Full-Scale Accelerated Performance Testing for Superpave & Structural Validation

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Outcomes - Ongoing Activities - Future APT Experiments

SEAUPG
Southeastern Asphalt User/Producer Group

Hilton Head Island, South Carolina
November 9-12, 2009

FHWA Turner-Fairbank Highway Research Center
Office of Infrastructure R&D
Nelson Gibson, nelson.gibson@dot.gov

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Background

- **Superpave Performance Grade Purchase Specification**

PG 64 17 -22

|G*| sinδ

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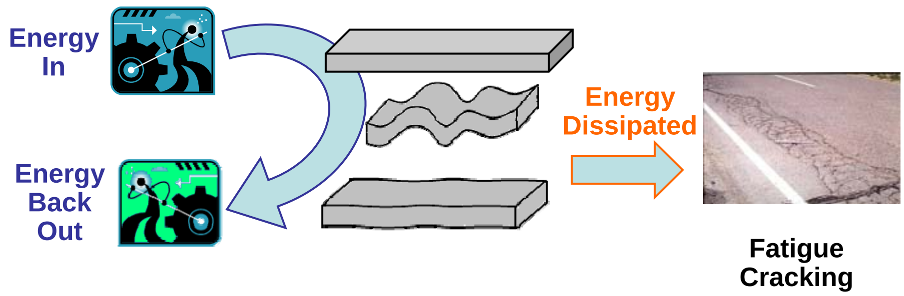
Background



How good is this?

Value to the community?

|G*| sinδ

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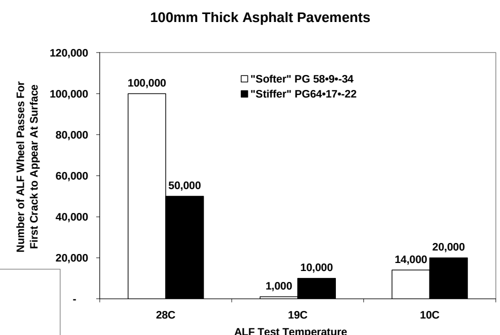
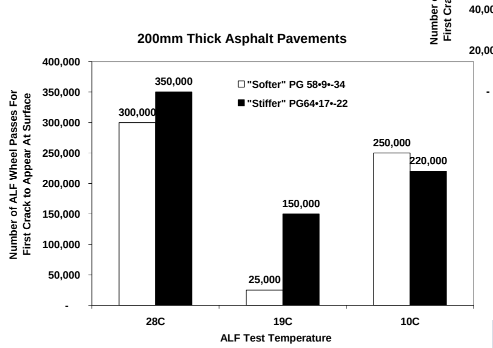
Post-SHRP 1993 FHWA ALF

Better fatigue performance at cooler and warmer





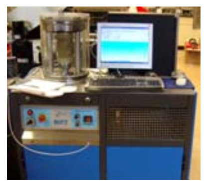
Stiffer binder performed better at intermediate temperature

Not intent of specification

OBJECTIVES for *Full-Scale Accelerated Performance Testing for Superpave & Structural Validation*

- **Recommendations that provide AASHTO with a binder purchase specification that is "blind" to the type of modification.**

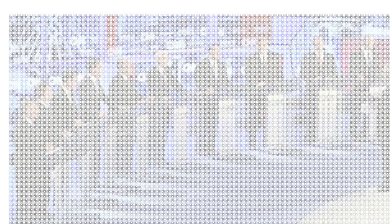
Secondary Objectives

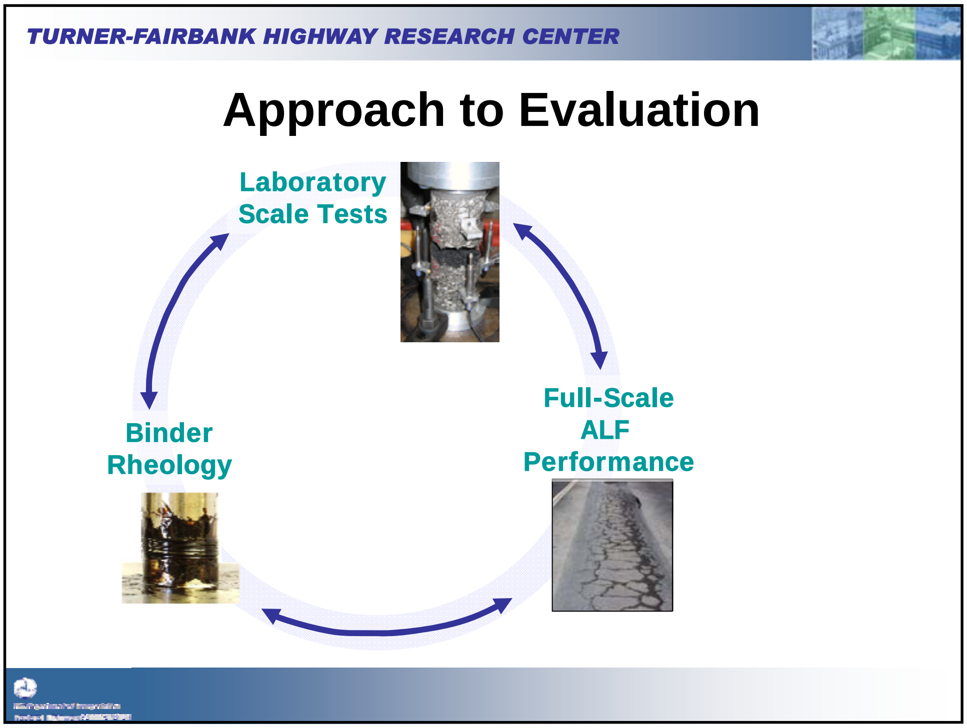


Candidate Binder Parameters

- **Stiffness Reduction**
  - **Time Sweep**

  - **Stress Sweep**
  - **Large Strain Time Sweep Surrogate**
- **Strength**
  - **Binder Yield Energy**
- **Fracture**
  - **CTOD**
    Critical Tip Opening Displacement

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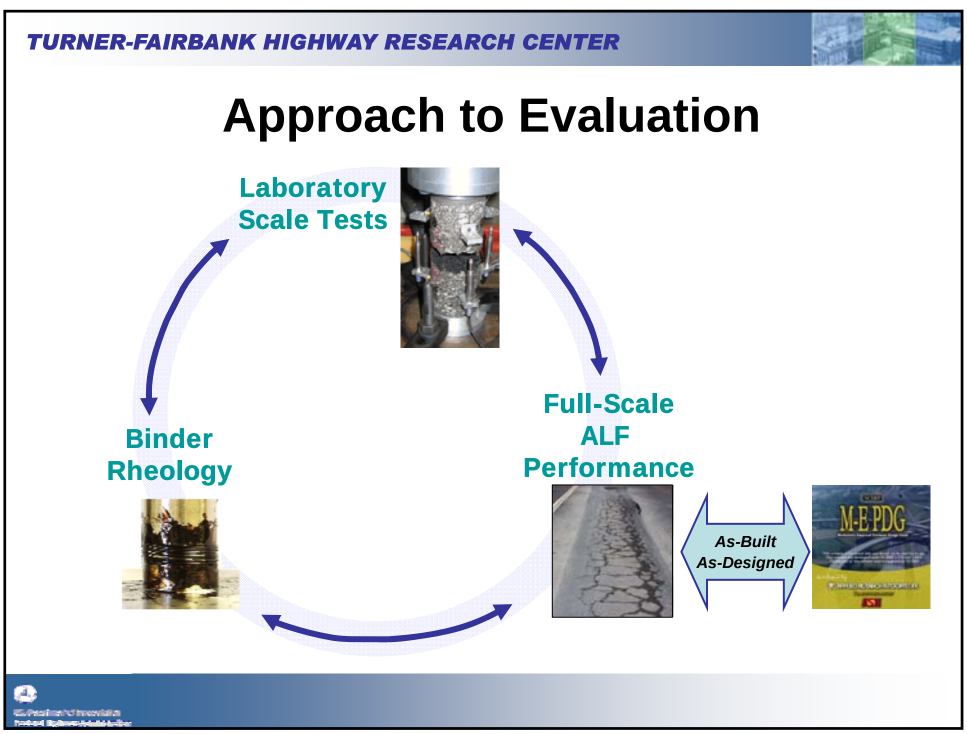
Approach to Evaluation
Laboratory Scale Tests
Full-Scale ALF Performance
Binder Rheology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Approach to Evaluation
Laboratory Scale Tests
Full-Scale ALF Performance
Binder Rheology
As-Built
As-Designed
M-E PDG

