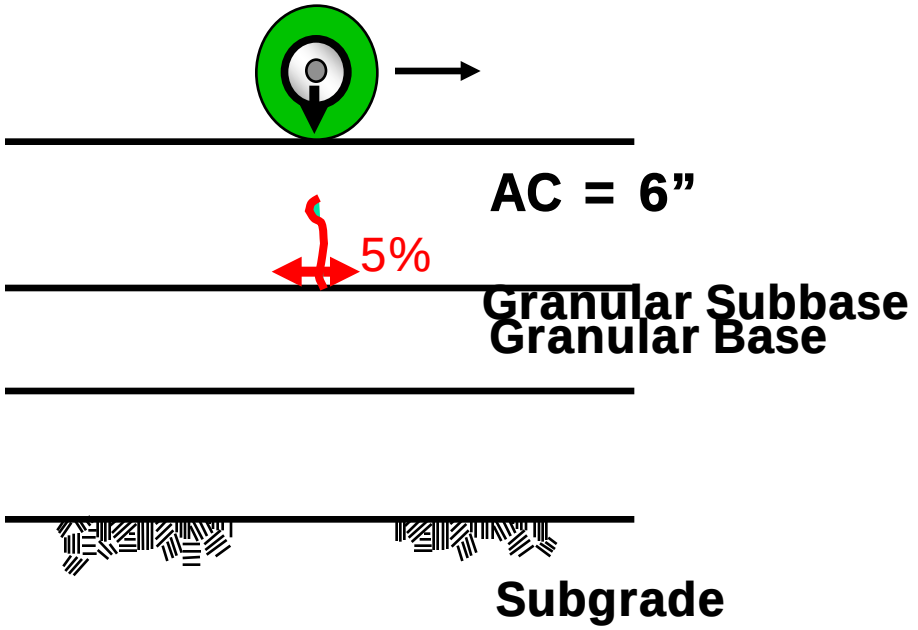
$$N_f = Ck_1\left(\frac{1}{\varepsilon_t}\right)^{k_2}\left(\frac{1}{E}\right)^{k_3}$$

Fracture Energy from IDT

- N_f=fatigue life in lab
- E=dynamic modulus of HMA
- ε_t=strain at bottom of HMA
- K_1, k_2, k_3=regression coeff.
- C=shift factor from lab to field

Effect of HMA Layer Thickness





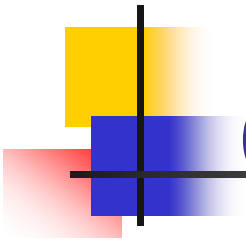
HMA Layer Thickness

$$N_f = Ck_1\left(\frac{1}{\varepsilon_t}\right)^{k_2}\left(\frac{1}{E}\right)^{k_3}$$

Fracture Energy from IDT

Proposed Fatigue Model:

