NCHRP 9-59-Binder Fatigue Test: Update

September 15, 2016

FHWA Binder ETG

Fall River, MA

National Center for Asphalt Technology
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Advanced Asphalt Technologies, LLC

"Engineering Services for the Asphalt Industry"

NCHRP 9-59 Objective

The primary objective of NCHRP 9-59 is to develop a test or tests that will help to effectively and efficiently control the properties of asphalt binders that contribute to the fatigue resistance of asphalt mixtures

Presentation Objective

- Describe general approach to developing an improved binder fatigue test
- Provide summary of results to date
- Describe future efforts

Problem

Hwy 41 North of Kaladar (1999)

Hesp et al., *Proceedings CTAA*, 2009

Bill Ahearn, Pamela Marks, Simon Hesp

Questions

- Can |G*| sin(δ) be improved? Added to? Replaced?
- How does modulus affect fatigue performance?
- Relationship between fracture and fatigue performance of binder and mixture?

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Strain-Based Cracking Model

$$N_f = k_1 \left(\frac{1}{\varepsilon_t} \right)^{k_2} \left(\frac{1}{S_{mix}} \right)^{k_3}$$

$$N_f = \left(\frac{FSC}{\varepsilon_{binder}} \right)^{1.38(90/\delta)}$$

FSC = fatigue strain capacity

$$N_f = \left\{ \frac{FSC}{\left[\varepsilon_{mix} / (VBE/100) \right]} \right\}^{1.38(90/\delta)}$$

Generalized Failure Theory

$$N_f = \left(\frac{FSC}{\varepsilon_{binder}} \right)^{1.38(90/\delta)}$$

FSC = fatigue strain capacity

$$FSC = \left\{ N_f * e_{binder}{}^{(1.38(90/d))} \right\}^{d/(90´ 1.38)}$$

$$D = \sum_{i=1}^{n} N_i \left[\left(e_{binder} \right)_i \right]^{1.38(90/d)}$$

Phase angle δ is for the binder, not the mix…

$$FSC = D^{\delta/(90 \times 1.38)}$$

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Generalized Failure Theory

$$N_f = \left(\frac{FSC}{\varepsilon_{binder}} \right)^{1.38(90/\delta)}$$

$$N_f = \left\{ \frac{FSC}{\left[\varepsilon_{mix}/(VBE/100)\right]} \right\}^{1.38(90/\delta)}$$

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$$FSC = D^{\delta/(90 \times 1.38)}$$

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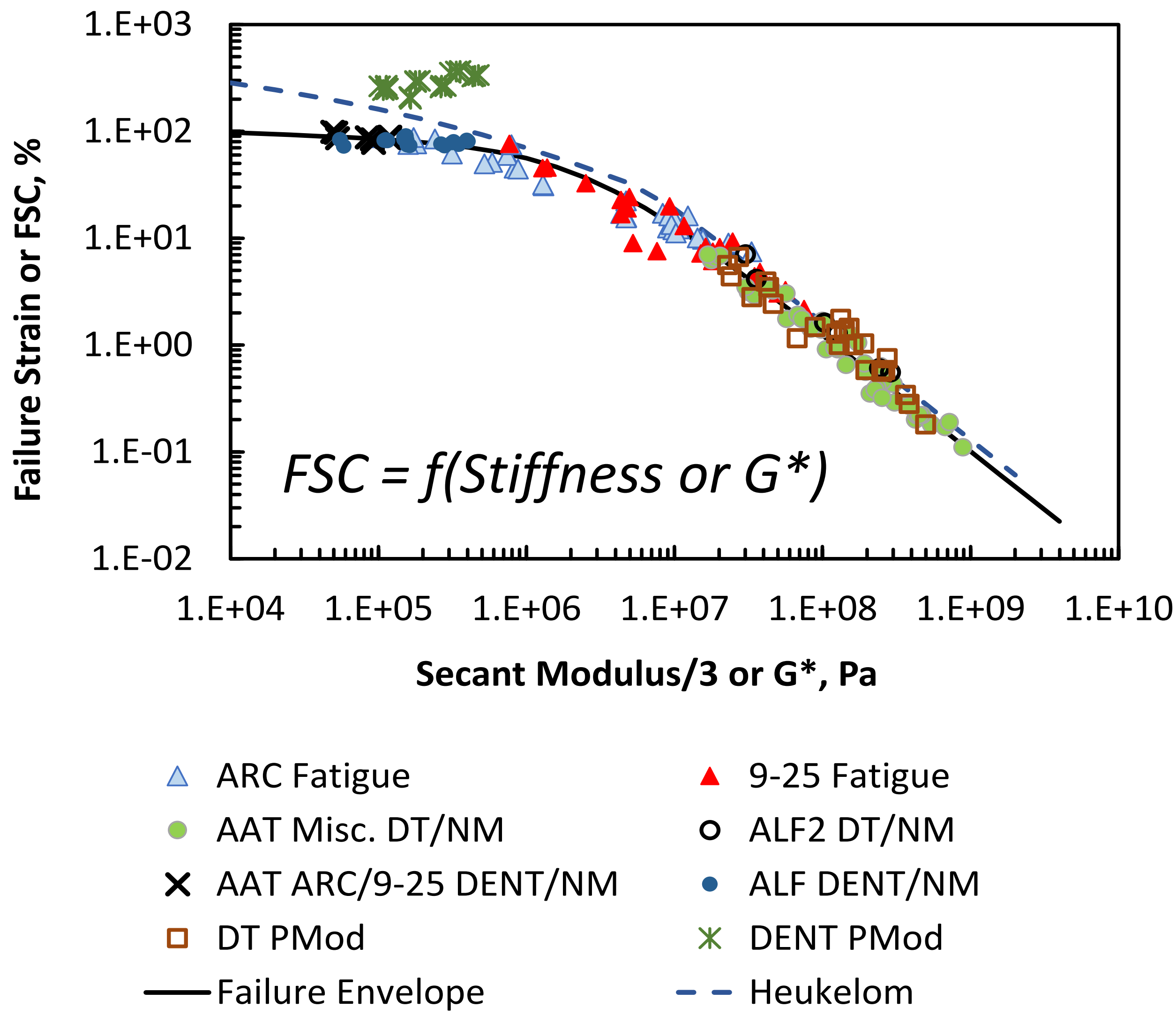
Phase angle δ is for the binder, not the mix…

Typical Failure Envelope



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Fatigue/Fracture Performance Ratio, FFPR

$$Typical\ FSC\ or\ \varepsilon^* = \frac{1}{6.56\times10^{-3} S(T,t)^{0.0482} + 1.35\times10^{-9} S(T,t)^{1.10}}$$

FFPR is defined as the ratio of observed to expected failure strain. Values significantly above 1 are good, below 1 are bad. The equation above is preliminary.

$$FFPR = \frac{Measured\ FSC\ or\ \varepsilon^*}{Typical\ FSC\ or\ \varepsilon^*}$$

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Preliminary Results: Testing of ALF Binders

