Road Materials and Mixture Design to prevent Permanent Deformation- Rutting

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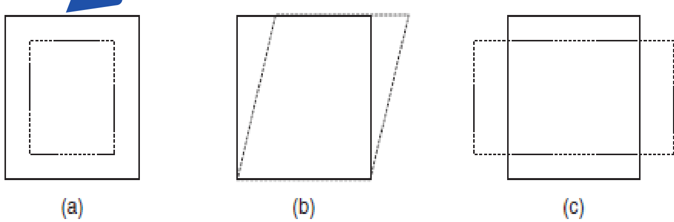
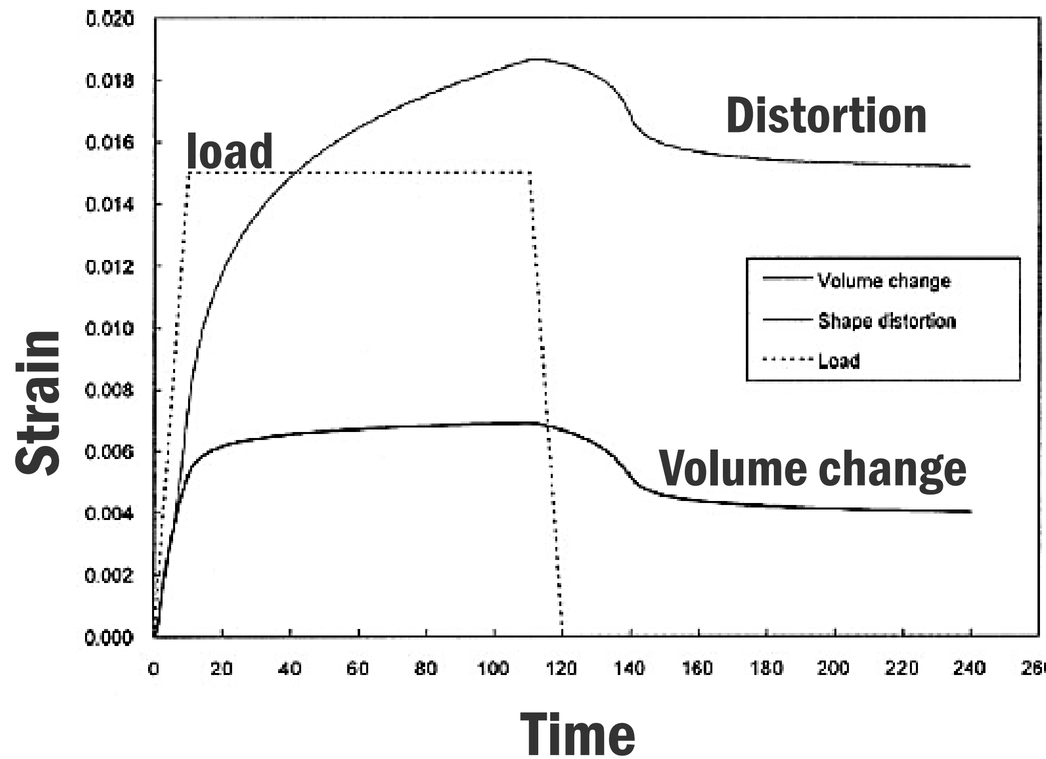
Rutting: The most damaging Pavement Failure

