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Full-Scale Accelerated Performance Testing for Superpave & Structural Validation

•

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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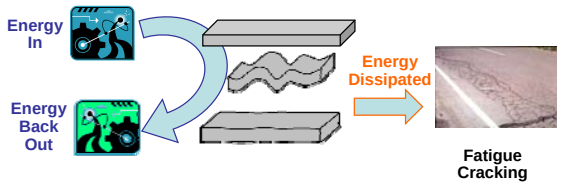
Background



How good is this?
Value to the community? → **|G*| sinδ**

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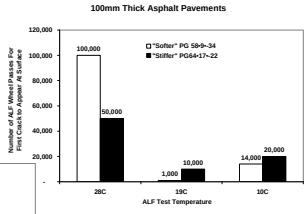
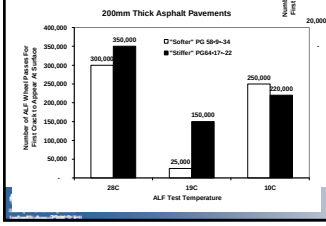
Post-SHRP 1993 FHWA ALF

Better fatigue performance at cooler and warmer





Stiffer binder performed better at intermediate temperature

Not intent of specification

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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

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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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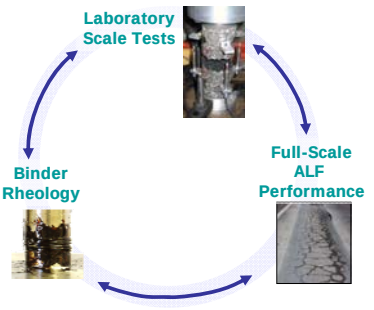
Approach to Evaluation



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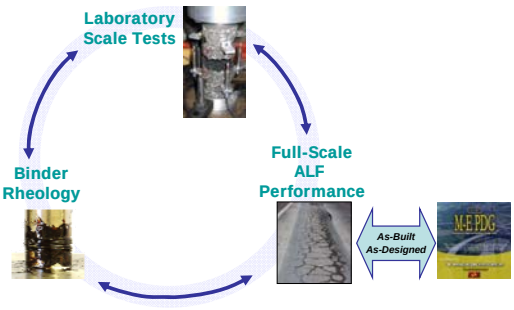
Approach to Evaluation



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Lane 1	Lane 2	Lane 3	Lane 4	Lane 5	Lane 6	Lane 7	Lane 8	Lane 9	Lane 10	Lane 11	Lane 12
100 mm Asphalt Pavement Layer							150 mm Asphalt Pavement Layer				

CR-AZ / PG70-22	PG 70-22	Air-Blown	SBS LG	CR-TB	Elvaloy	Fiber	PG 70-22	SBS 64-40	Air-Blown	SBS LG	Elvaloy
Removed 100 mm of Existing CAB											
100 mm of New No. 21A CAB Under All 12 Lanes							Removed 50 mm of Existing CAB				

Existing VDOT No. 21A Crushed Aggregate Base (CAB)
(25-mm Nominal Maximum Aggregate Size)

Existing Depths of CAB are 560 mm under Lanes 1 and 2
And 460 mm under Lanes 3 to 12

Bottom of CAB to Pavement Surface is 660 mm

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	(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*|sinδ (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

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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	(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*|sinδ (PAV) = 5MPa	26.7	25.4	26.1		22.6		14.3		17.7		8.6	17.9

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The Pavement Test Facility

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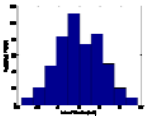
Loading Conditions



64ºC (147ºF)
100 psi Inflation
10,000 pounds
No Wander

19ºC (66ºF)
120 psi Inflation
16,000 pounds
Wheel Wander

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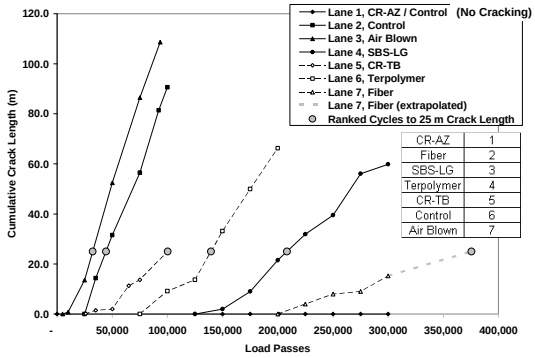

