ARC
Asphalt Research Consortium

Asphalt Binder Expert Task Group

ARC Update - Binder Fatigue

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September 16, 2009

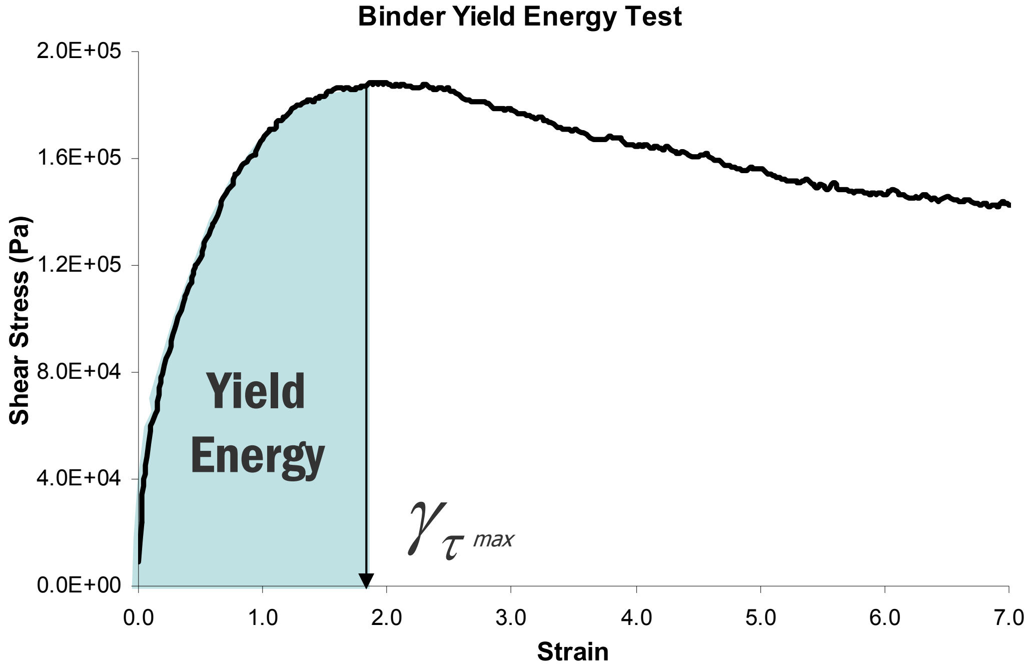
Binder Fatigue Update

- Background
  - Where we left off at the previous meeting
- Binder Yield Energy Test (BYET) update
  - Fatigue Task Group meeting in April 2009
  - Modeling challenges remain

- Accelerated cyclic fatigue developments
  - Amplitude sweep test
  - Adaptation of VECD analysis
- LTPP binder testing preliminary findings
- Next steps

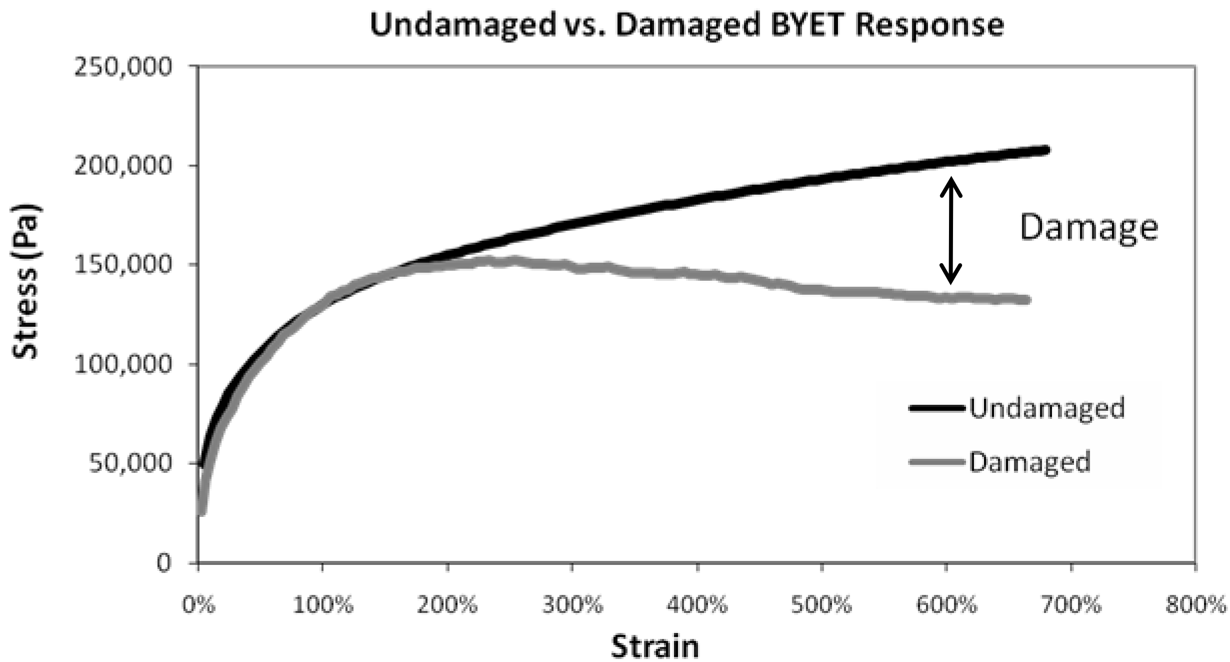
Binder Yield Energy Test

- Monotonic (non-cyclic) test
- Done at 0.01 /sec



BYET Damage Modeling

$$\tau(t) = R\int_0^t G(t-\tau)d\tau \longrightarrow \tau(t) = R\left[G_\infty t + \sum_{i=1}^{N} G_i\rho_i\left(1-e^{-\frac{t}{\rho_i}}\right)\right]$$