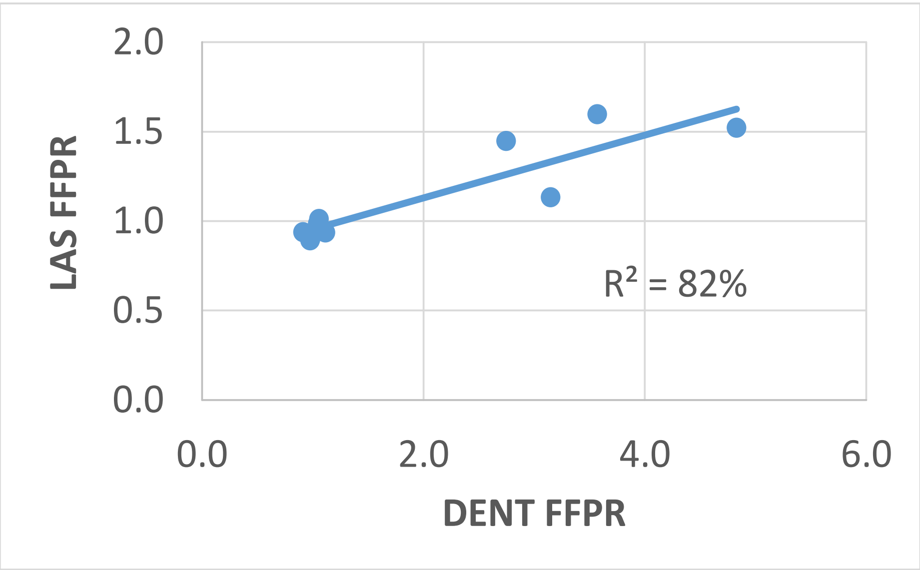
ALF Fatigue Experiments

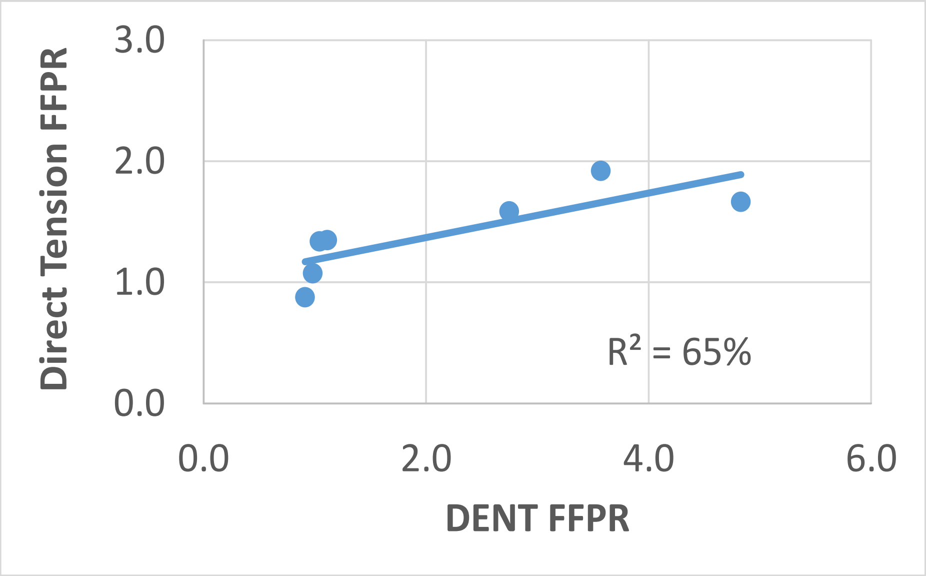
- Most of the binders for the first and second ALF fatigue experiments were tested
- These included PG 70-22, air blown binder, Terpolymer, SBS-LG, crumb rubber binder, AC 5 and AC 20
- RTFOT aging

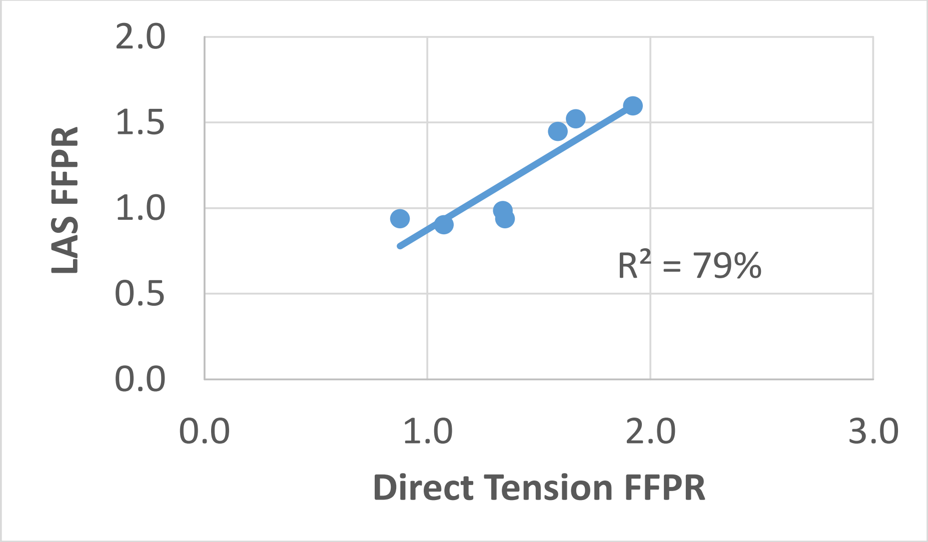
Binder Test Methods

- DSR frequency sweep (R value)
- Modified double edge notched tension (DENT)
- Linear amplitude sweep (LAS)
- Single edge notched bending (SENB)
- Various others from existing data