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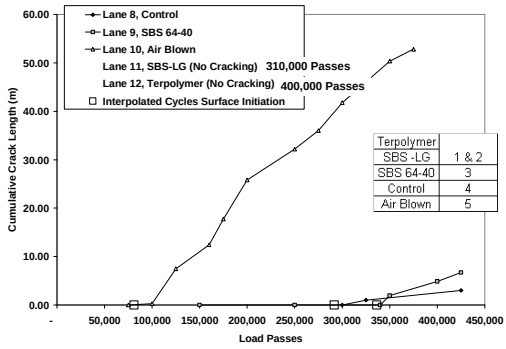

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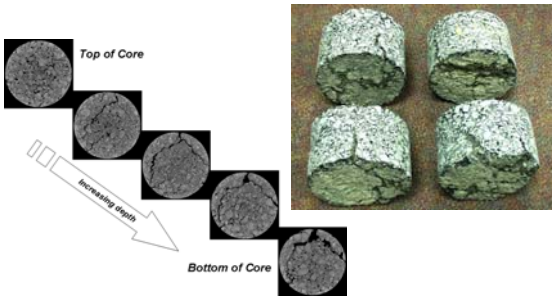
Confirmation of Bottom Up Cracking



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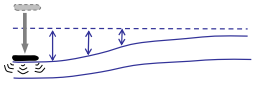
As-Built Consistency

Falling Weight Deflectometer



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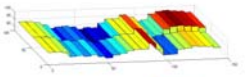
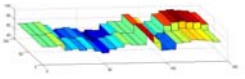
As-Built Consistency

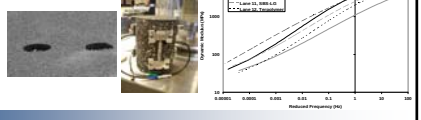
Crushed Aggregate Base Stiffness



A-4 Subgrade Stiffness



HMA Stiffness |E*|



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Laboratory Scale Fatigue Performance

Then…

…Now

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Laboratory Scale Fatigue Performance

Lab Fabricated

Field Compacted

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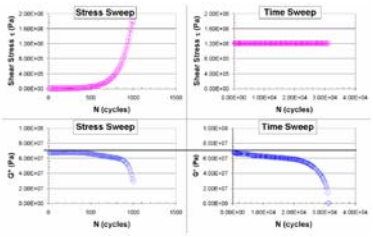
Time Sweep and Stress Sweep

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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Time Sweep and Stress Sweep

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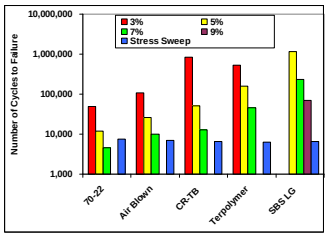

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Large Strain Time Sweep Surrogate

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

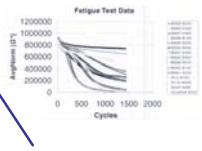
T=15ºC γ = 0.1% → γ = 80%

T=20ºC γ = 0.1% → γ = 80%

T=25ºC γ = 0.1% → γ = 80%

T=30ºC γ = 0.1% → γ = 80%

T ºC where γ = 25% & |G*| = 1 MPa



X62 larger than PG

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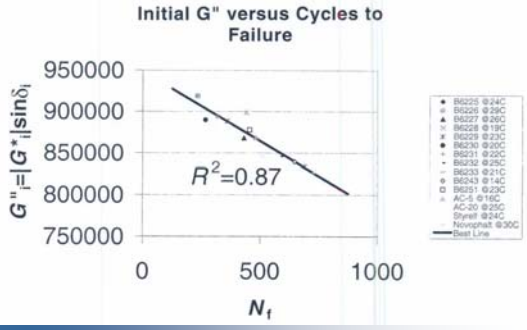
Large Strain Time Sweep Surrogate



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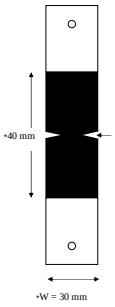
Critical Tip Opening Displacement



