Using Damage Testing to Relate Binder Properties to Pavement Performance

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Research Team

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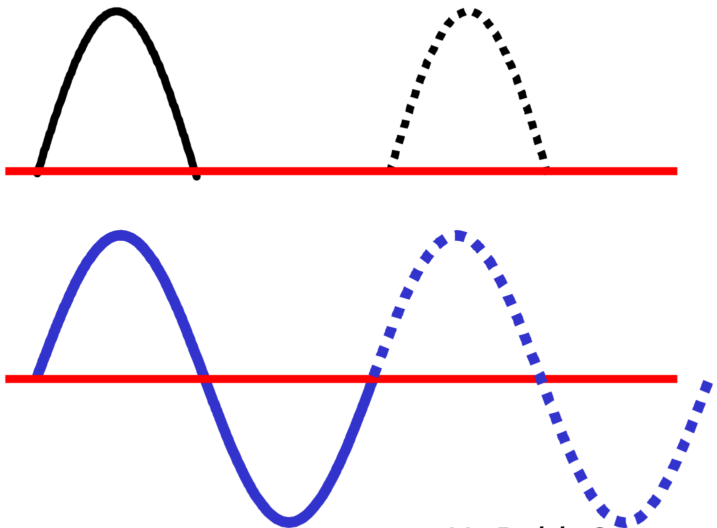
Background (1)

- Load associated damage:
  - Rutting (permanent deformation)
  - Fatigue cracking
- Both are caused by application of traffic loading.

- Rutting is:Non-steady cyclic
  (repeated creep)
- Fatigue: Steady state cyclic
  (reversal cyclic)



Background (2)

- What is Damage ?
- Change in material's structure .. (Disturbance).
  - Loss of stiffness or strength due to change in bonding…. May be re-orientation of bonds…
- This change consumes ENERGY…
  - Damage is associated with energy dissipation
    - Cracking requires energy.
    - Viscous/plastic flow requires energy.

Background (3)

- Energy lost is a good indicator of damage.
- Less energy lost

  = Better resistance to damage

How to measure/estimate energy lost?

- Pre-failure–Linear visco-elastic testing (SHRP)
- Damage testing- (NCHRP 9-10)

Background (4)

Why Damage Testing ?

- Pavements economics dictate a compromise:

  " Design to control progressive damage "
- Linear VE is not always a good indicator of damage.
  - Energy lost in LVE confounds damping with damage.
- Modifiers are reinforcements to limit damage.
  - They are activated at different stages of damage.

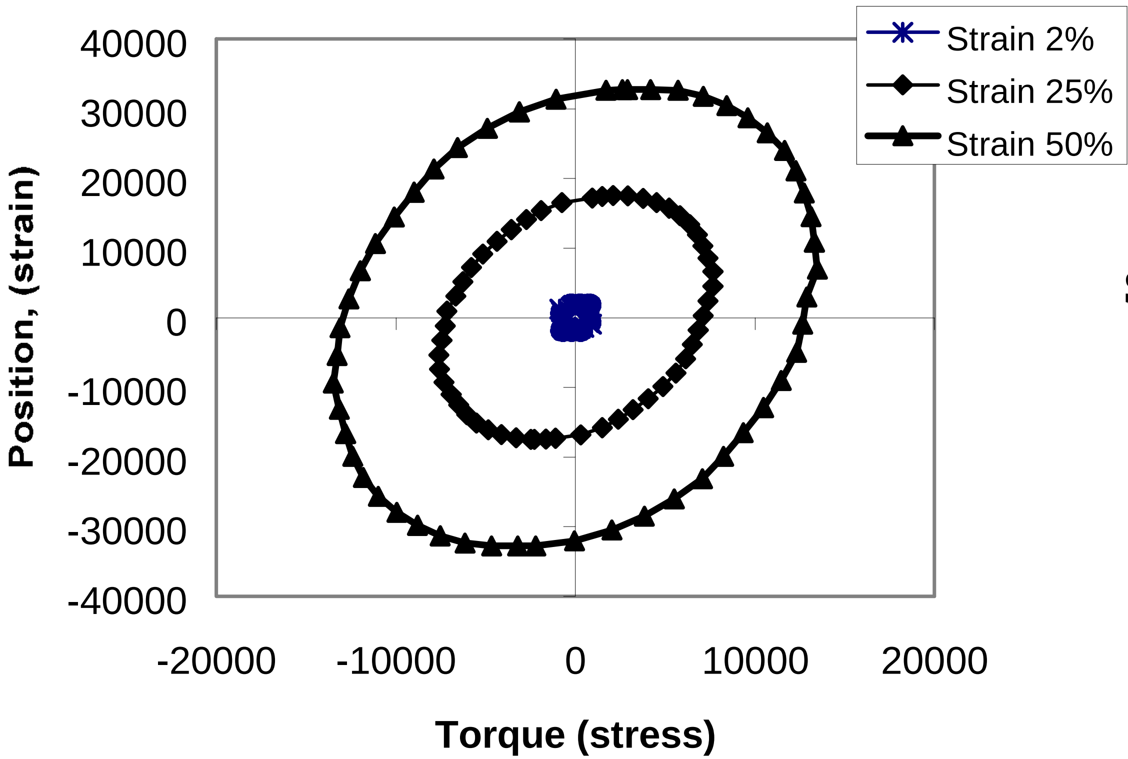
Binder Rutting Measurements

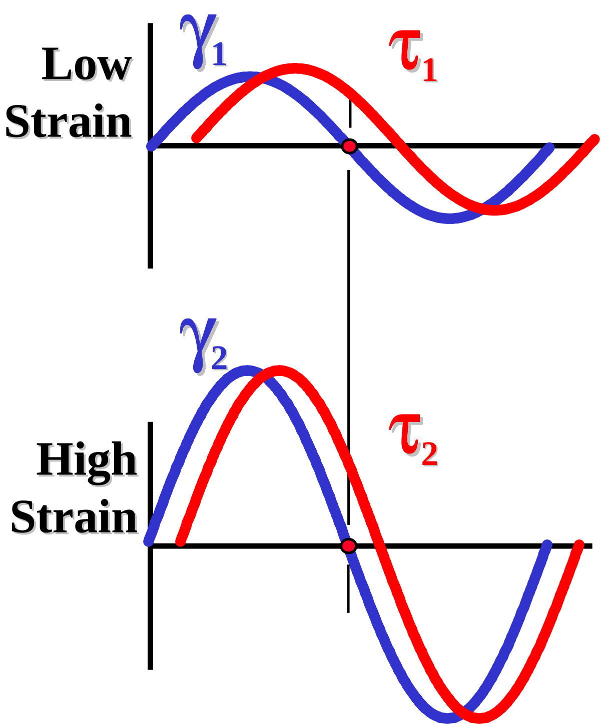
- Current concept: In the specification, $G^*/\sin\delta$ is used to rate the binder contribution to rutting damage resistance.
- Selected based on the dissipated energy concept as applied to linear visco-elastic materials.

$$\Delta W = \pi \cdot \tau_i \cdot \gamma_i \cdot \sin\delta \,; \quad \gamma_i = \tau_{i/G^*}$$

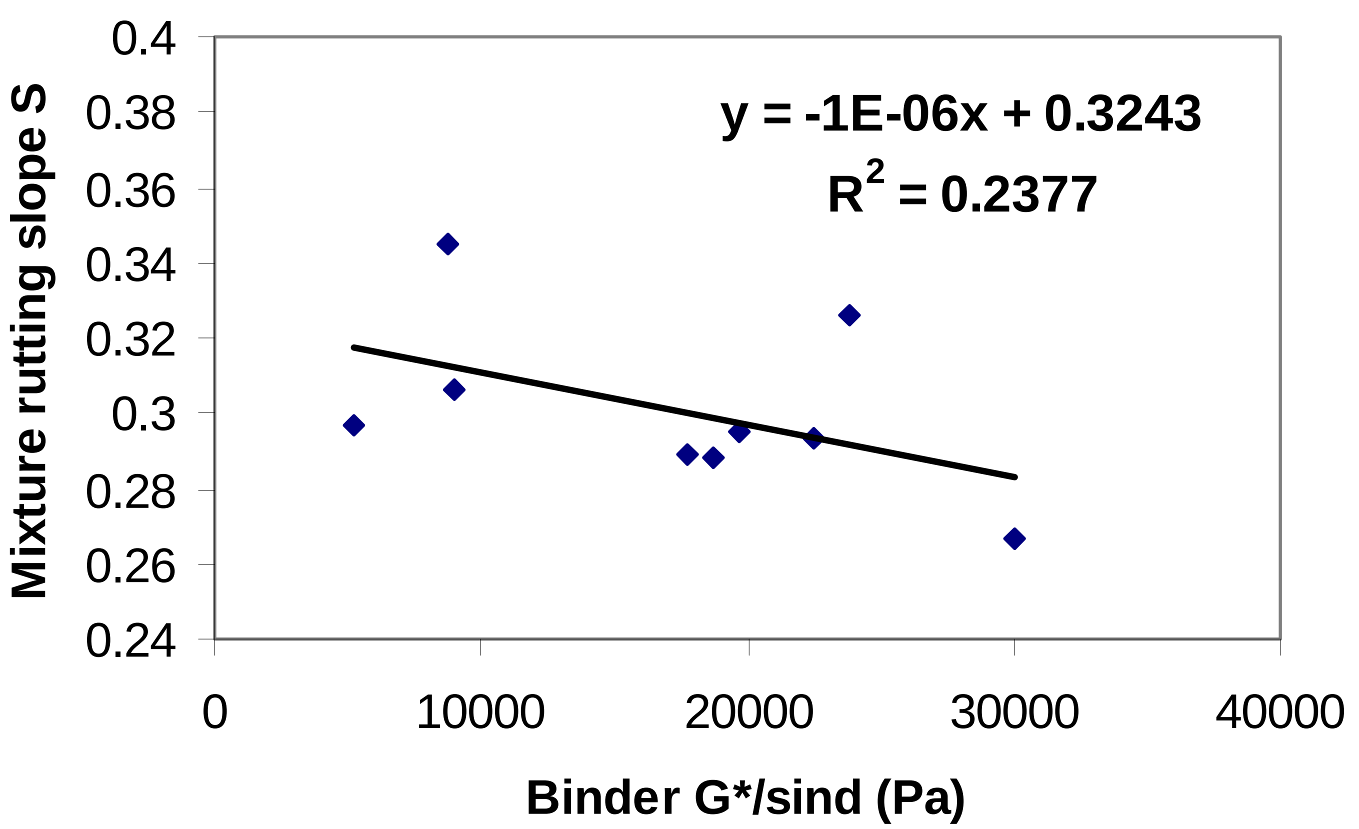
$$= \pi \cdot \tau_i^2 \cdot \sin\delta / G^*$$