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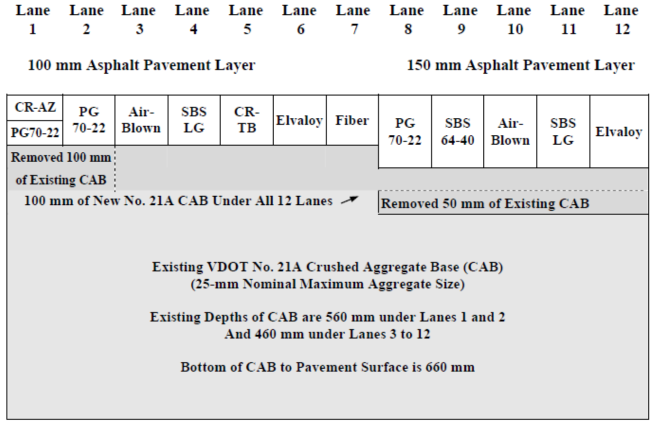

PG 70-22	=	Unmodified Asphalt Binder Control
CR-AZ	=	Crumb Rubber Asphalt Binder, Arizona DOT Wet Process
CR-TB	=	Crumb Rubber Asphalt Binder, Terminal Blend
Elvaloy	=	Ethylene Terpolymer Modified Asphalt Binder
SBS LG	=	Styrene-Butadiene-Styrene Modified Asphalt Binder with Linear Grafting
SBS 64-40	=	Styrene-Butadiene-Styrene Modified Asphalt Binder Graded to be a PG 64-40
Air-Blown	=	Air-Blown Asphalt Binder
Fiber	=	Unmodified PG 70-22 Asphalt Binder with 0.2 Percent Polyester Fiber by Mass of the Aggregate.

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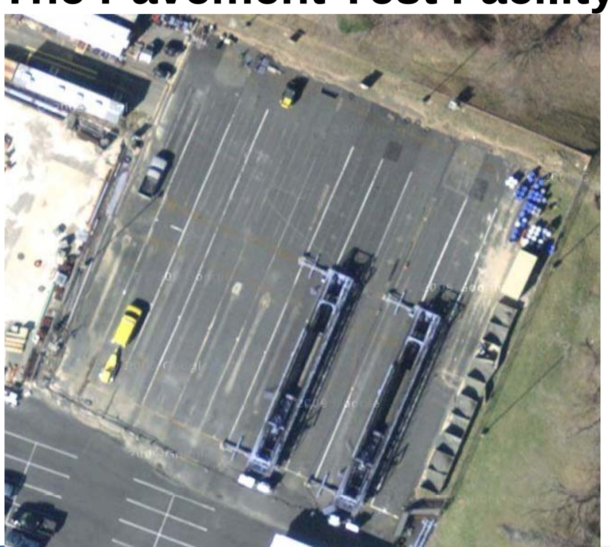
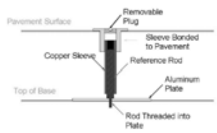
Binder Description	Control 70-22		Control 70-22		Control 70-22		Air Blown		Terpolymer		SBS-LG		SBS 64-40		CR-TB	
PTF Test Lane	1 (Bottom)		2		7	8	3	10	6	12	4	11	9		5	
Asphalt Thickness (mm)	50		100		100	150	100	150	100	150	100	150	150		100	
Performance Grade (PG)	70	-22	70	-22	70	-22	70	-28	70	-28	70	-28	70	-34	76	-28
Continuous Performance Grade	72	-23	72	-23	72	-23	74	-28	74	-31	74	-28	71	-38	79	-28
T(°C) when MVR(orig)=50@1.225kg	73.5		74.6		72.6		74.8		81.2		77.2		77		80.6	
T(°C) when |G*|/sinδ (ORIG) = 1kPa	73.2		72.8		72.1		75.5		78		75.1		71.7		79.5	
T(°C) when |G*|/sinδ (RTFOT) = 2.2kPa	72.3		72.9		73.2		74.1		74.5		74.4		71.8		81.4	
T(°C) when |G*|xsinδ **(PAV)** = 5MPa	26.7		25.4		26.1		22.6		14.3		17.7		8.6		17.9	
T(°C) when S(60) (PAV) = 300MPa	-13.5		-13.8		-13.5		-18.9		-21.3		-22.7		-28.5		-22.9	
T(°C) when m(60) (PAV) = 0.3	-13.3		-13.8		-13		-18.3		-24.1		-19.3		-29.5		-17.6	
Cracking T (°C) using BBR + DT	-20.3		-23.5		-21.8		-26.8		-33.1		-35.2		-41		-31.6	
Cracking T (°C) using BBR alone	-21.3		-22.2		-22.9		-27.1		-31.1		-33.7		-36		-32.9	

Binder Description	Control 70-22		Control 70-22		Control 70-22		Air Blown		Terpolymer		SBS-LG		SBS 64-40		CR-TB	
PTF Test Lane	1 (Bottom)		2		7	8	3	10	6	12	4	11	9		5	
Asphalt Thickness (mm)	50		100		100	150	100	150	100	150	100	150	150		100	
Performance Grade (PG)	70	-22	70	-22	70	-22	70	-28	70	-28	70	-28	70	-34	76	-28
T(°C) when |G*|xsinδ **(PAV)** = 5MPa	26.7		25.4		26.1		22.6		14.3		17.7		8.6		17.9	

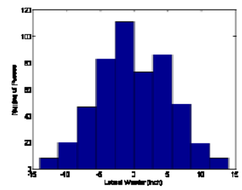
The Pavement Test Facility



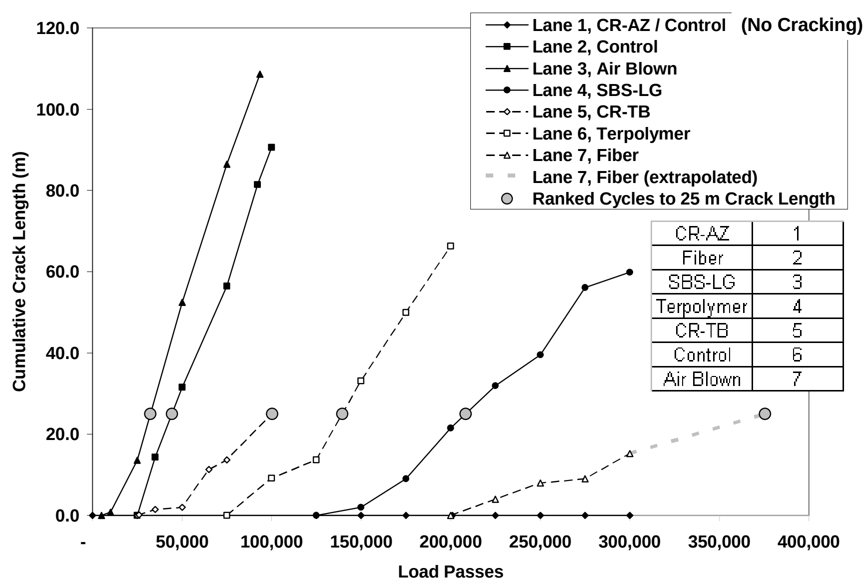
Loading Conditions



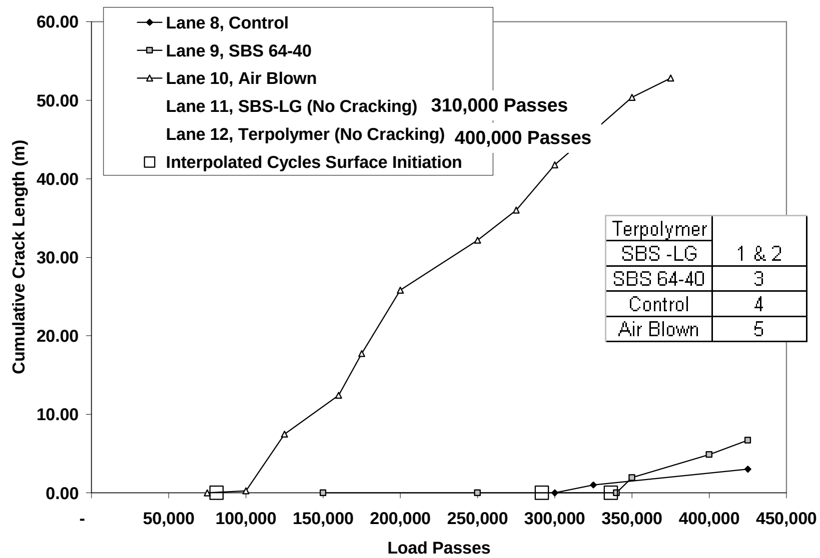
64°C (147°F)
100 psi Inflation
10,000 pounds
No Wander