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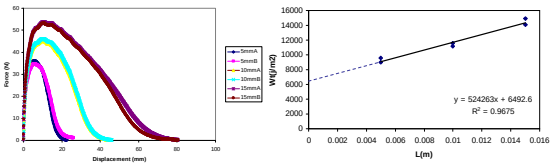
Critical Tip Opening Displacement

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

Ontario MTO Test Method LS-299



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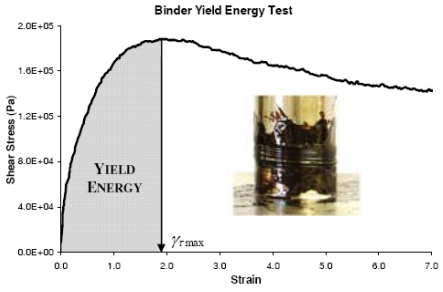
Binder Yield Energy Test



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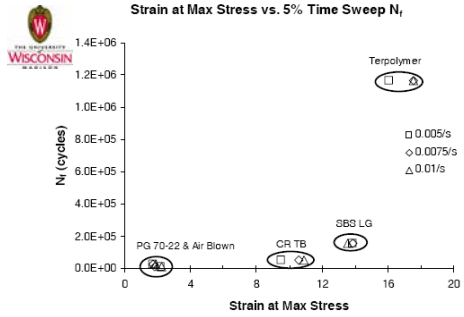
Binder Yield Energy Test



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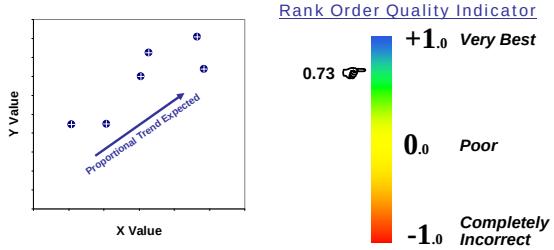
How will Binder Parameter Candidates be Compared to Each Other?



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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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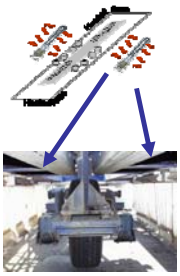
Ongoing: Accelerated Aging



- 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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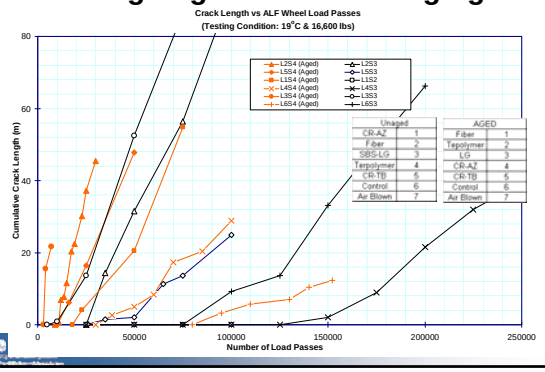
Ongoing: Accelerated Aging



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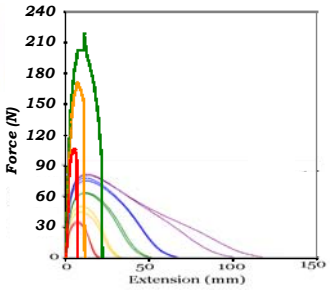
Ongoing: Accelerated Aging

PAV Aged ~ Ductile

Recovered ~ Brittle



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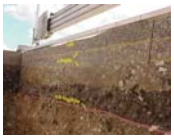
Research where full-scale accelerated performance testing provides a role

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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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 $|G^*|\sin\delta$
  - CTOD and BYET appear to be among the most promising
  - ONGOING: 32 Binders From LTPP Test Sections

Asphalt Research Consortium

- 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

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Acknowledgements

State DOT & Industry

TPF 5(019)
SPR 2(174)

- 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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Q & A

Nelson.Gibson@dot.gov

Database Application (portable) has been developed

250-page Detailed Report

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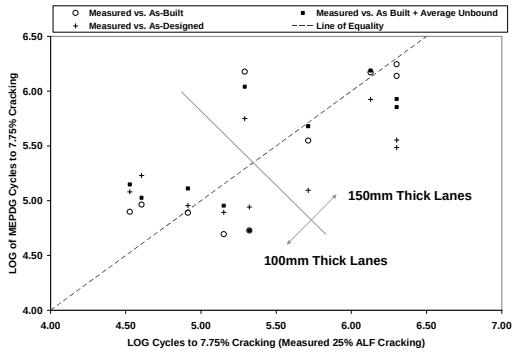