Current Test: Cyclic Loading





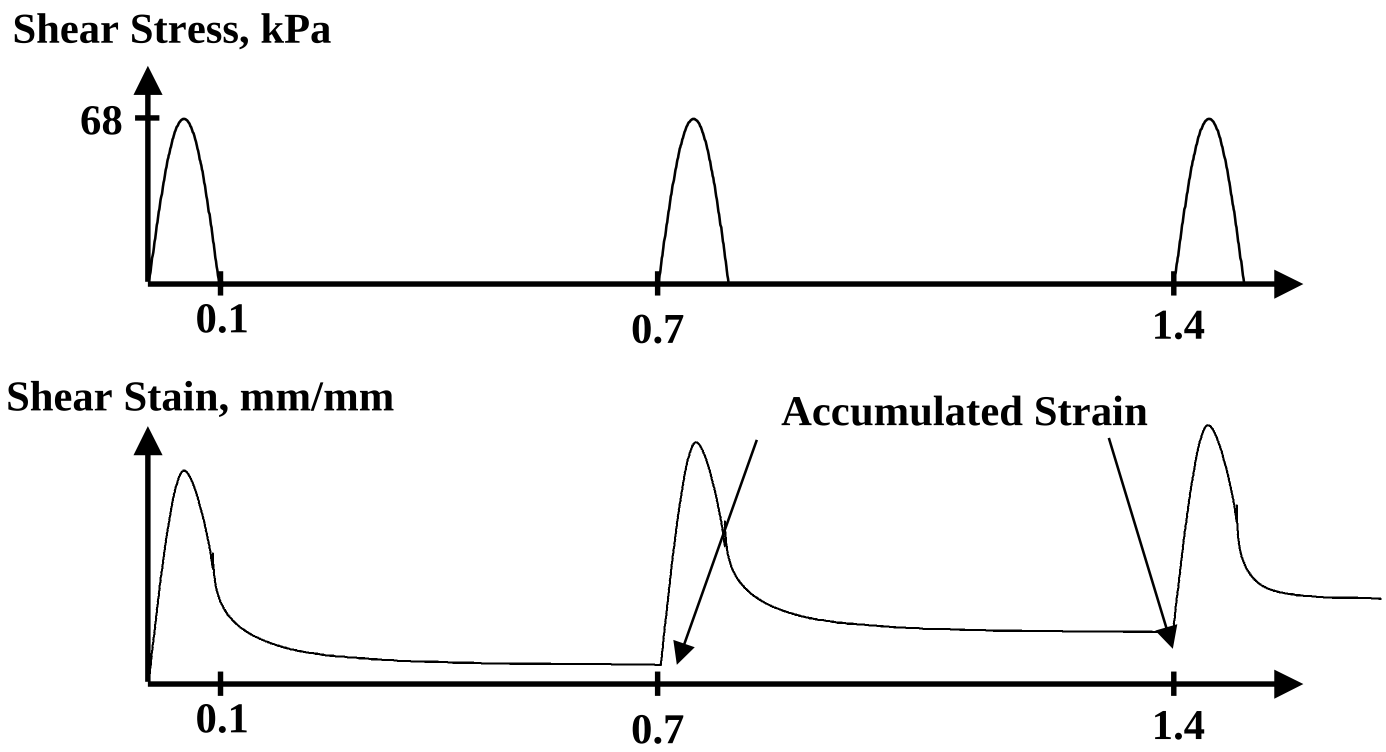
Evaluation of Current Binder Parameter



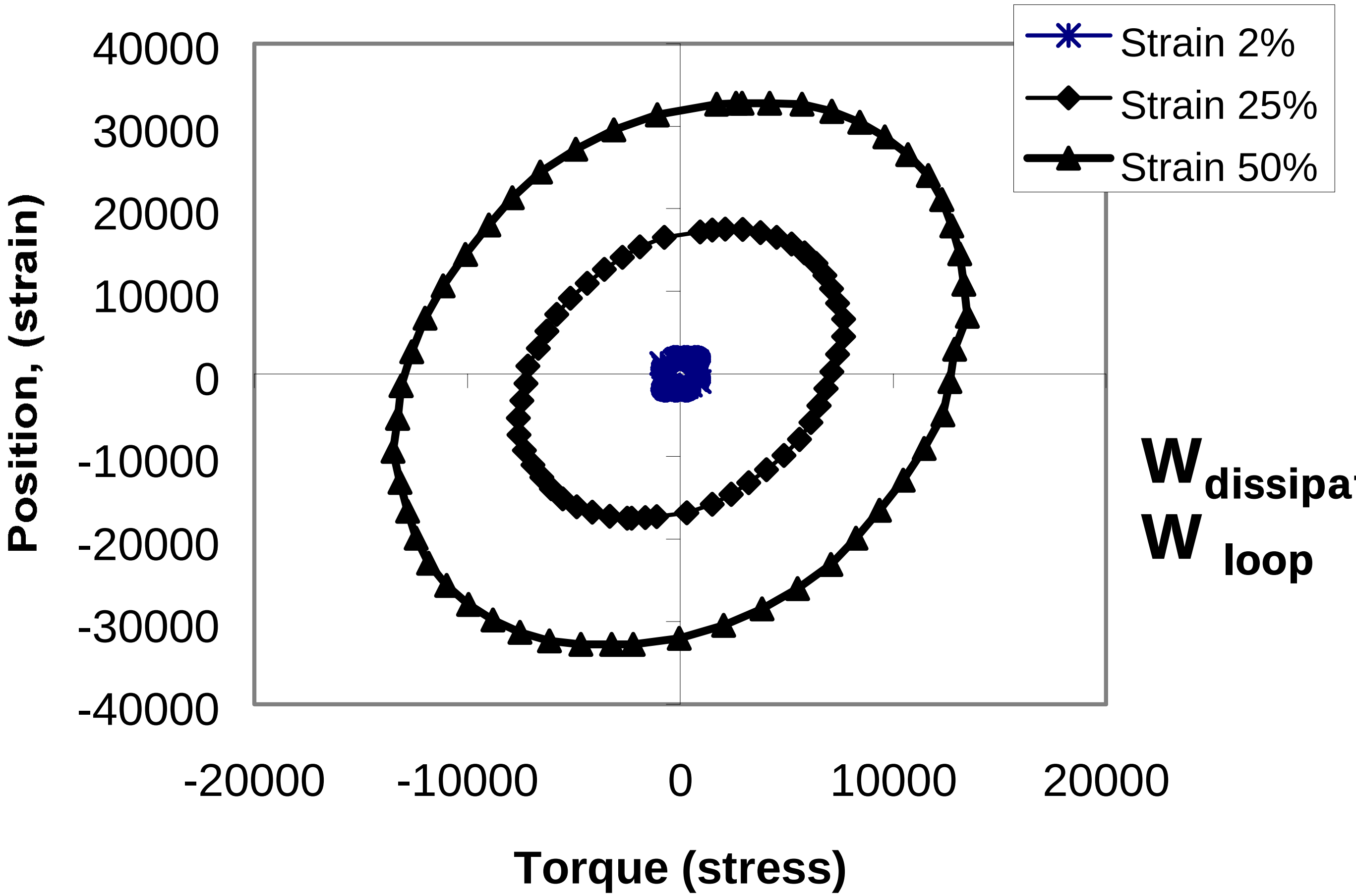
Main Hypothesis to Explain Lack of Relationship

- The cyclic loading with complete reversal in strain or stress is not appropriate for rating contribution of binders to rutting resistance.

