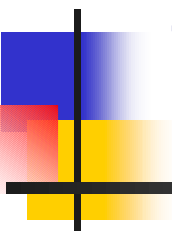


Using Damage Testing to Relate Binder Properties to Pavement Performance



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The University of Wisconsin
Asphalt Group

*The First International Symposium on
Binder Rheology and Pavement
Performance*

Calgary, Alberta, CA – August 13-15, 2000

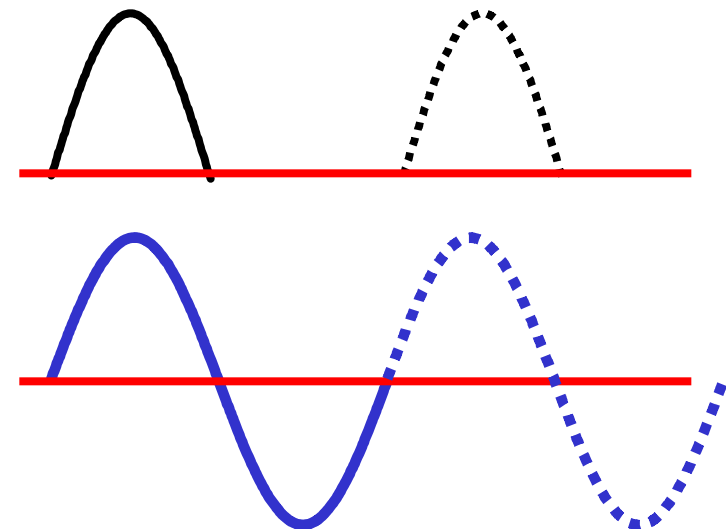


Research Team

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 - Yu Hu

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.

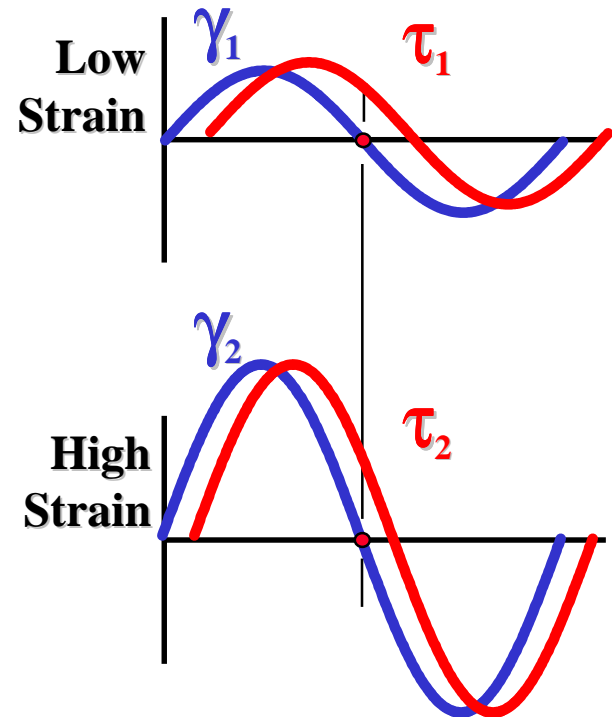
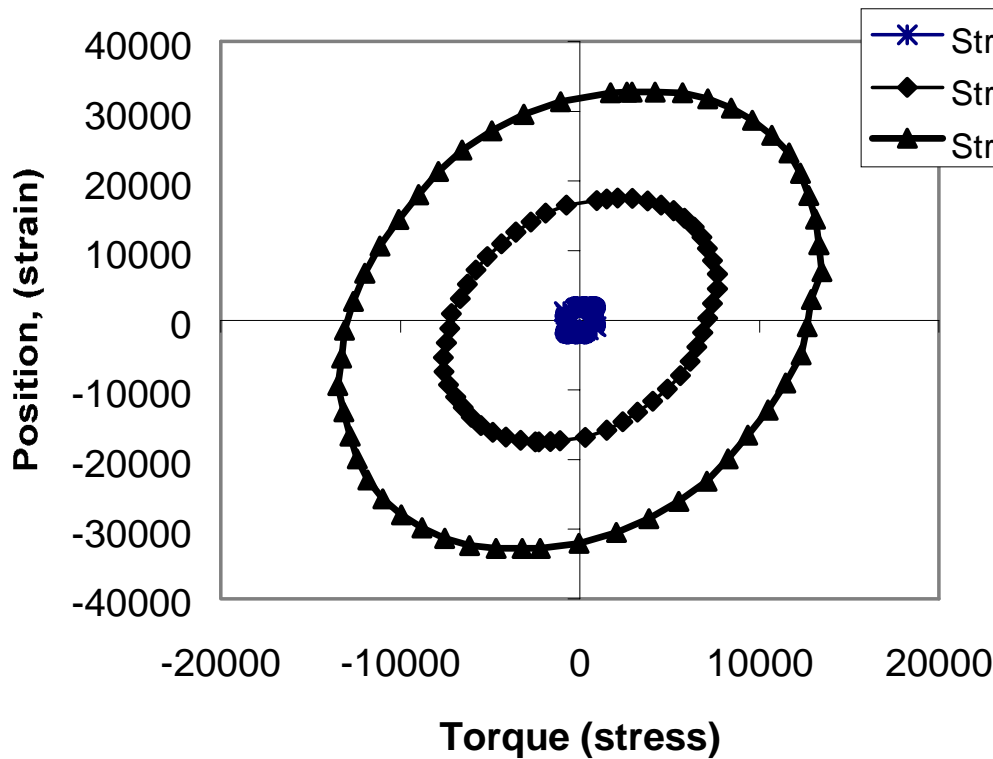


Binder Rutting Measurements

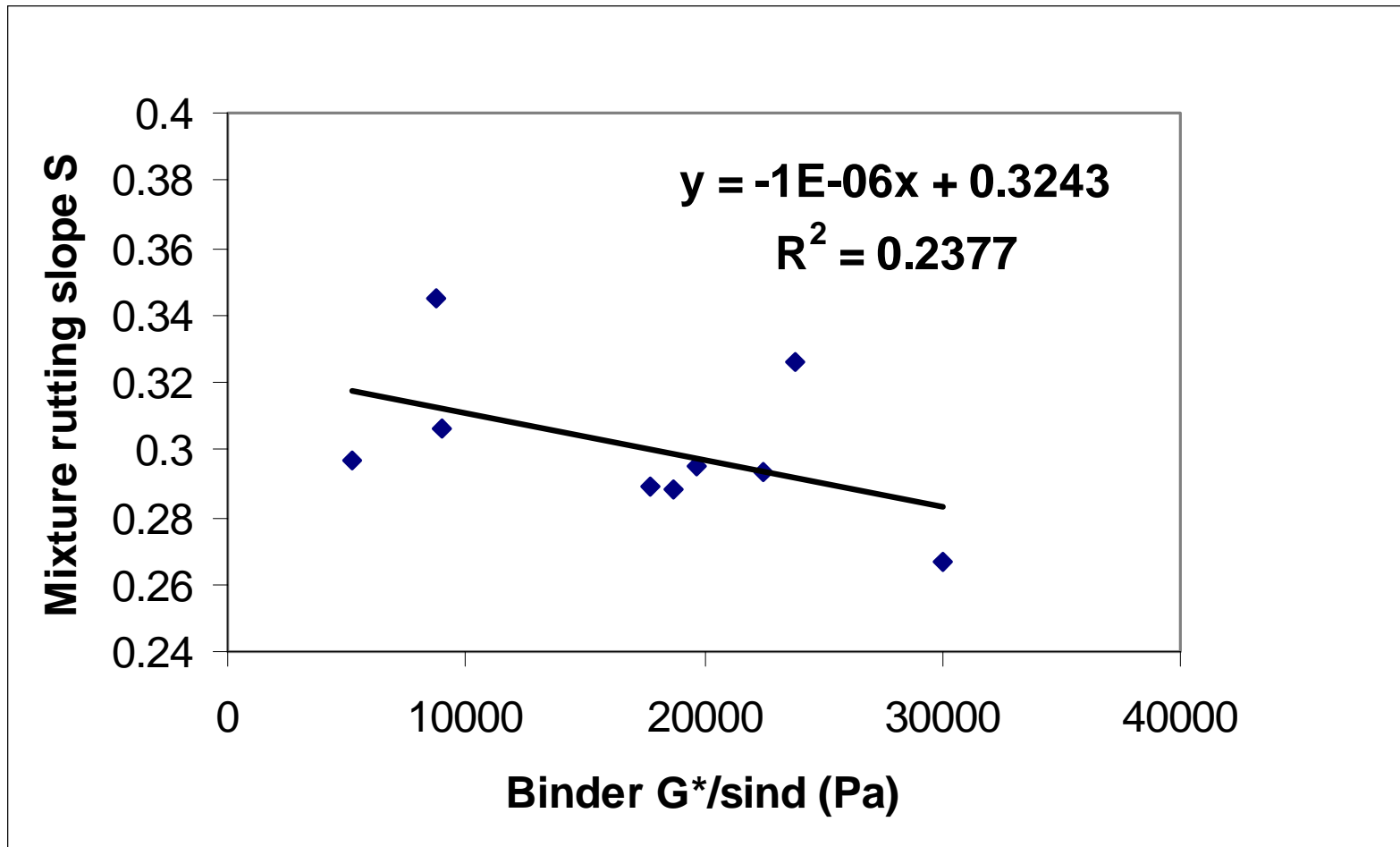
- Current concept: In the specification, $G^*/\sin\delta$ is used to rate the binder contribution to rutting damage resistance.
- Selected based on the dissipated energy concept as applied to linear visco-elastic materials.

$$\begin{aligned}\Delta W &= \pi \cdot \tau_i \cdot \gamma_i \cdot \sin \delta ; \quad \gamma_i = \tau_i / G^* \\ &= \pi \cdot \tau_i^2 \cdot \sin \delta / G^*\end{aligned}$$