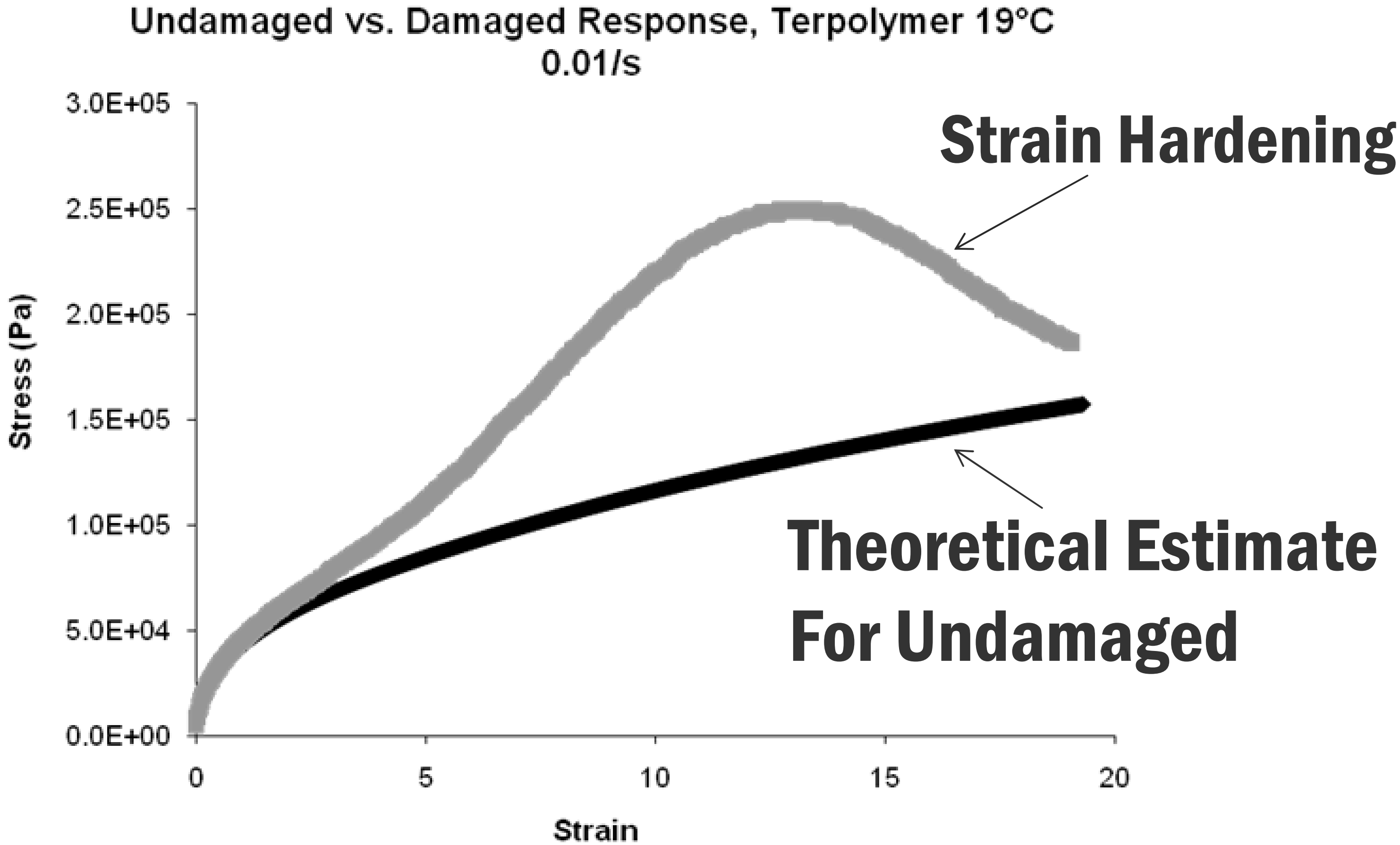


Proposed Limits for Yield Energy, MPa (February 2009)

(Adjusted to 1.0 MPa, at **IT-8C**)

Pavement Micro-strain		1000	600	200
	Binder Strain	5%	3%	1%
Traffic ESALs	(S) 1000000	***1.20***	***0.90***	***0.25***
	(H) 3000000	***1.35***	***<u>1.00</u>***	***0.30***
	(VH)10000000	***1.50***	***1.10***	***0.35***

Modeling Challenges with Modified Binders
AAPT 2009 Paper (Johnson, Wen, Bahia)



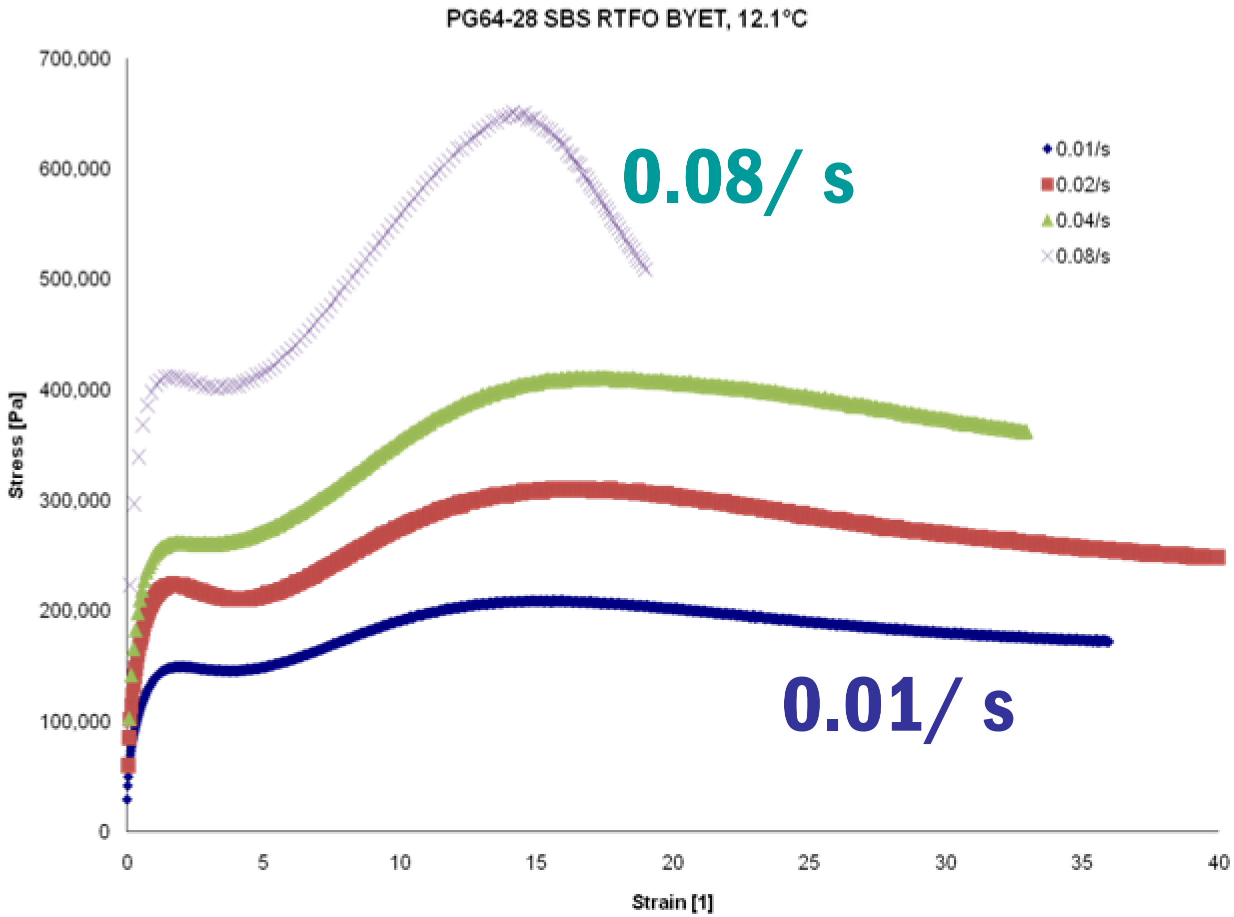
Follow up steps

- Based on discussion at AAPT, it was recommended that higher loading rates be used.
- Detailed communications with Professor Richard Kim
  - Goal of higher rates is to isolate visco-elasticity from visco-plasticity in mixture testing.
- Meeting with fatigue task group (April 09)