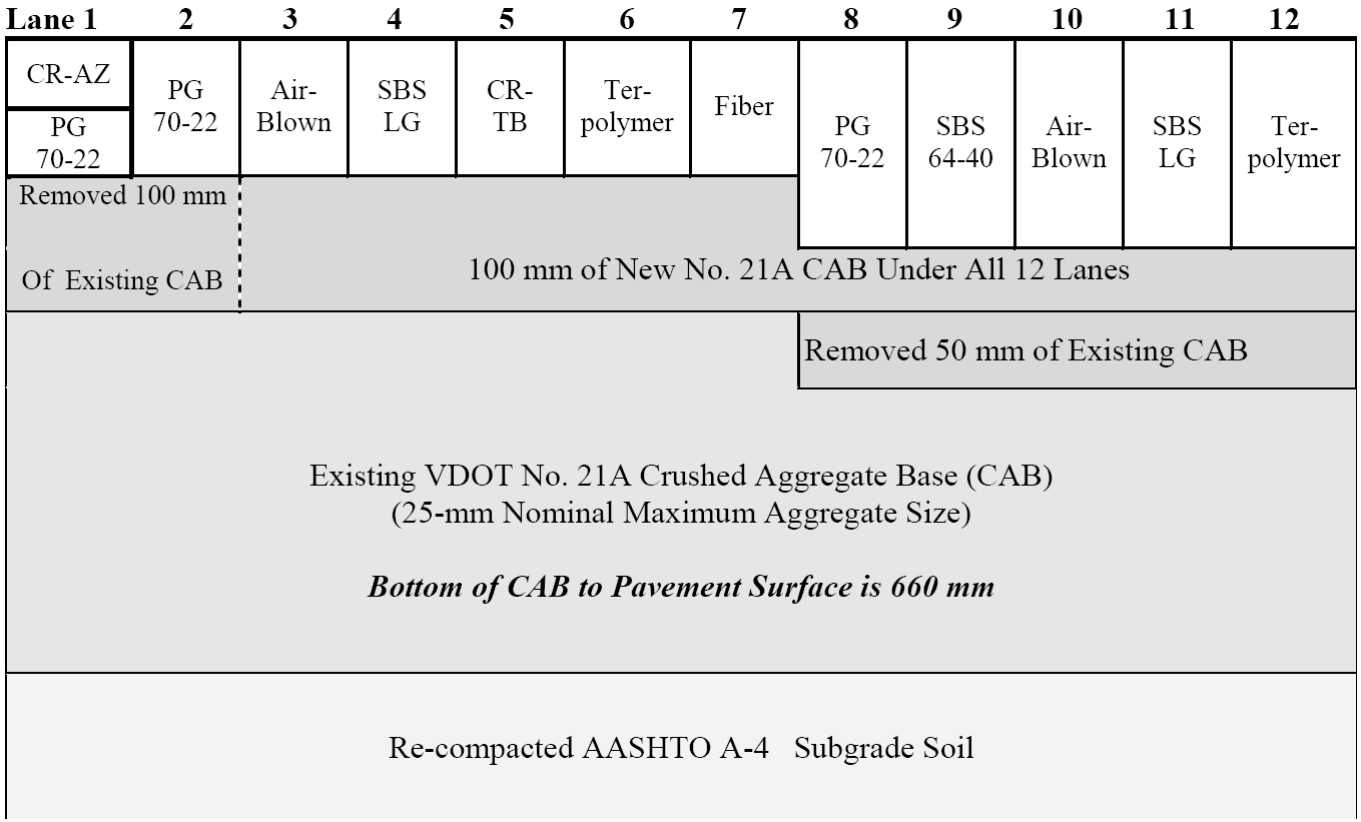
$$N_f = a\left(\frac{1}{\varepsilon_t}\right)^{b}\left(\frac{1}{FE}\right)^{c} h^{d}$$



Outline

- Introduction to fatigue model
- Experiments and data collection
- Development of model
- Conclusions and recommendations

FHWA ALF Test Sections



(Qi et al 2006)

Experiments and data collection (FHWA)

- Dynamic modulus (Uniaxial)
- IDT strength tests
- Tensile strain at bottom of HMA layer from instrumentation

Experiments and data collection (FHWA)

- Dynamic Modulus (Uniaxial)
- IDT Strength Tests
- Tensile strain at bottom of HMA layer from instrumentation
- No of passes to 3% fatigue cracking