ALF Binders: Correlation among FFPR Values







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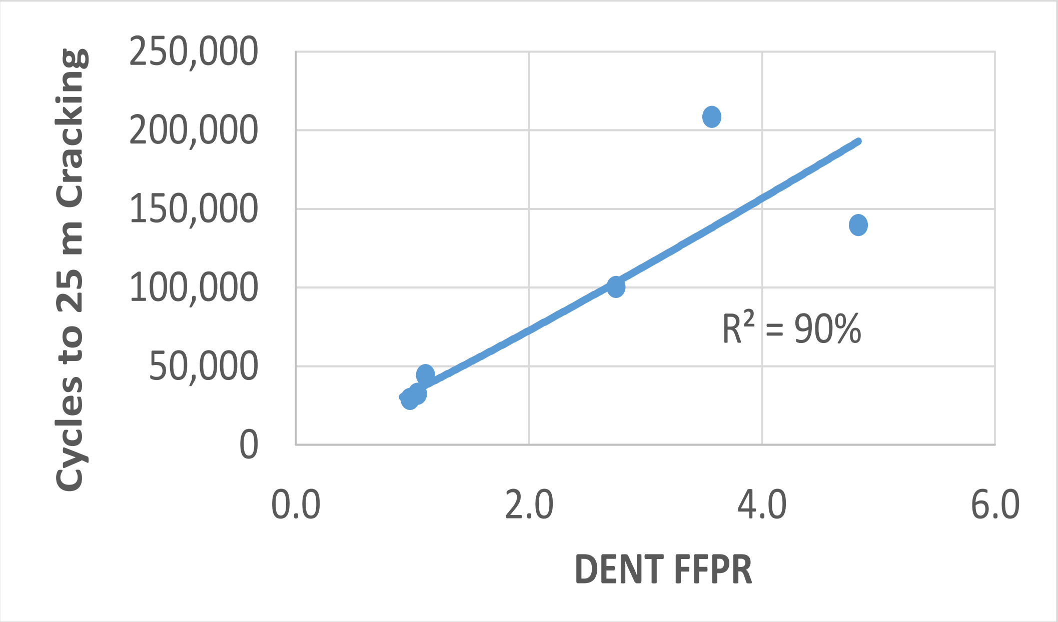
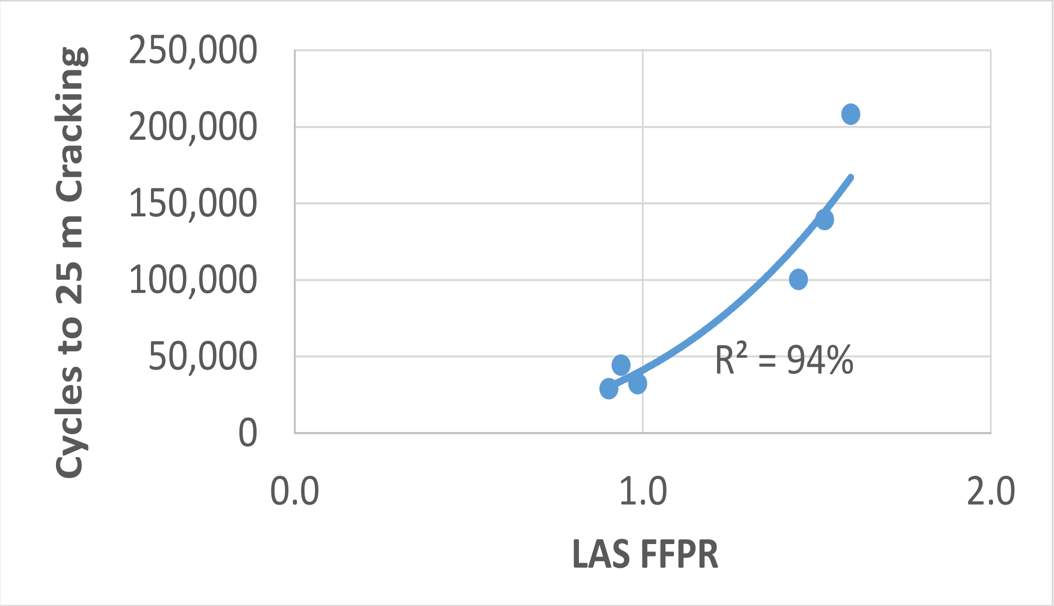
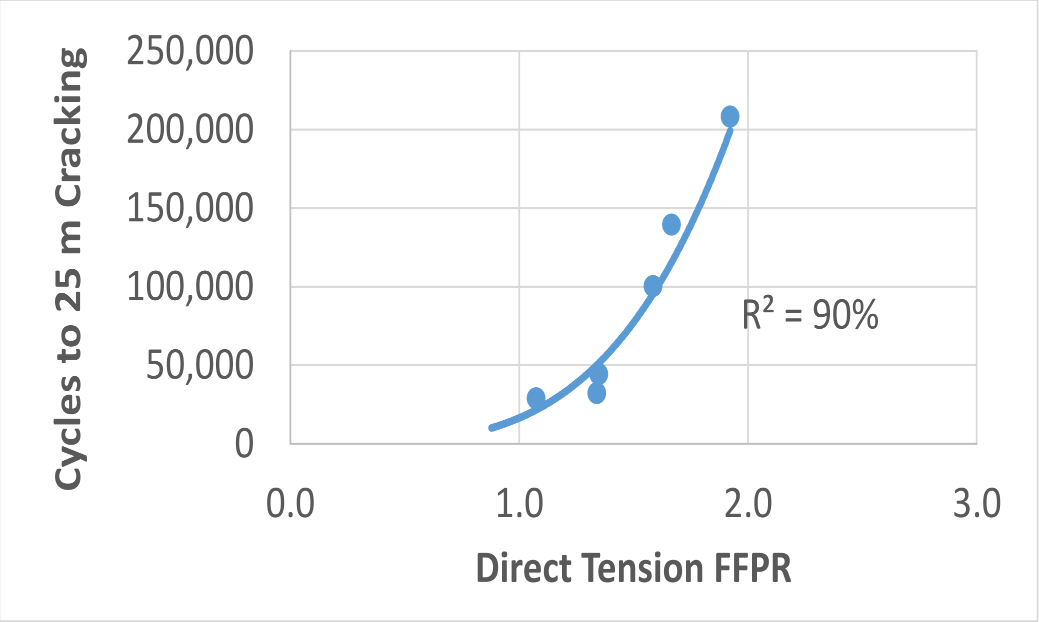
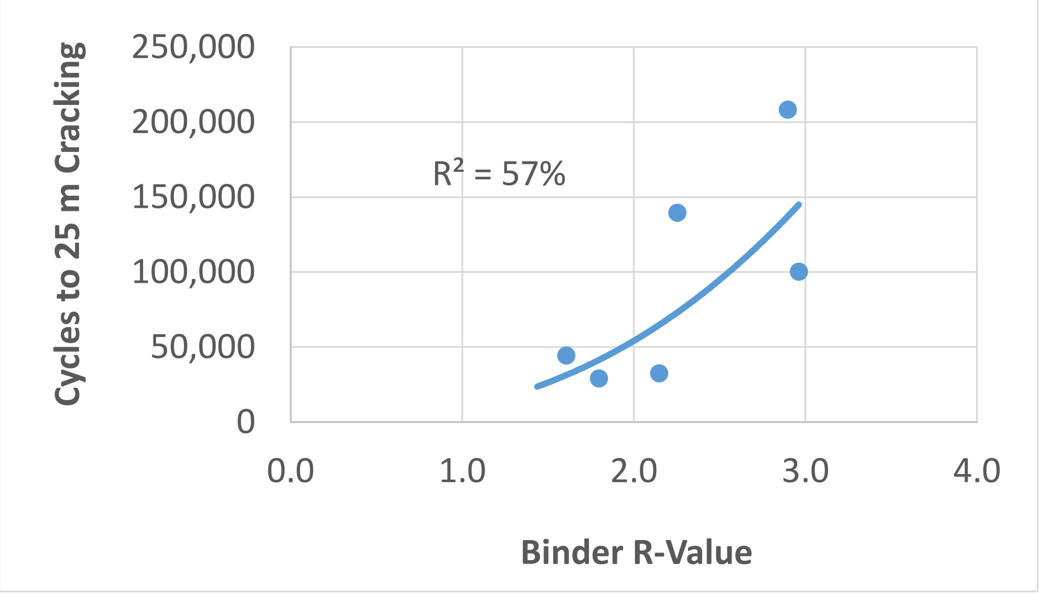
ALF Binders: Correlation Between Cracking and FFPR: ALF 1 & 2, 100 mm Test Sections





ALF Binders: Correlation Between Cracking and FFPR: ALF 1 & 2, 100 mm Test Sections





NCHRP 9-59 Test Plans

NCHRP 9-59 Tests

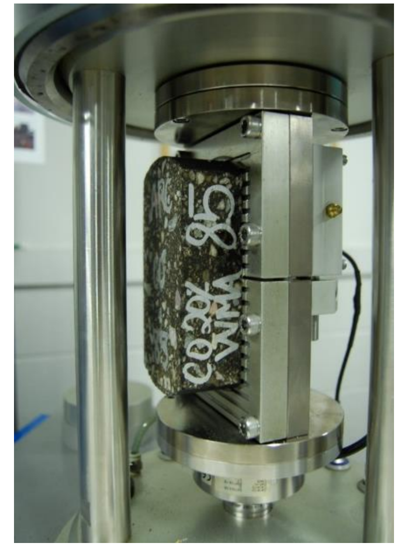
- Many binder tests correlated to ALF fatigue performance
- Will this approach work for 9-59 materials and test methods?
  - Will binder and mixture test data correlate?
  - Will test data match expected performance

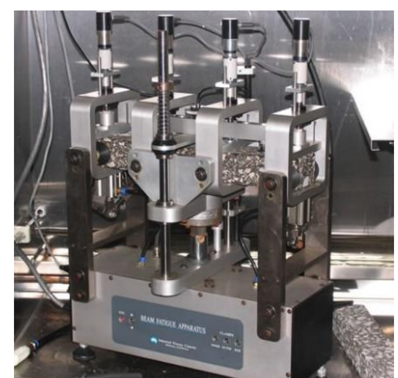
NCHRP 9-59 Binders

No.	Additive	PG	Comments
1	SBS	88-22	Grade is approximate; 64-22 base, 6 %+ SBS
2	SBS	76-28	
3	SBS/PPA	76-22	
4	SBS	64-28	Base binder = 58-28; SBS % = 2.0-2.5%
5	SBR	70-22	Base binder = 64-22; SBR % = 2.5-3.5% (terminal)
6	EVA	76-22	
7	---	58-28	
8	---	64-22	source 1
9	---	64-22	source 2; significantly different chemistry/rheology
10	GTR	70-22	terminal blend
11	oxidized	70-22	
12	oxidized	76-16	
13	REOB	58-28	source 1
14	REOB	58-28	source 2; significantly different chemistry/rheology
15	Terpolymer	58-34	
16	PPA	70-22	