Current Test: Cyclic Loading



Evaluation of Current Binder Parameter

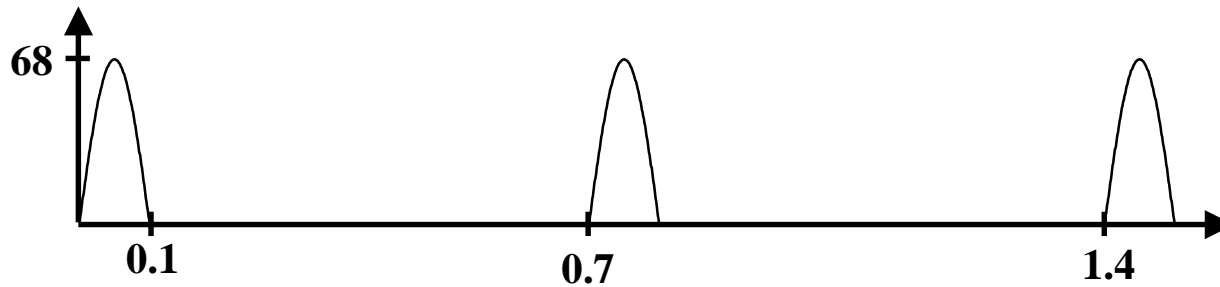


Main Hypothesis to Explain Lack of Relationship

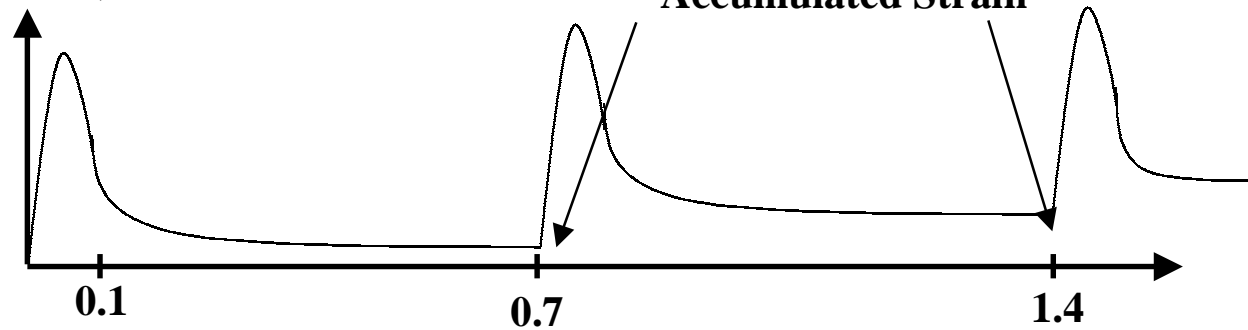
- The cyclic loading with complete reversal in strain or stress is not appropriate for rating contribution of binders to rutting resistance.

Asphalt Mixture Testing

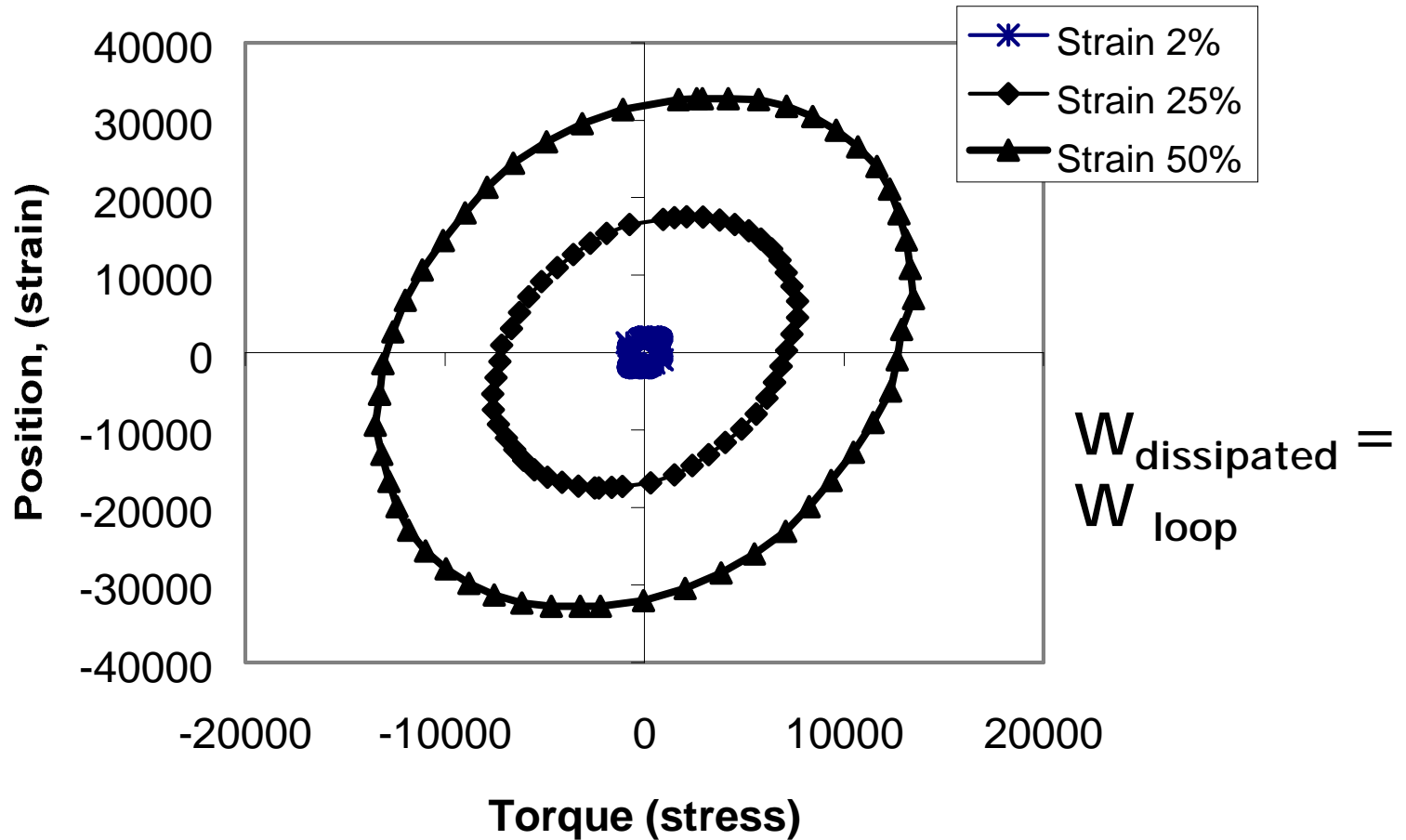
Shear Stress, kPa



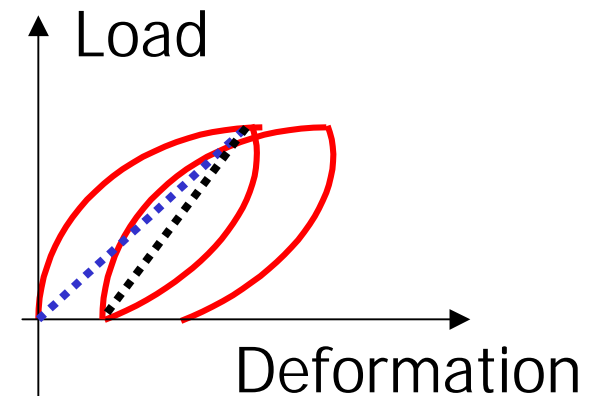
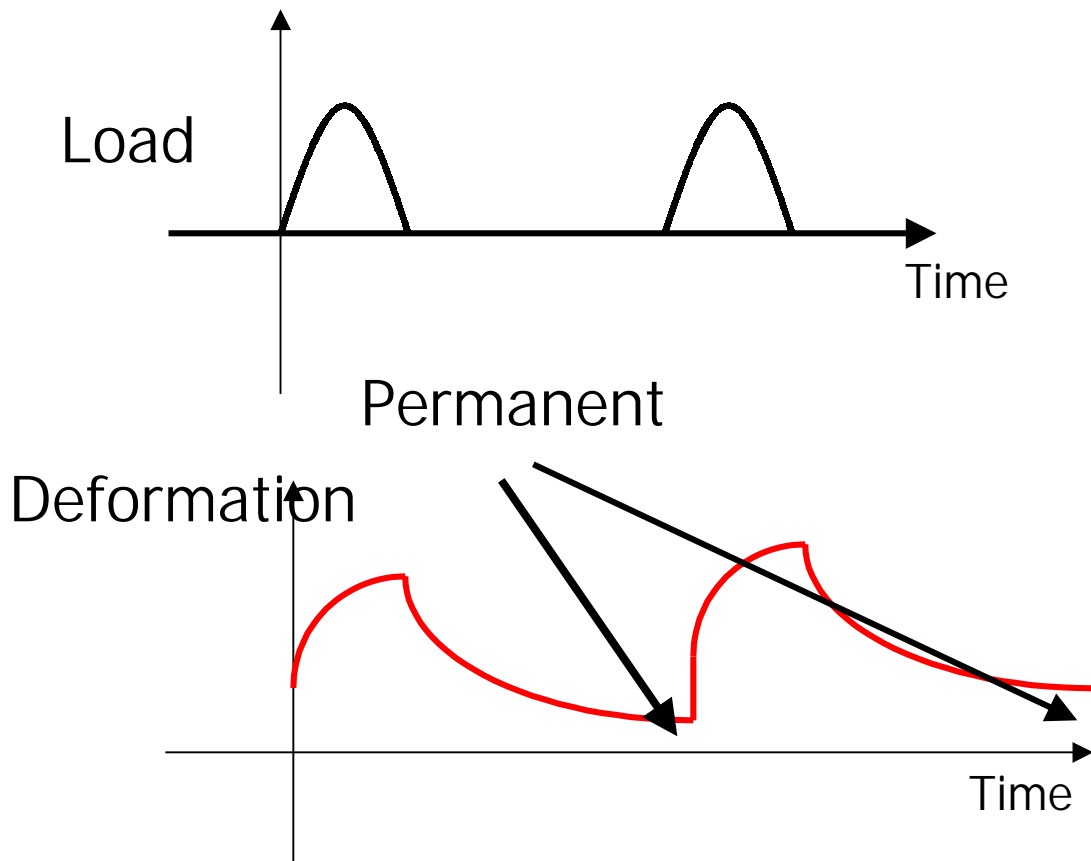
Shear Strain, mm/mm