Fatigue Task Group (April 2009) Meeting Objectives

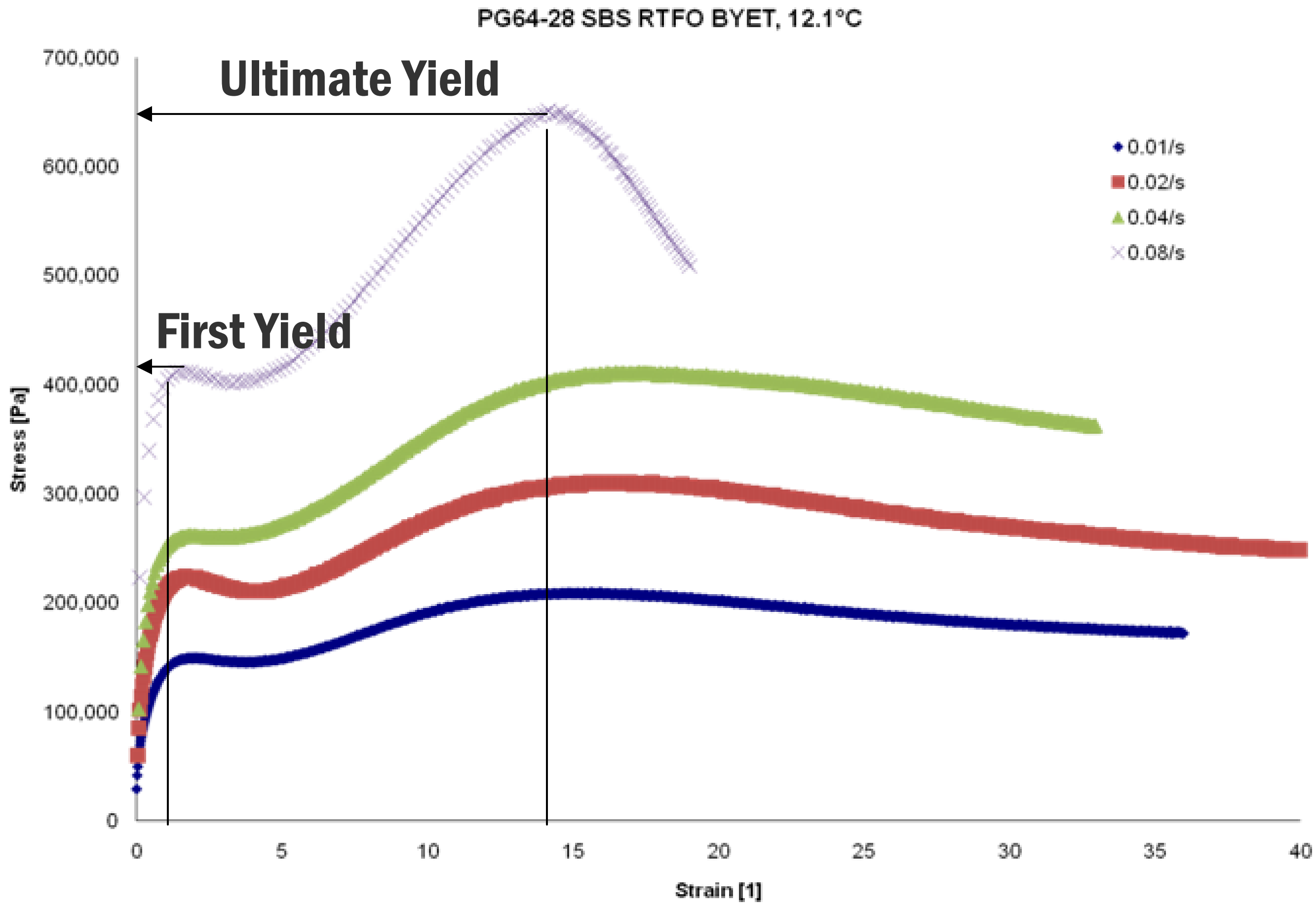
- Identify tests, and details, to be evaluated for binder fatigue validation (LTPP binders)
  - Monotonic
  - Stress or strain sweep
- Identify mixture testing required
  - Beam fatigue
  - IDT
  - Others

Effect of Rate on Monotonic Test- Feb-March 08

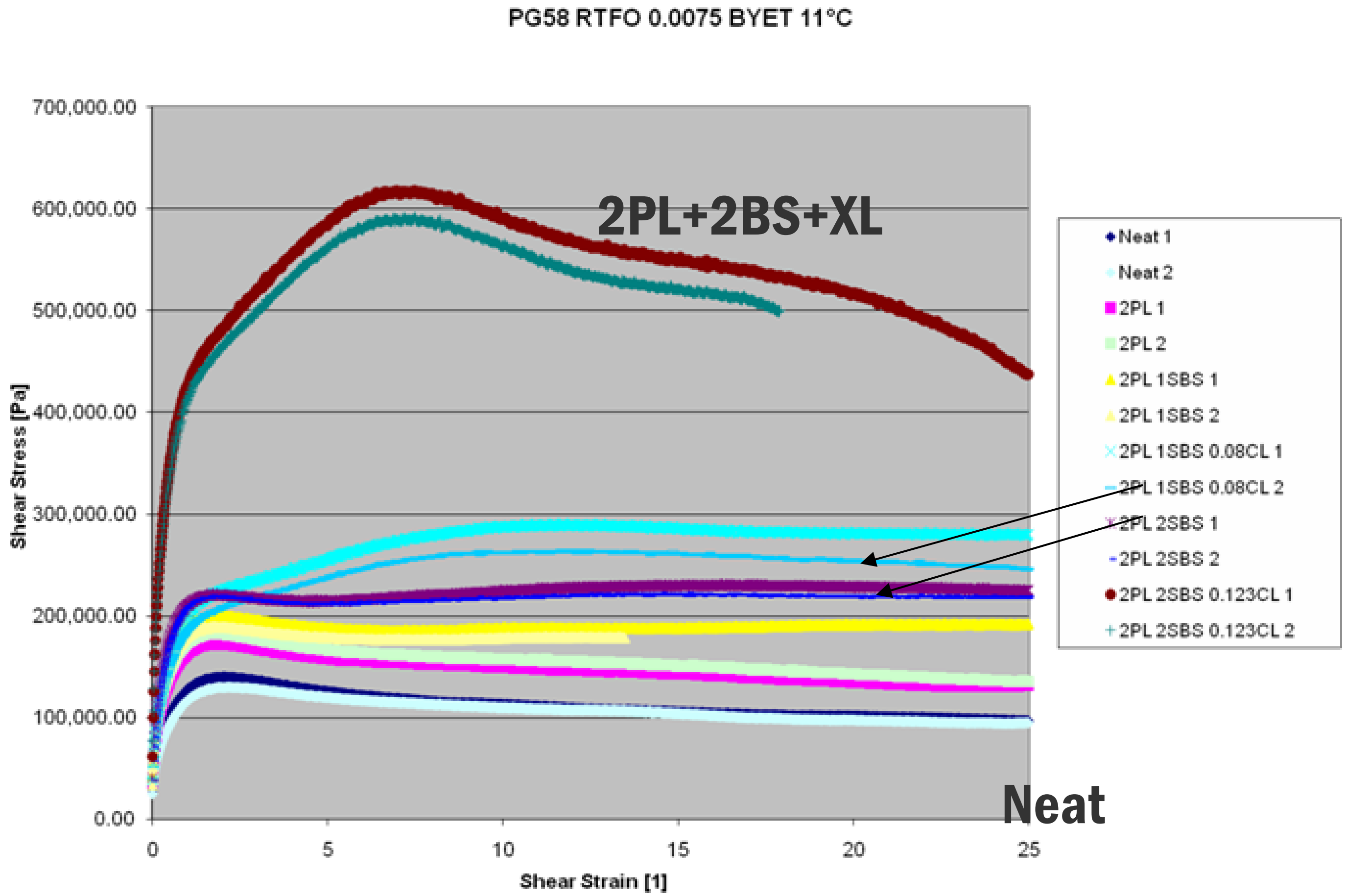


- Slippage began to occur at shear rates of 8% per second
- Limited by equipment capabilities