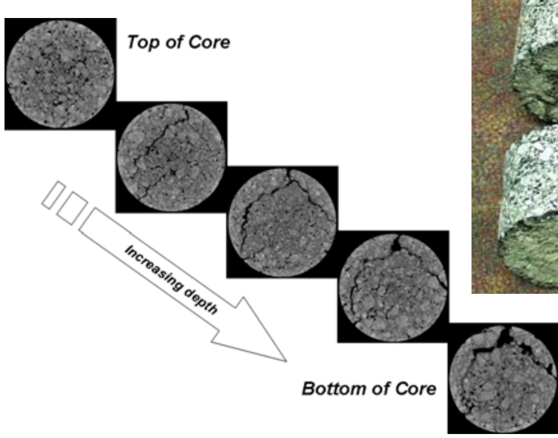
19°C (66°F)
120 psi Inflation
16,000 pounds
Wheel Wander



CR-AZ	1
Fiber	2
SBS-LG	3
Terpolymer	4
CR-TB	5
Control	6
Air Blown	7

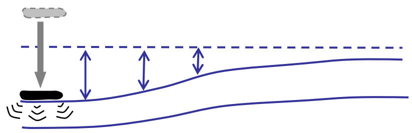


Confirmation of Bottom Up Cracking



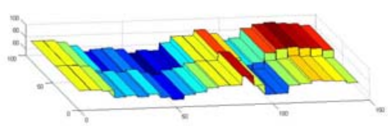
As-Built Consistency

Falling Weight Deflectometer

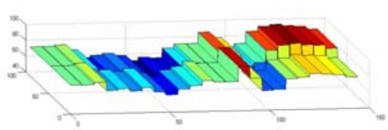


As-Built Consistency

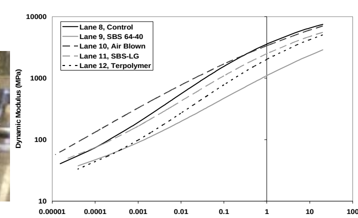
Crushed Aggregate Base Stiffness



A-4 Subgrade Stiffness



HMA Stiffness |E*|



Laboratory Scale Fatigue Performance

Then…

…Now

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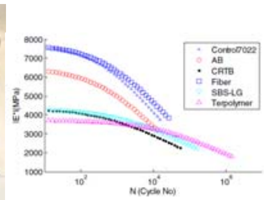
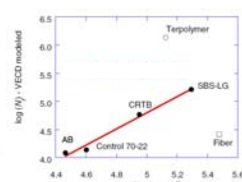
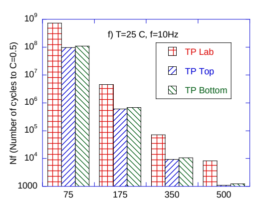
Laboratory Scale Fatigue Performance

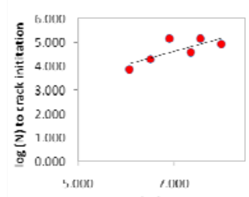
Lab Fabricated





Field Compacted





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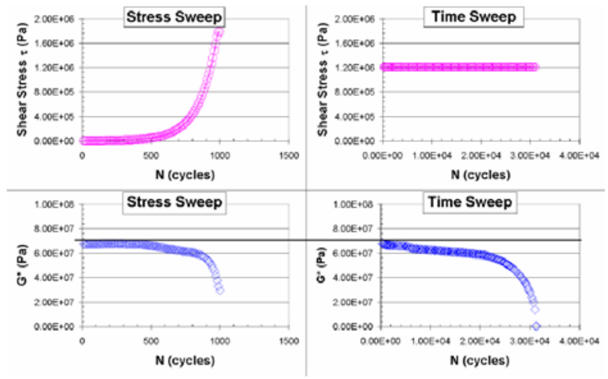
Time Sweep and Stress Sweep

Martono, W. and H. Bahia, "Developing a Surrogate Test for Fatigue of Asphalt Binders," TRB 87th Annual Meeting Compendium of Papers DVD (2008)



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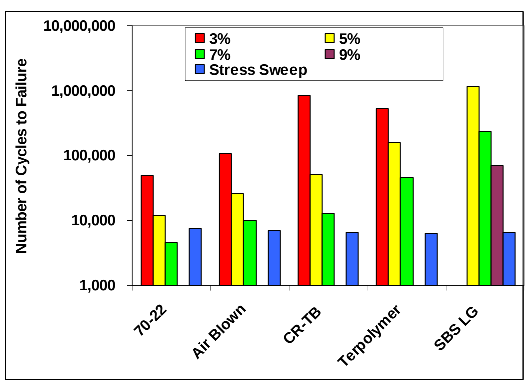

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Large Strain Time Sweep Surrogate

Shenoy, A., (July 2002) "Fatigue Testing and Evaluation of Asphalt Binders Using the Dynamic Shear Rheometer," *ASTM Journal of Testing and Evaluation*, Vol. 30, No. 4, pp 303-312

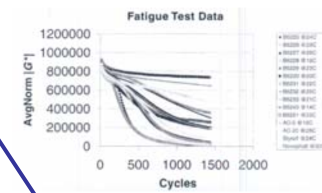
T=15°C γ = 0.1% → γ = 80%

T=20°C γ = 0.1% → γ = 80%

T=25°C γ = 0.1% → γ = 80%

T=30°C γ = 0.1% → γ = 80%

T °C where γ = 25% & |G*| = 1 MPa



X62 larger than PG

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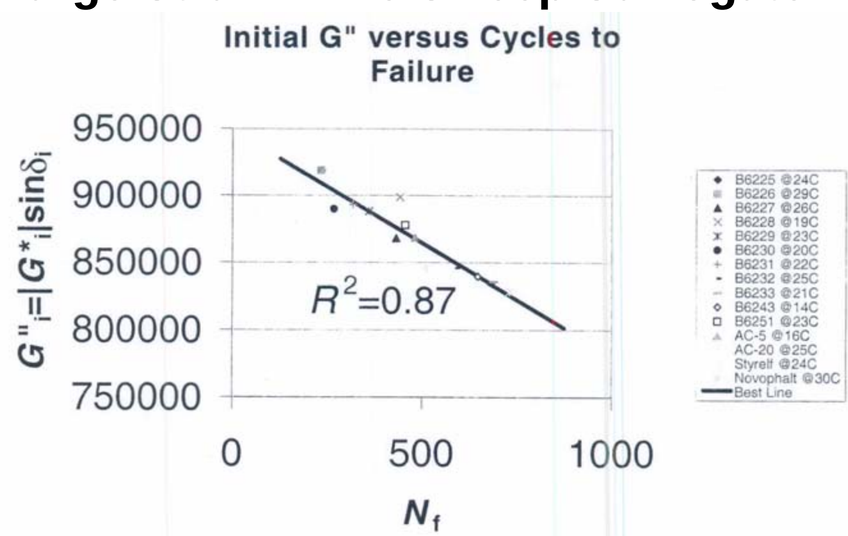
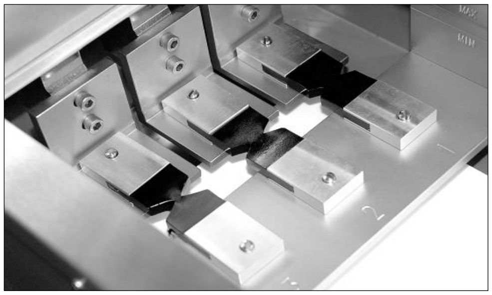
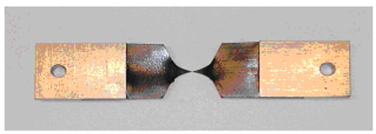
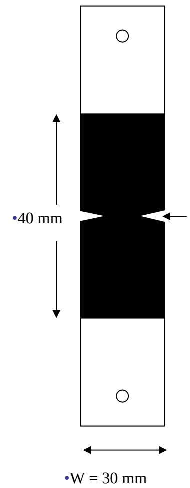
Large Strain Time Sweep Surrogate