Hypothesis: Cyclic Loading

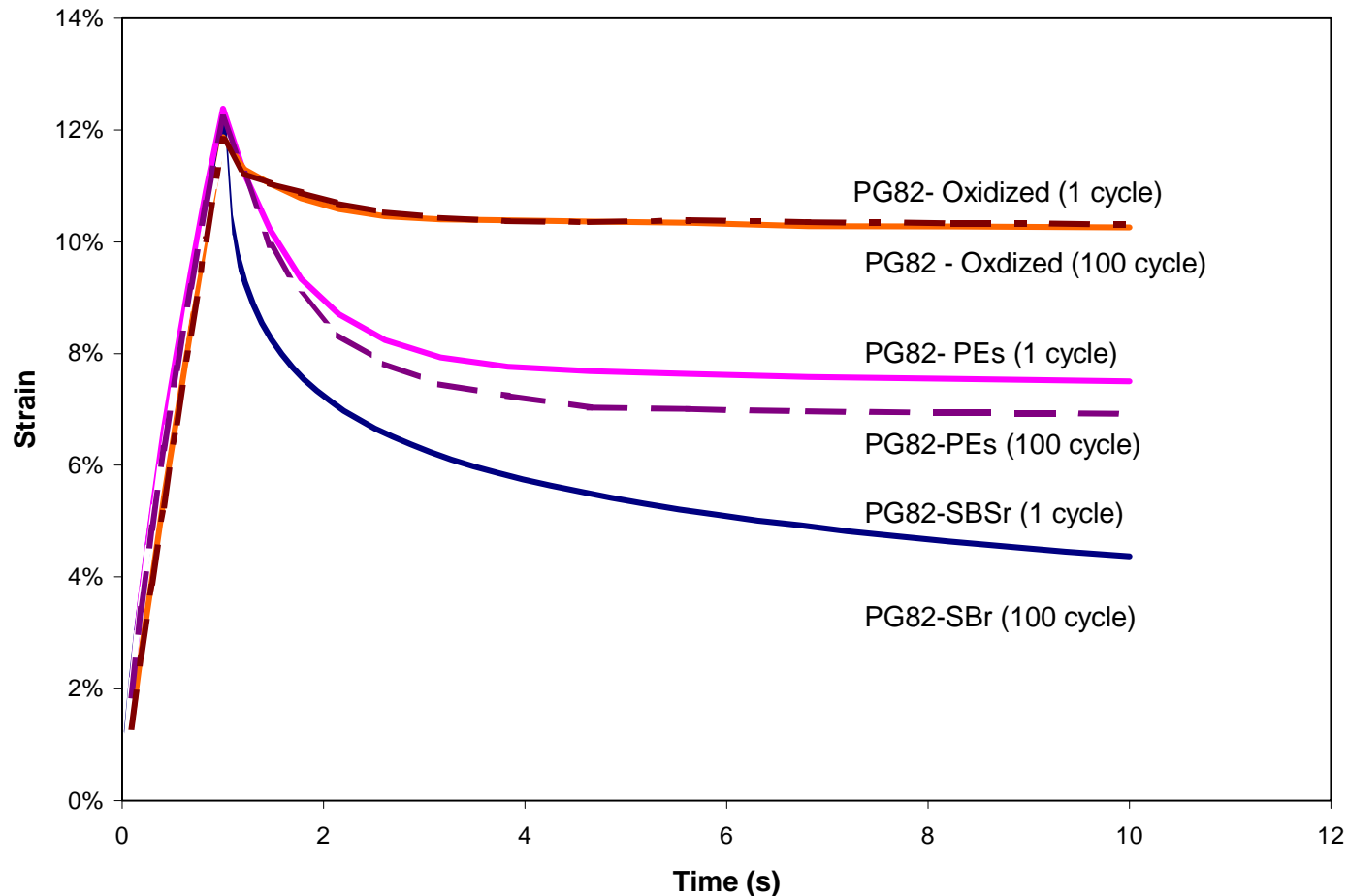


Better Binder Rutting Test

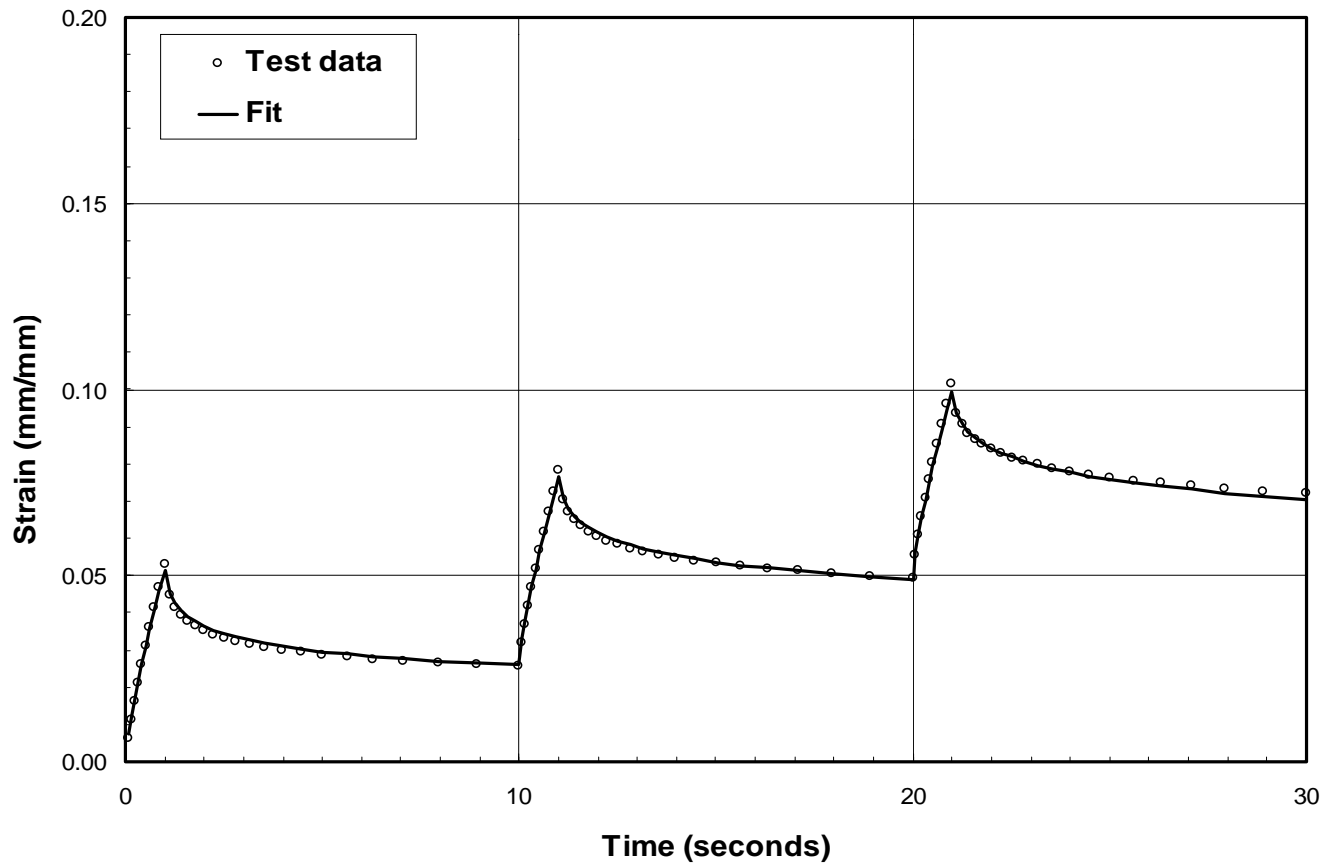


$$W_{\text{dissipated}} = W_{\text{loop}} - W_{\text{stored}}$$

Repeated Creep Test for Binders (Single Cycle)