New Parameters for the Monotonic Test were Considered

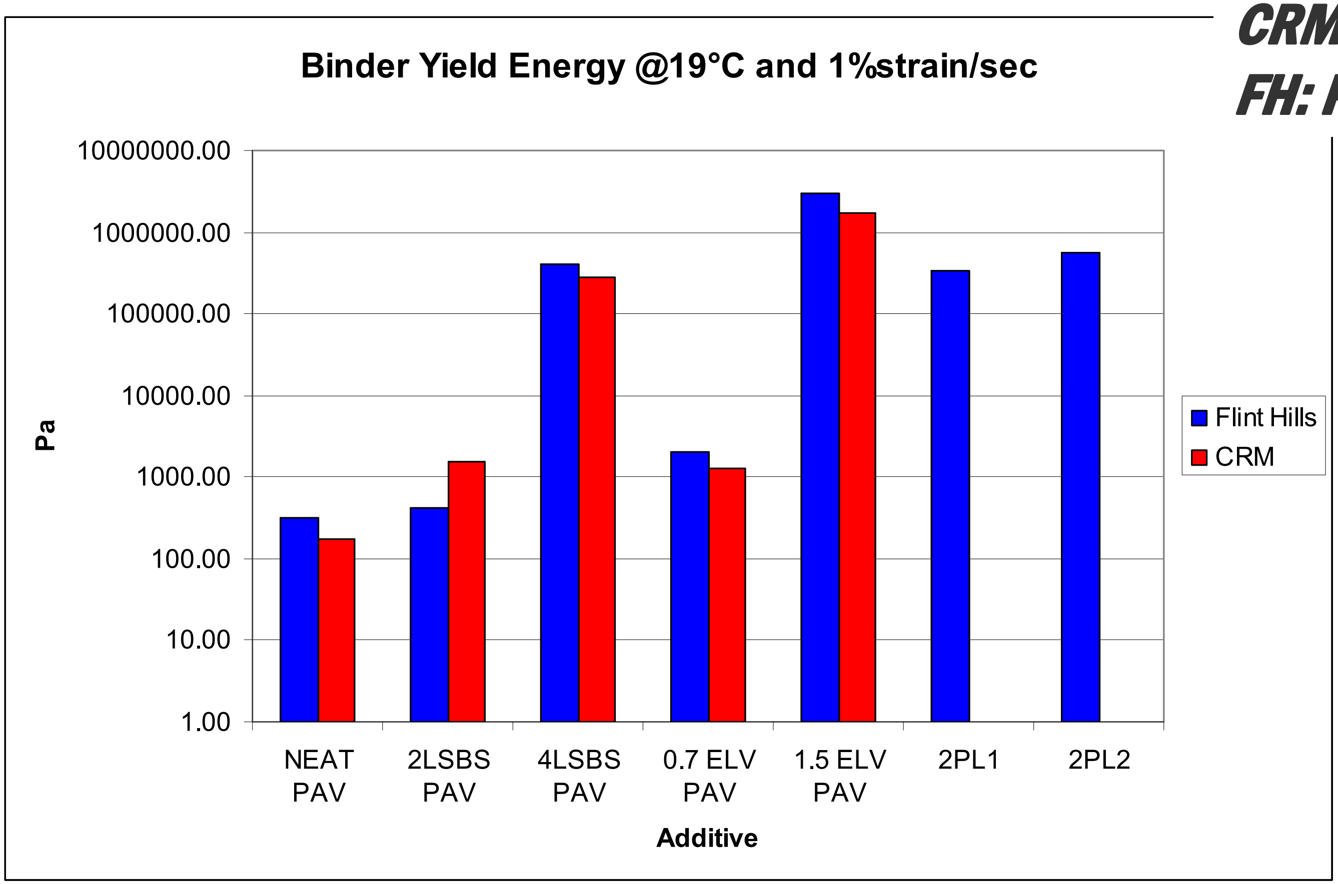


Effects of Modification Type, Level and Cross-linking



Effect of Polymers (After PAV) (Elastomers W/WO XL & Plastomers)

CRM: PG 58-28
FH: PG 64-22



Interim Findings

- Test is practical
- Test is repeatable
- Can easily identify modification and possibly cross-linking

- Cannot be used for damage analysis (VECD theory)
- More later

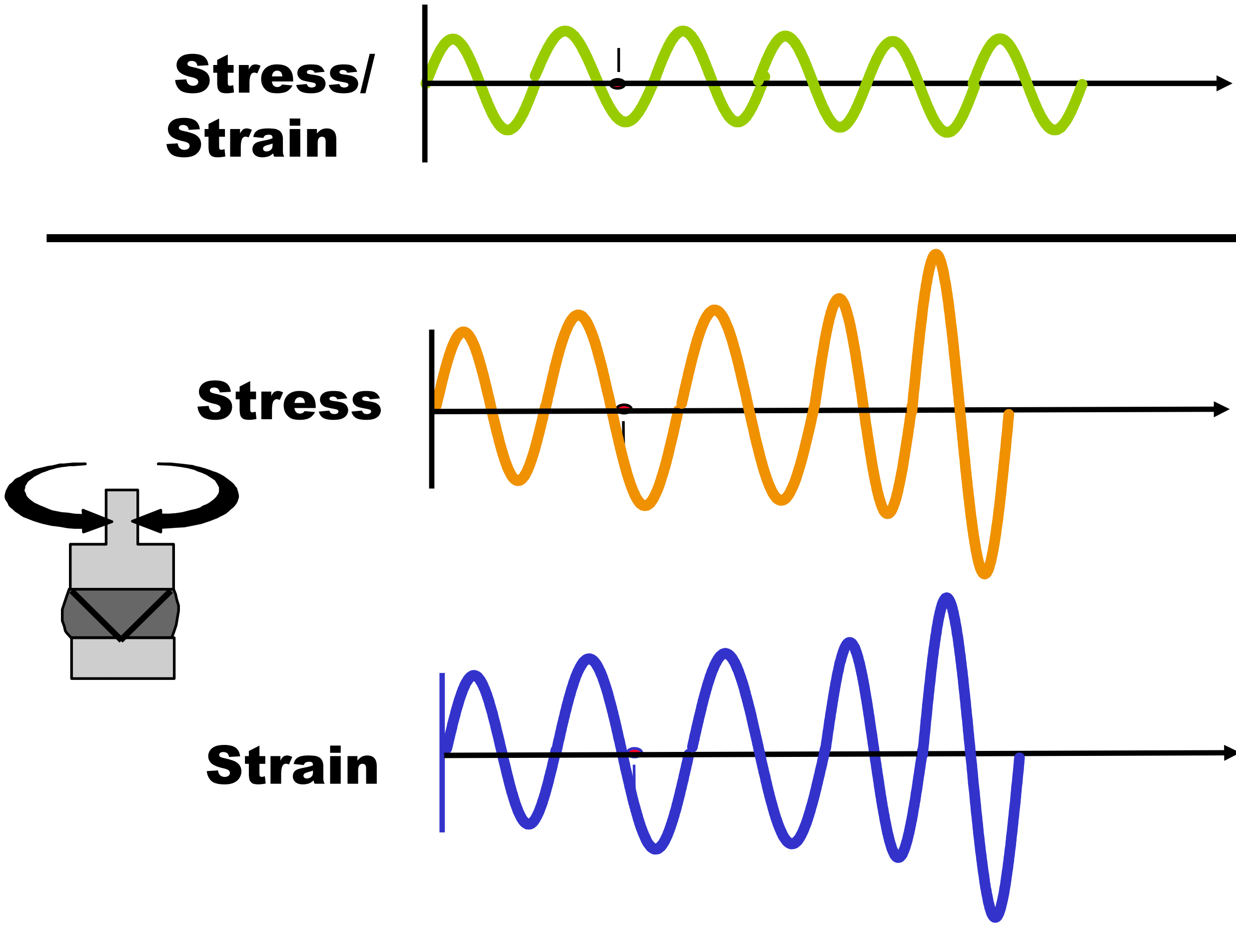
Fatigue Task Group Meeting Outcomes

- Binder test Protocol
  - Monotonic
    - Strain rate: based on analysis of ALF mixtures
    - Aging condition: RTFO and PAV (1), + 2, +3 – 6C)
  - Stress / strain sweep (Yes) – ALF binders +
    - Frequency: 1.59 ?
    - Aging condition: RTFO ?
- Mixture Testing
  - Uni-axial Test – 3 strain levels – correlate to binder monotonic
    - Define what rates we should use for BYET
    - Richard Kim / Nelson Gibson data for mixtures --- ?
  - Beam fatigue (no)?
  - IDT monotonic (yes) ?
  - Next meeting, June 8-10 (CA), NAPA .