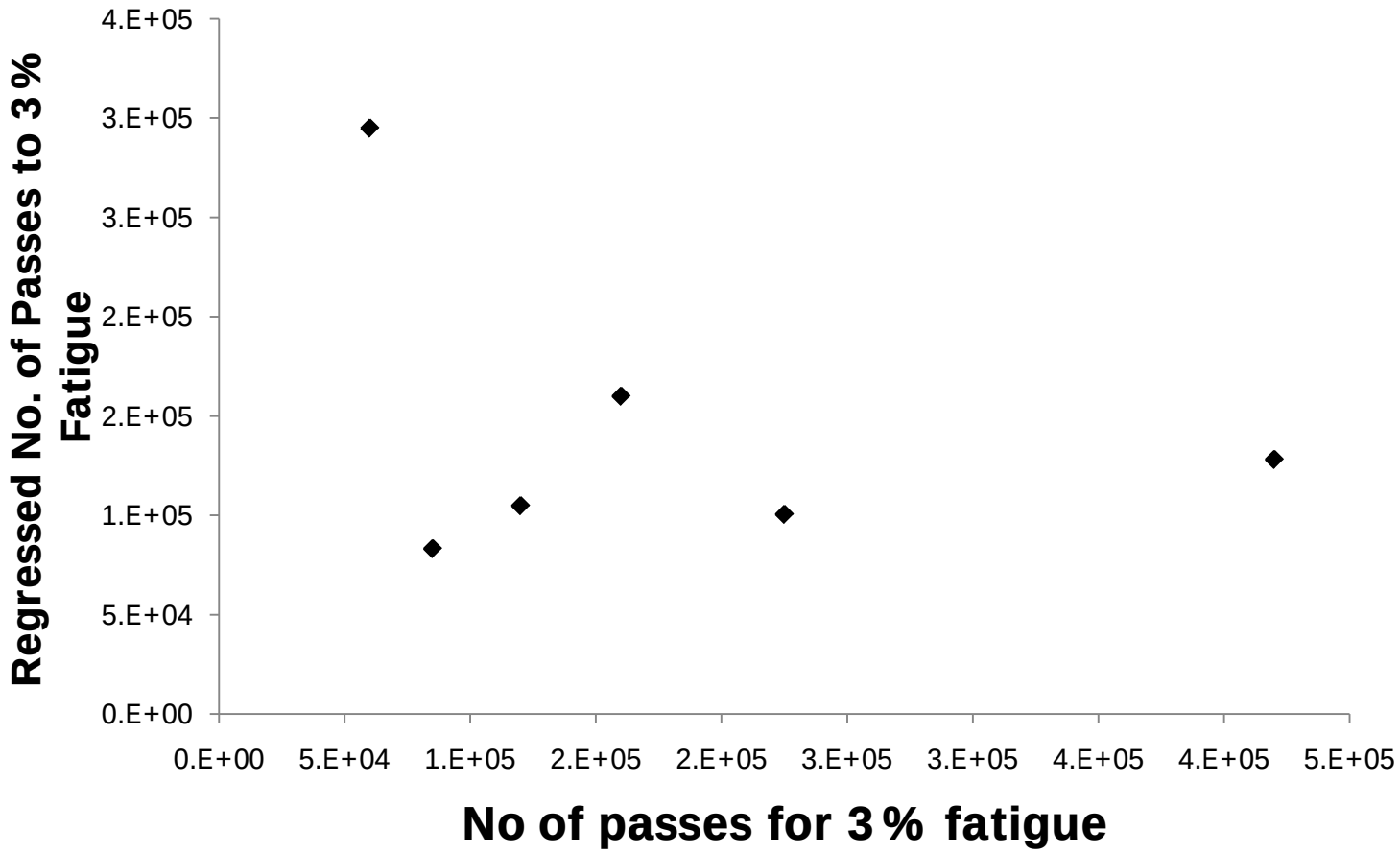
Data collected

Materials	Fracture Energy, Pa	No of Passes to 3% Fatigue Cracking	Transverse Tensile Strain
Lane 4/SBS LG	1495271	160000	970
Lane 5/CR-TB	865994	60000	1524
Lane 6/Terpolymer	841847	85000	927
Lane 7/Fiber	985263	225000	540
Lane 8/PG 70-22	1248486	420000	475
Lane 10/Air-Blown	394186	120000	488

Outline

- Introduction to fatigue model
- Experiments and data collection
- Verification of model
- Conclusions and recommendations