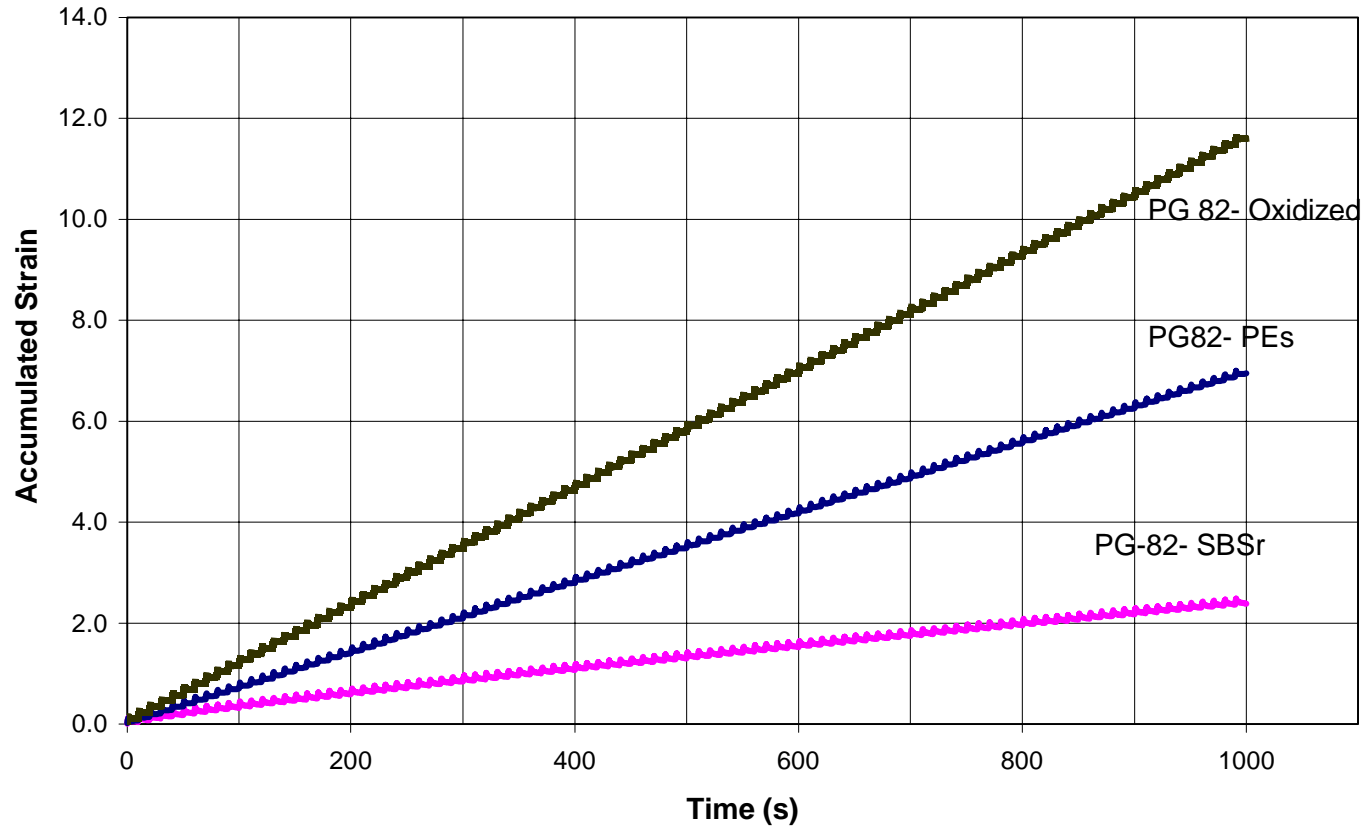


Damage Behavior

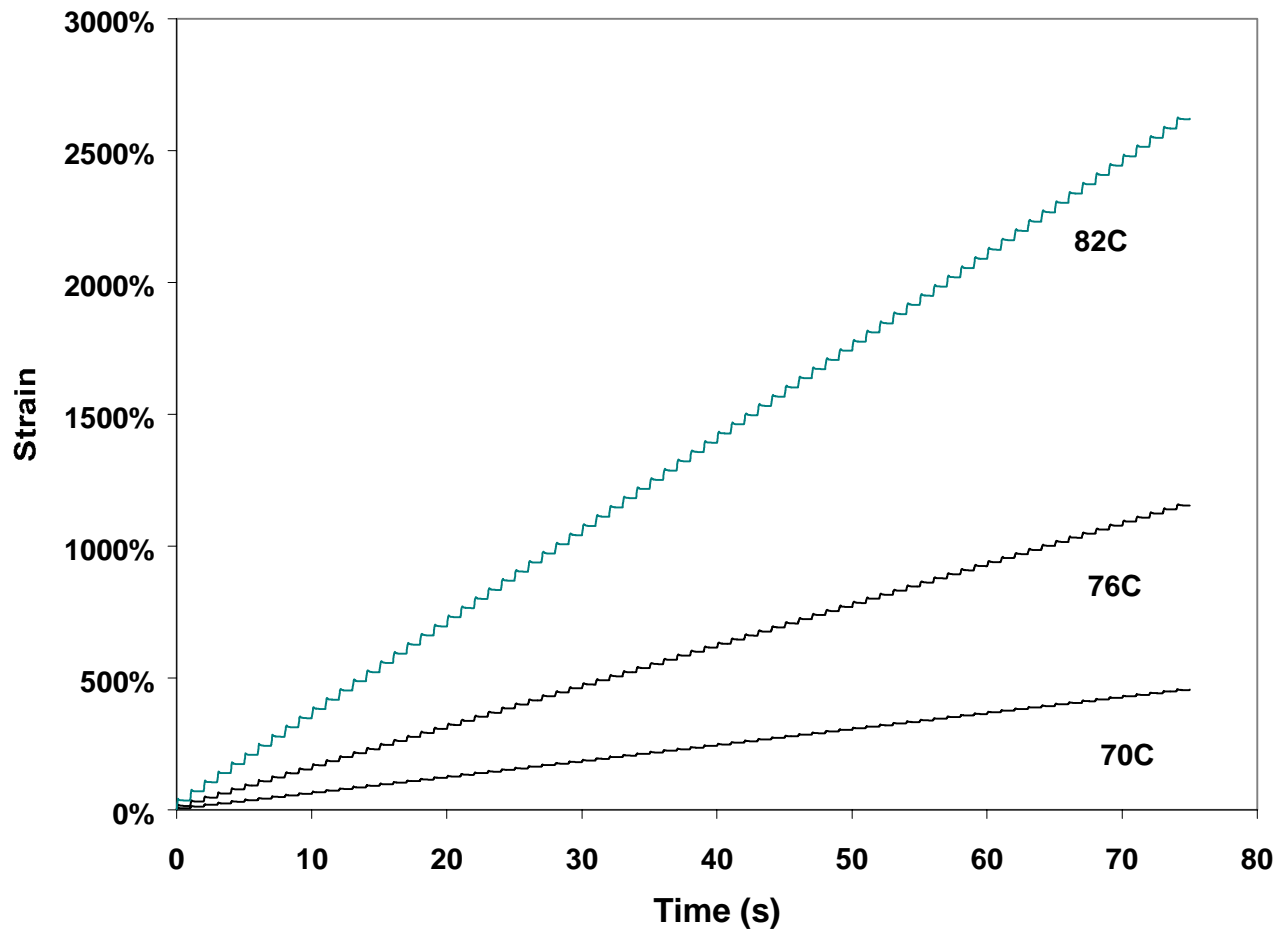


Repeated Creep Test for Binders

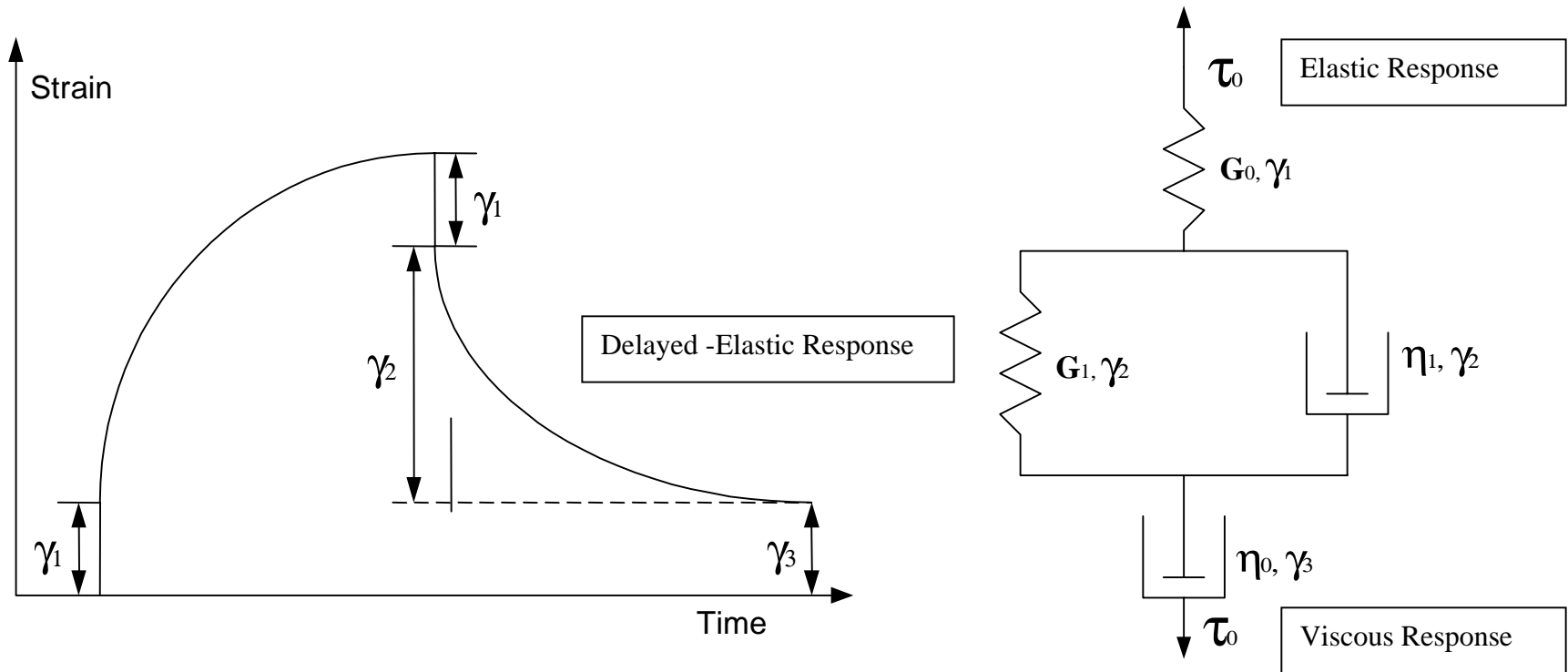
Creep Tests at 70C, 300 Pa shear stress
(Loading 1s Recovery 9s) 100 cycles



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 ($G_v = 1/J_v$).
- G_v is defined as the viscous component of the creep stiffness.