Asphalt Mixture Testing

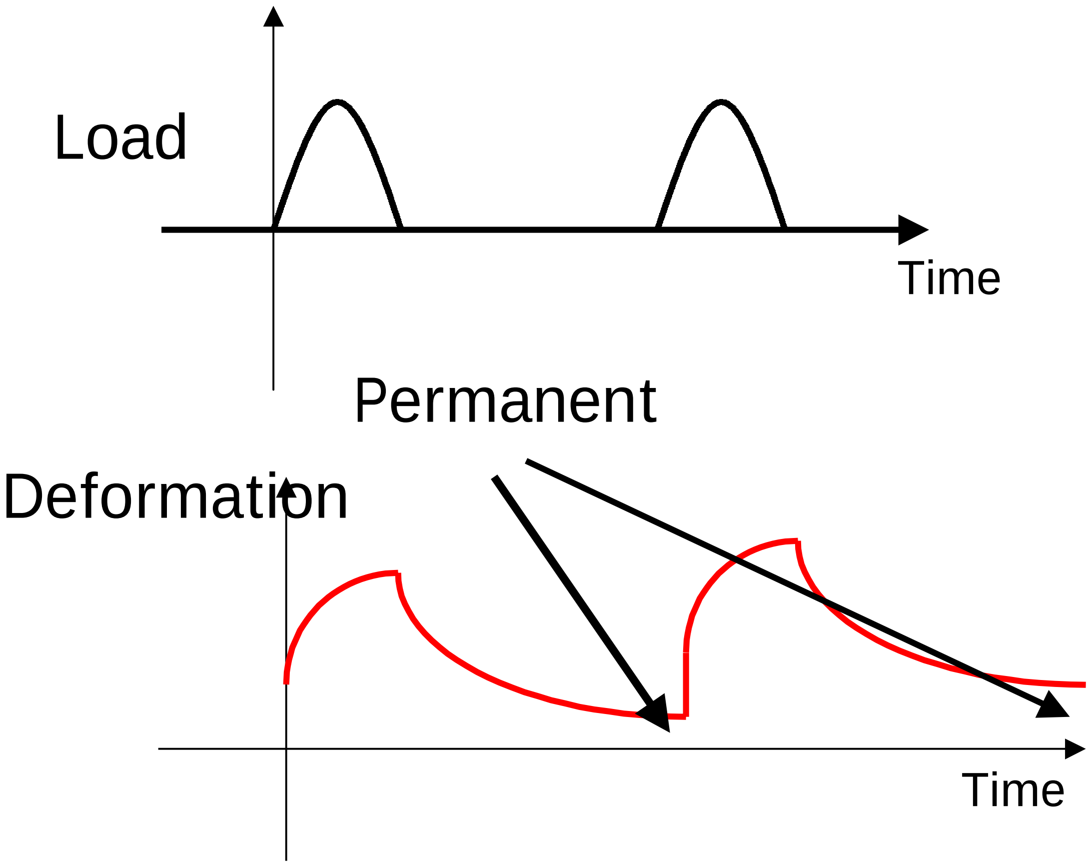


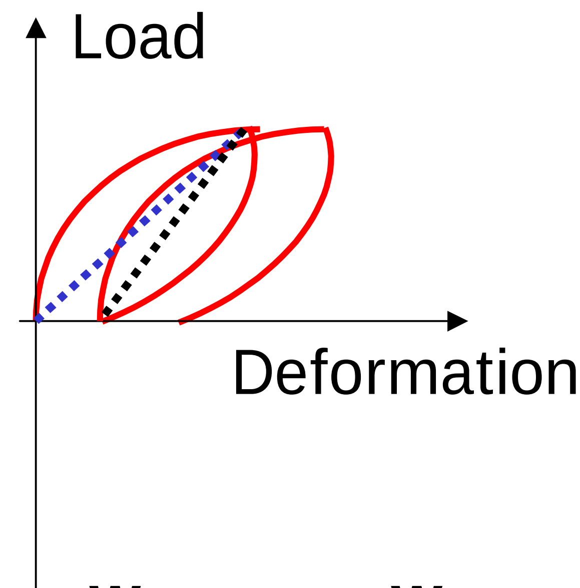
Hypothesis: Cyclic Loading



$W_{dissipated} = W_{loop}$

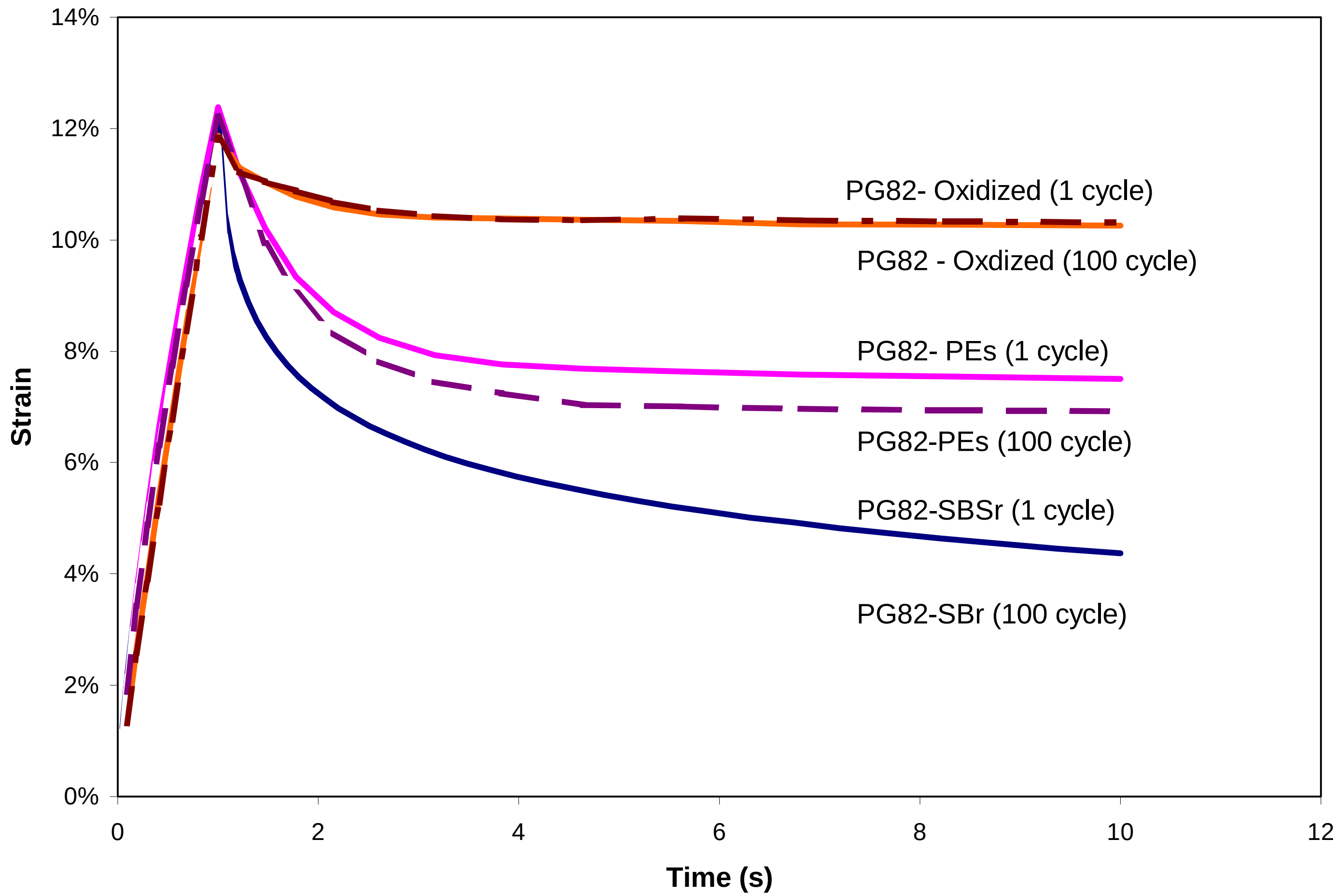
Better Binder Rutting Test



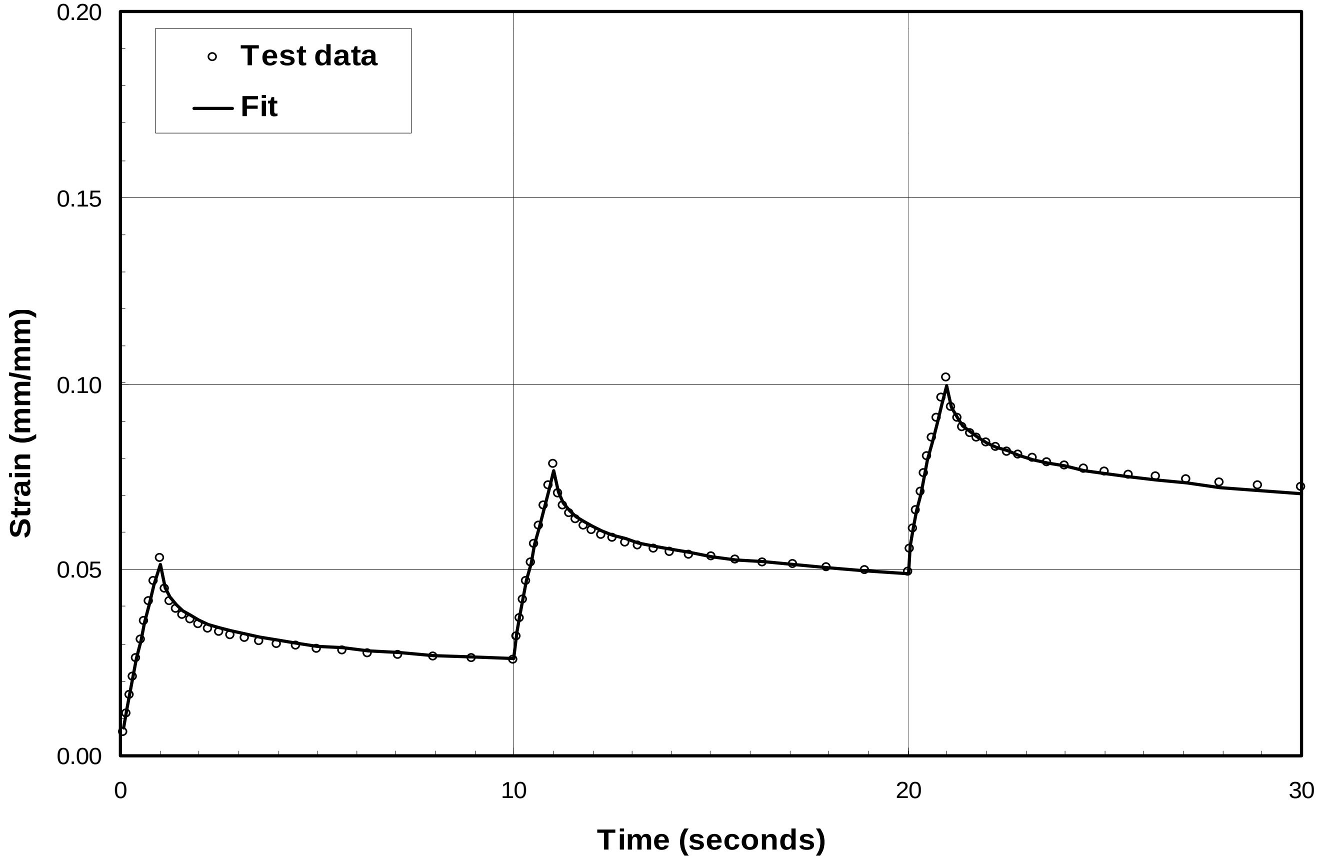


$$W_{dissipated} = W_{loop} - W_{stored}$$

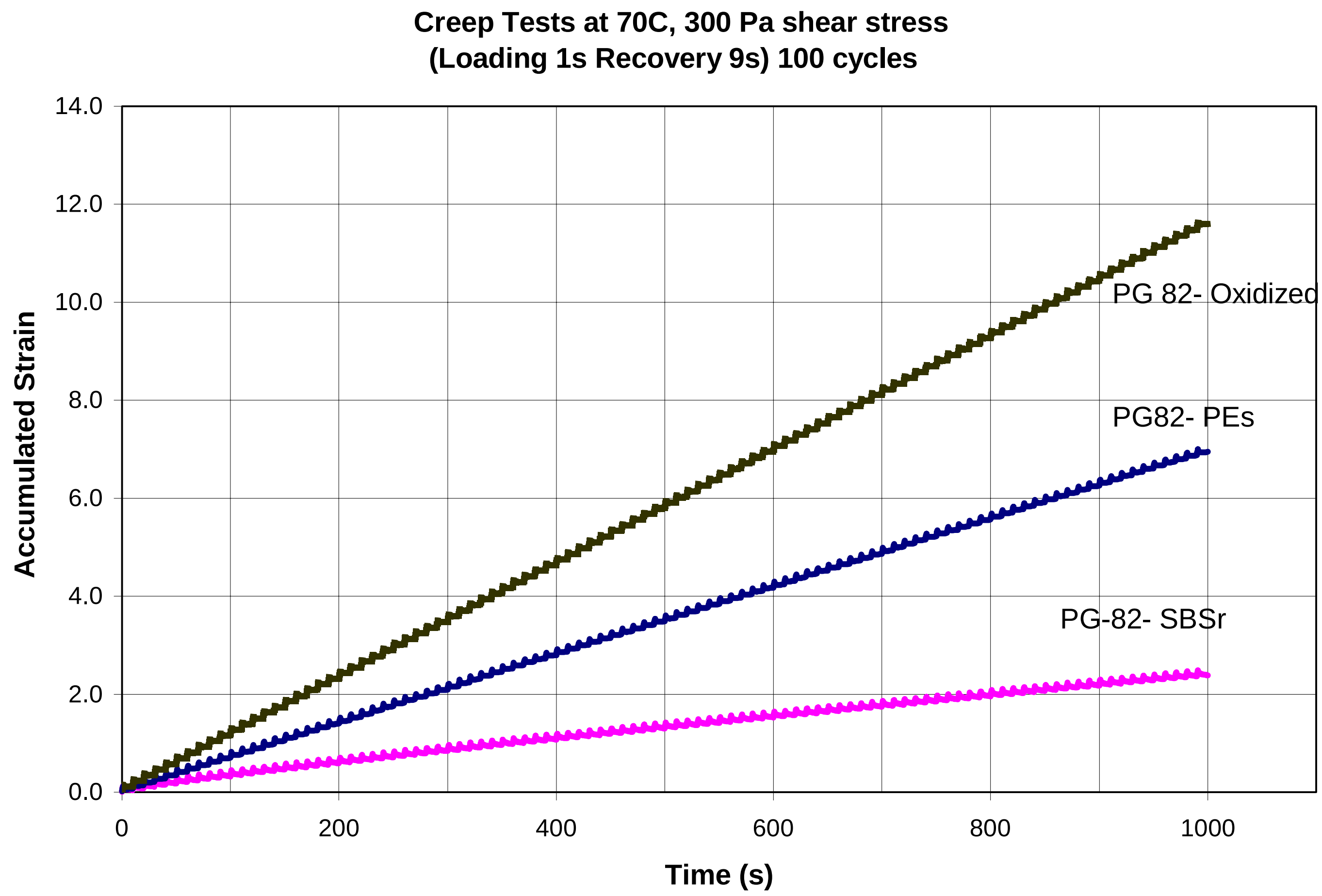
Repeated Creep Test for Binders (Single Cycle)