Cyclic Test Development

- Higher rates possible during cyclic testing due to lower amplitudes (20% vs. 2,000%).
- Cyclic testing more indicative of fatigue-type failure
- Refinement of amplitude sweep procedure allows easier application of damage modeling (VECD)
  - Strain sweep with linear ramping

Time Sweep and Amplitude Sweeps

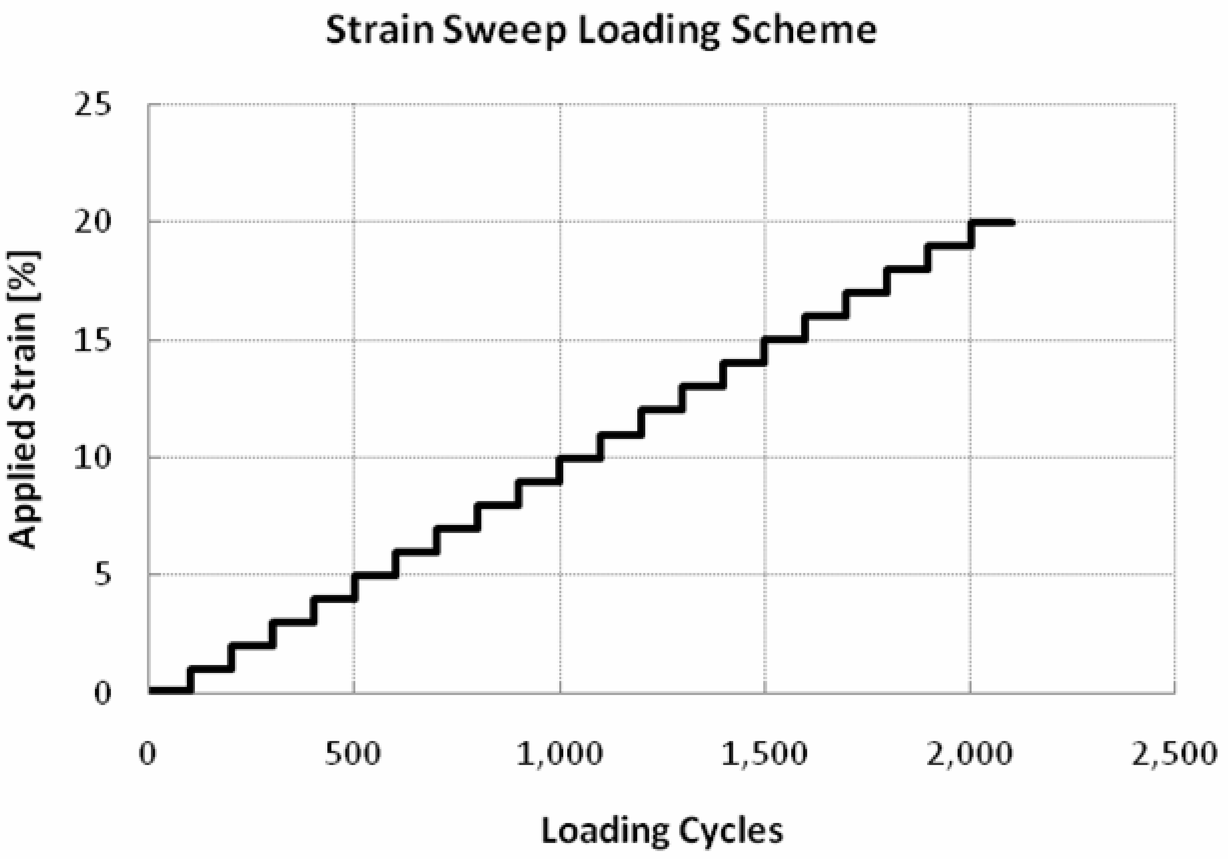


1. Time Sweep
Damage due to cycles

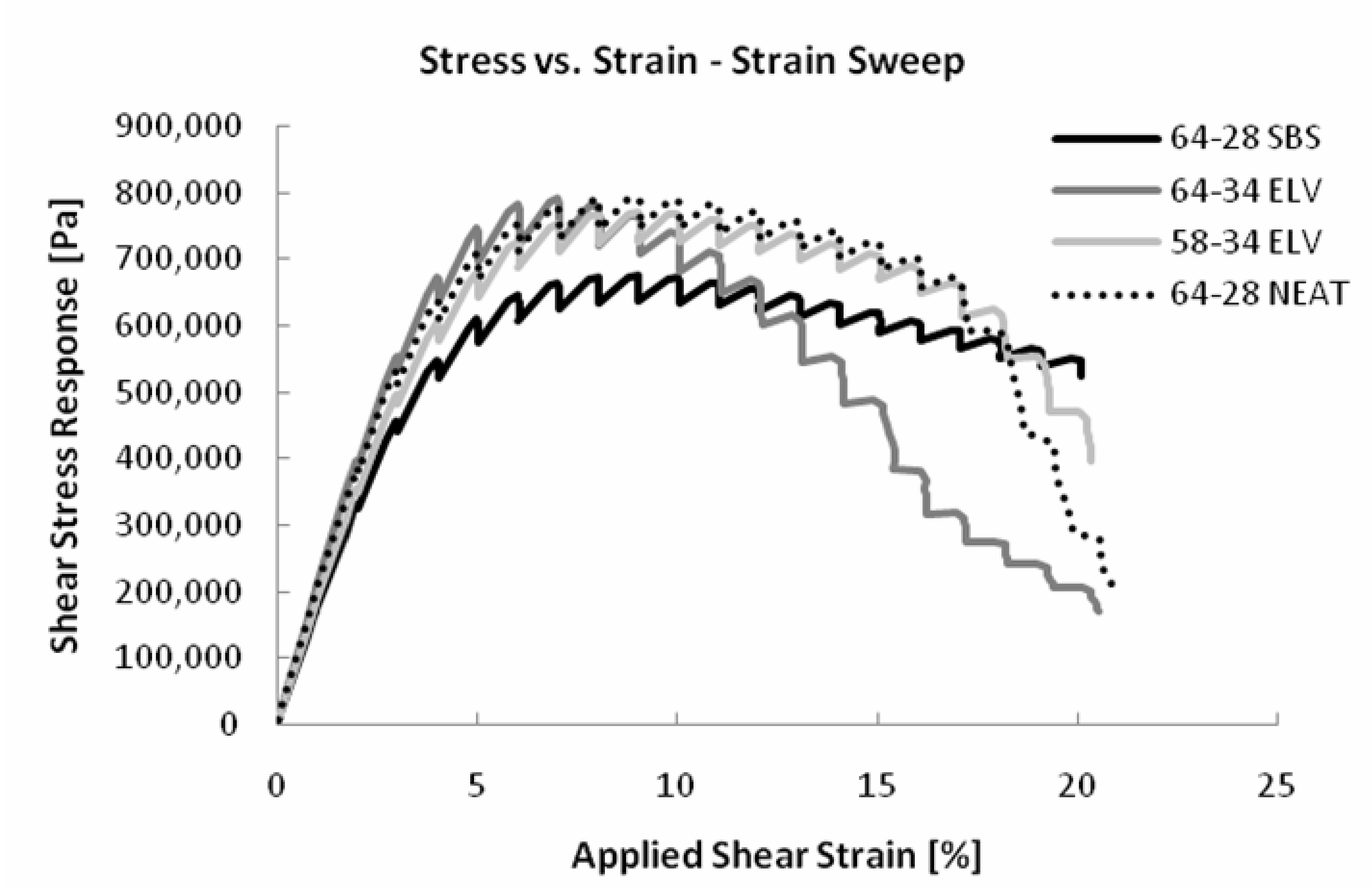
2. Stress Sweep
Damage due to Increased stress