NCHRP 9-59 Mixture Testing

- Uniaxial fatigue (SVECD)
  - Two temperatures
  - Three replicates
- Overlay test (OT)
  - 20°C
  - Three replicates
- Bending beam fatigue





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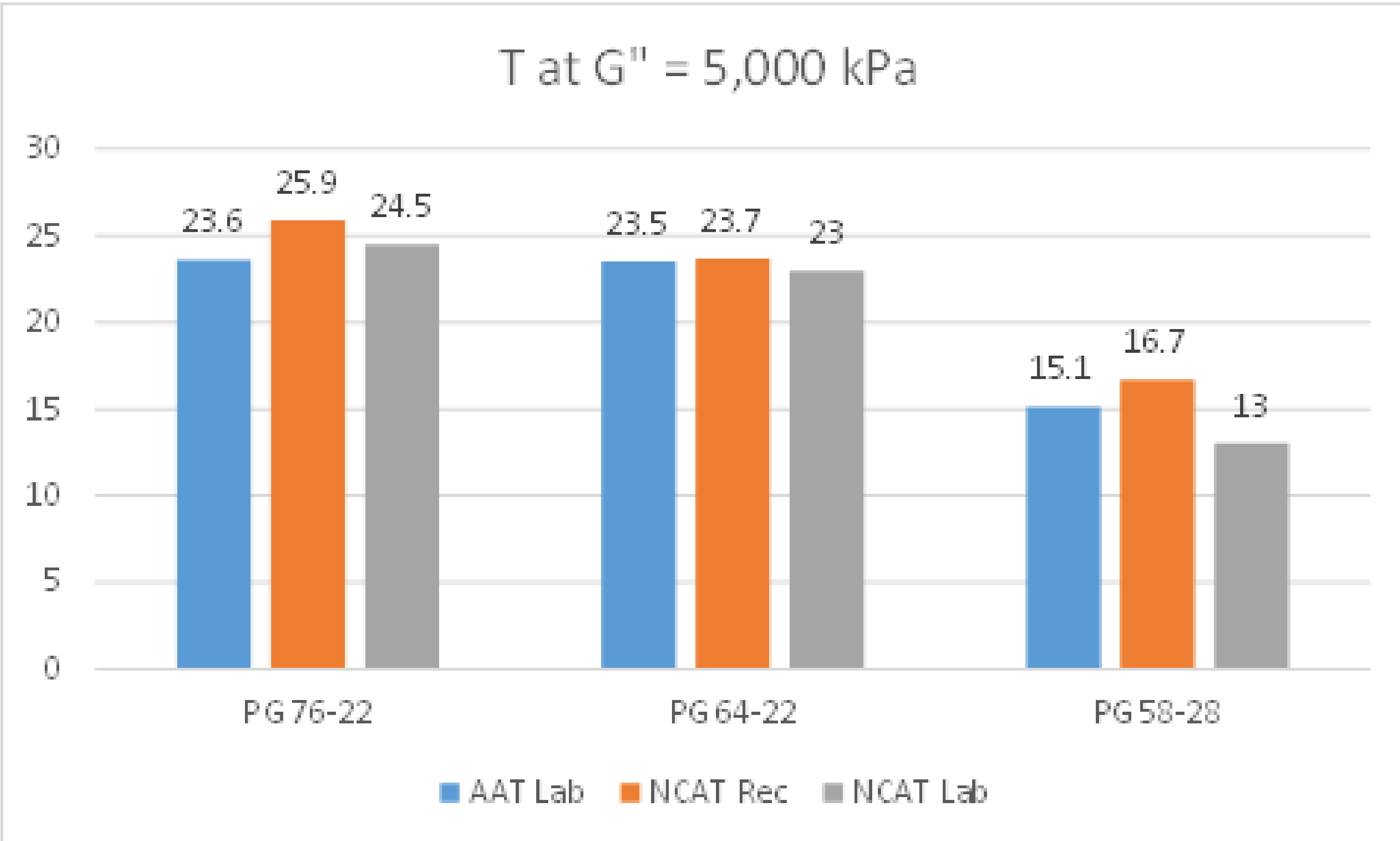
NCHRP 9-59: Laboratory Aging

- Binders: RTFOT + 40 hour PAV
- Mixture: Standard short term aging followed by loose mix aging at 95°C for 5 days.
- Based on data available at the start of the project, which was very limited

Comparison of Mix and Binder Laboratory Aging



Preliminary NCHRP 9-59 Results

Modified DENT Test Results

Binder	Temp	Stiff/3, Pa	Fail. Strain, %	Expected FS, %	FFPR
PG 76-22 SBS	15	1.07E+06	71	55	1.30
	20	2.40E+05	105	68	1.55
PG 64-22	15	1.26E+06	53	52	1.03
	20	6.23E+05	62	64	0.97
PG 58-28 REOB	15	6.07E+05	50	65	0.78
	10	1.05E+06	47	55	0.86

LAS Test Results

Binder	Temp	G*, Pa	Avg. FSC, %	Exp. FSC, %	FFPR
PG 76-22 SBS	20	2.28E+07	8.01	5.84	1.37
PG 64-22	20	1.70E+07	6.76	7.82	0.86
PG 58-28 REOB	20	1.80E+07	7.71	7.39	1.04

Uniaxial Fatigue Results

Binder	Temp	G*	Avg. FSC, %	Exp. FSC, %	Avg. FFPR
PG 76-22 SBS	15	4.49E+07	3.30	2.90	1.14
	21	2.28E+07	7.57	5.84	1.31
PG 64-22	12	5.49E+07	1.75	2.35	0.74
	18	3.01E+07	4.38	4.40	0.99
PG 58-28 REOB	6	4.19E+07	1.96	3.12	0.63
	12	2.38E+07	3.78	5.60	0.67

Texas Overlay Test Results

Binder	Temp	G*	Cycles	Avg. FSC, %	Exp. FSC, %	Avg. FFPR
PG 76-22 SBS	20	3.59E+06	102	44	29	1.51
PG 64-22	20	3.95E+06	24	29	27	1.07
PG 58-28 REOB	20	1.86E+06	32	28	43	0.65