M-E Fatigue Model

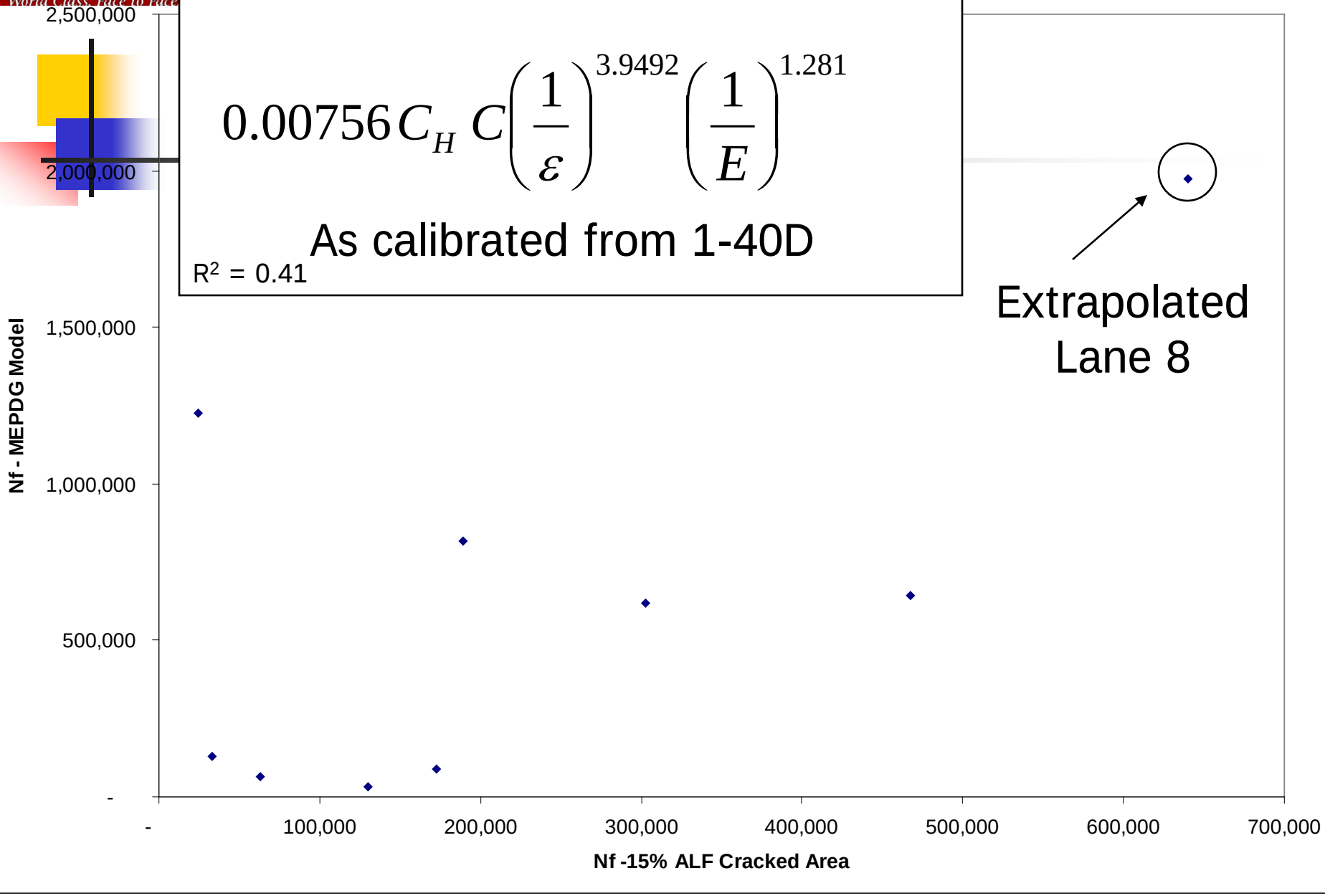


τ= +0.28, n=9, S=N_C-N_D= +10

$$0.00756\,C_H\,C\left(\frac{1}{\varepsilon}\right)^{3.9492}\left(\frac{1}{E}\right)^{1.281}$$