3. Strain Sweep
Damage due to Increased stress

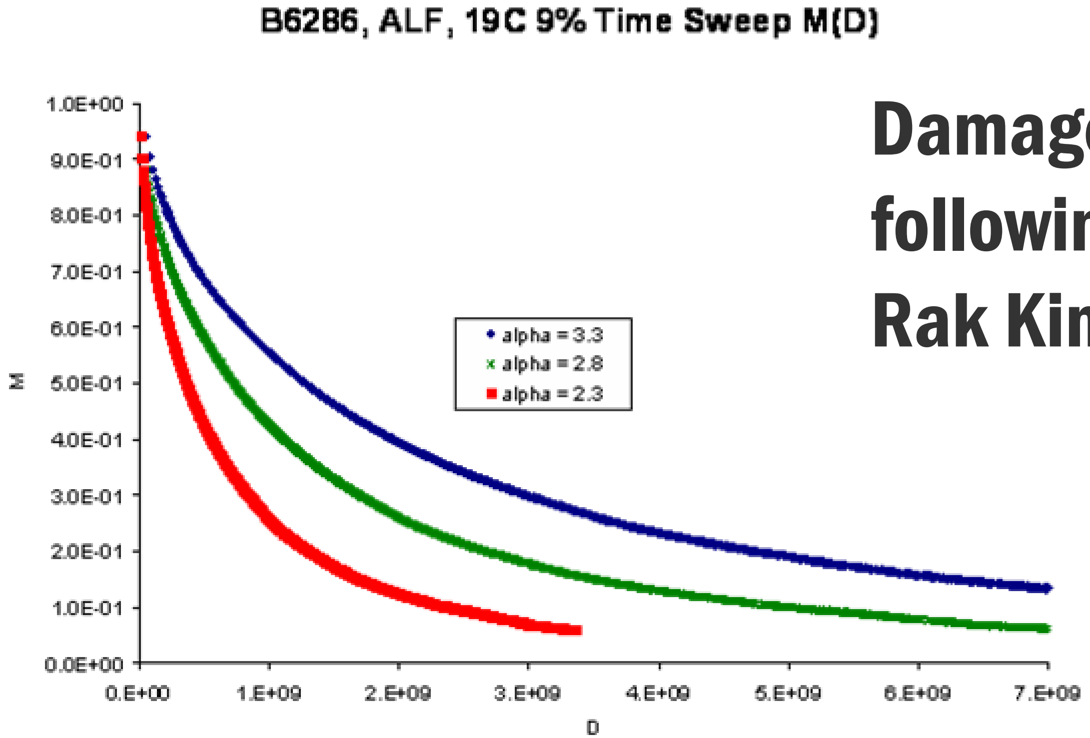
Linear Step Strain Sweep



Strain Sweep Example Data



Analysis of Strain Sweep



Damage equation following Prof. Yong-Rak Kim (2006):

$$D(t) \cong \sum_{i=1}^{N} \left[\pi \cdot I_D \cdot \gamma_0^2 \left(|G^*| \sin \delta_{i-1} - |G^*| \sin \delta_i \right) \right]^{\frac{\alpha}{1+\alpha}} \left(t_i - t_{i-1} \right)^{\frac{1}{1+\alpha}}$$

VECD Fatigue Prediction Model

- With the VECD curve fit to a simple numeric equation:

$$|G*|\sin\delta = C_0 - C_1(D)^{C_2}$$

- Fatigue life can be predicted using:

$$N_f = \frac{f(D_f)^k}{k\left(\pi \frac{I_D}{|G^*|} C_1 C_2\right)^{\alpha}} |G^*|^{-\alpha} (\gamma_{max})^{-2\alpha}$$

$$k = 1 + (1 - C_2)\alpha$$

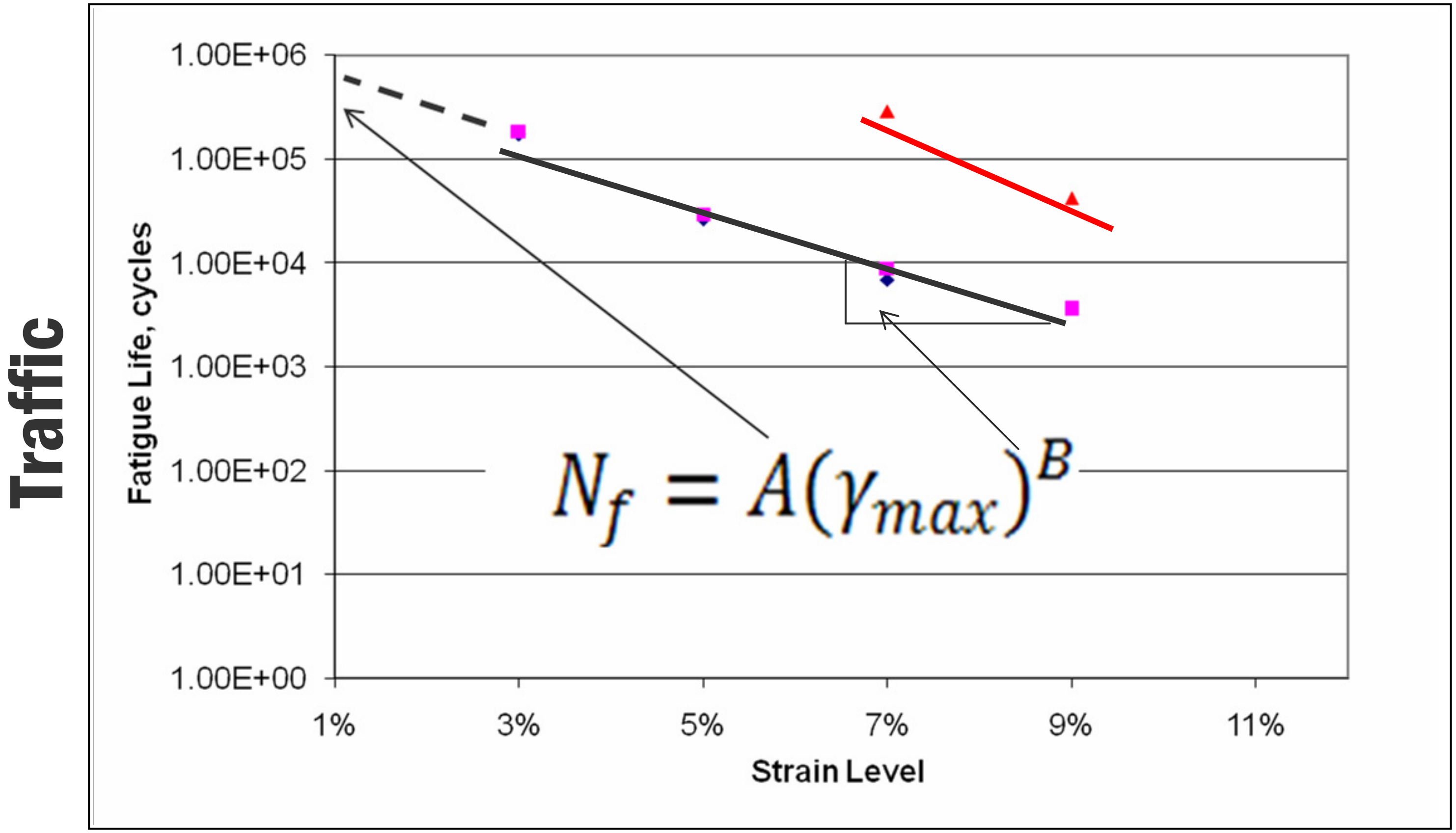
VECD Fatigue Prediction Model

- The fatigue life equation can be further simplified in the form of the common fatigue law:

$$N_f = A(\gamma_{max})^B$$

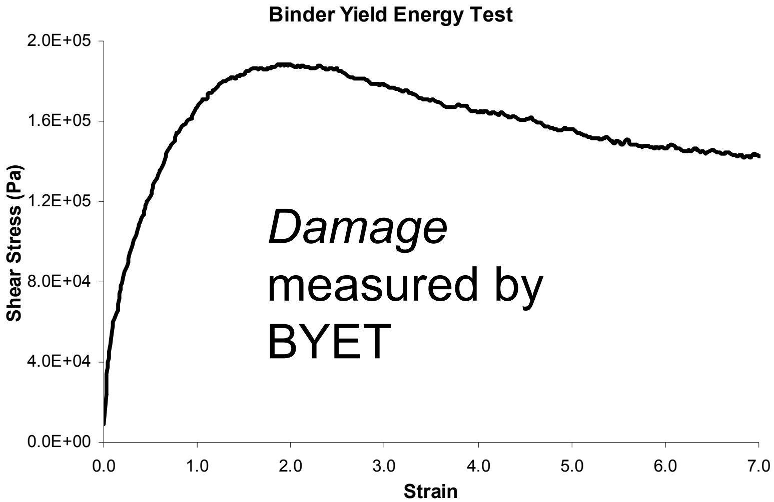
- Parameters *A* and *B* were determined from both strain and time sweep results.

Simulated Fatigue



Pavement Structure

Relating Amplitude Sweeps to Pavement Performance – Mechanistic Approach



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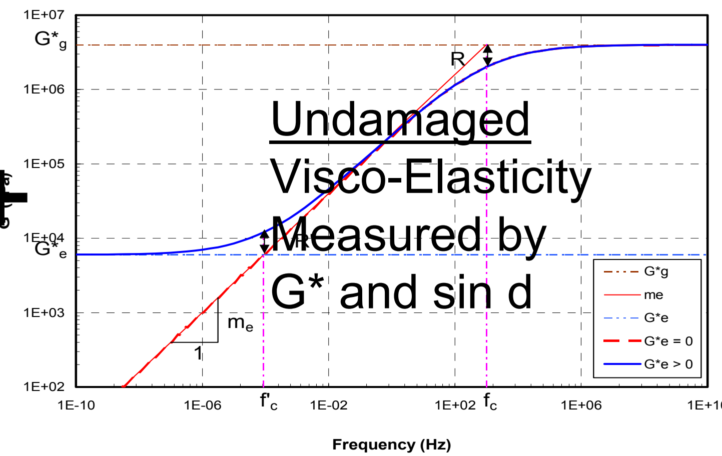
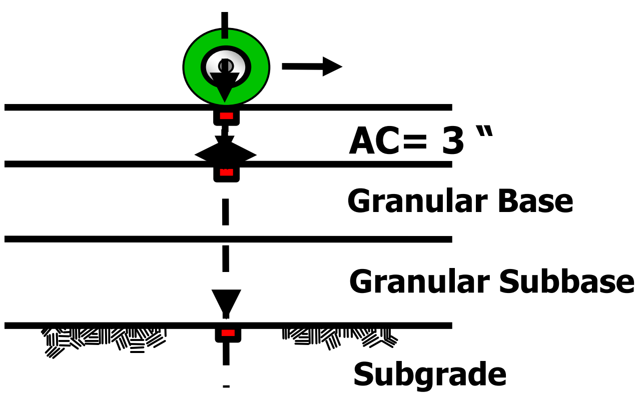
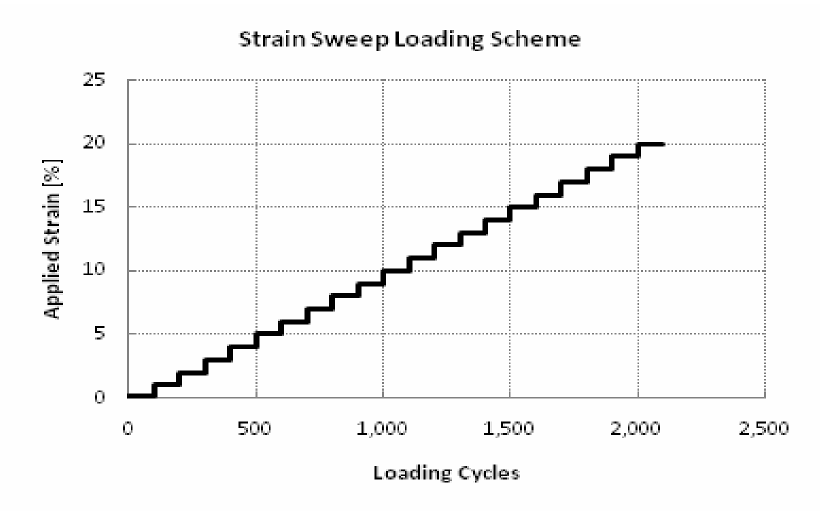




Traffic Volume
Climate

Relating Amplitude Sweeps to Pavement Performance – Mechanistic Approach



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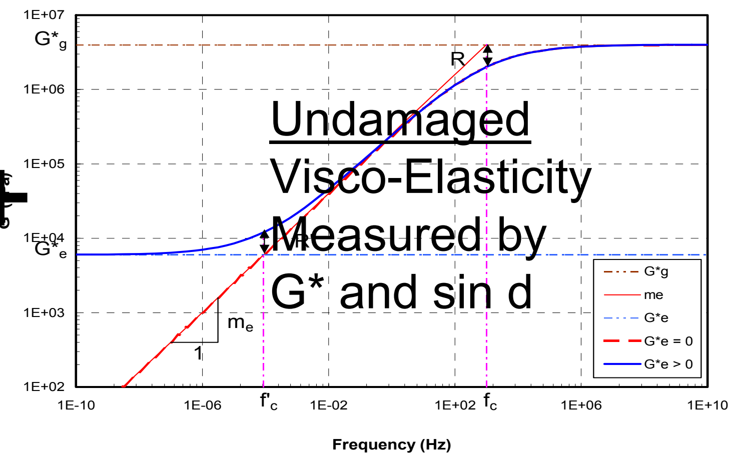
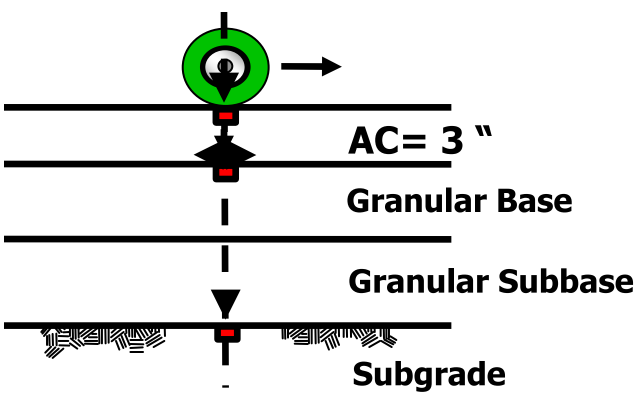




Traffic Volume
Climate

Specification-Type Protocol

- **Proposed accelerated fatigue procedure:**
  1. **Perform following tests:**

     - G* vs frequency >> Determine the value of the factor α.