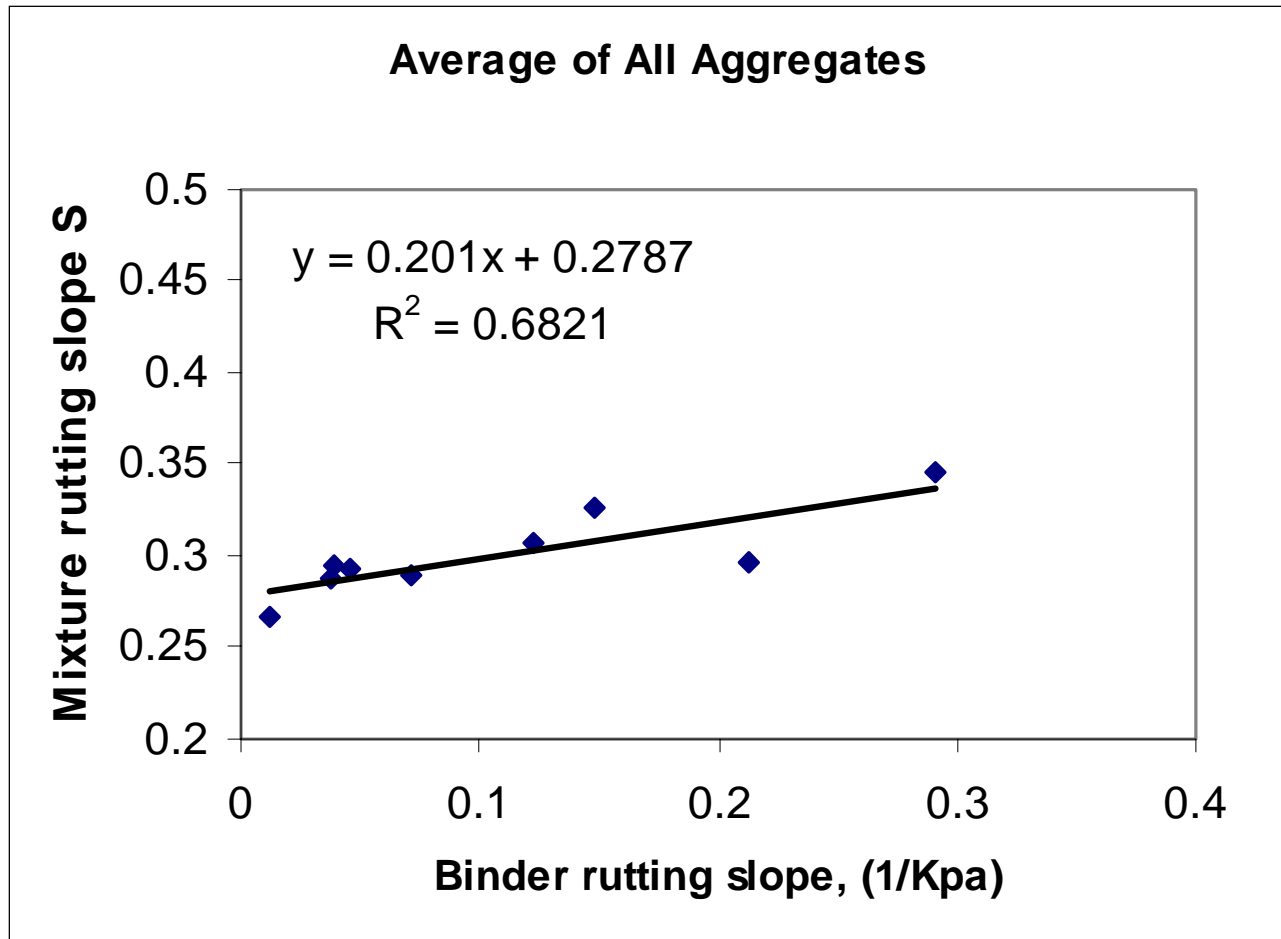
Error Due to Using Initial Cycles

ID	Test strain @ 100	Using Cycles 1, 2, and 3		Using Cycles 50, 51, and 52	
		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%

Creep Indicators vs $G^*/\sin\delta$

	<i>R1B02</i>	<i>R1B09A</i>	<i>R1B15</i>
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
$\sin\delta$	0.831	0.869	0.961
$G^*/\sin\delta$	13224	13100	15895
ϵ_L/ϵ_p at 1 cycle	2.787	1.656	1.169
ϵ_L/ϵ_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)

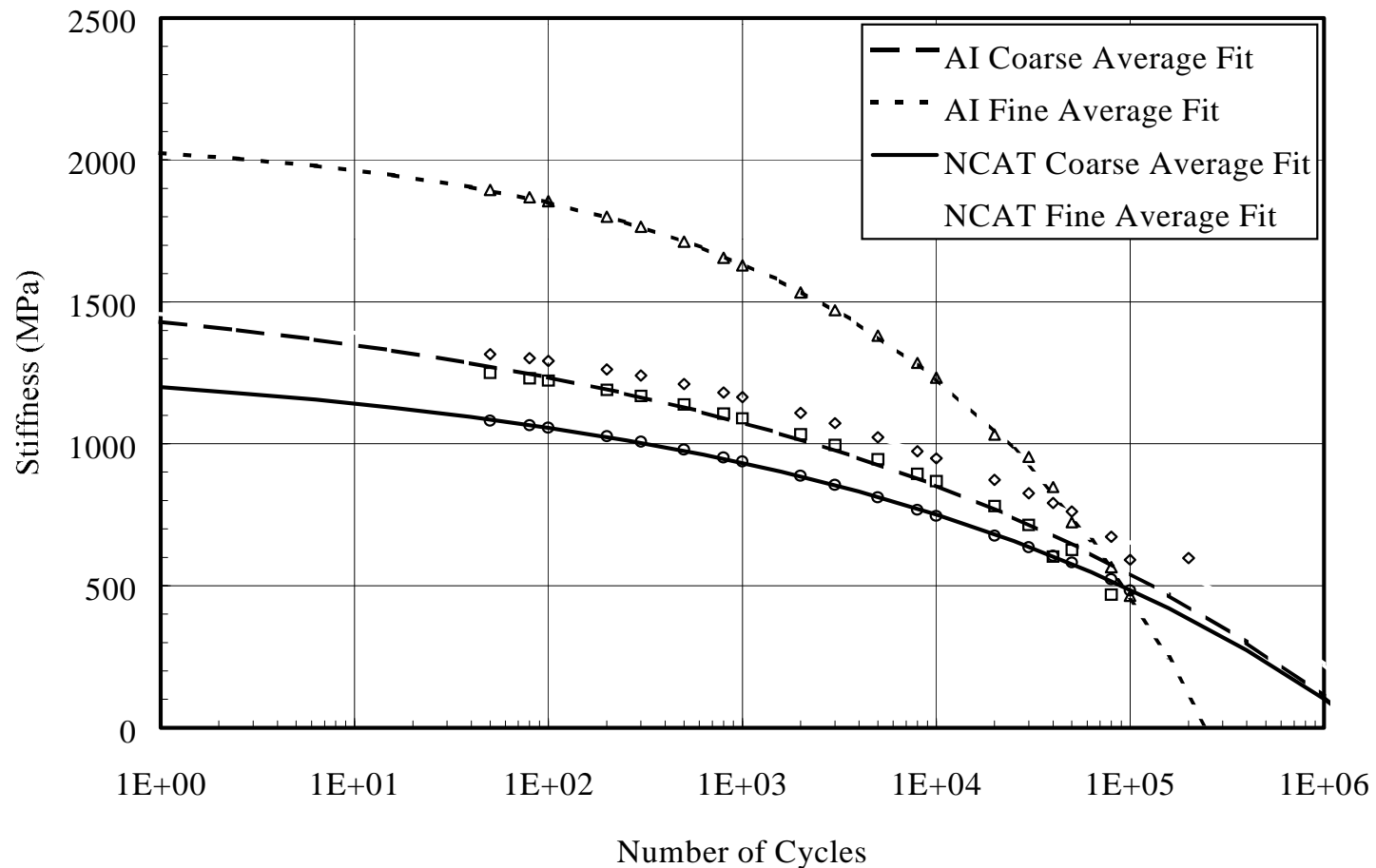
- Fatigue of asphalt pavement can be:
 - controlled-stress phenomenon (typical of strong, thick layers),

$$\begin{aligned}\Delta W_{ds} &= \pi \cdot \tau_i \cdot \gamma_i \cdot \sin \delta ; \quad \gamma_i = \tau_i / G^* \\ &= \pi \cdot \tau_i^2 \cdot \sin \delta / G^*\end{aligned}$$