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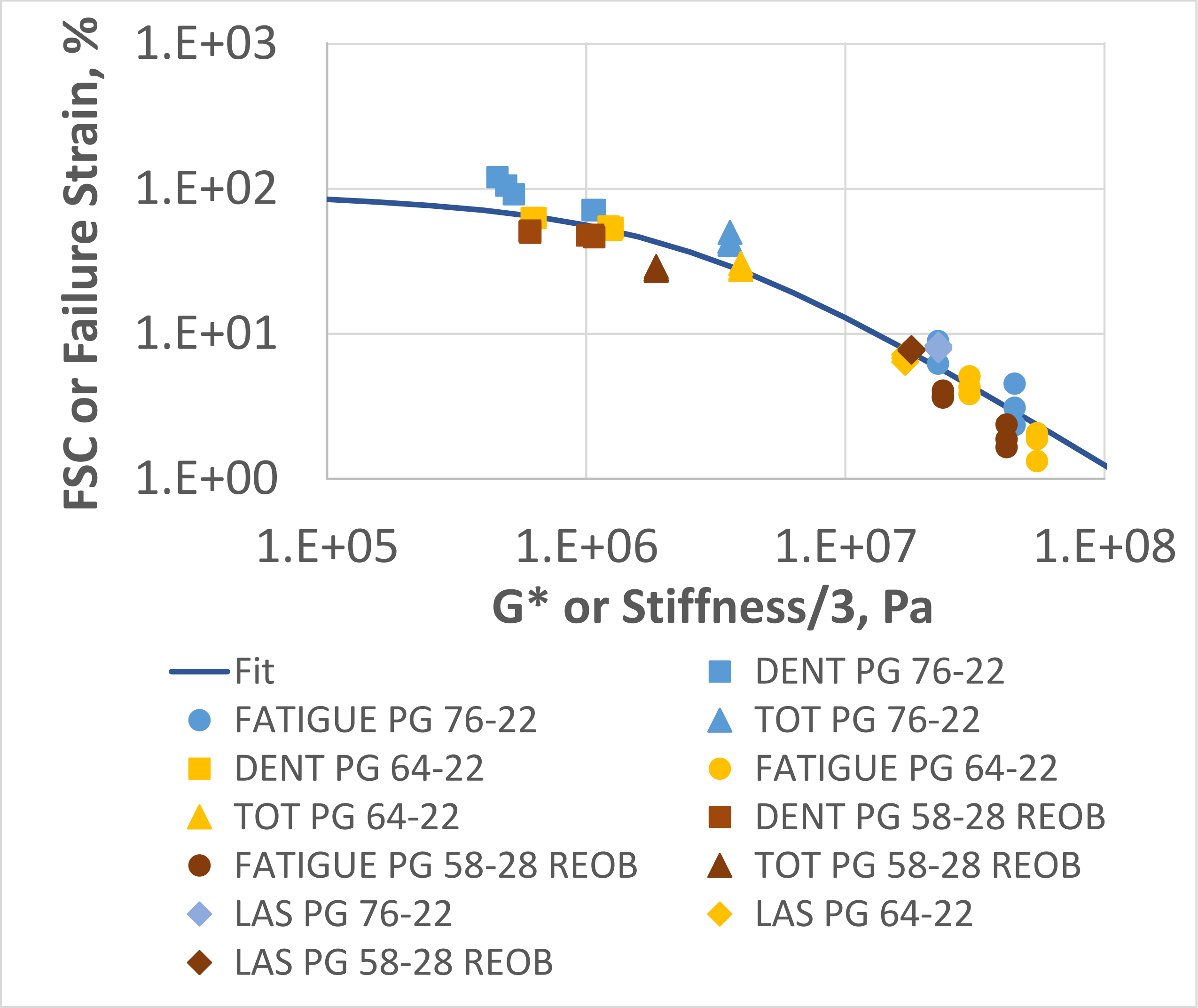
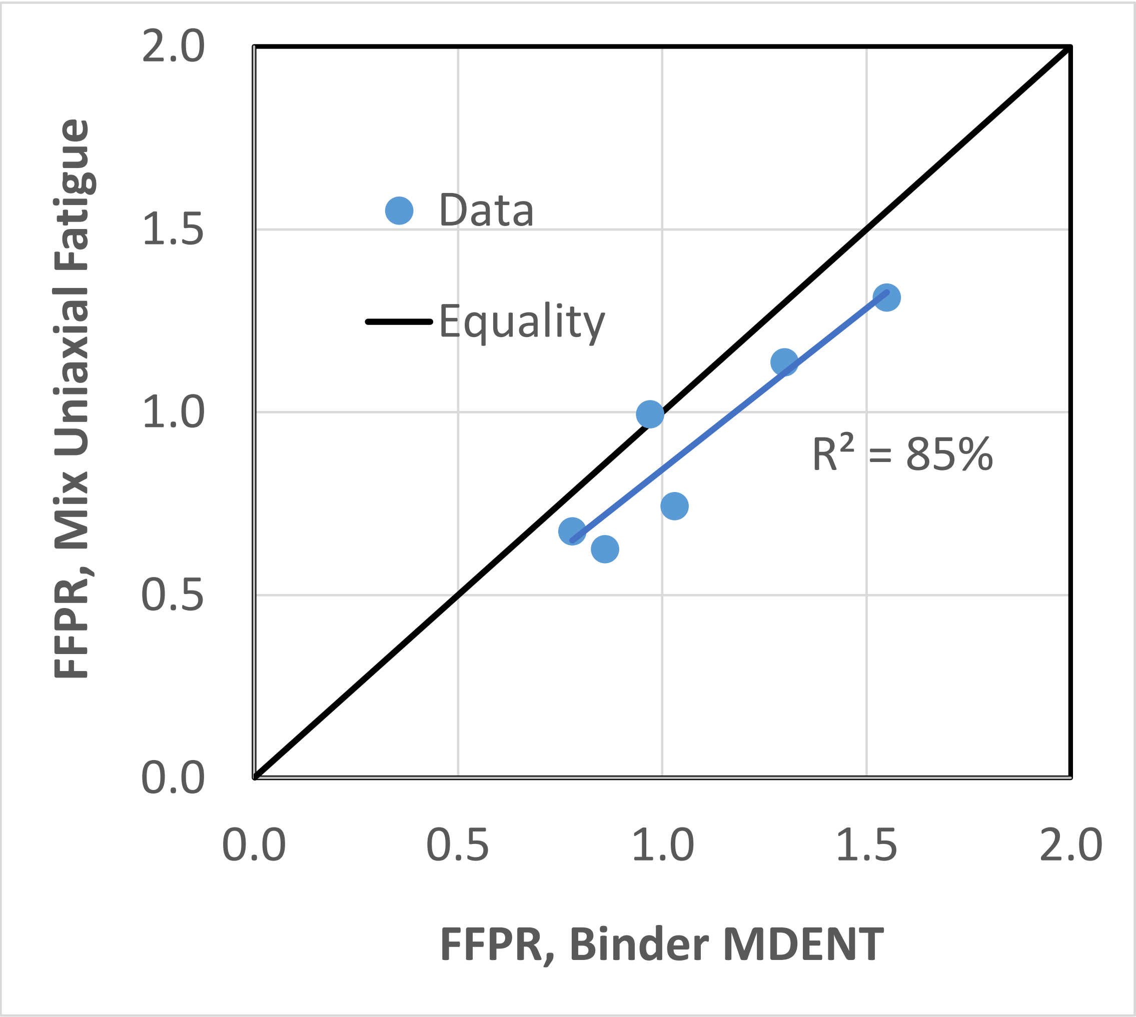
NCHRP 9-59 Data Compared to Typical Failure Envelope