     - Perform the amplitude sweep at IT grade temperature.

  2. **Calculate the following parameters**

     - Damage intensity to build VECD curve.

     - Determine curve fit coefficients to calculate *A* and *B*.

  3. **Predict number of cycles to failure (Nf) using appropriate strain level based on pavement structure and traffic loading.**

Binder Nf Estimated from Amplitude Sweep + VECD analysis

$$N_f = \frac{f(D_f)^k}{k\left(\pi \frac{I_D}{|G^*|} C_1 C_2\right)^{\alpha}} |G^*|^{-\alpha} (\gamma_{max})^{-2\alpha}$$

Where $k = 1 + (1 - C_2)\alpha$;
f = loading frequency, Hz;
$|G^*|$ = undamaged complex shear modulus;
D_f = damage accumulation at failure.

Kim, Y., H. J. Lee, D. N. Little and Y. R. Kim, "A simple testing method to evaluate fatigue fracture and damage performance of asphalt mixtures", *J. Assn. Asphalt Paving Technologists*, v75, 755-788, 2006.

- **Fatigue model: Nf = A $(\gamma_{max})^B$**
  - **Can be calculated automatically by DSR software**

Example Results of Amplitude Sweep Analysis

Strain Sweep VECD model inputs and results.

Binder	D_f	**2.5%** N_f	**5.0%** N_f	A	B
64-SBS	1,015	57,894	1,480	7.371E+06	-5.290
64-ELV	1,143	18,622	573	1.855E+06	-5.022
58-ELV	1,015	53,053	1,587	5.491E+06	-5.063
64-NEAT	1,156	32,028	781	4.343E+06	-5.358

$$Nf = A\,(\gamma_{max})^B$$

Proposed Limits for Binder (Nf / ESALs) Estimated from Amplitude Sweep

(Measured at **IT**)

Pavement Micro-strain		1000	600	200
	Binder Strain	5%	3%	1%
Traffic ESALs	(S) 1,000,000	***1.20***	***0.90***	***0.25***
	(H) 3,000,000	***1.35***	***1.00***	***0.30***
	(VH) 10,000,000	***1.50***	***1.10***	***0.35***

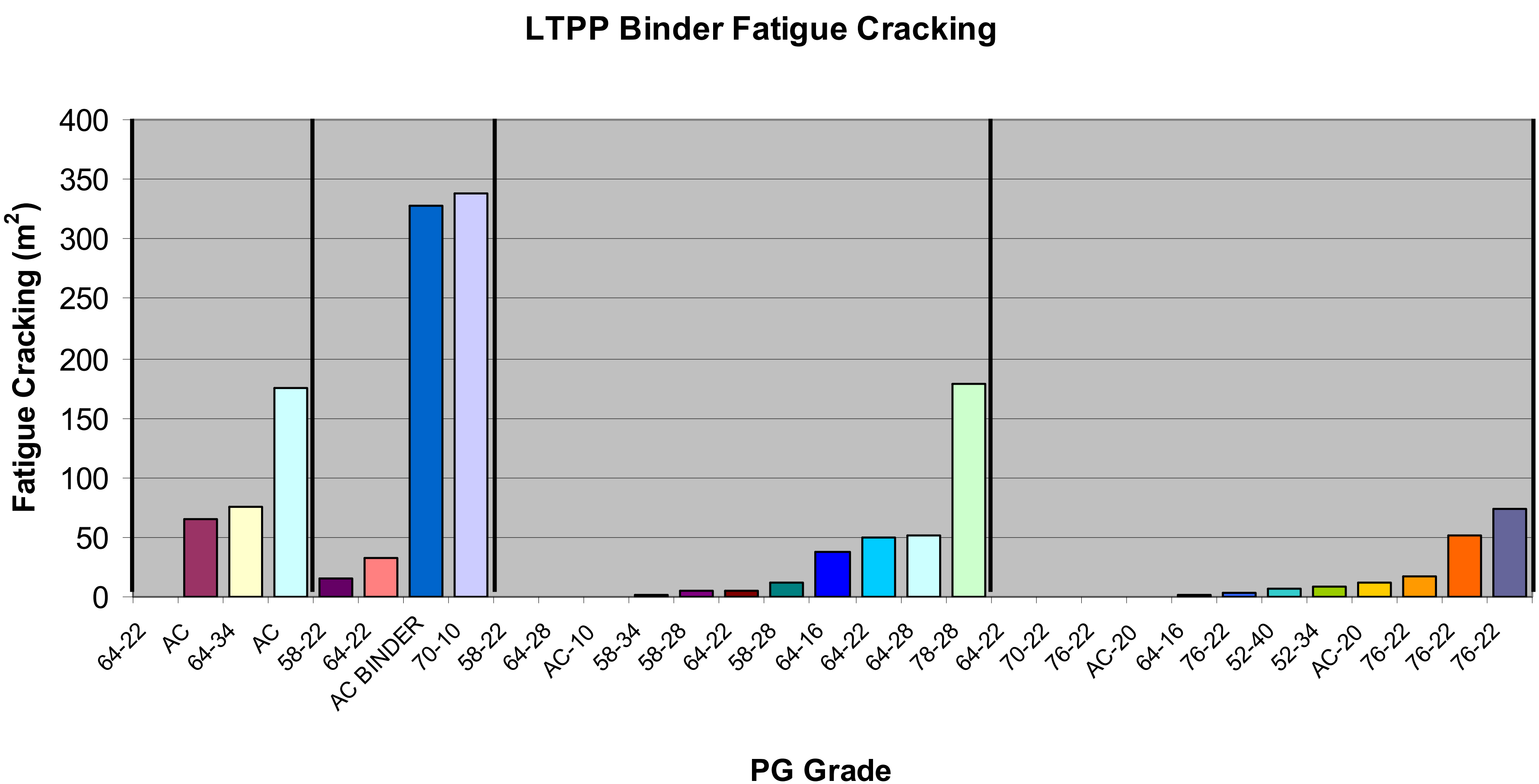
Next Steps

- Draft an AASHTO Procedure for Linear Amplitude Sweep and VECD modeling .
  - Estimate A, B and binder Nf
- Draft an AASHTO Procedure for Binder Yield Energy Test (BYET)
- Continue testing for validation
  - LTPP
  - More modified binders (F2a)
- Working with TFHRC Group
  - Sharing a common set of binders
  - TFHRC can perform Double-Edged Notched Tensile (DENT) testing to calculate Equivalent Work of Fracture (EWF)

LTPP Study

- 30 binders ordered from the LTPP MRL
  - From all four climate types
    - (DN, DF, WF, WN)
  - PG-grades range from 52-40 to 76-22.
  - Area of fatigue cracking ranges
    - from 0 – 338 m^2.
- Compare binder fatigue test results to pavement performance

LTPP Binders



Thank You!

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