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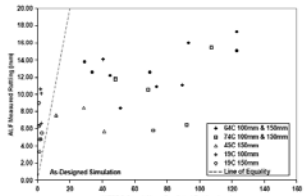

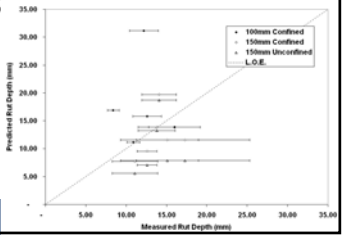

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Abraham Maslow's
Law of the Instrument

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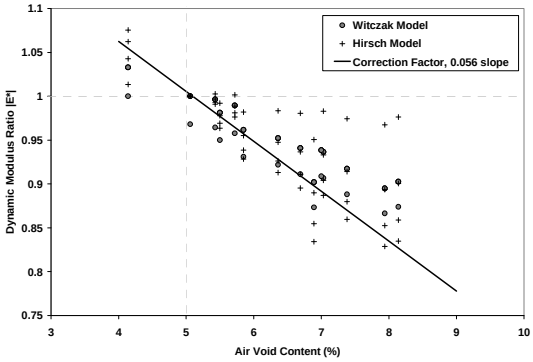

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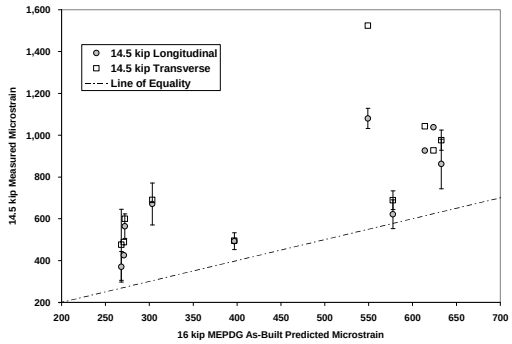

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Binder Yield Energy Test

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."

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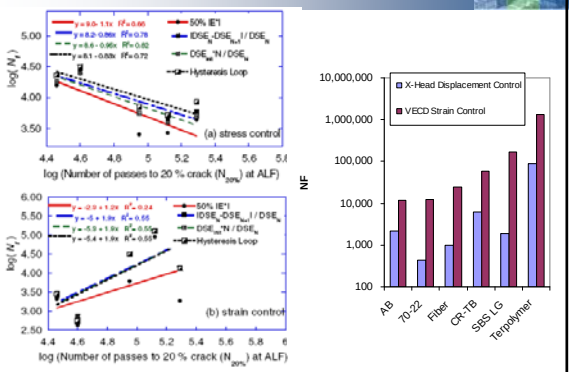

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Summary

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

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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

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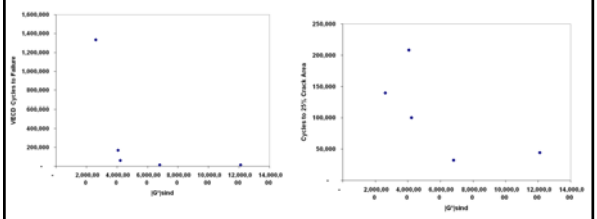
Scatter Plot - Superpave



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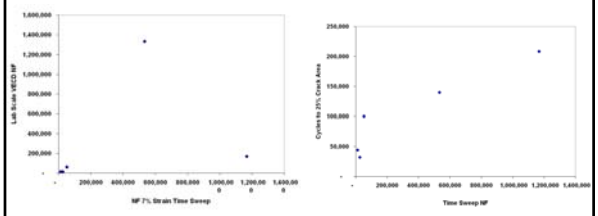
Scatter Plot – Time Sweep



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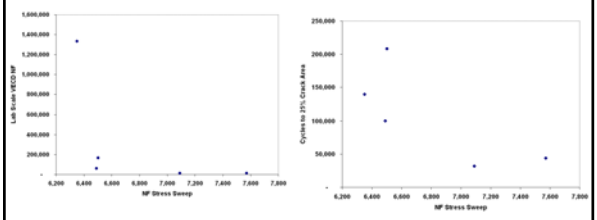
Scatter Plot – Stress Sweep