1. Mechanism
2. Modeling
3. Binder Testing
4. Mixture Testing
5. Imaging and Micro structure

Mechanics of Permanent Deformation for Rutting Modeling

- **Volume change** vs. **Shape distortion**

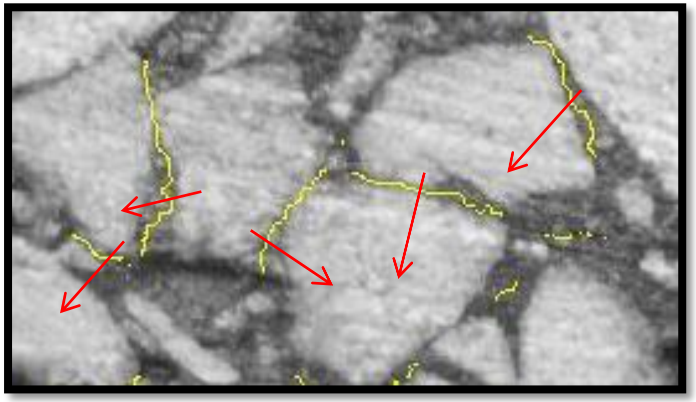


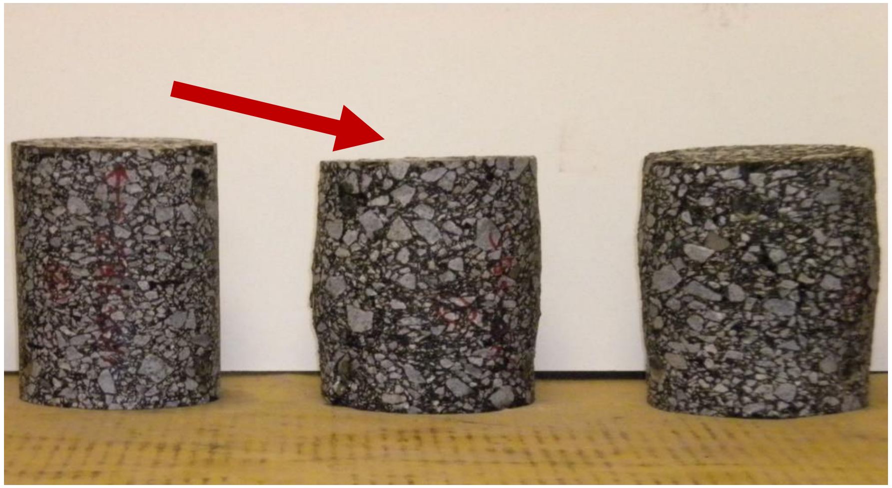


Mechanisms of Rutting: Volume and Shape changes

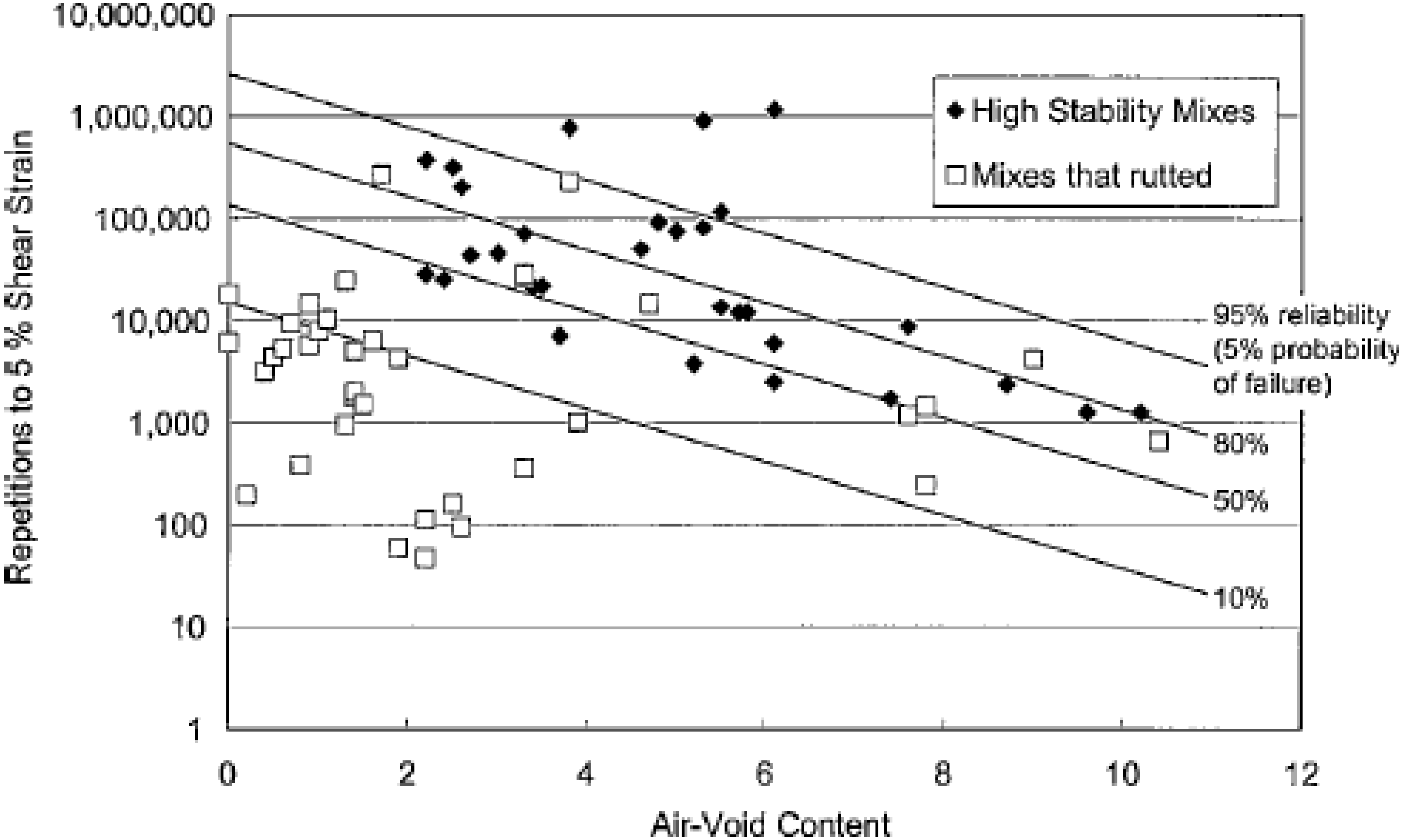
Factors Affecting Rutting

1. Traffic loading (cyclic).
2. Temperature: Most critical at high.
3. Un-aged binder: Early in pavement life
4. Permanent dislocation of aggregate.
5. Accumulate gradually with traffic.





Importance of Air Voids in Rutting: High voids = less traffic to same rut



*Kim, R. *Modeling of Asphalt Concrete* (2009)

Mechanistic Empirical Rutting Models

Asphalt Mixture Permanent Strain Model

– Witczak et al.

$$\log\varepsilon_p = -14.97 + 0.408\log(N) + 6.865\log(T) + 1.107\log(\sigma_d) - 0.117\log(\eta) + 1.908\log V_{\text{beff}} + 0.971(V_a)$$

T = temperature, °F
σ_d = mechanistically determined deviator stress (psi) in the asphalt layer
η = the binder viscosity at 70°F, 10^6 poise
V_{beff} = effective asphalt volume, %
V_a = volume of air voids, %

Mechanistic Empirical Rutting Models MEPDG

Permanent to Resilient Strain Ratio Model

– NCHRP 1-37A

$$log\left(\frac{\varepsilon_p}{\varepsilon_r}\right) = B_{\sigma 3}[a_1\beta_{r1} + a_2\beta_{r2}log(T) + a_3\beta_{r3}log(N)]$$

ε_r = resilient elastic strain calculated at the mid-depth of an HMA sublayer at temperature T
N = number of axle loads over time interval for a specific axle type
T = temperature of the HMA at mid-depth, °F
$B_{\sigma 3}$ = adjustment factor for lateral confinement
a_i = nonlinear regression coefficients
β_{ir} = regional calibration factors