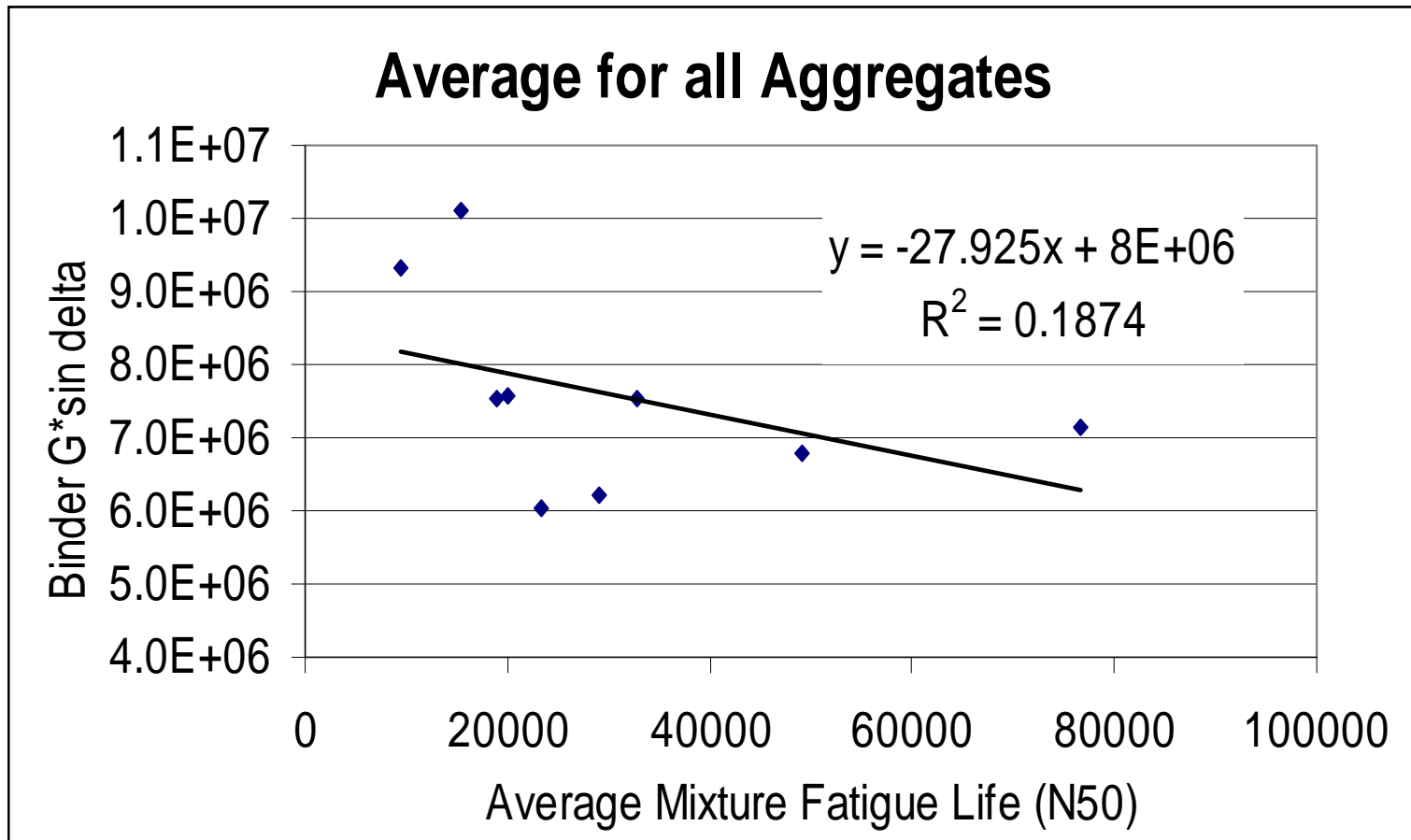
- controlled-strain phenomenon (typical of weak, thin layers).

$$\begin{aligned}\Delta W_{dw} &= \pi \cdot \tau_i \cdot \gamma_i \cdot \sin \delta ; \quad \tau_i = \gamma_i \cdot G^* \\ &= \pi \cdot \gamma_i^2 \cdot \sin \delta \cdot G^*\end{aligned}$$