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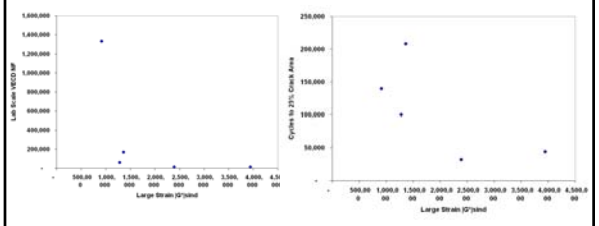
Scatter Plot – Large Strain Time Sweep Surrogate



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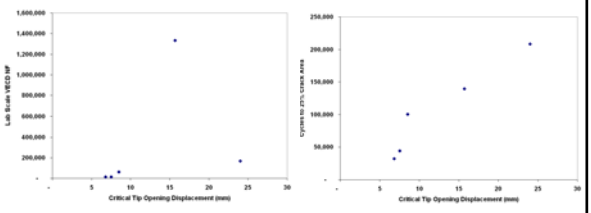
Scatter Plot – CTOD



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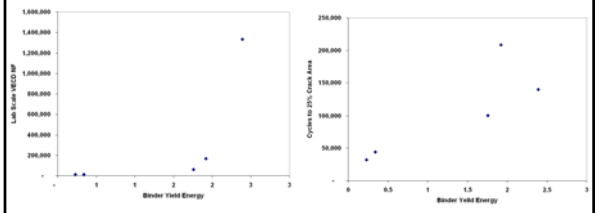
Scatter Plot – BYET



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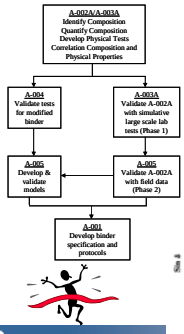
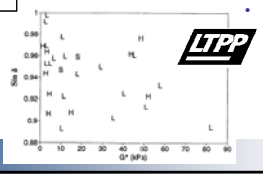
Historical Perspectives: SHRP



- 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**

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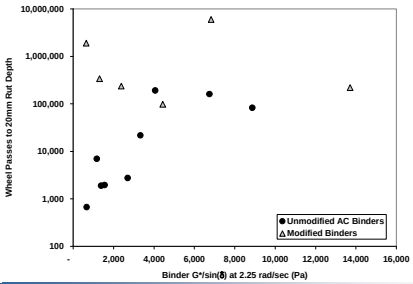
Historical Perspectives: Post-SHRP

- **FHWA ALF**



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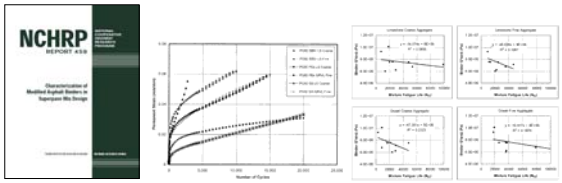
Historical Perspectives: Post-SHRP

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



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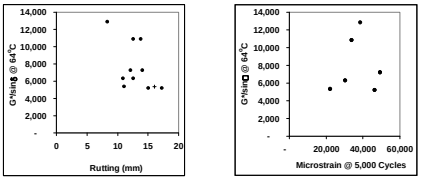
Rutting: |G*|/sinδ



	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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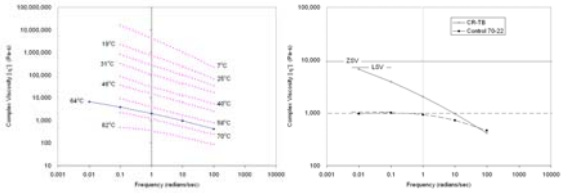
Rutting: Zero- & Low-Shear Viscosity

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

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



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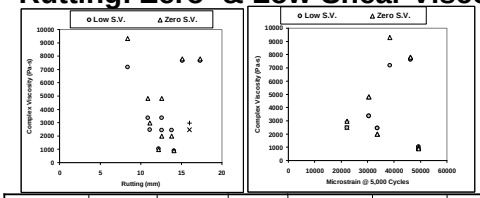
Rutting: Zero- & Low-Shear Viscosity