Critical Tip Opening Displacement



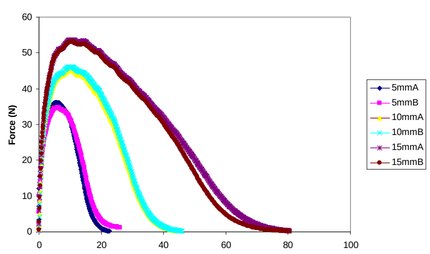


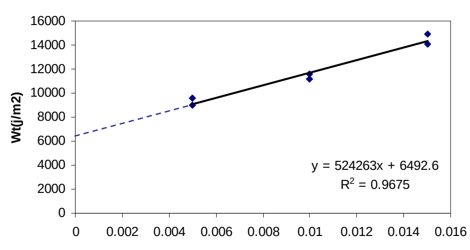


Critical Tip Opening Displacement

- **CTOD is a measure of strain tolerance in the presence of a crack**

Ontario **MTO Test Method LS-299**





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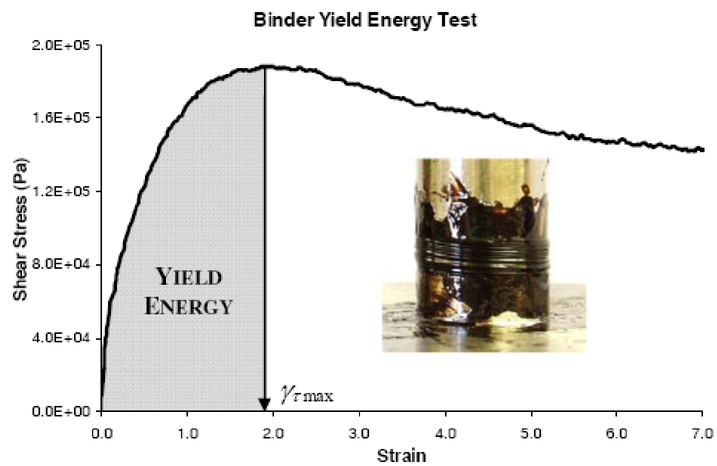
Binder Yield Energy Test



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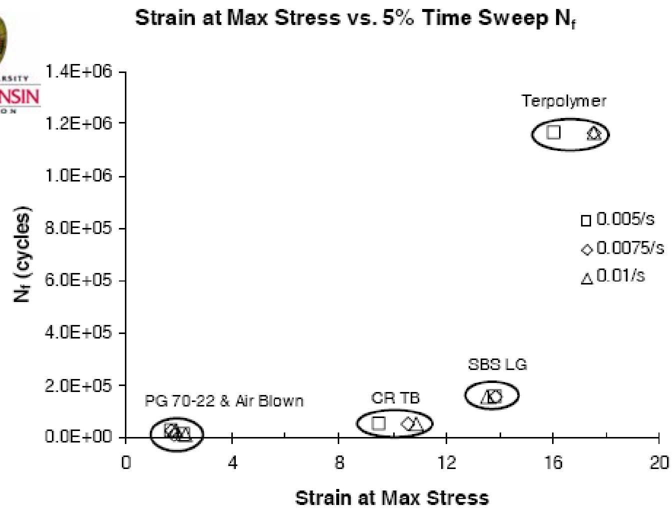
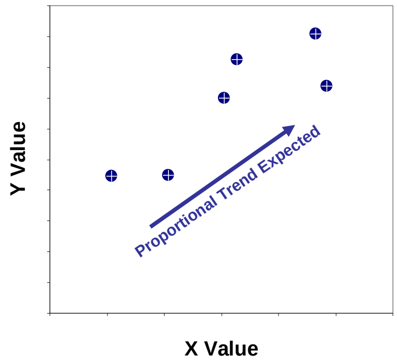
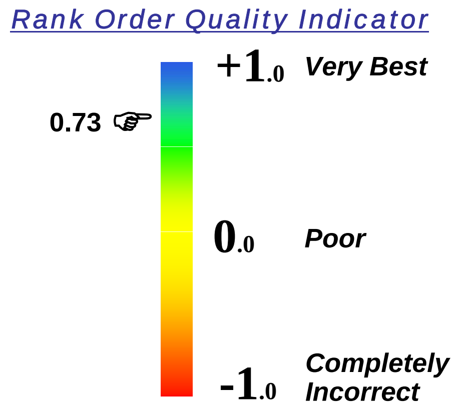
Binder Yield Energy Test



How will Binder Parameter Candidates be Compared to Each Other?





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Binder Parameter	Rank Order Quality Indicator	
	Lab-Scale Fatigue Ranking	Full-Scale ALF Cracking
Superpave	-0.8 ↘	-0.6 ↘
Time Sweep	+0.6 ↗	+0.8 ↗
Stress Sweep	-0.6 ↗ ✗	-0.4 ↗ ✗
Large-Scale Time Sweep Surrogate	-0.6 ↘	-0.4 ↘
CTOD	+0.8 ↗	+1.0 ↗
BYET	+1.0 ↗	+0.8 ↗

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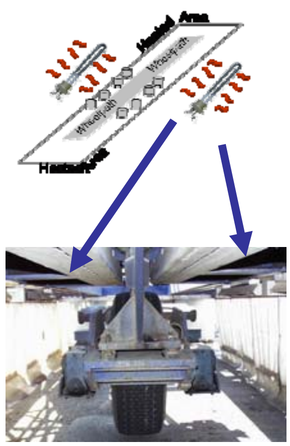
Ongoing: Accelerated Aging



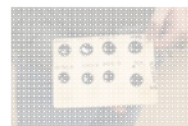
- **Objective: Double (X2) the number of data points**

Full Scale Fatigue Cracking

"UN-AGED"
CR-TB Air Blown
Control Terpolymer
SBS 64-40 SBS-LG

"AGED"
CR-TB Air Blown
Control Terpolymer
SBS 64-40 SBS-LG

Binder Parameters



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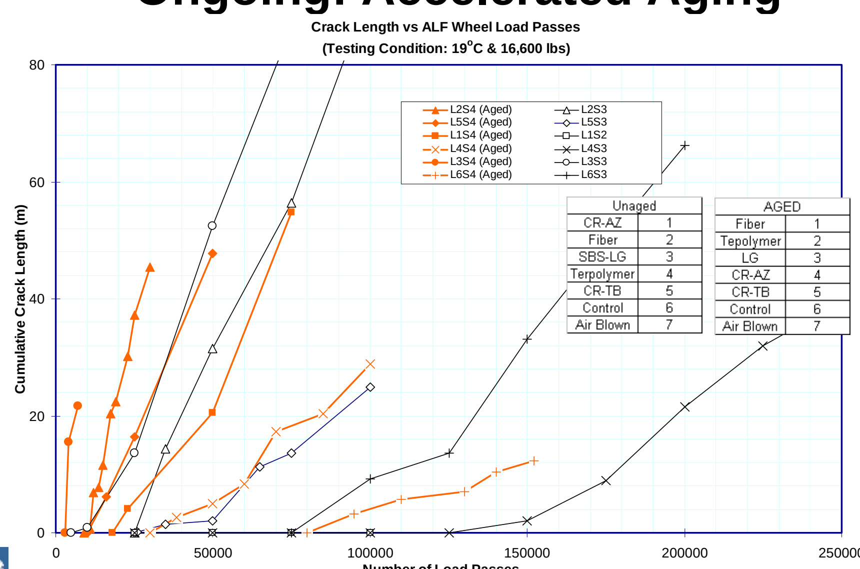
Ongoing: Accelerated Aging



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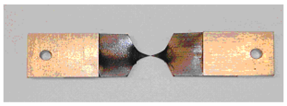
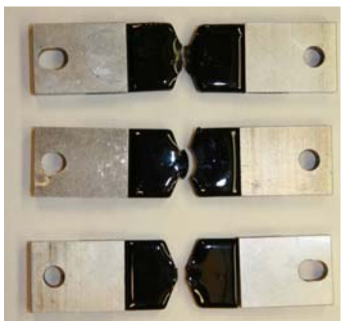
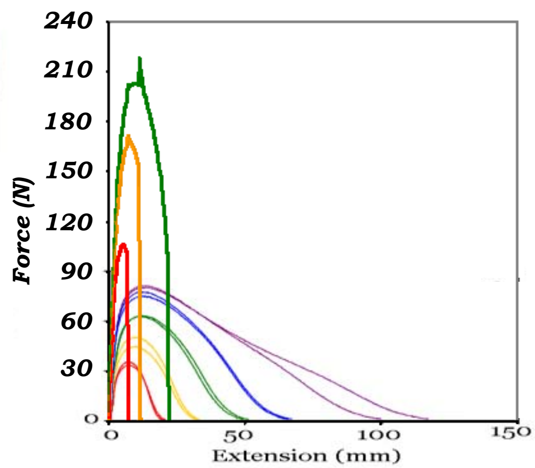
Ongoing: Accelerated Aging

PAV Aged ~ Ductile



Recovered ~ Brittle





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Research where full-scale accelerated performance testing provides a role

Your Input ______________________________

RANK ______________________________

- ___ More structure oriented experiments and less binder-oriented experiments
- ___ Shorter turn-around time; less ambitious
- ___ Fatigue performance of High RAP HMA and HMA Overlays
- ___ Cracking and durability of Ultrathin HMA overlays as pavement preservation
- ___ Thinner & Cheaper Perpetual Pavements with Premium HMA
- ___ Cost effectiveness of high-modulus high-binder HMA base