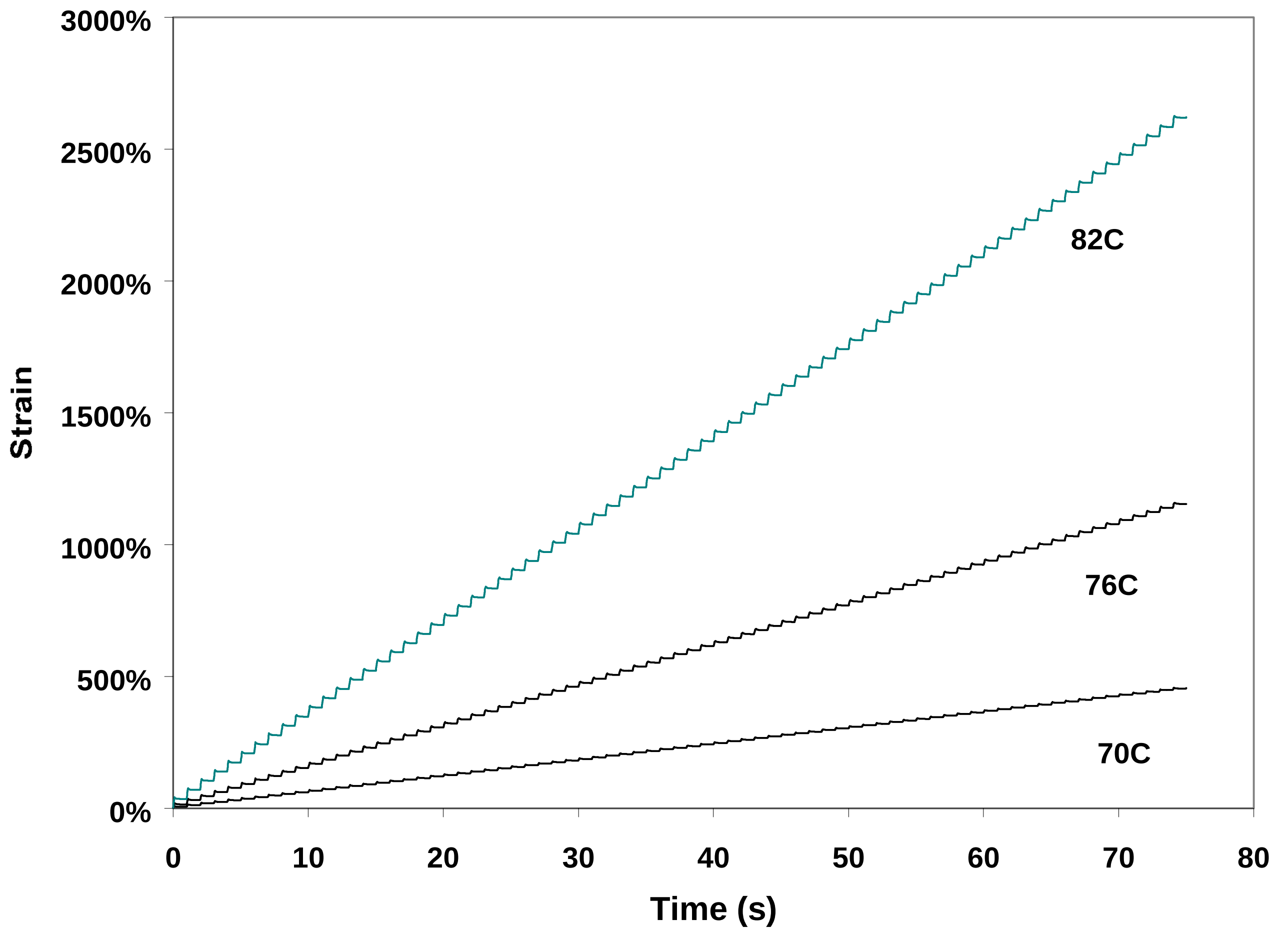
Damage Behavior



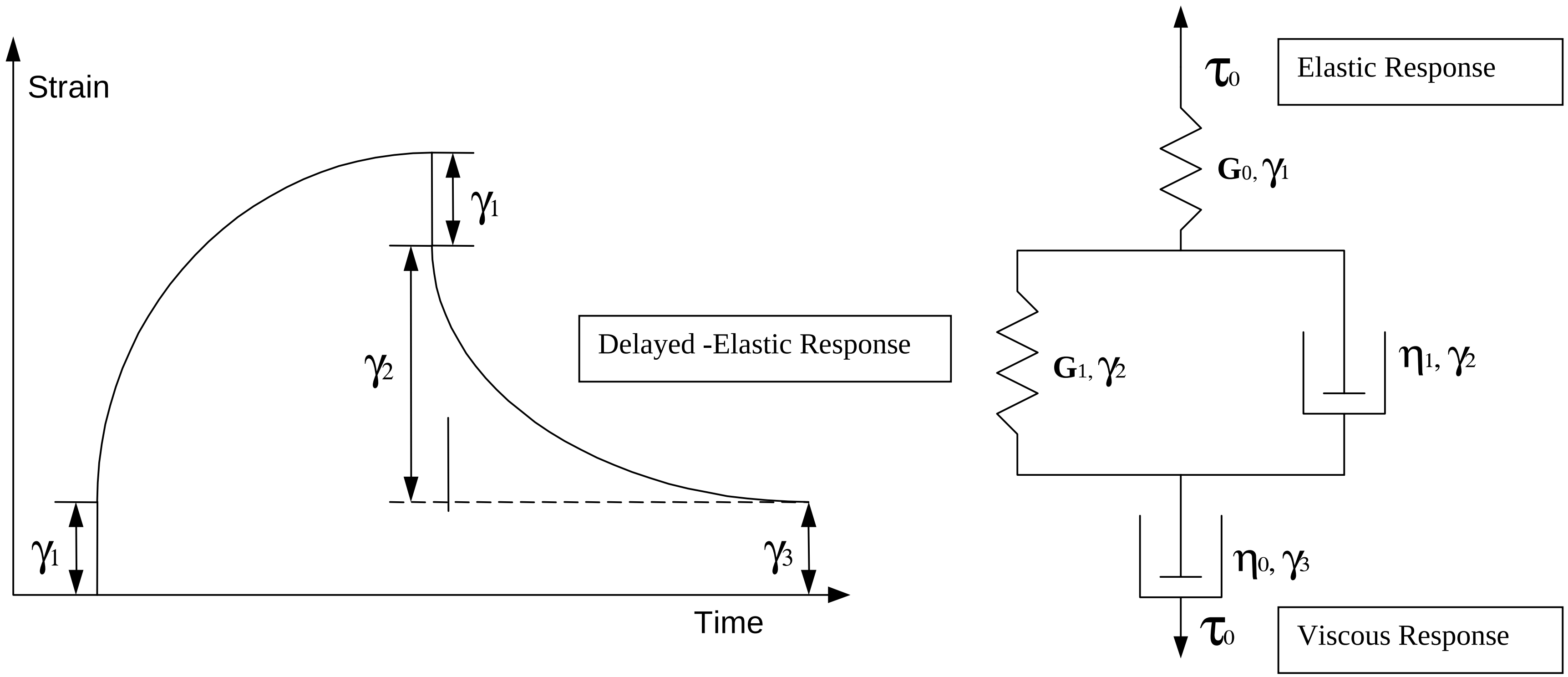
Repeated Creep Test for Binders



Linearity of Creep and Recovery Response (Temperature)



Four-Element (Burgers) Model



Binder Rutting Parameter

- The creep compliance, J(t), in terms of its elastic component (J_e), the delayed-elastic (J_{de}), and the viscous component (J_v):