	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. με @ 5k Cycles	0	0.04%	- 0.14	61%	-0.0003	0
ZSV vs. με @ 5k Cycles	0	0.04%	- 0.14	61%	-0.0003	0

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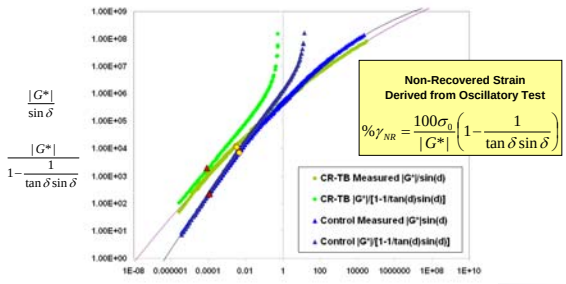
Rutting: Shenoy's Estimate for Non-Recovered Strain

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



Non-Recovered Strain Derived from Oscillatory Test

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

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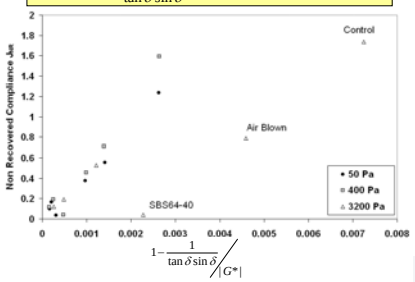
Rutting: Shenoy's Estimate for Non-Recovered Strain

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



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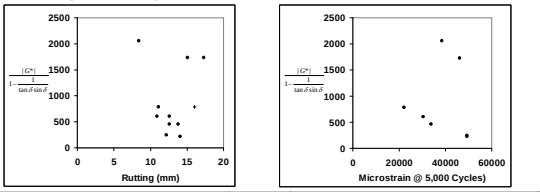
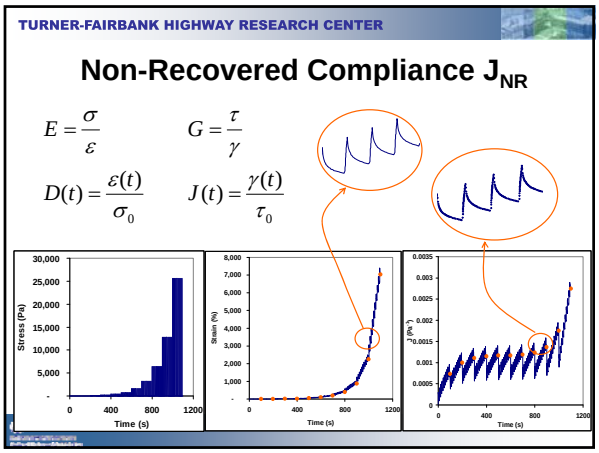
Rutting: Shenoy's Estimate for Non-Recovered Strain



	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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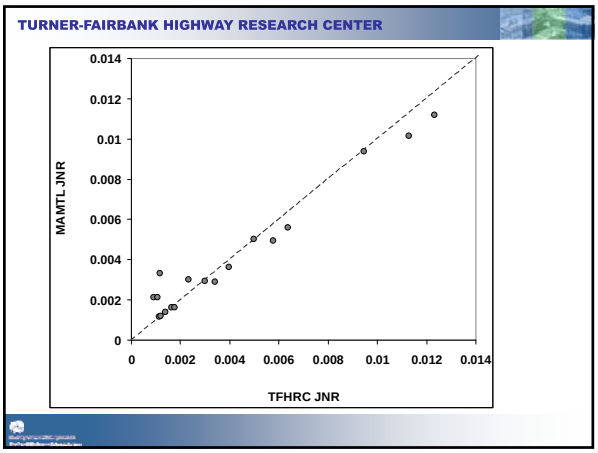
Non-Recovered Compliance J_{NR}
$E = \frac{\sigma}{\varepsilon}$
$G = \frac{\tau}{\gamma}$
$D(t) = \frac{\varepsilon(t)}{\sigma_0}$
$J(t) = \frac{\gamma(t)}{\tau_0}$
Stress (Pa)
Strain (%)
Time (s)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MAMTL JNR
TFHRC JNR
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014