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	Thumbs Up	Thumbs Down	#1 Rank	#2 Rank	#3 Rank	#4 Rank	#5 Rank	#6 Rank	Average Score
More structure oriented experiments and less binder-oriented experiments	3	-4	0	2	3	3	2	5	4.3
Shorter turn-around time; less ambitious	2	-2	0	1	3	1	5	5	4.7
Cracking and durability of Ultrathin HMA overlays as pavement preservation	4	-3	4	3	2	2	3	2	3.2
Fatigue performance of High RAP HMA and HMA Overlays	6	0	5	7	1	3	1	0	2.3
Thinner & Cheaper Perpetual Pavements with Premium HMA	5	-2	6	3	5	2	1	0	2.4
Cost effectiveness of high-modulus high-binder HMA base	2	-3	2	1	2	4	3	3	3.9

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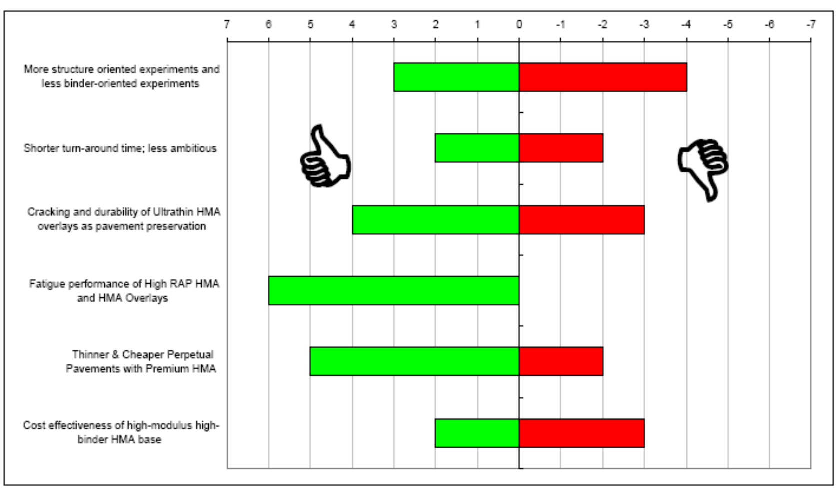

Conclusions

- Similarly PG graded materials exhibit different fatigue cracking performance
- MEPDG evaluated construction variation and it is small
- Composite structure with wet process crumb rubber has the ability to arrest or slow propagating cracks
- Fibers are very effective in reducing fatigue cracking
- Aging has significant influence on ranked order of performance

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Conclusions

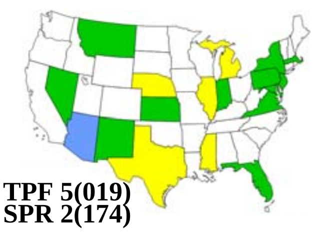
- There are better properties than |G*|sinδ
  - CTOD and BYET appear to be among the most promising
  - ONGOING: 32 Binders From LTPP Test Sections

The University of Wisconsin Madison | Asphalt Research Consortium | Western Research Institute

- Binder tests cannot easily provide insight for structural effects (100 mm vs. 150 mm thick), fiber modified mixtures and composite pavements with CR-AZ
  - Stresses the importance of testing mix
  - Simplified fatigue testing in AMPT is of high value

Acknowledgements

State DOT & Industry



- Citgo
- Dow
- Dupont
- Koch
- Paramount
- TexPar
- Trifinery, GCA
- Trumbull
- Wright Asphalt
- Martin Color Fi

- Bit Mat
- Mathy Construction
- Hot Mix Industries
- FNF Construction
- Consulpav
- Rubber Producers Assoc.
- ISS
- RTG
- NAPA

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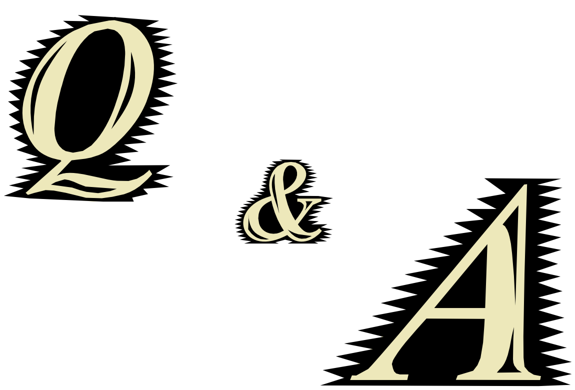
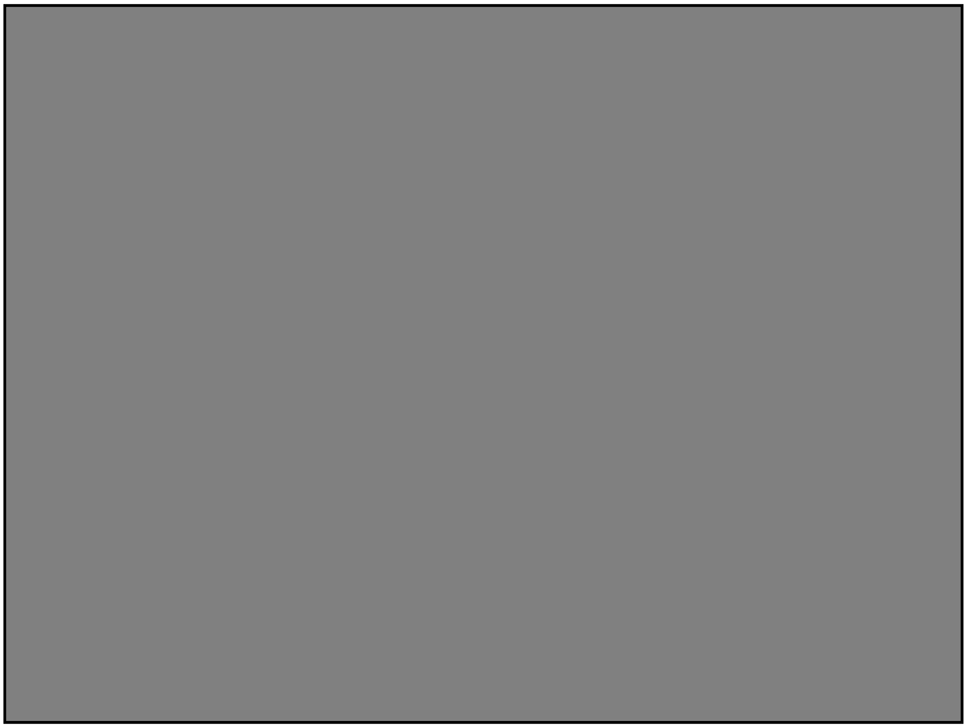


Nelson.Gibson@dot.gov



Database Application (portable) has been developed

250-page Detailed Report

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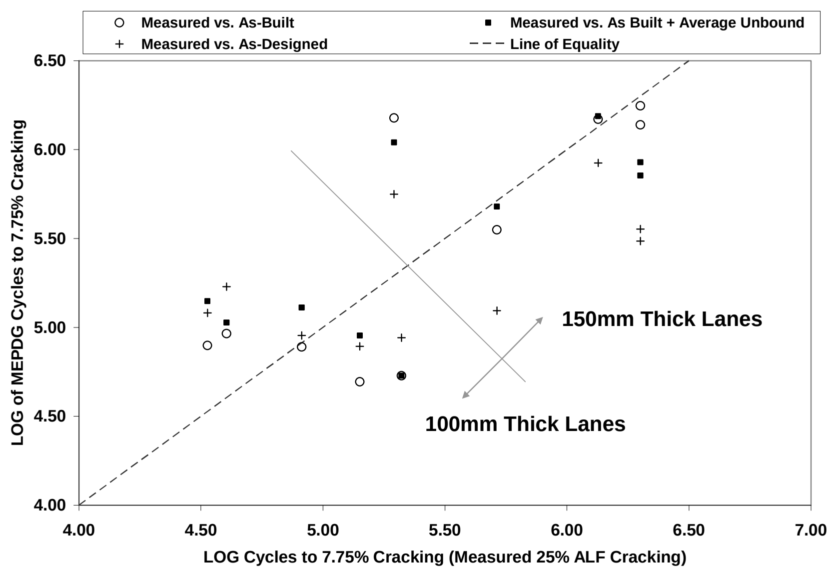

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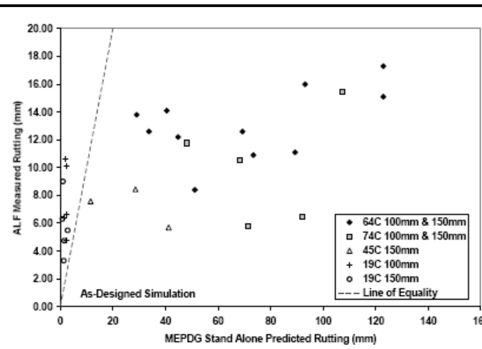
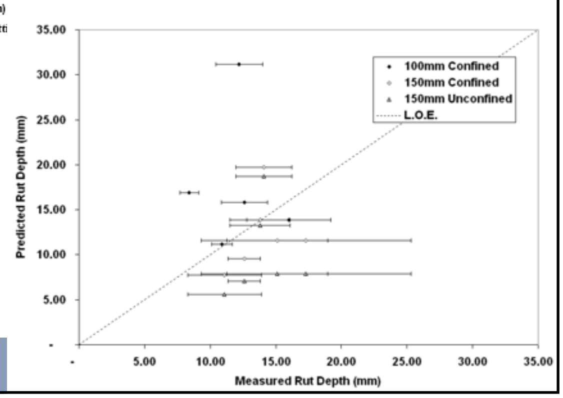