As calibrated from 1-40D

R^2 = 0.41

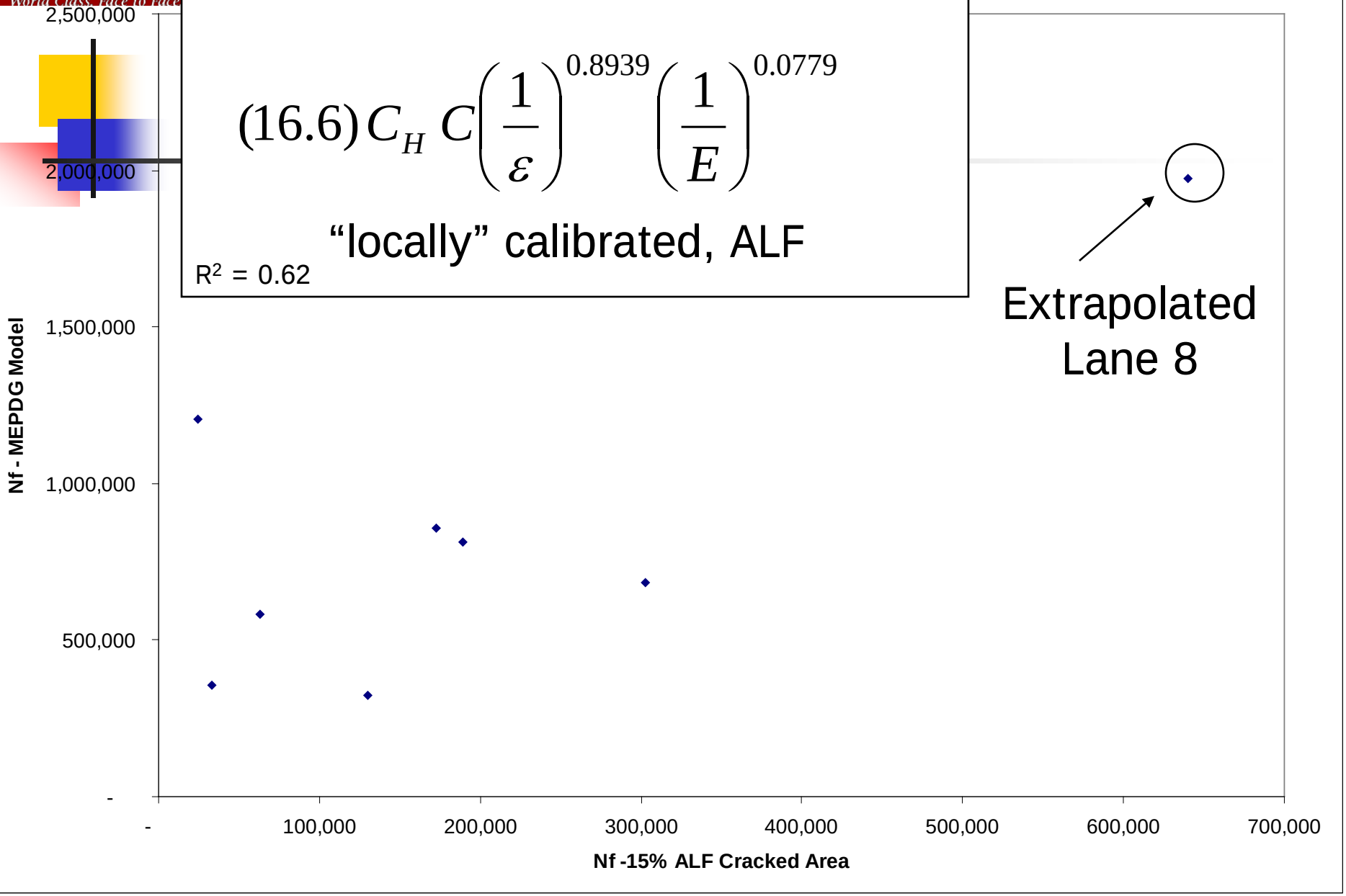


τ= +0.39, n=9, S=N_C-N_D= +14