$$B_{\sigma 3} = (C_1 + C_2 z) \times 0.3282^z$$

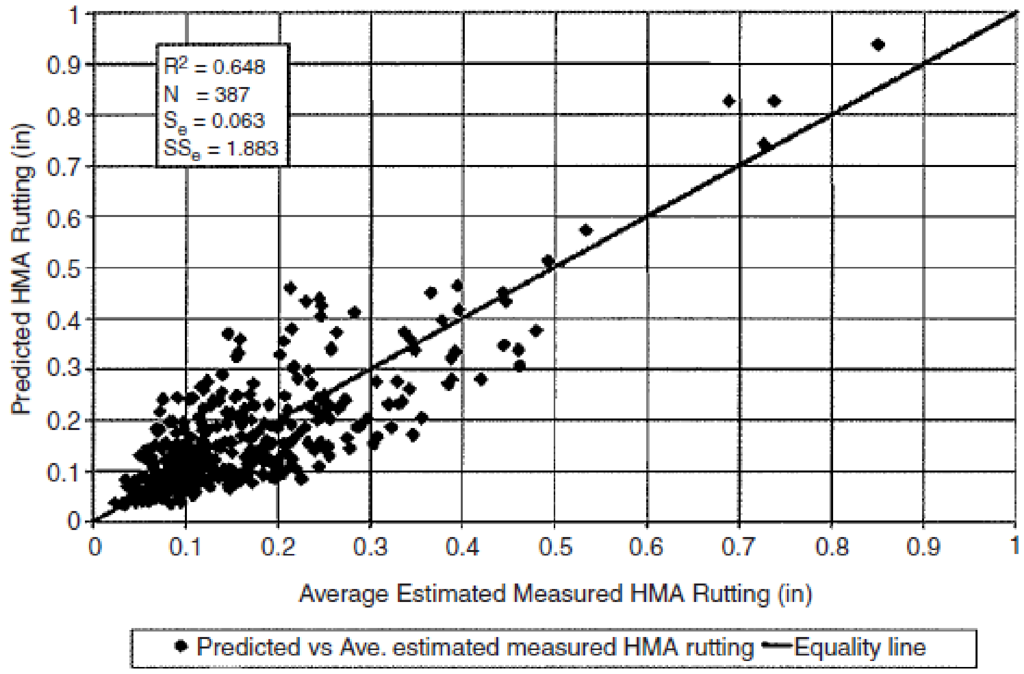
$$C_1 = -0.1039H^2_{HMA} + 2.4868H_{HMA} - 17.342$$

$$C_2 = 0.0172H^2_{HMA} + 1.7331H_{HMA} + 27.428$$

Mechanistic Empirical Rutting Models

Good correlation with Field - Strain Ratio Model

– NCHRP 1-37A=> Predicted vs. Estimated



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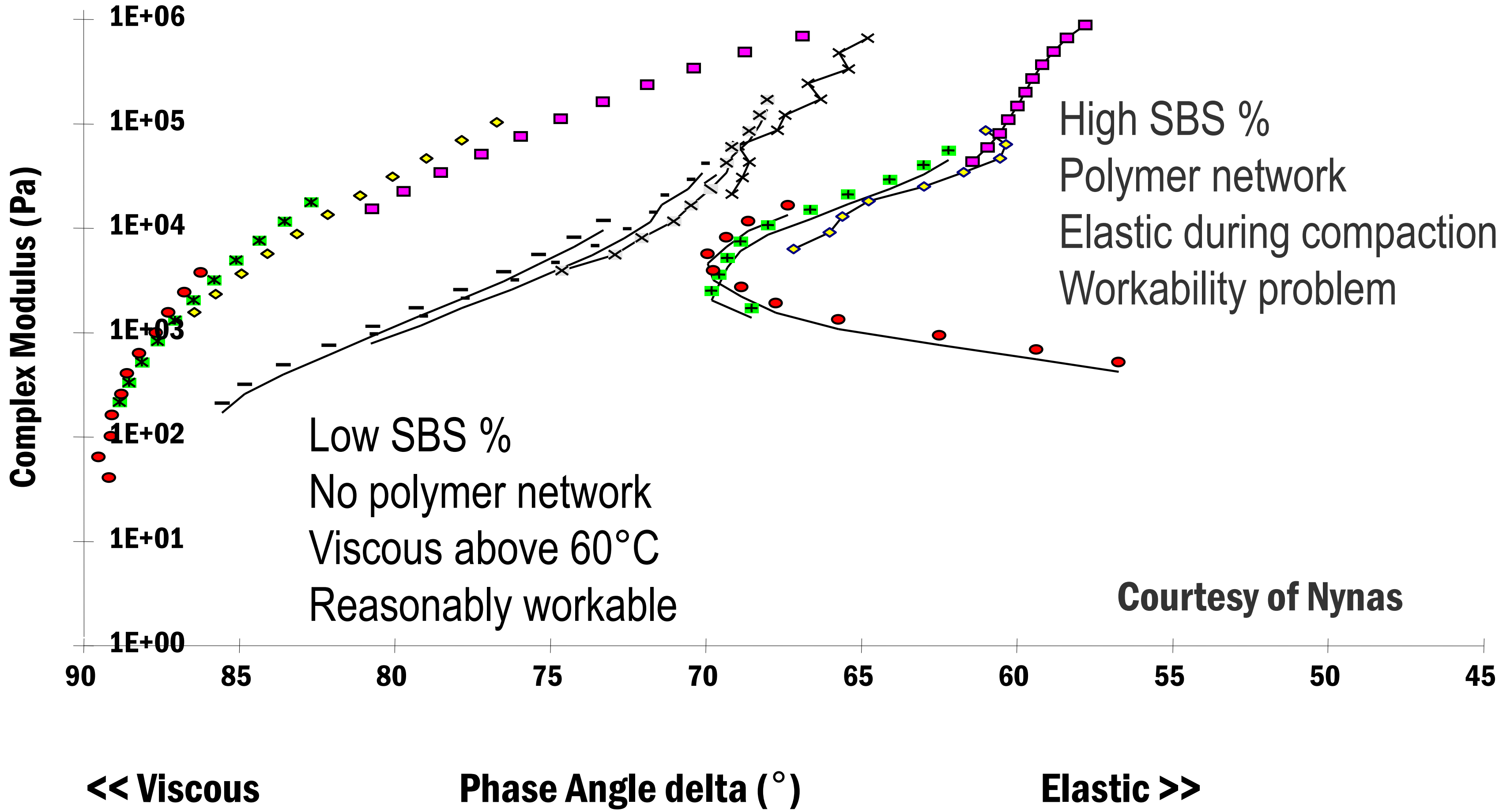
How to Measure Rutting Resistance