Figure 67. Measured and As-Designed predicted rutti



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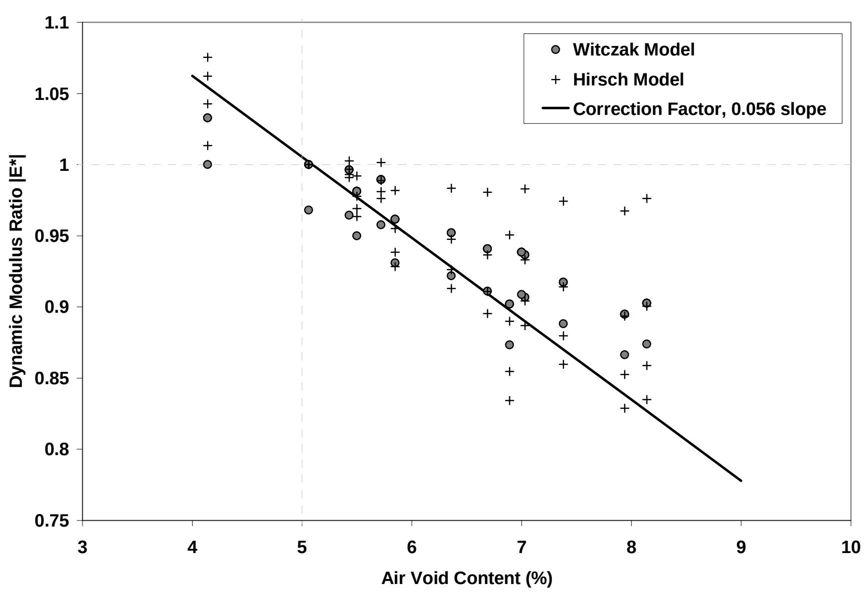

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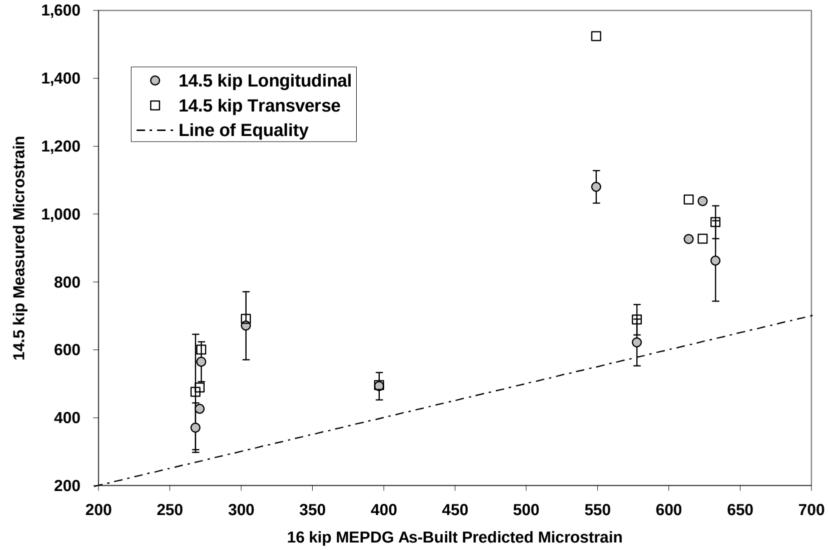

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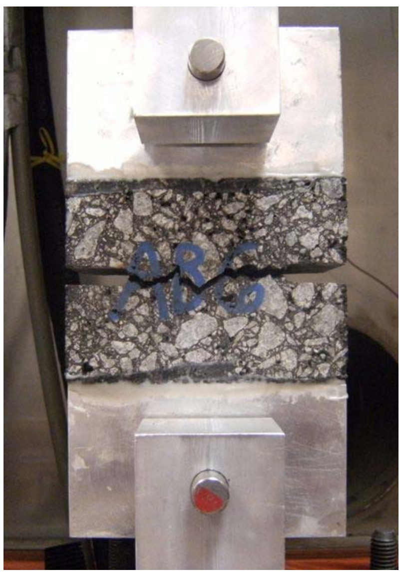
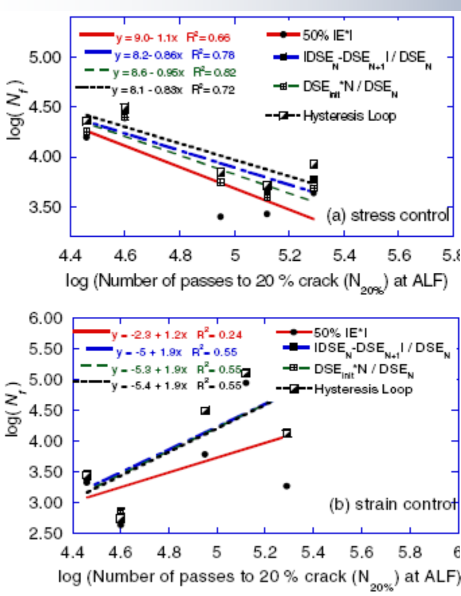
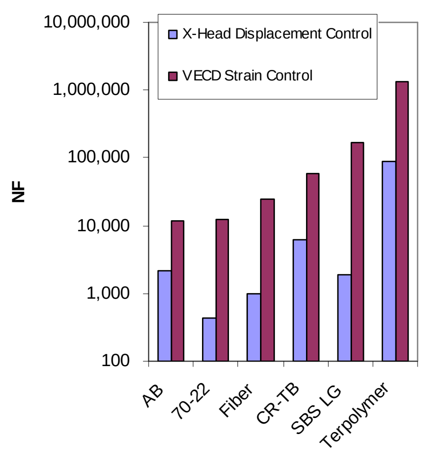


Binder Yield Energy Test

Johnson, C.M., H. Bahia and H. Wen, "Practical Application of Viscoelastic Continuum Damage Theory to Asphalt Binder Fatigue Characterization," *Asphalt Paving Technology*, Journal of the Association of Asphalt Paving Technologists (forthcoming).

"…based on the idea that [in HMA mixtures] there is an energy threshold where a material's resistance to deformation and resistance to damage are both overcome, leading to the propagation of cracking."





Summary

Binder Parameter	Regression Significance (1 - p•value)	
	Lab-Scale Fatigue Ranking	Full-Scale ALF Cracking
Superpave	67%	79%
Time Sweep	37%	98%
Stress Sweep	67%	86%
Large-Scale Time Sweep Surrogate	66%	80%
CTOD	43%	99%
BYET	72%	92%

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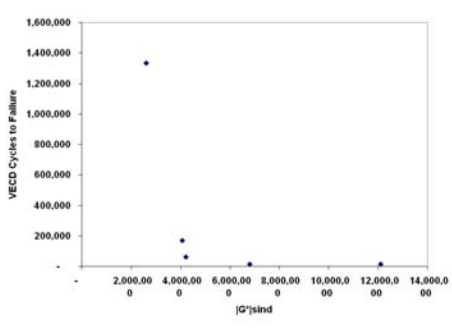
Summary

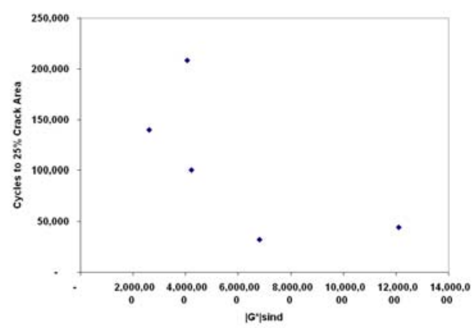
Binder Parameter	Correlation Coefficient, R	
	Lab-Scale Fatigue Ranking	Full-Scale ALF Cracking
Superpave	-0.56	-0.68
Time Sweep	+0.29	+0.94
Stress Sweep	-0.75	-0.55
Large-Scale Time Sweep Surrogate	-0.55	-0.69
CTOD	+0.34	+0.95
BYET	+0.68	+0.83

Summary

Binder Parameter	Coefficient of Determination, R^2	
	Lab-Scale Fatigue Ranking	Full-Scale ALF Cracking
Superpave	0.31	0.46
Time Sweep	0.09	0.88
Stress Sweep	0.31	0.57
Large-Scale Time Sweep Surrogate	0.30	0.48
CTOD	0.12	0.92
BYET	0.46	0.69