Average Fatigue Response



Correlation between $G^* \sin \delta$ and Mixture Fatigue Life

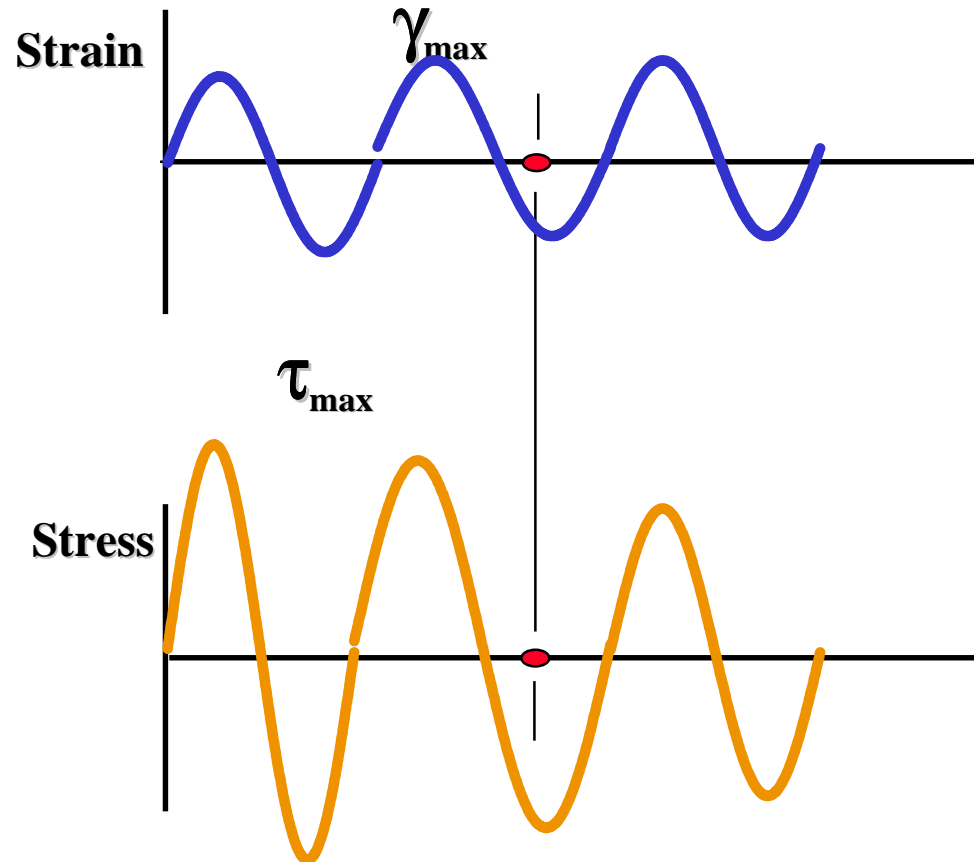




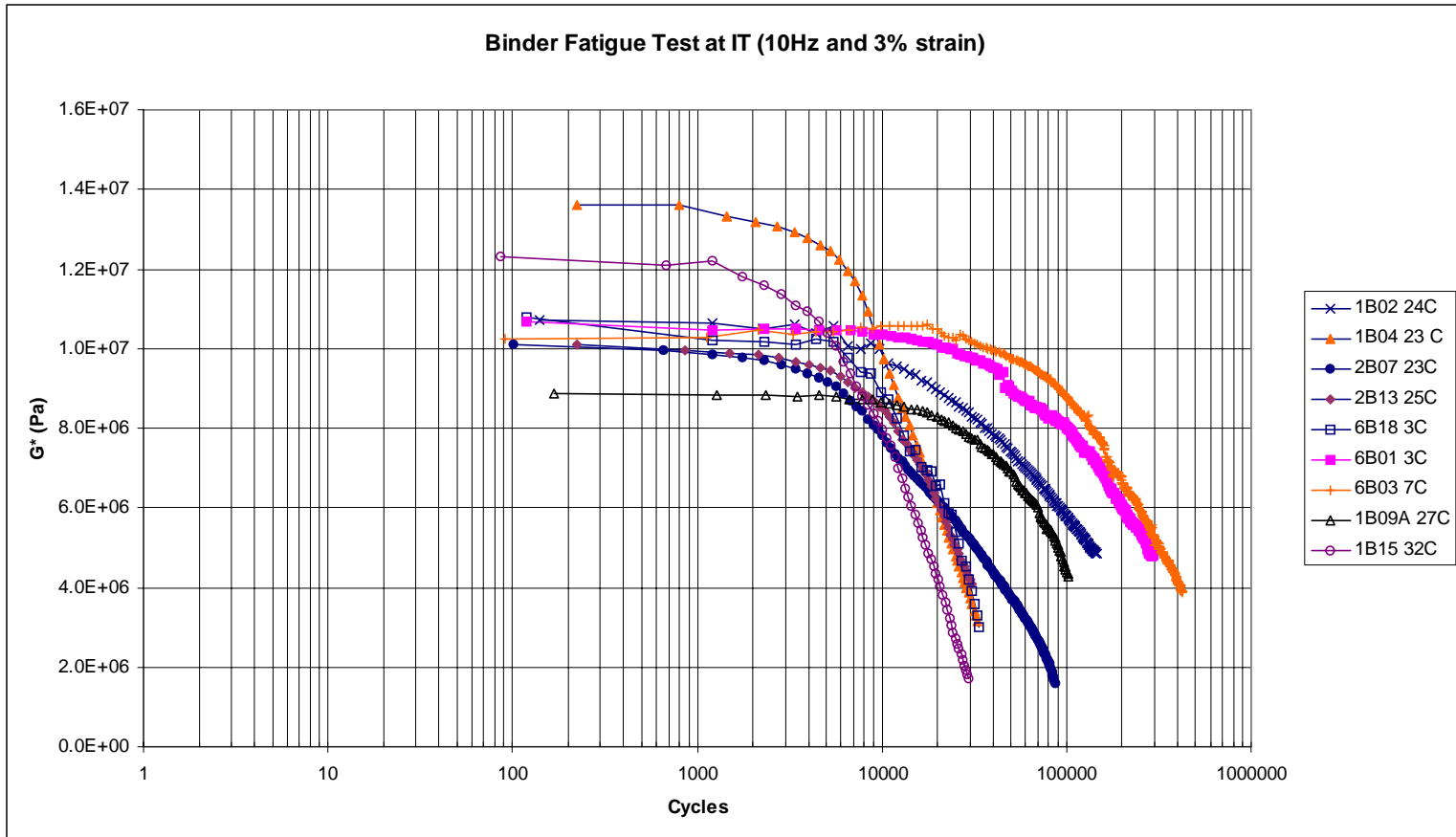
Binder-only Fatigue Test

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

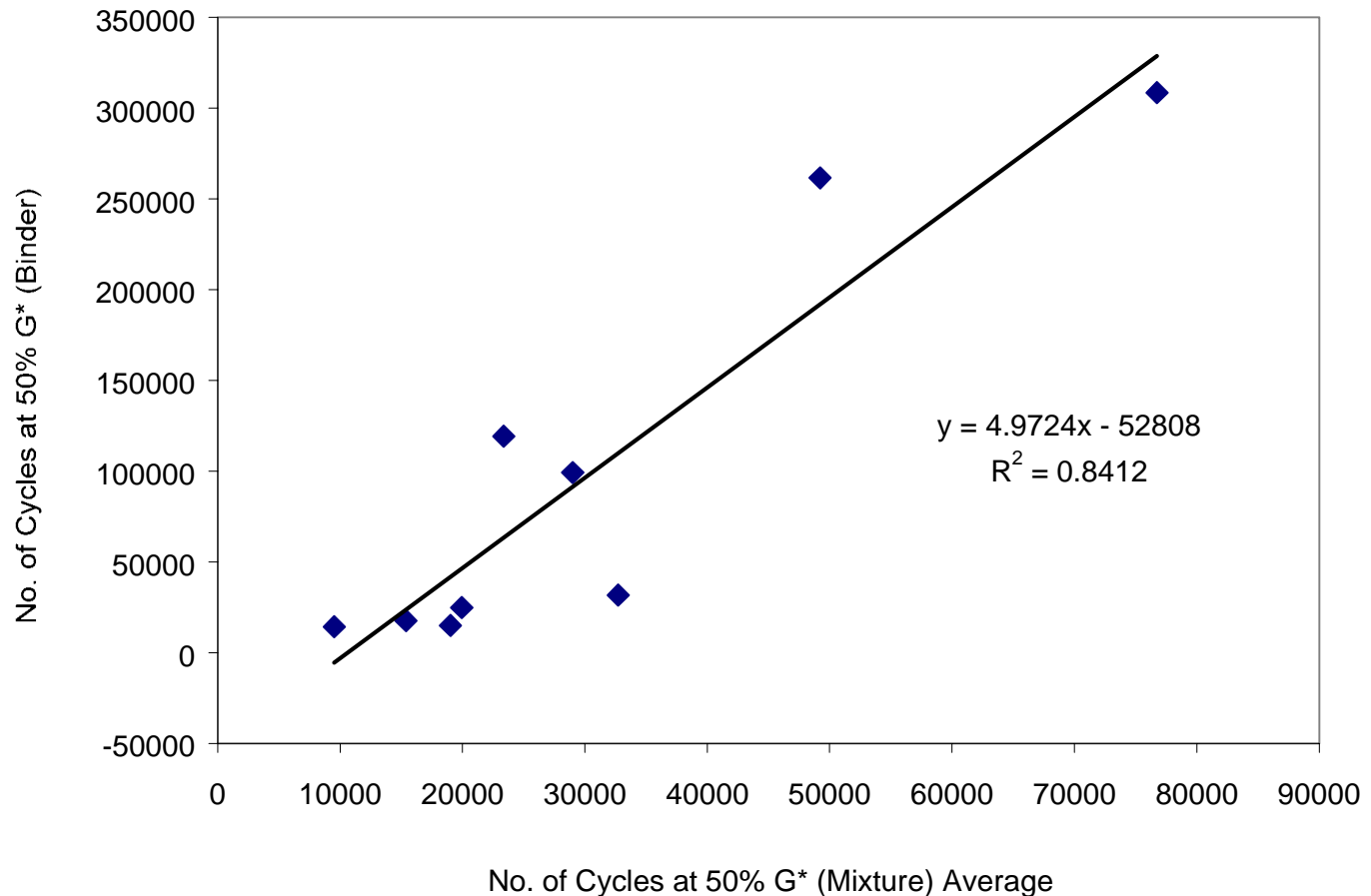
Binder Time Sweep



Test Results (DSR)



Correlation between Binder and Mixture Fatigue Lives (Average)



Development of a Binder Fatigue Parameter

- 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:

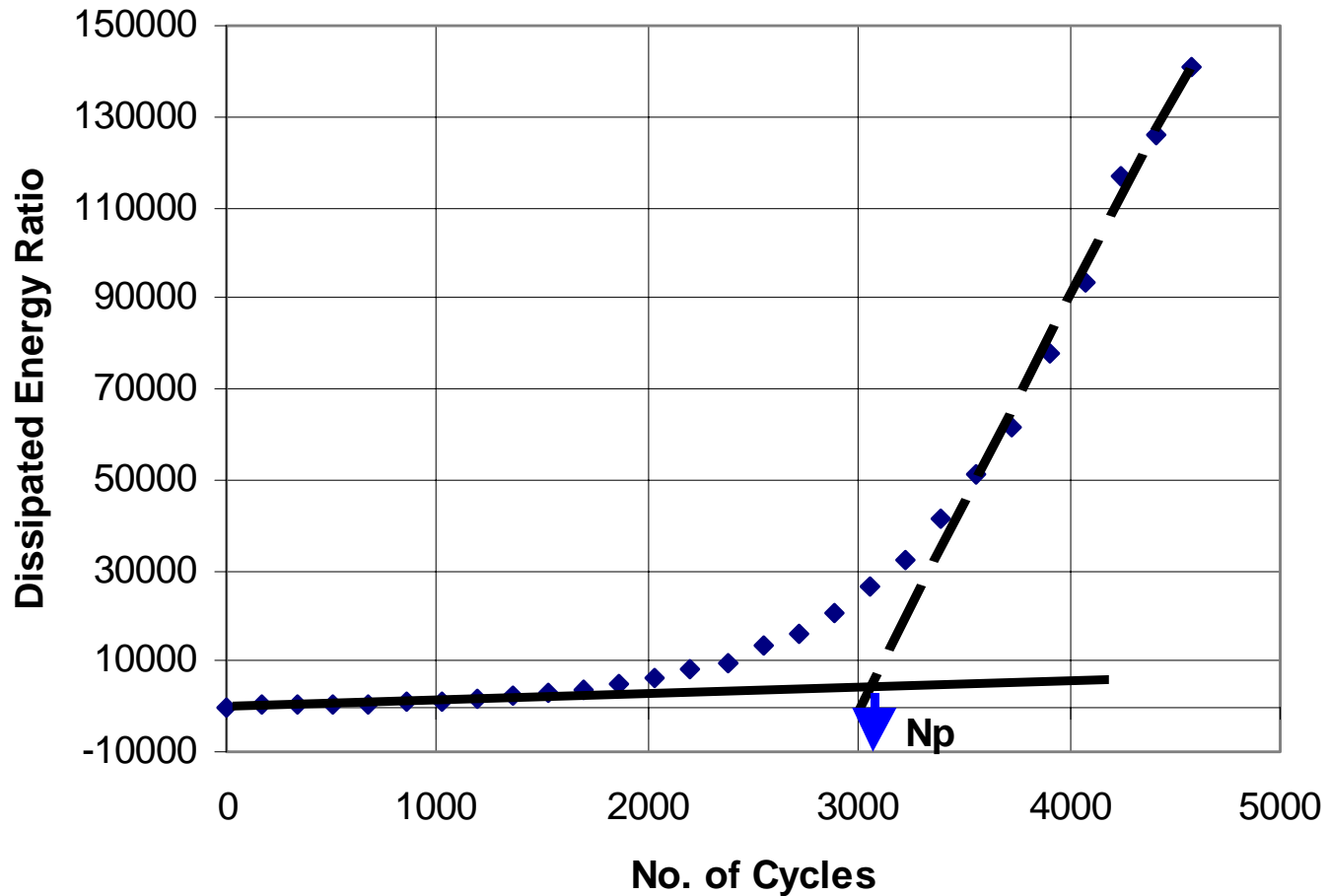
$$R_{de} = \frac{W_n}{\Delta W_n}$$

In which

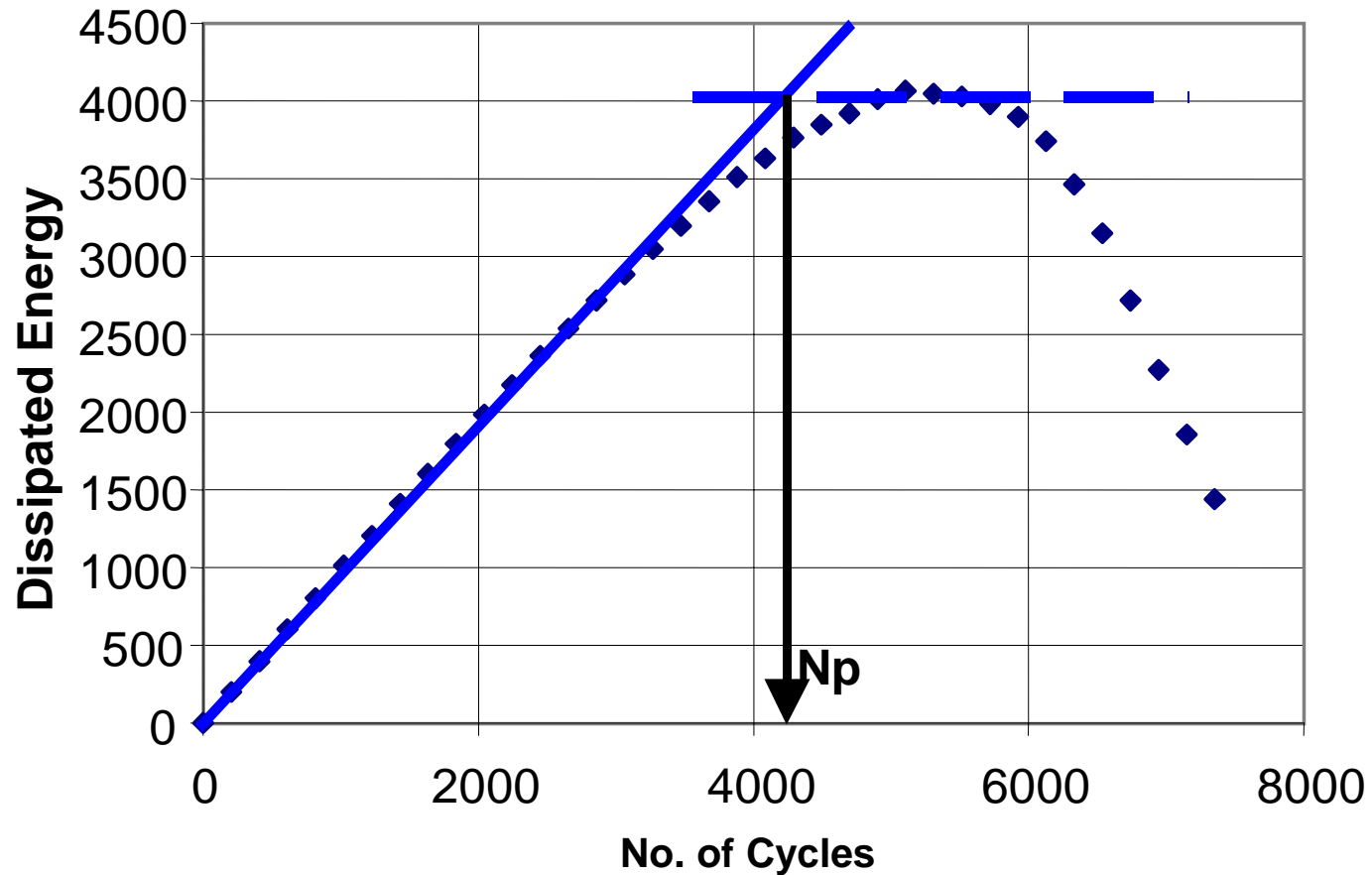
W_n = the total sum of the dissipated energy up to cycle n , and