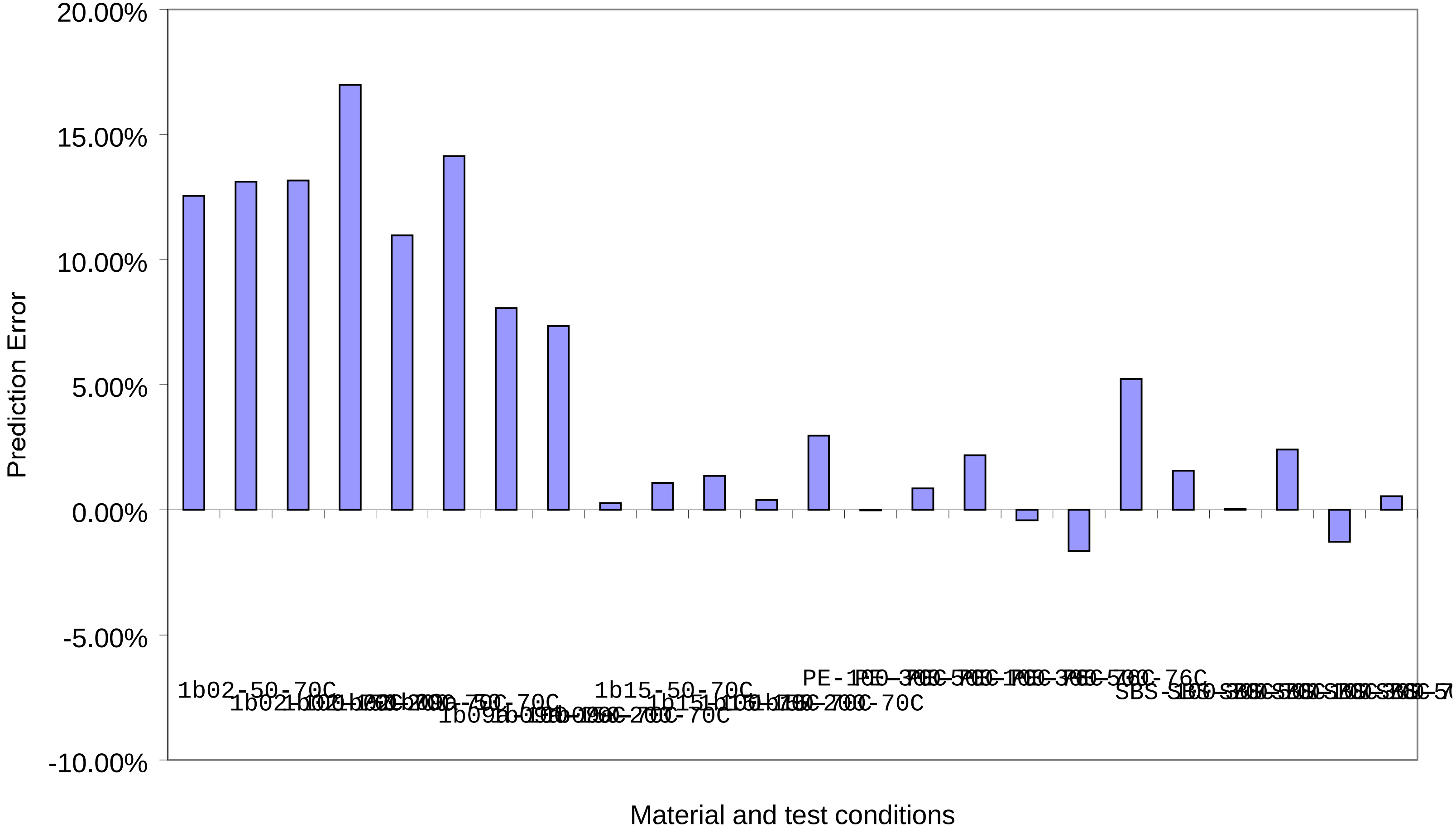
$$J(t) = J_e + J_{de} + J_v$$

- Calculate the inverse of the compliance (Gv= 1/Jv).
- Gv is defined as the viscous component of the creep stiffness.

Error Due to Using Initial Cycles

		Using Cycles 1,2, and 3			Using Cycles 50, 51, and 52		
ID	Test strain @ 100	Predict Strain	Prediction Error		Predict Strain	Prediction Error	
SBSr-50-70C	0.288	0.596	**107.0%**		0.324	**12.5%**	
PEs-50-70C	0.571	1.016	**78.1%**		0.633	**11.0%**	
Oxd-50-70C	1.689	1.725	**2.1%**		1.694	**0.3%**	
PE-100-70C	6.355	7.931	**24.8%**		6.544	**3.0%**	
PE-500-70C	37.443	42.994	**14.8%**		37.764	**0.9%**	
PE-100-76C	10.636	13.474	**26.7%**		10.868	**2.2%**	
PE-500-76C	88.122	85.037	**-3.5%**		86.677	**-1.6%**	
SBS-100-70C	2.550	3.898	**52.9%**		2.683	**5.2%**	
SBS-300-70C	8.409	12.188	**44.9%**		8.540	**1.6%**	
SBS-100-76C	7.216	9.418	**30.5%**		7.390	**2.4%**	
SBS-300-76C	24.520	27.322	**11.4%**		24.206	**-1.3%**	

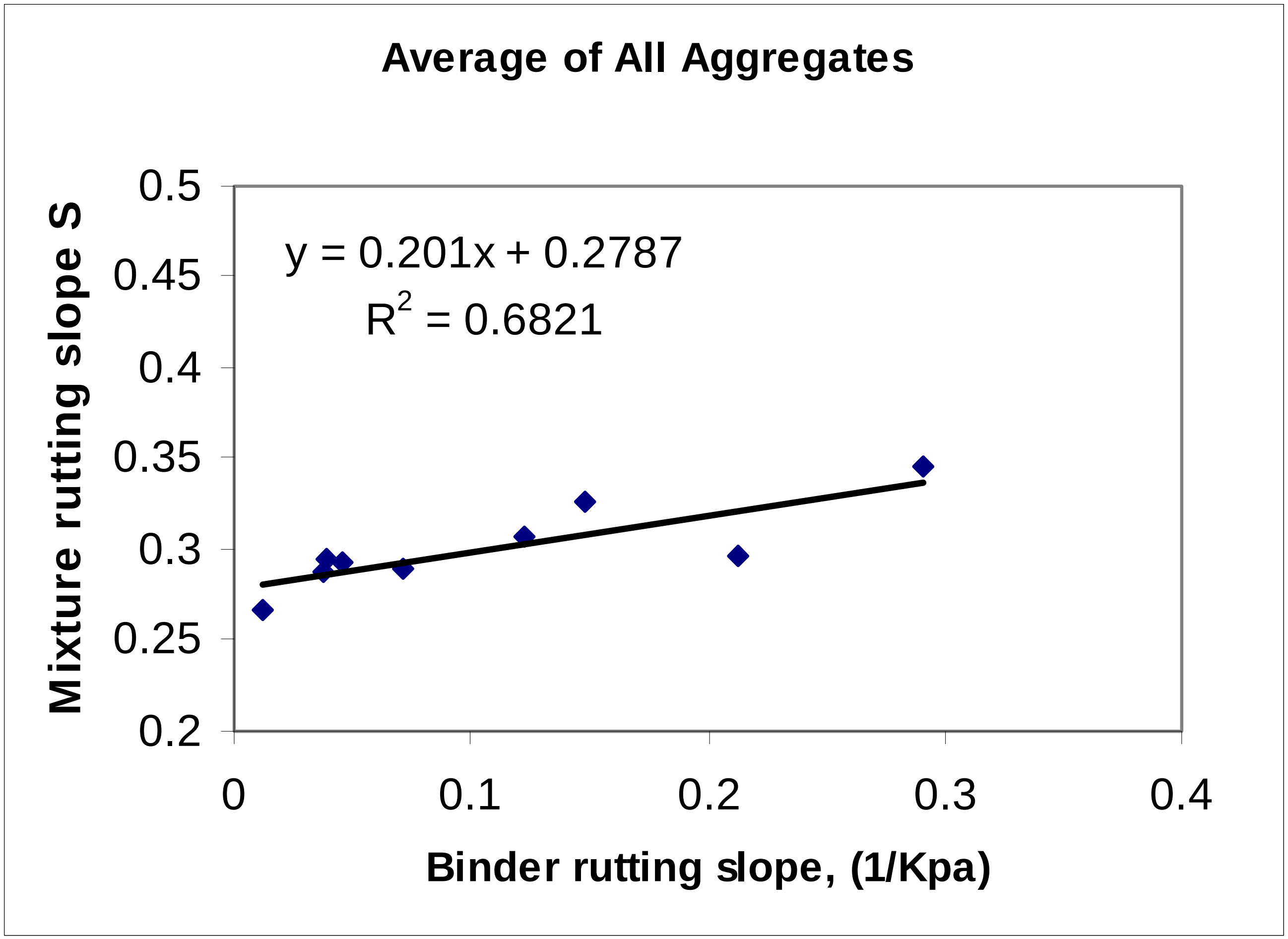
Test Results vs Curve Fitting



Creep Indicators vs G*/sinδ

	R1B02	R1B09A	R1B15
ε_{total}	2.389	6.948	11.599
G* at 300 Pa	10989	11379	15272
δ at 300 Pa	56.2	60.3	73.9
sinδ	0.831	0.869	0.961
G*/sinδ	13224	13100	15895
$\varepsilon_L/\varepsilon_p$ at 1 cycle	2.787	1.656	1.169
$\varepsilon_L/\varepsilon_p$ at 100 cycle	5.571	1.764	1.179

Correlation with Mixture Performance (Average)



Fatigue Behavior of Binders and Mixtures

Can we use damage behavior to relate binder role in mixture fatigue ?

Background-Fatigue (1)

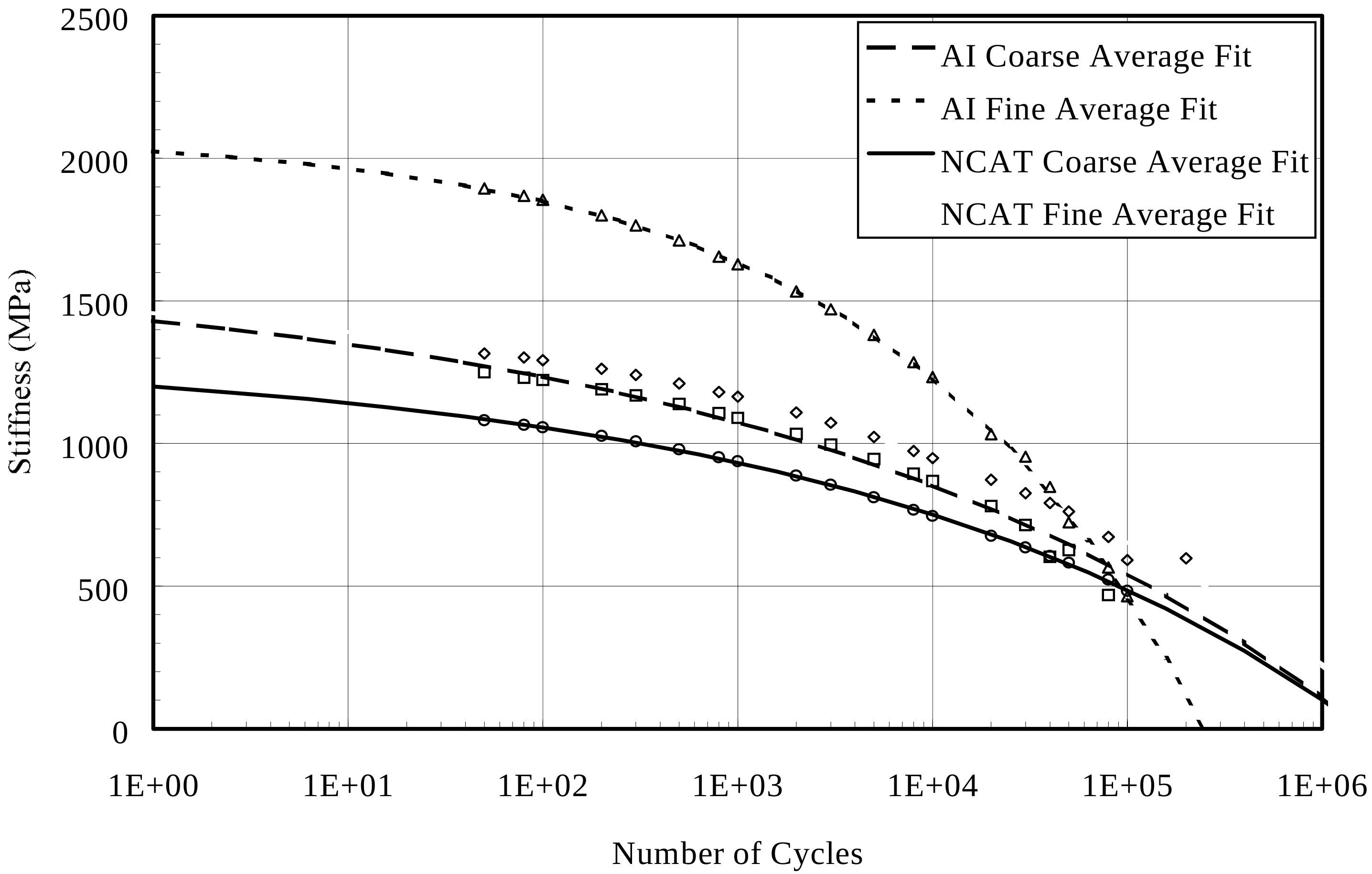
- Fatigue of asphalt pavement can be:
  - controlled-stress phenomenon (typical of strong, thick layers),

$$\Delta W_{ds} = \pi .\tau_i .\gamma_i .\sin \delta ; \quad \gamma_i = \tau_{i/G*}$$
$$= \pi .\tau_i^2 .\sin \delta / G*$$