Scatter Plot - Superpave





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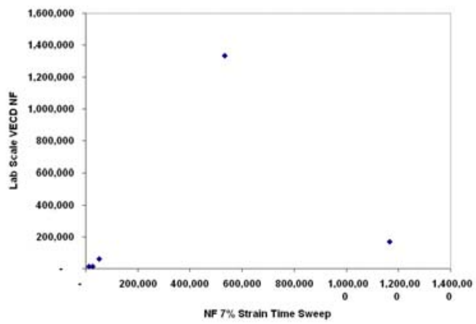
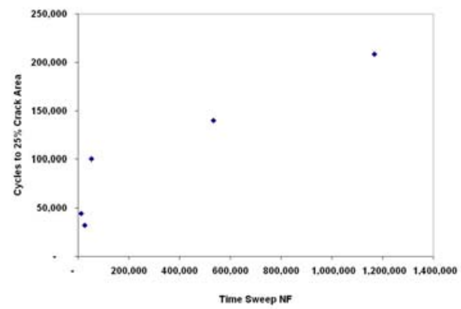
Scatter Plot – Time Sweep





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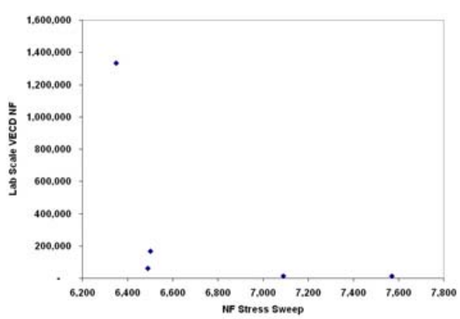
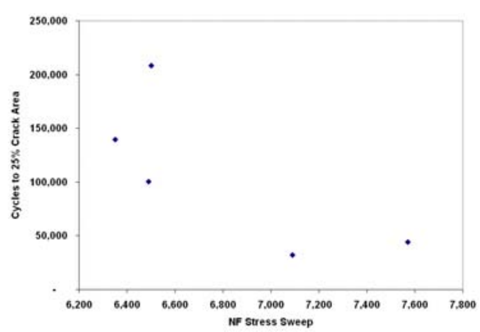
Scatter Plot – Stress Sweep





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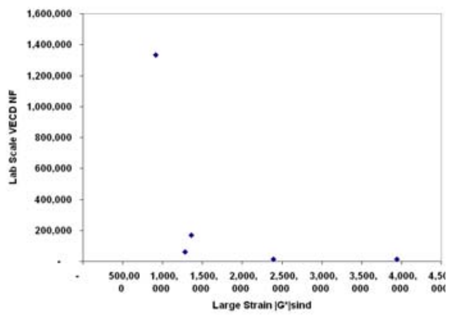
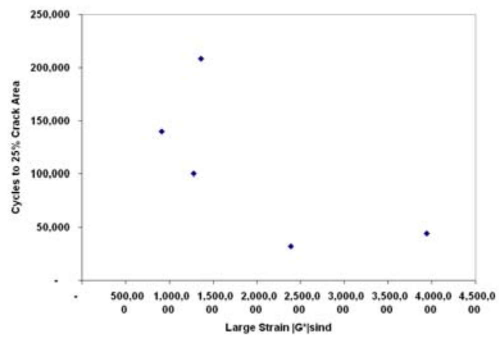
Scatter Plot – Large Strain Time Sweep Surrogate





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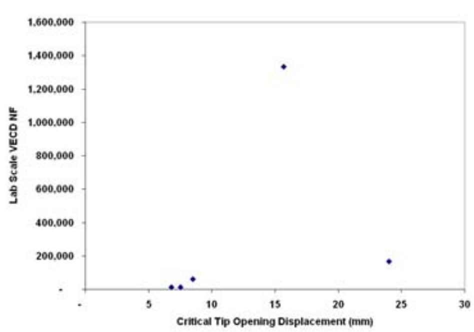
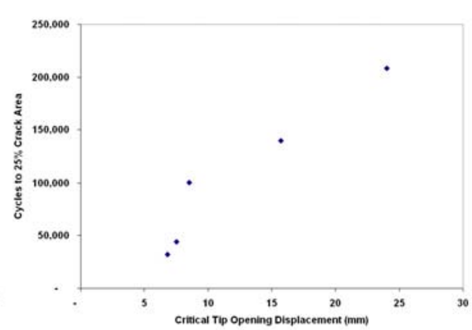
Scatter Plot – CTOD





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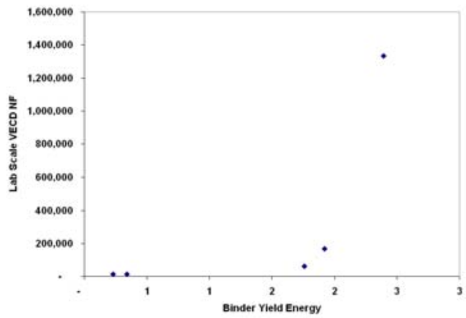
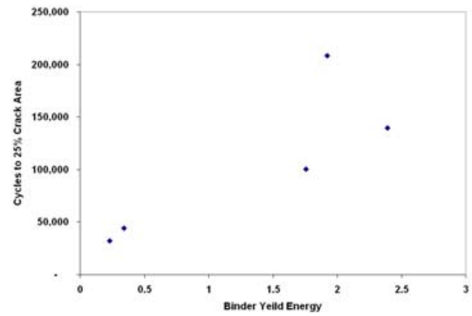
Scatter Plot – BYET





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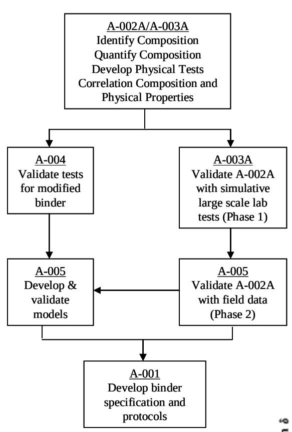
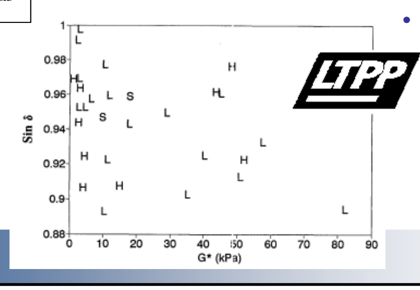
Historical Perspectives: SHRP



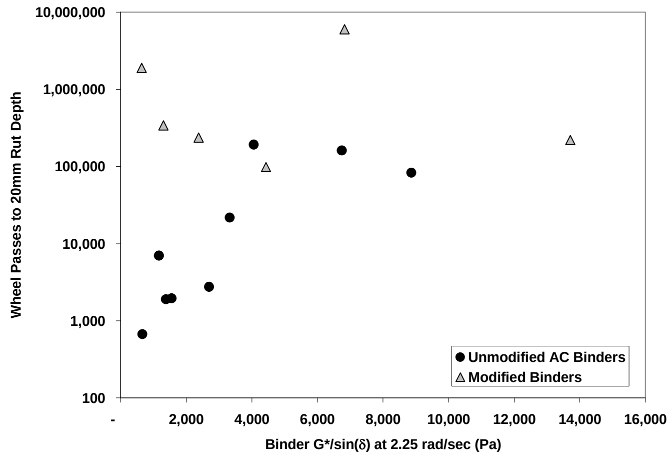
- Researchers were well aware of complexities and advanced tests & theories
- Introduction of DSR radically changed direction of research
- Linked dissipated energy to binder beam fatigue and Zacca-Wigmore test road
- Linked stress relaxation to "viscous component of stiffness" to wheel tracking



- **Field validation from early LTPP test sections showed no binder specification by itself can explain field performance**

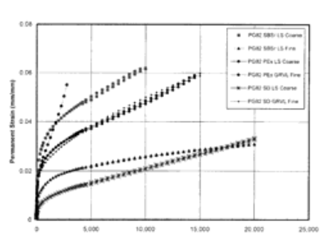
Historical Perspectives: Post-SHRP

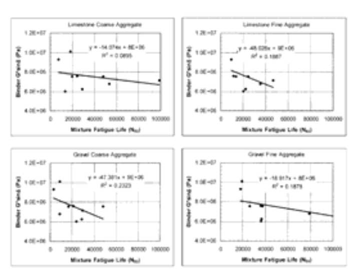
- **FHWA ALF**



Historical Perspectives: Post-SHRP

- **NCHRP 9-10**
  - HMA fatigue did not correlate to |G*|sinδ
    - **Binder fatigue time-sweep identified as potential candidate**
  - HMA permanent deformation did not correlate to |G*|/sinδ
    - **Binder creep and recovery identified as potential candidate**