Mix Uniaxial Fatigue vs Binder MDENT



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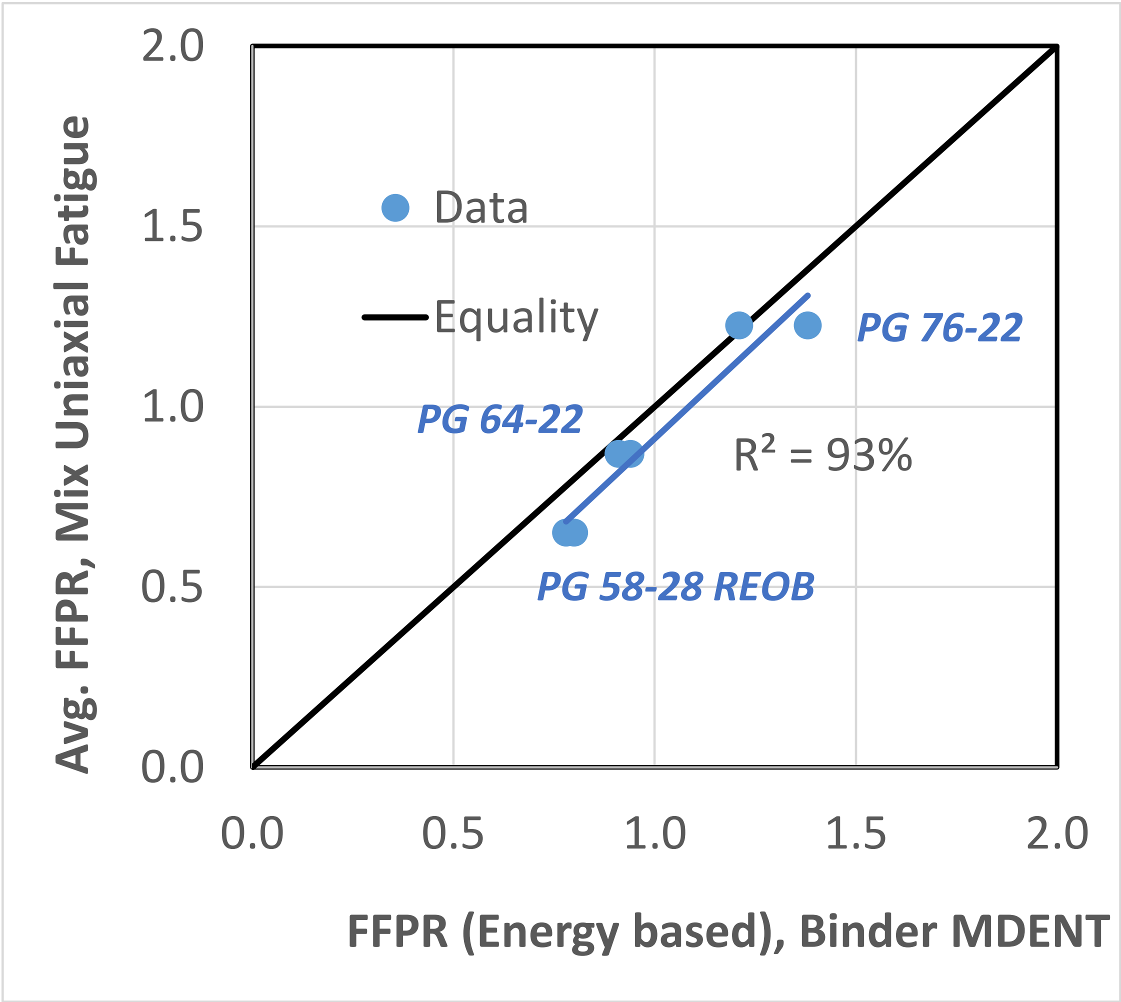
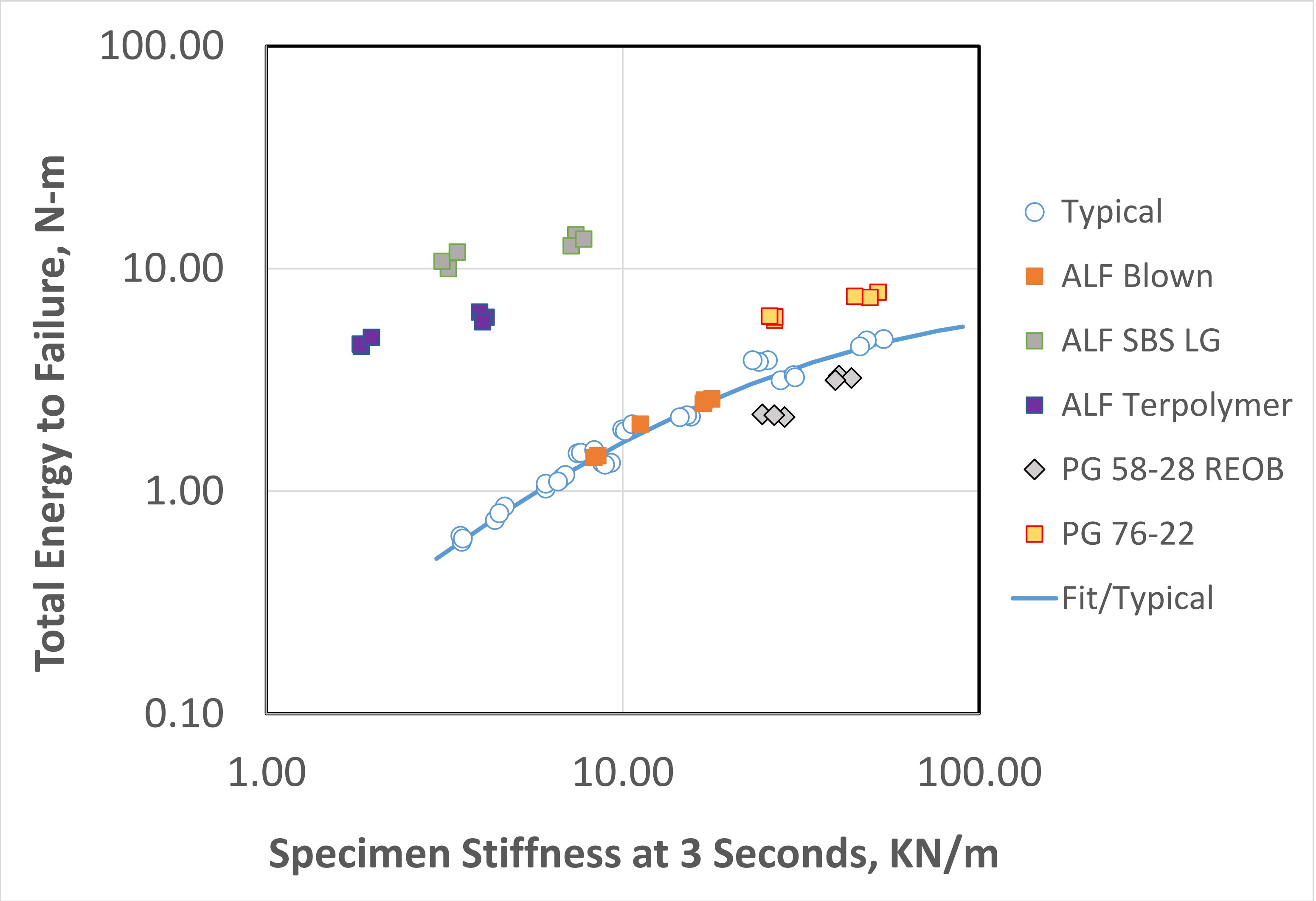
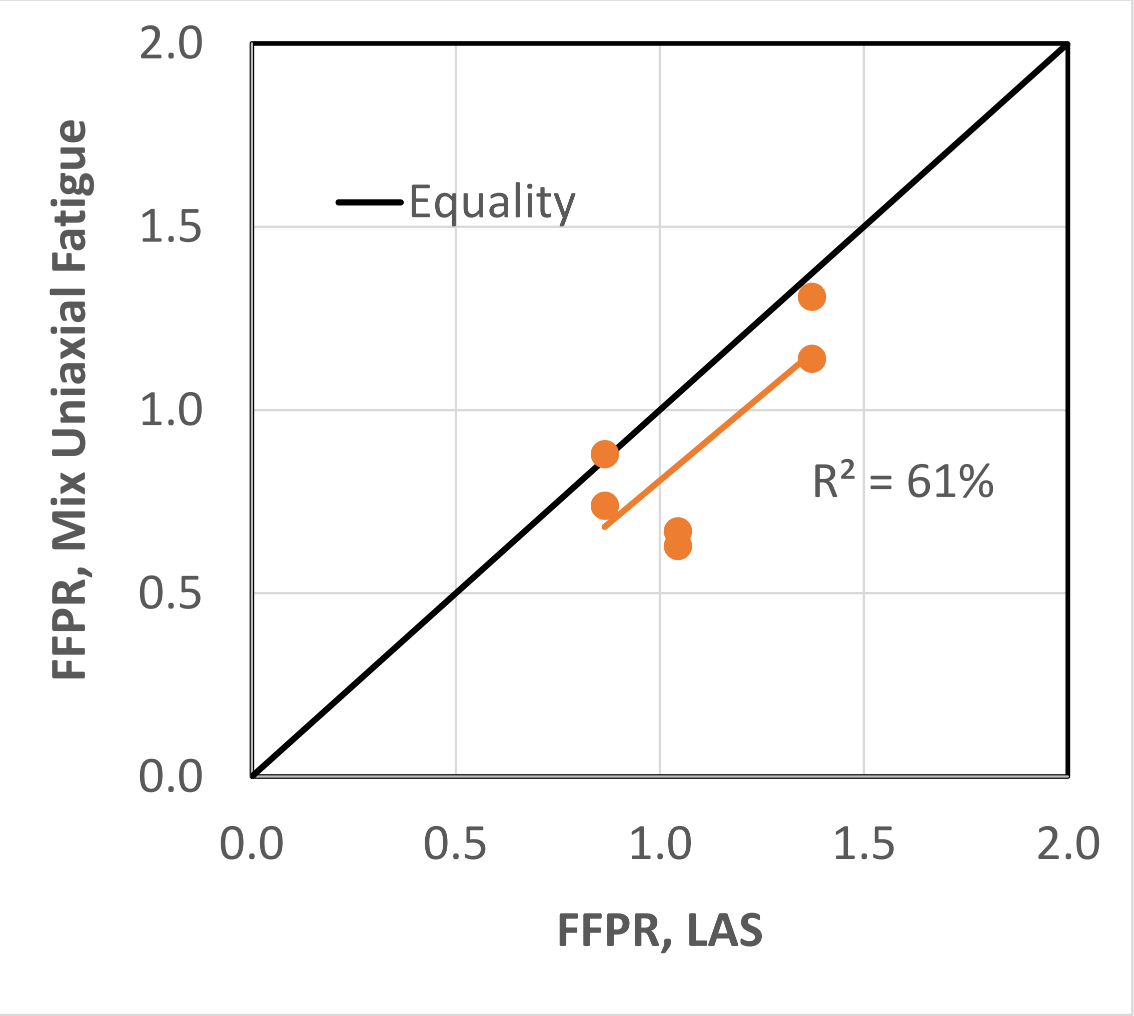
Using Average Mix FFPR and Energy-Based DENT FFPR