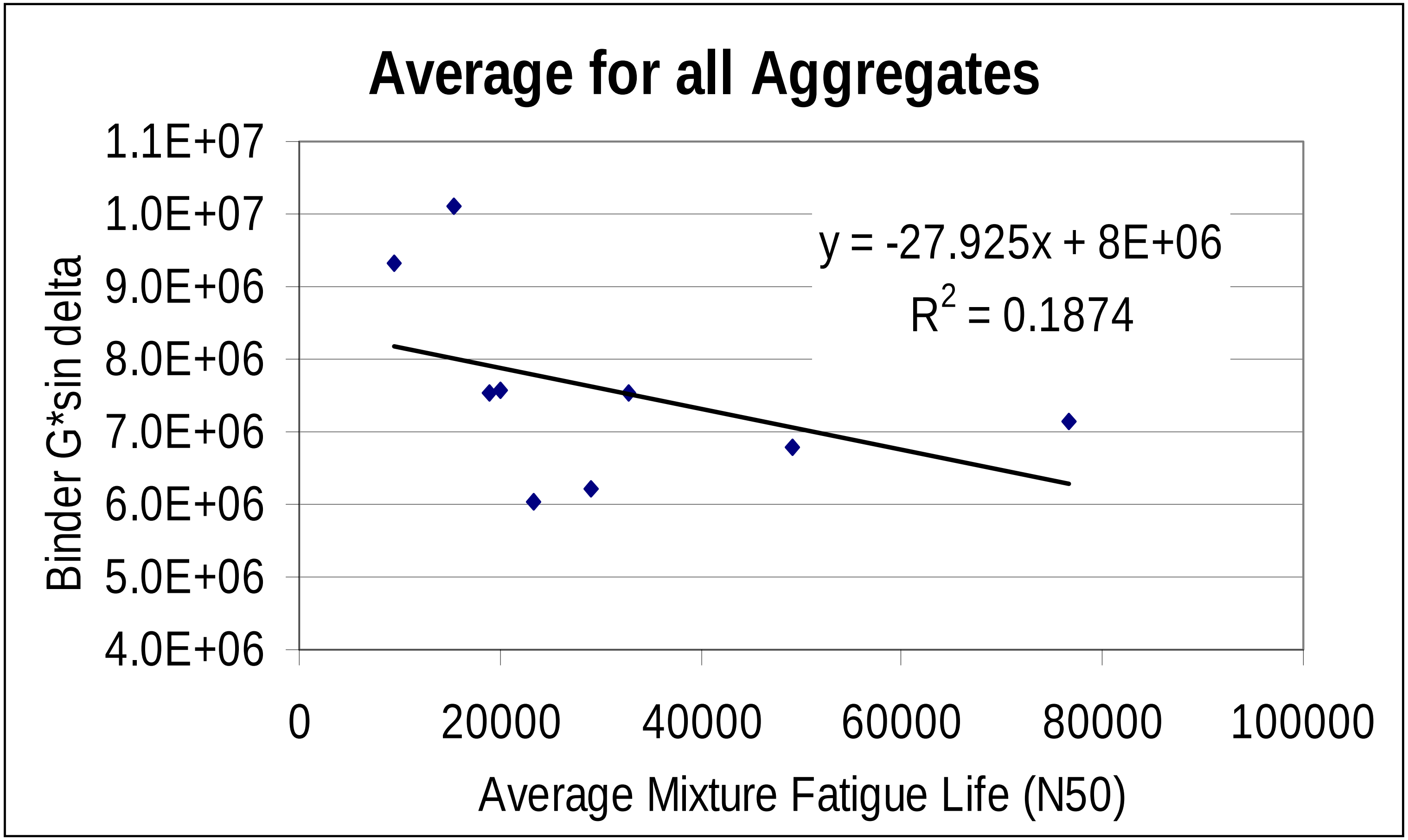
  - controlled-strain phenomenon (typical of weak, thin layers).

$$\Delta W_{dw} = \pi .\tau_i .\gamma_i .\sin \delta ; \quad \tau_i = \gamma_{i.G*}$$
$$= \pi .\gamma_i^2 .\sin \delta . G*$$

Average Fatigue Response



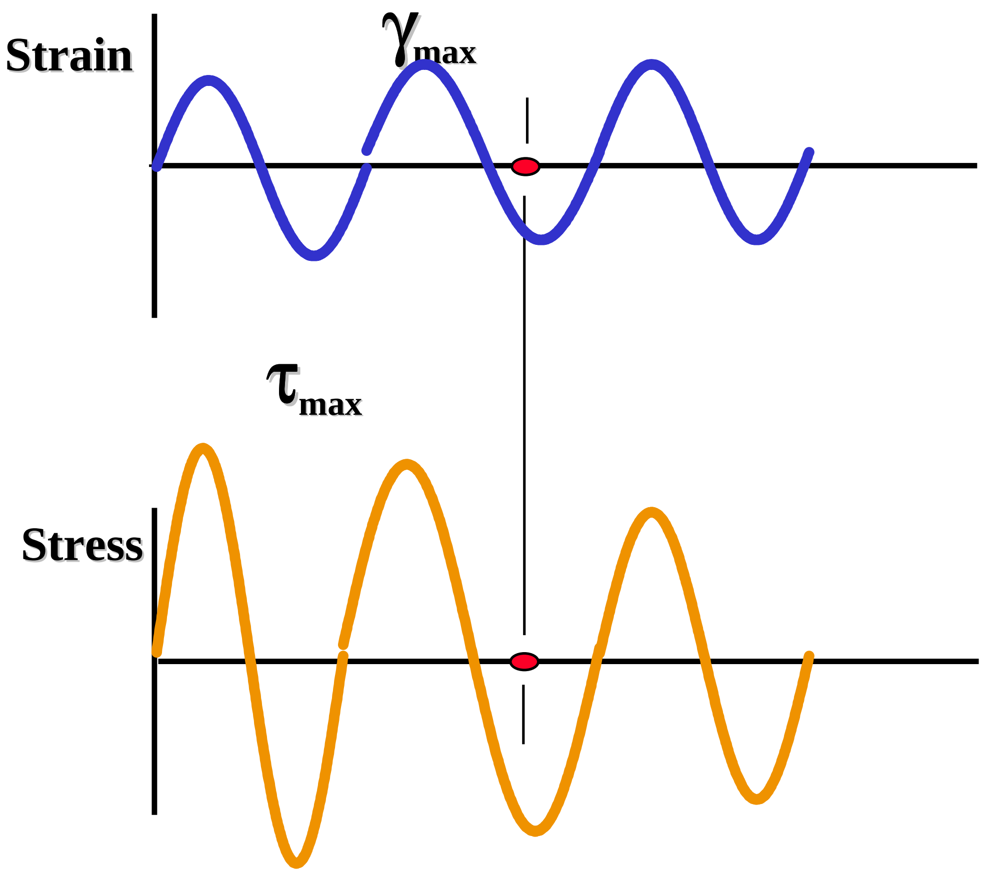
Correlation between G*sinδ and Mixture Fatigue Life



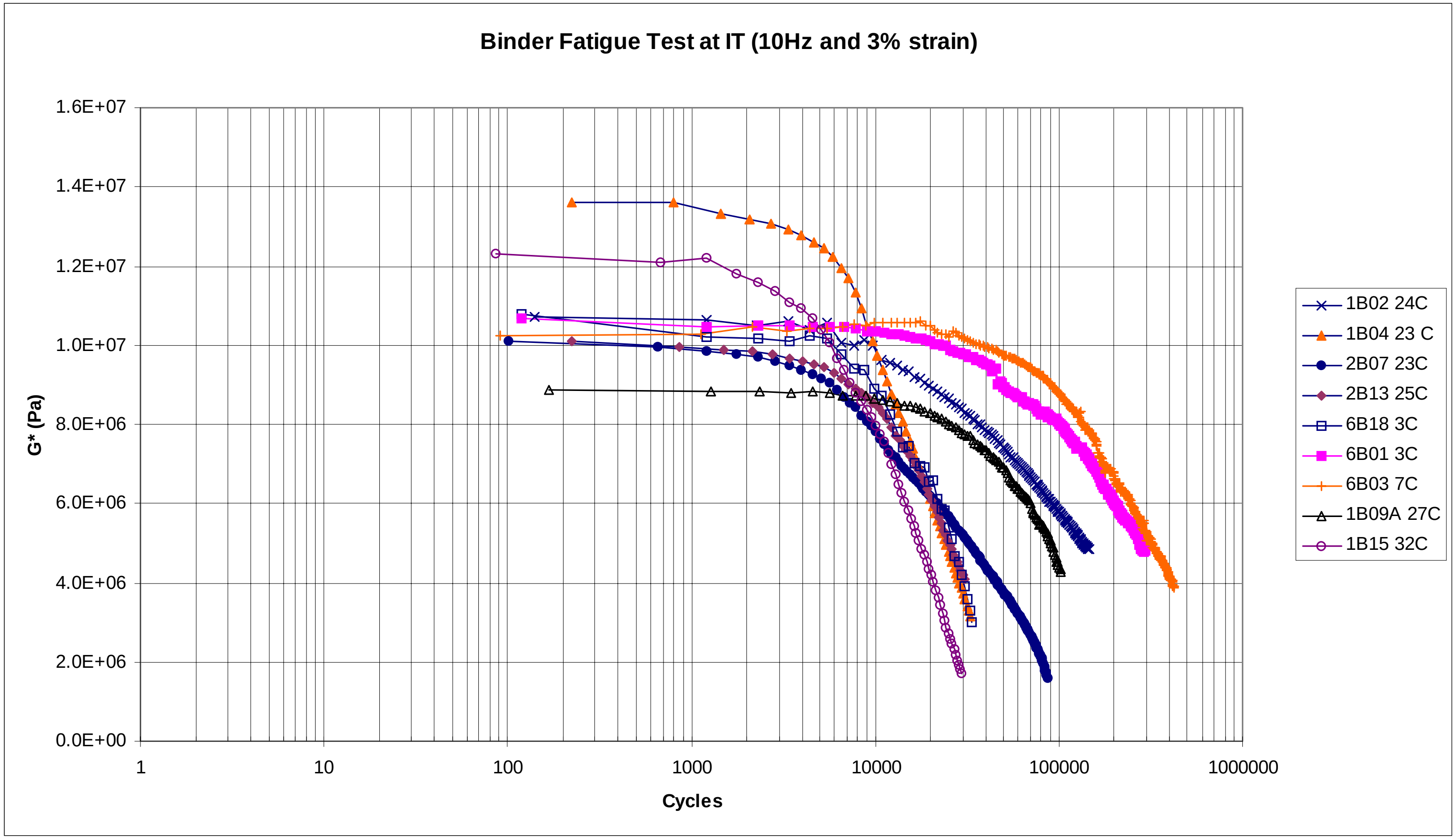
Binder-only Fatigue Test

- Time Sweep
  - RTFO Aged.
  - DSR.
  - 10 Hz.
  - Intermediate temperature.
  - Strain-controlled to compare with mixture.