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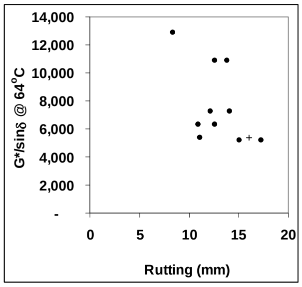
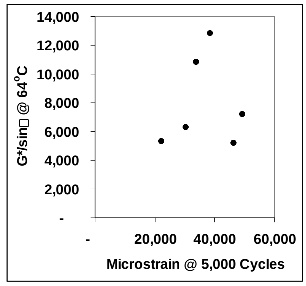
Rutting: |G*|/sinδ





	Slope	Regression Significance (1-pvalue)	Kendall's tau	Kendall's tau Significance	R	R^2
|G*|/sinδ vs. Rutting	- Correct	92%	- 0.31	98%	- 0.55	0.30
|G*|/sinδ vs. Microstrain at 5,000 Cycles	+ Incorrect	11.2%	+ 0.2	64%	+0.078	0.006

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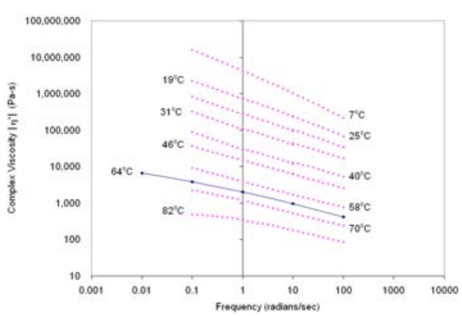
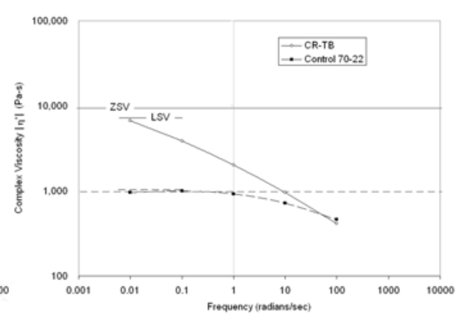
Rutting: Zero- & Low-Shear Viscosity

- **Calculated from complex viscosity**
  - **ZSV**
  - **LSV**

$$\eta_0^* = \lim_{\omega \to 0} \frac{G''}{\omega} = \lim_{\omega \to 0} \frac{|G^*| \times \sin\delta}{\omega} \quad \& \quad \eta_L\Big|_{\varpi = 0.01 rad/\sec} = \frac{|G^*| \times \sin\delta}{\omega}$$





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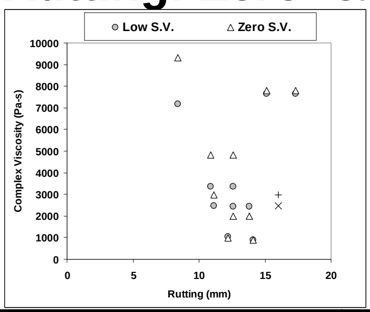
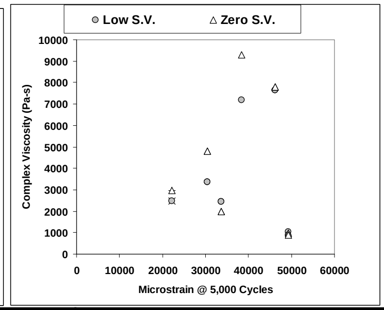
Rutting: Zero- & Low-Shear Viscosity





	Slope	Regression Significance (1-pvalue)	Kendall's tau	Kendall's tau Significance	R	R^2
LSV vs. Rutting	+ Wrong direction	26%	+ 0.09 Wrong direct	56%	+ 0.11	0.01
ZSV vs. Rutting	-	17%	+ 0.02	68%	- 0.07	0.005
LSV vs. $\mu\varepsilon$ @ 5k Cycles	0	0.04%	- 0.14	61%	-0.0003	0
ZSV vs. $\mu\varepsilon$ @ 5k Cycles	0	0.04%	- 0.14	61%	-0.0003	0

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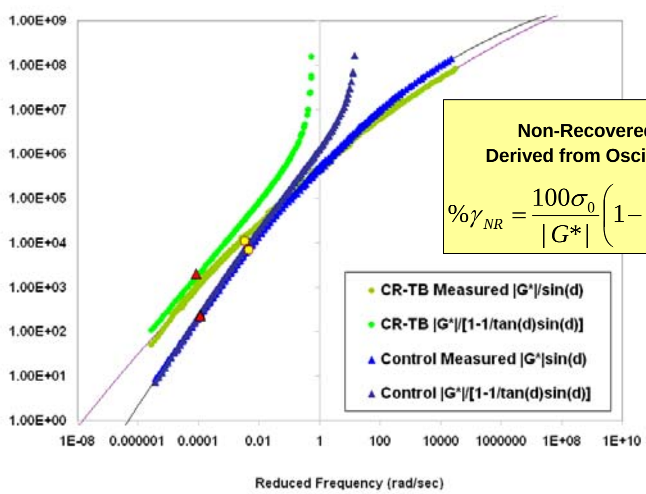
Rutting: Shenoy's Estimate for Non-Recovered Strain

Shenoy, Aroon (2001). "Refinement of the Superpave specification parameter for performance grading of asphalt." *J. Transportation Engineering*, 127(5), 357-362.

$$\frac{|G^*|}{\sin\delta}$$

$$\frac{|G^*|}{1-\frac{1}{\tan\delta\sin\delta}}$$

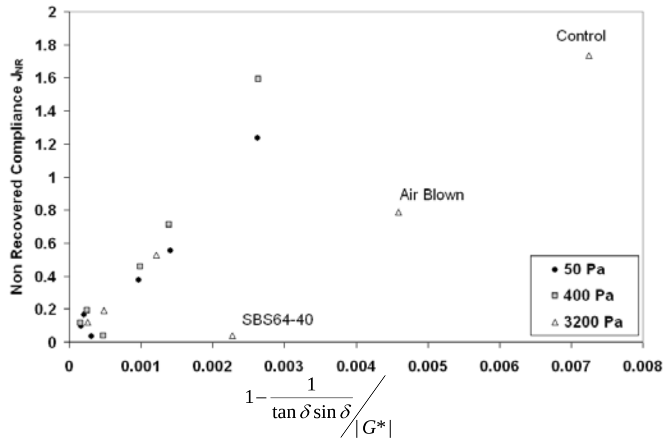


Non-Recovered Strain Derived from Oscillatory Test

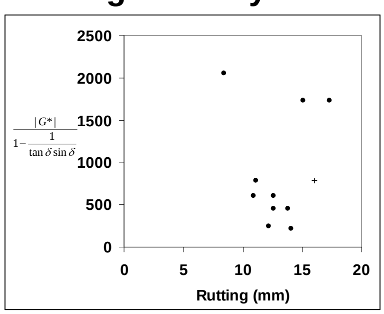
$$\%\gamma_{NR} = \frac{100\sigma_0}{|G^*|}\left(1-\frac{1}{\tan\delta\sin\delta}\right)$$

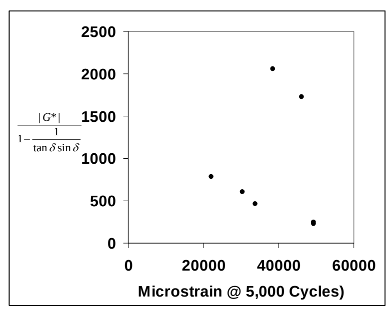
Rutting: Shenoy's Estimate for Non-Recovered Strain

$$parameter: \frac{|G^*|}{1-\frac{1}{\tan\delta\sin\delta}} \qquad J_{NR}\ estimate = \frac{1-\frac{1}{\tan\delta\sin\delta}}{|G^*|}$$



Rutting: Shenoy's Estimate for Non-Recovered Strain





	Slope	Regression Significance (1-pvalue)	Kendall's tau	Kendall's tau Significance	R	R^2
$\frac{\|G^*\|}{1-\frac{1}{\tan\delta\sin\delta}}$ vs. Rutting	+ Wrong direction	48%	+ 0.23 Wrong direction	68%	+ 0.22 Wrong direction	0.05
$\frac{\|G^*\|}{1-\frac{1}{\tan\delta\sin\delta}}$ vs. με @ 5k Cycles	-	6.3%	- 0.33	81%	- 0.037	0.001

Non-Recovered Compliance J_{NR}

$$E = \frac{\sigma}{\varepsilon} \qquad G = \frac{\tau}{\gamma}$$

$$D(t) = \frac{\varepsilon(t)}{\sigma_0} \qquad J(t) = \frac{\gamma(t)}{\tau_0}$$