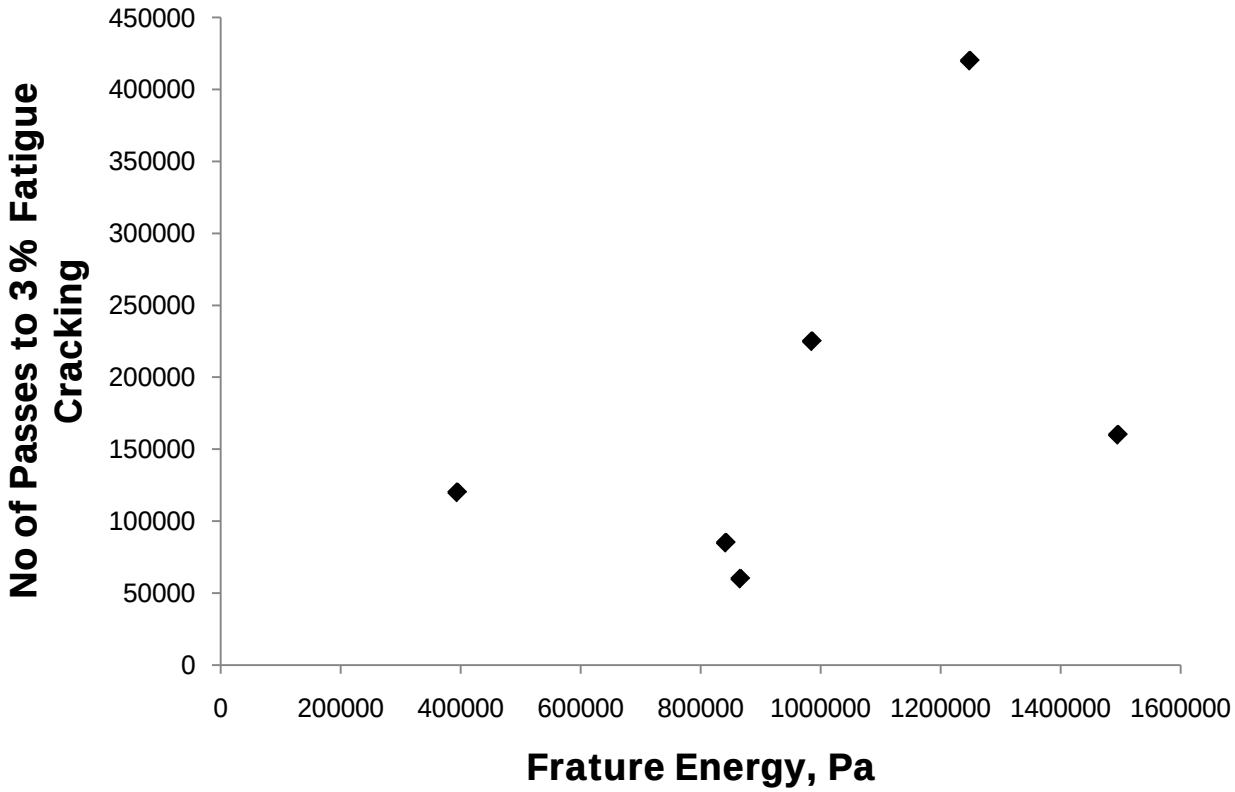
$$(16.6)\, C_H\, C \left(\frac{1}{\varepsilon}\right)^{0.8939} \left(\frac{1}{E}\right)^{0.0779}$$