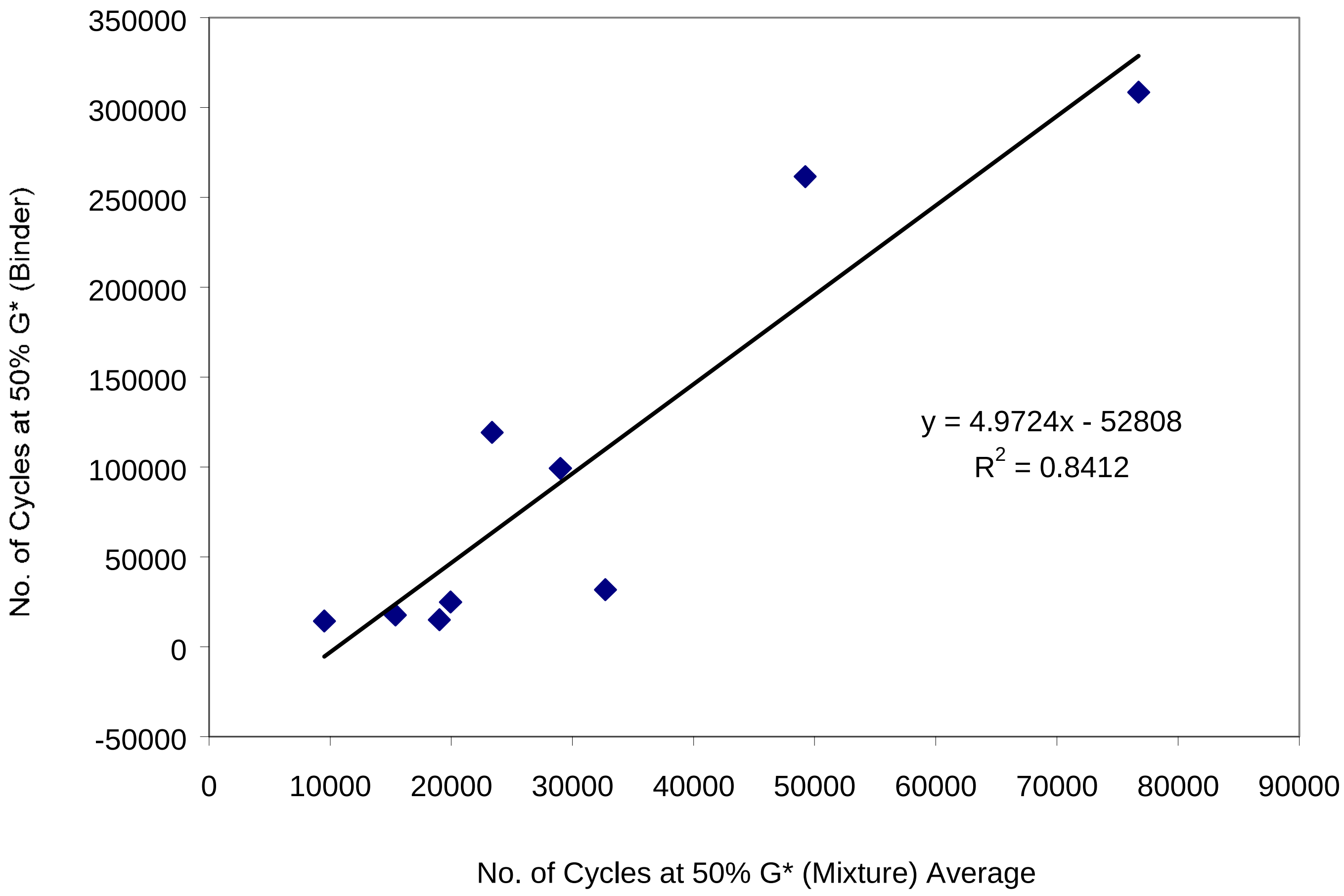
Binder Time Sweep



Test Results (DSR)



Correlation between Binder and Mixture Fatigue Lives (Average)



Development of a Binder Fatigue Parameter

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- Dissipated Energy Concept
  - The energy dissipated per cycle is calculated as follows:

$$\Delta W_i = \pi \tau_i \gamma_i \sin \delta$$

  - The accumulated dissipated energy after n cycles is:

$$W_n = \sum_{i=1}^{n} \Delta W_i$$

Rate of change of dissipated energy

- Ghuzlan and Carpenter (TRB 2000) defined the ratio of dissipated energy as:

$$\frac{\Delta DE}{DE} = \frac{W_i - W_{i+1}}{W_i}$$

in which

W_i = the total dissipated energy at cycle i, and

W_{i+1} = the total dissipated energy at cycle i+1.

Dissipated Energy Ratio

- Pronk defined the dissipated energy ratio (R_{de}) as follows:

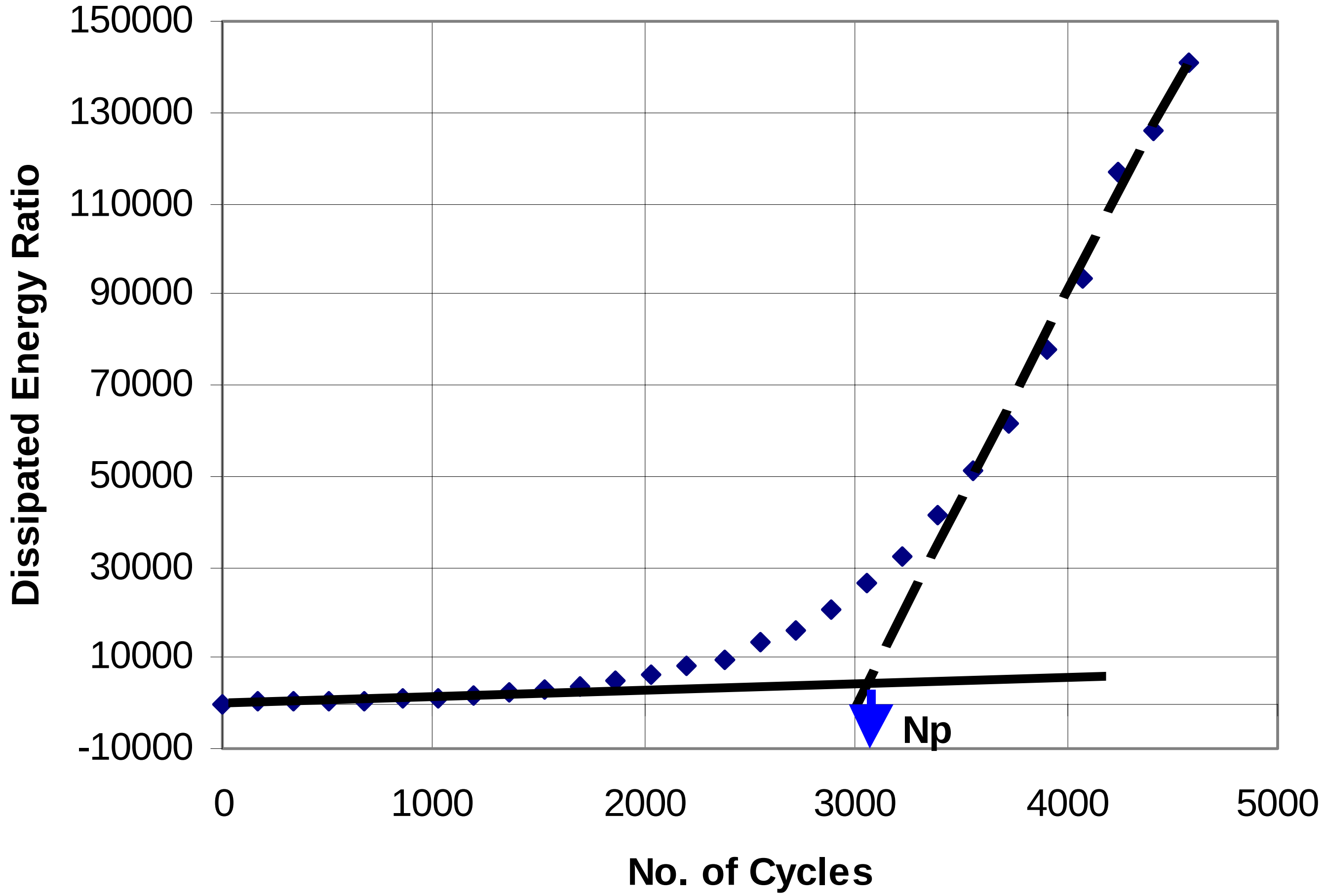
$$R_{de} = \frac{W_n}{\Delta W_n}$$

In which

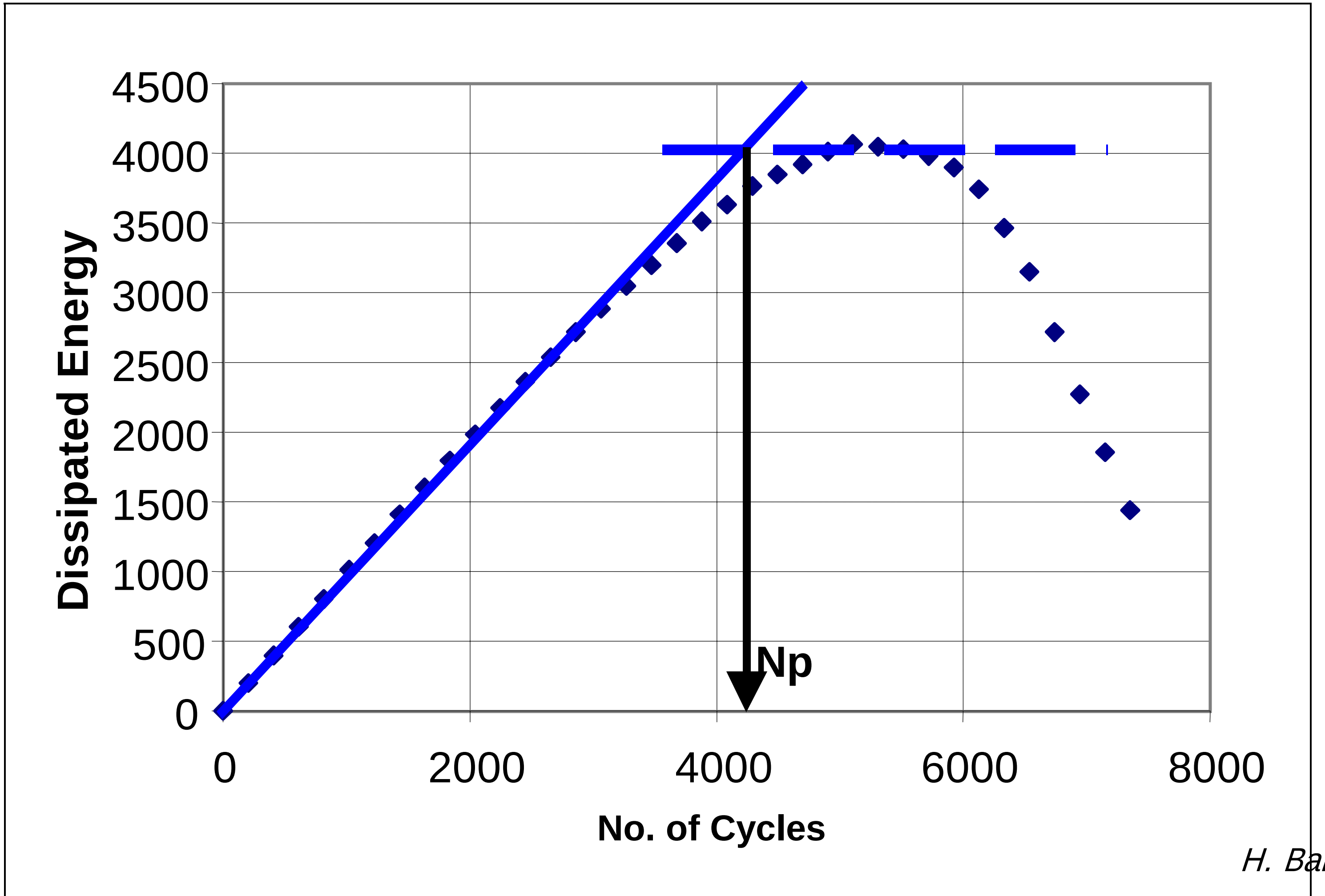
W_n = the total sum of the dissipated energy up to cycle n, and

ΔW_n = the dissipate energy at cycle n.

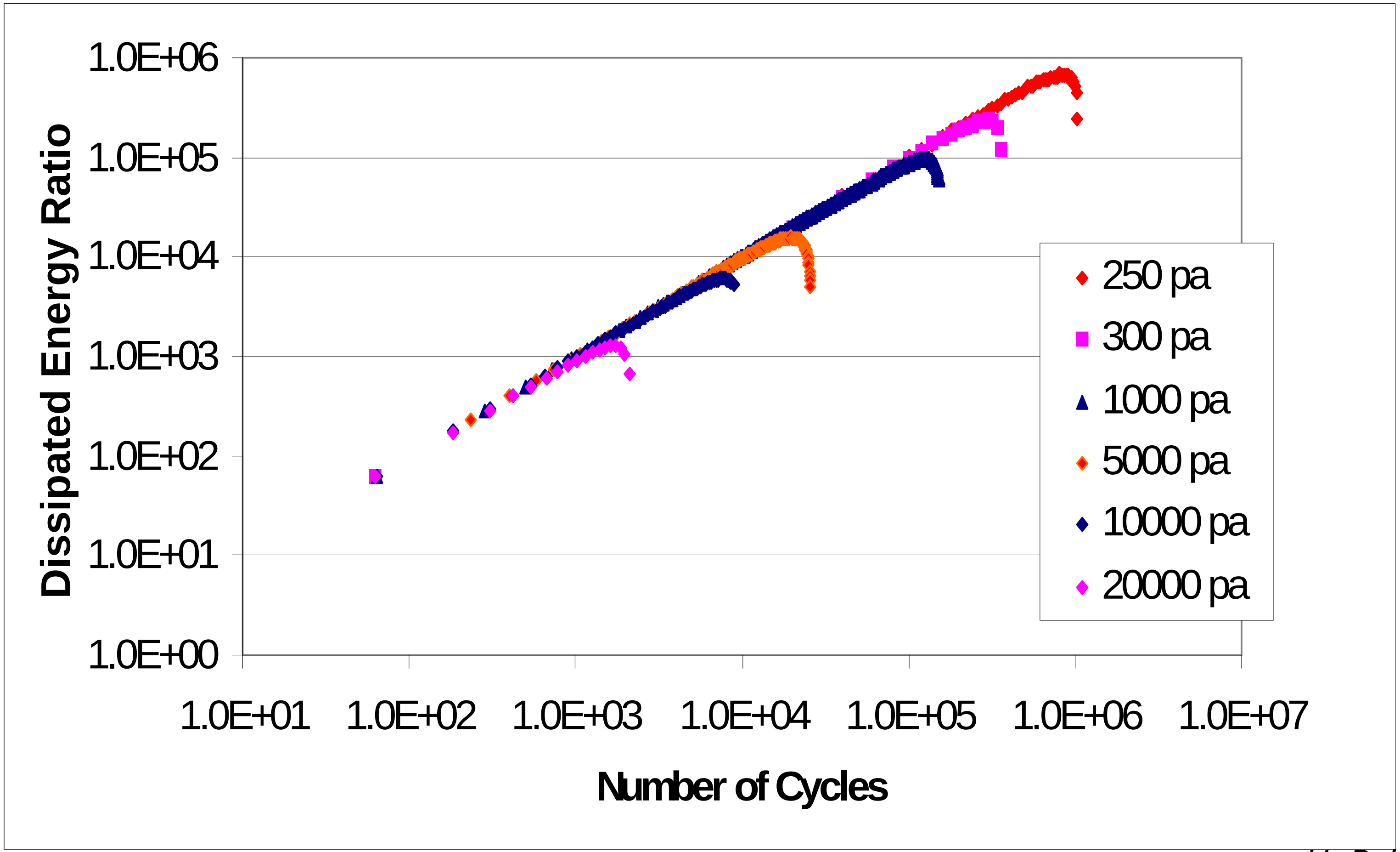
Used for Constant-Strain



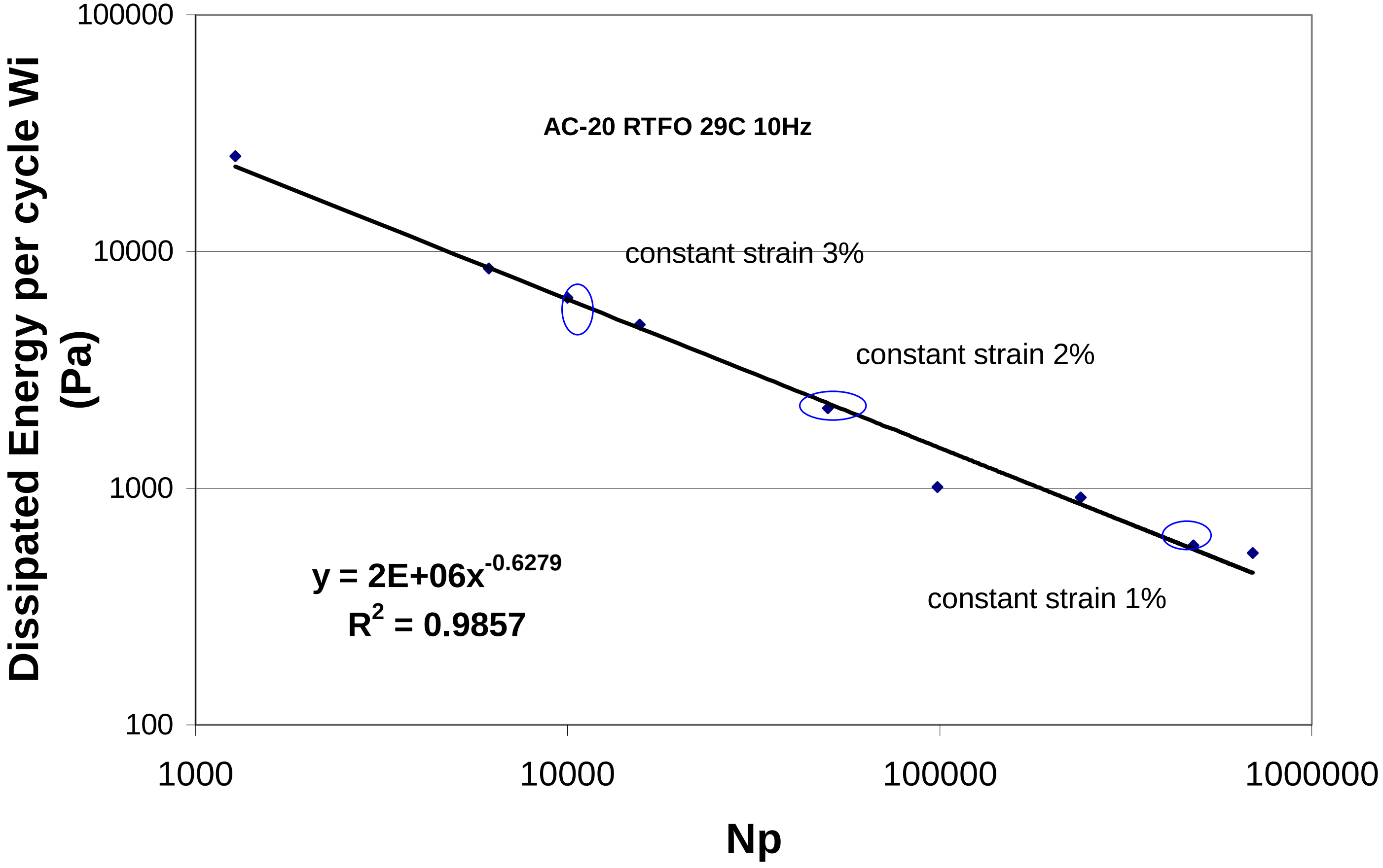
Used for Constant-Stress



Validation of Binder Fatigue Test



Validation of Independence of Loading Mode



Summary of Findings (1)

- There are critical questions about the validity of the binder rutting parameter G*/sinδ.
- *Damage behavior*, as measured by Repeated creep test of binders is introduced as a better method.
- The correlation between Gv and mixture rutting is found to be better than the current G*/sin δ.

Summary of Findings (2)

- The poor correlation of mixture fatigue with binder G*sinδ indicates that measuring damage behavior of binders is needed.
- Time sweep test is introduced as a promising binder-only damage fatigue test.
- The dissipated energy ratio approach shows superiority over current binder fatigue parameter in determining the fatigue life of binders.

Acknowledgments / Disclaimer

- Opinions and Conclusions are those of the researchers. They are not necessarily those of TRB, NRC, FHWA, and AASHTO.

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Thank You for this Opportunity

Questions !