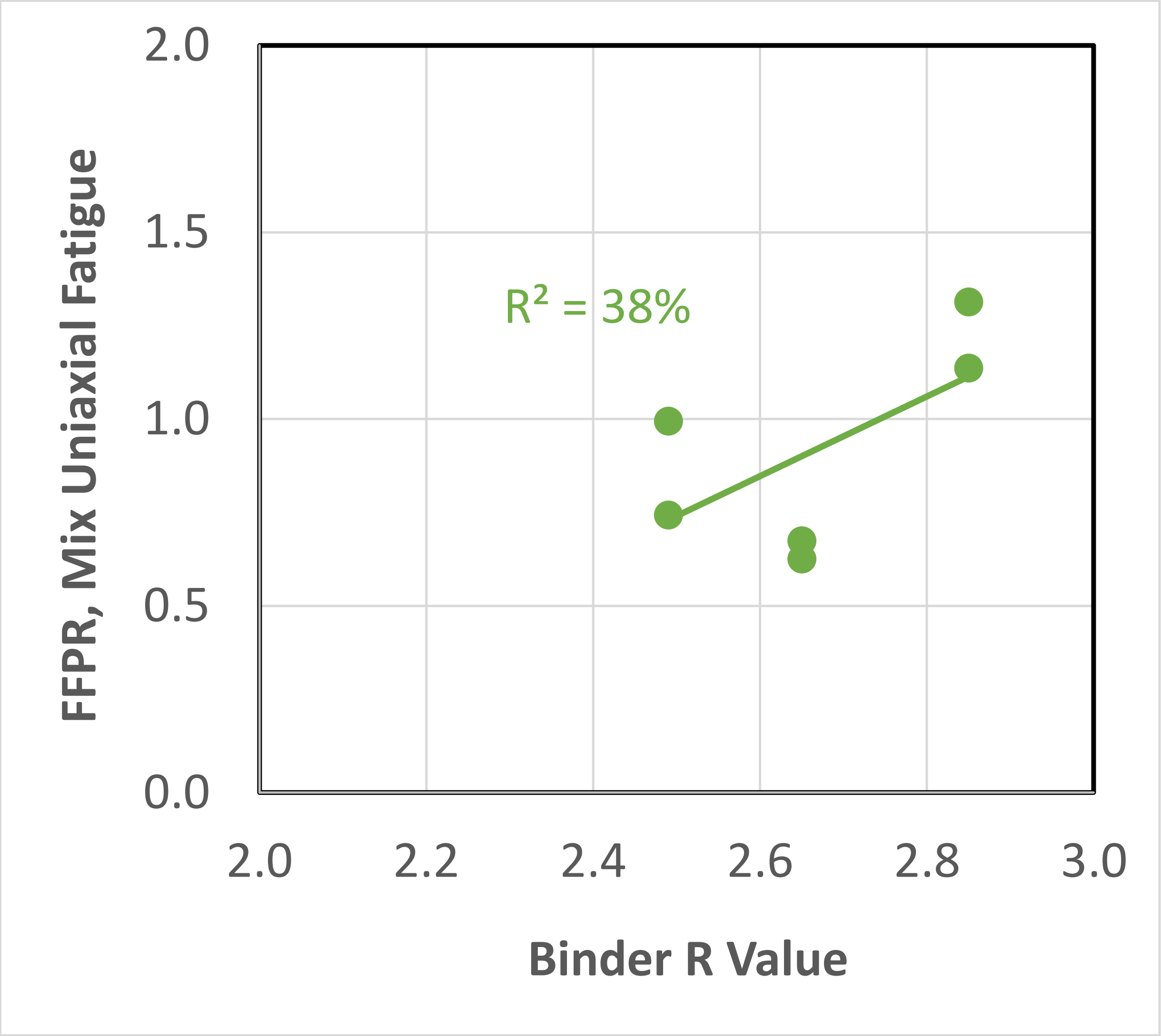
Energy-Based DENT FFPR



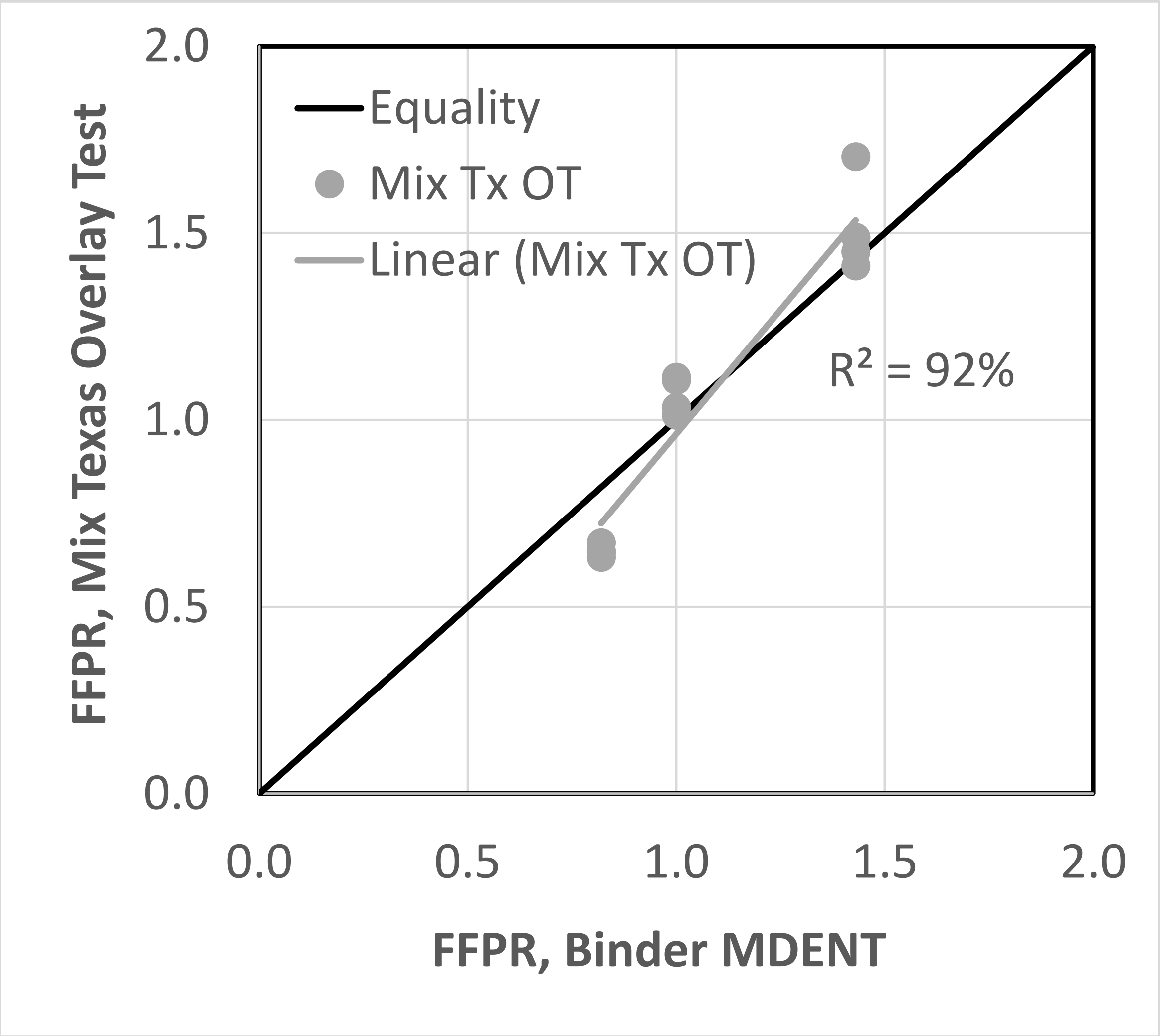
Mix Uniaxial Fatigue vs LAS



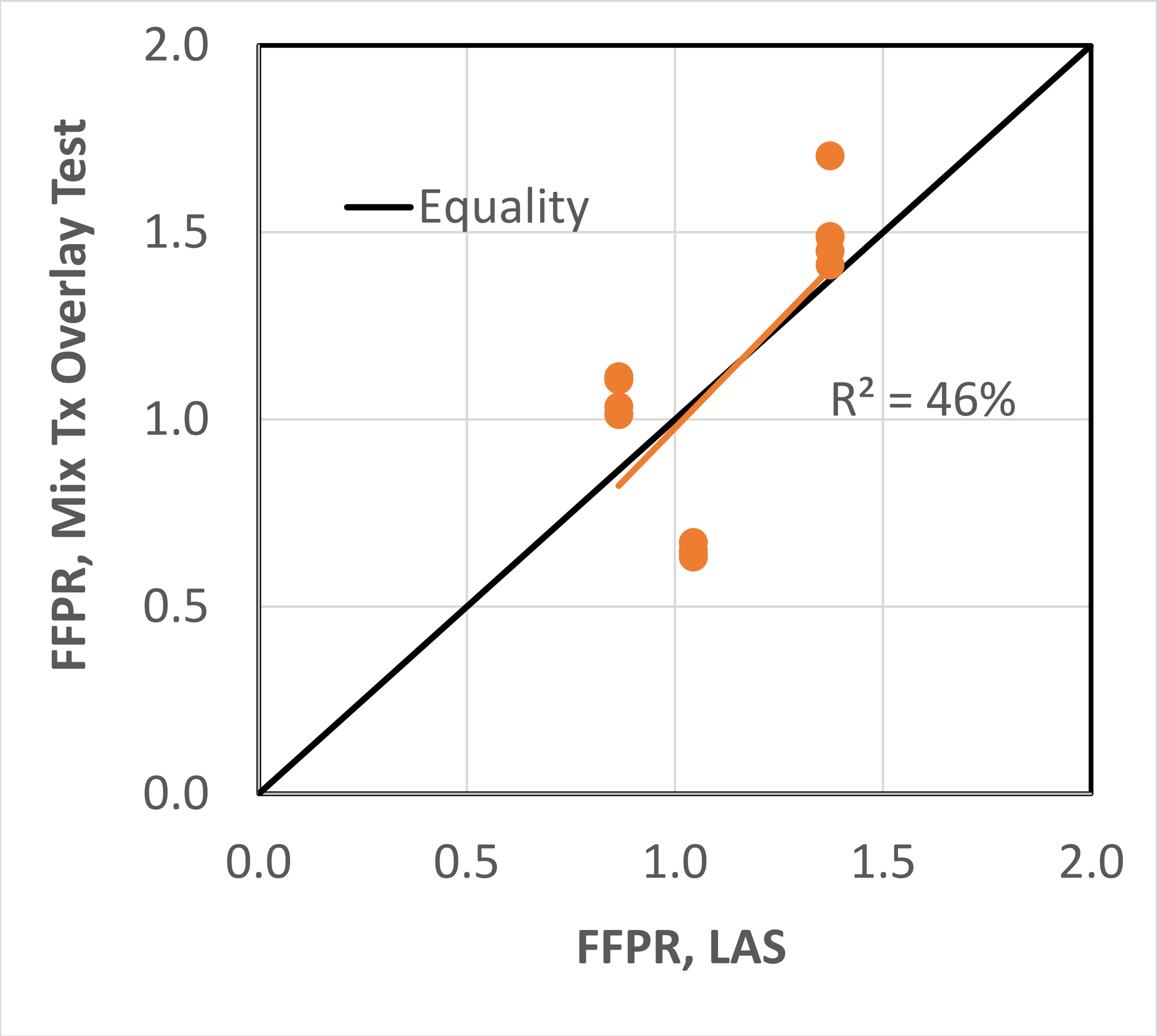
Mixture Uniaxial Fatigue vs R



Texas Overlay vs MDENT



Texas Overlay vs LAS



Interim Findings

- The proposed general failure theory and failure envelope appear to provide a powerful tool for evaluating the fatigue and fracture resistance of asphalt binders and mixes

Interim Findings

- The RTFOT + 40 hour PAV binder aging appears to produce a similar degree of aging as the 5 day loose mix aging at 95°C, but much more research is needed to verify and fine tune these aging protocols

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Interim Findings

- The modified DENT test correlates very well to both field fatigue performance in the FHWA ALF studies and in laboratory tests conducted in the first stage of NCHRP 9-59 testing.
- The LAS test is also promising…we may need to make adjustments

Future work

- Additional binder testing: 13 more binders and including SENB test
- Healing study
- Parametric study on relationship between modulus and fatigue performance
- Validation testing

Acknowledgements

- Those I have borrowed data from…
- Support of NCHRP
- The NCHRP Panel
- Industry suppliers
- Nam Tran and his associates at NCAT
- My associates at AAT, including Ray, Don, and Bob

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