"locally" calibrated, ALF

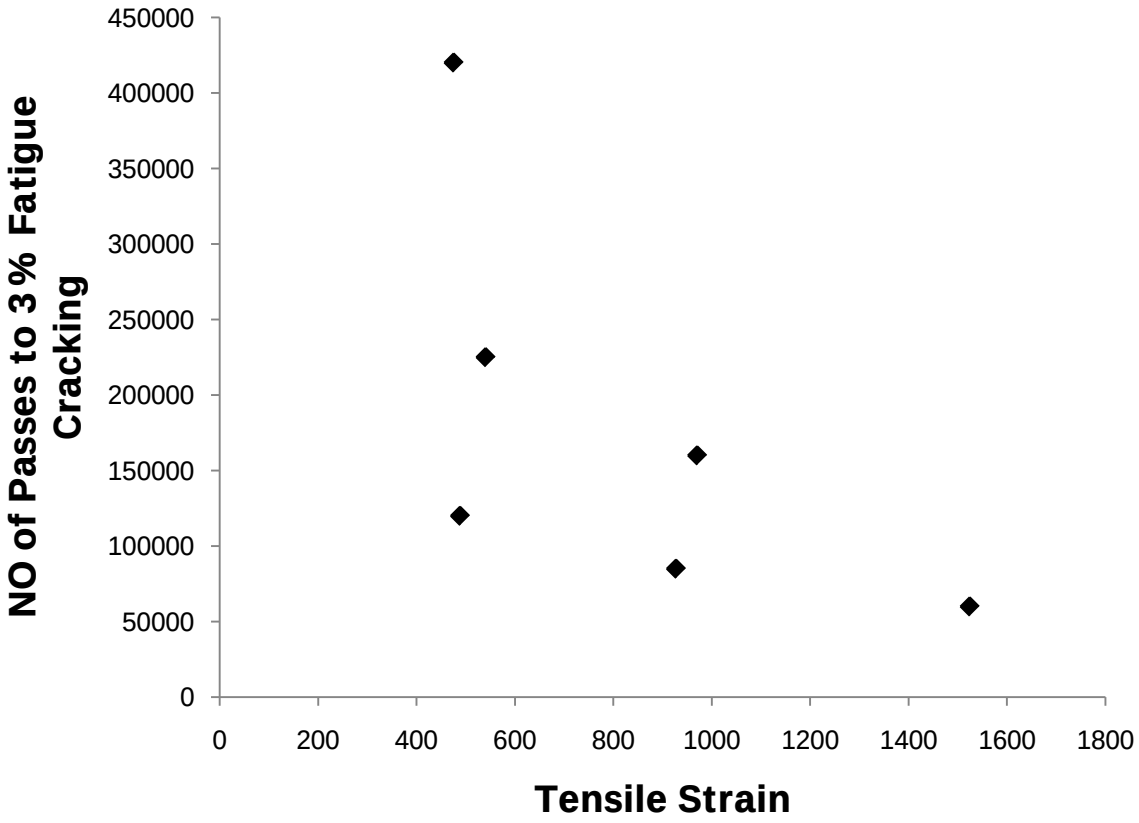
R^2 = 0.62



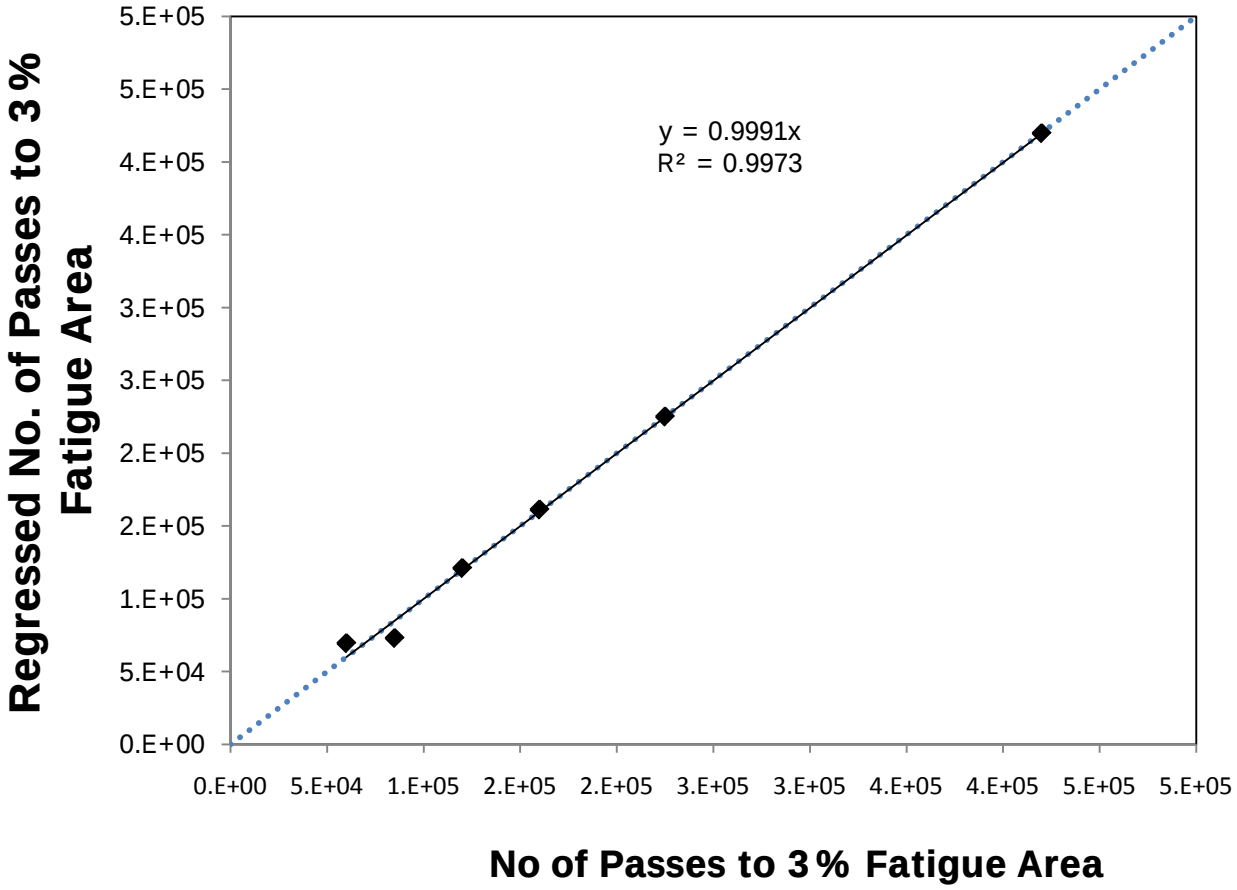
Fracture energy vs. No. of Passes

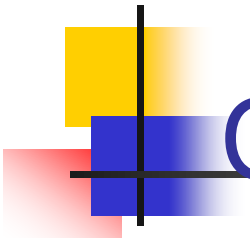


Tensile Strain vs. No. of Passes



Damage-based Model





Outline

- Introduction to fatigue model
- Experiments and data collection
- Development of model and its implications
- Conclusions and recommendations

Conclusions

- Currently, MEPDG is based on asphalt institute fatigue model
- Dynamic modulus is a key parameter of the model
- Dynamic modulus has limitations to be used as fatigue indicator
- MEPDG fatigue model did not work well for ALF pavements

Conclusions

- Damage-based fatigue model worked well for ALF pavement and has shown great potential to be implemented
- The damage-based model needs to be validated by large database, such as LTPP materials and performance data

Acknowledgement

- Nelson Gibson and Jack Youtcheff of FHWA for providing data
- Emin Kutay of Michigan State University

Thank you!