ΔW_n = the dissipated energy at cycle n .

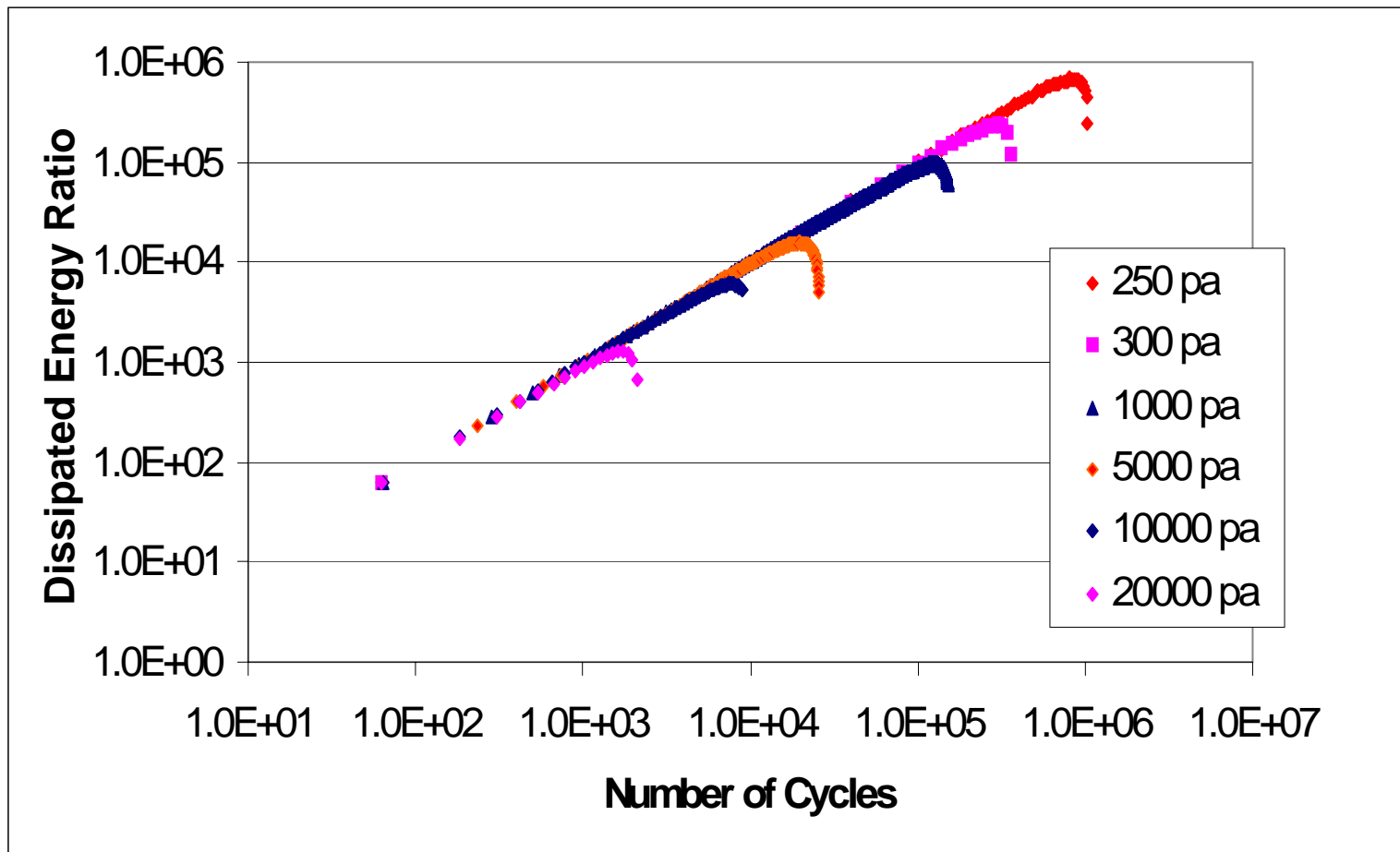
Used for Constant-Strain



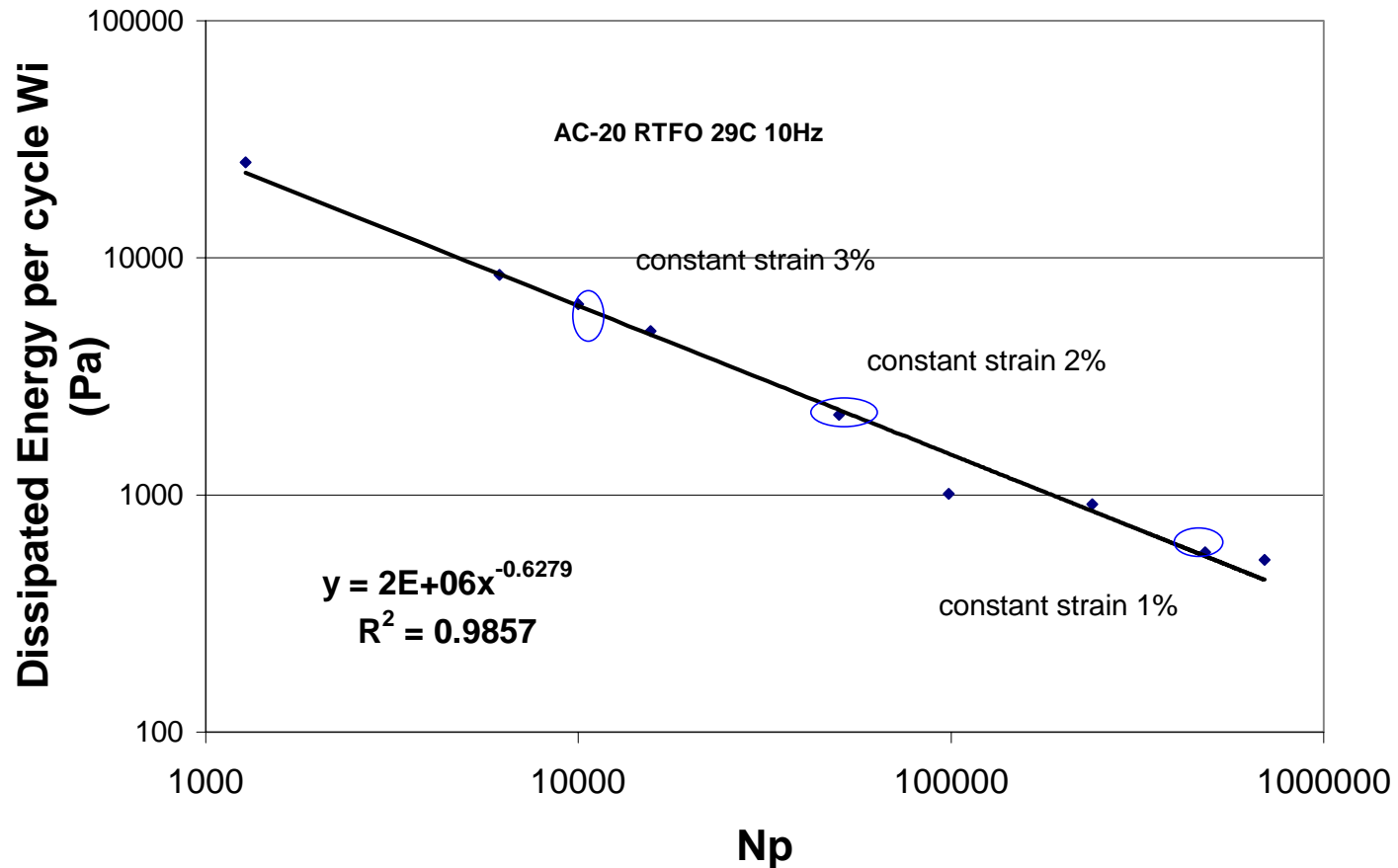
Used for Constant-Stress



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 $G^*/\sin\delta$.
- *Damage behavior*, as measured by Repeated creep test of binders is introduced as a better method.
- The correlation between G_v and mixture rutting is found to be better than the current $G^*/\sin\delta$.



Summary of Findings (2)

- The poor correlation of mixture fatigue with binder $G^* \sin \delta$ 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.
- Work is part of NCHRP 9-10. The support and encouragement of Dr. Ed Harrigan, the project officer, and the Project Panel are greatly appreciated.
- The input and help of Mr. Doug Hansen of the NCAT and Mr. Mike Anderson of TAI are greatly appreciated.



Thank You for this
Opportunity

Questions !