Option A: Rheology

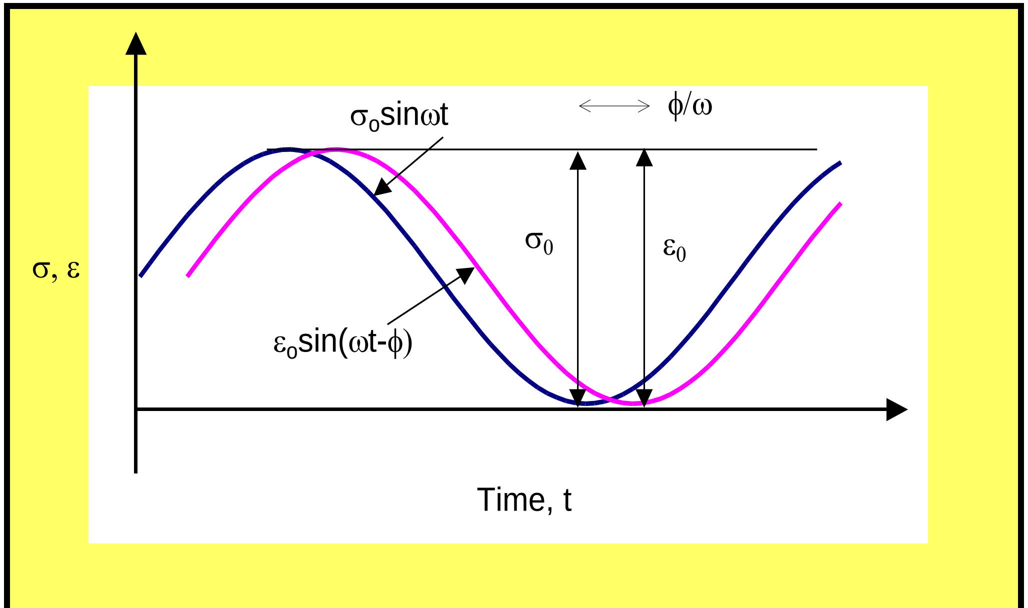
Option B: Damage Resistance

The focus in Rheology is on Linear Visco-Elasticity: G*, delta



Rheology of Binders and Mixtuers

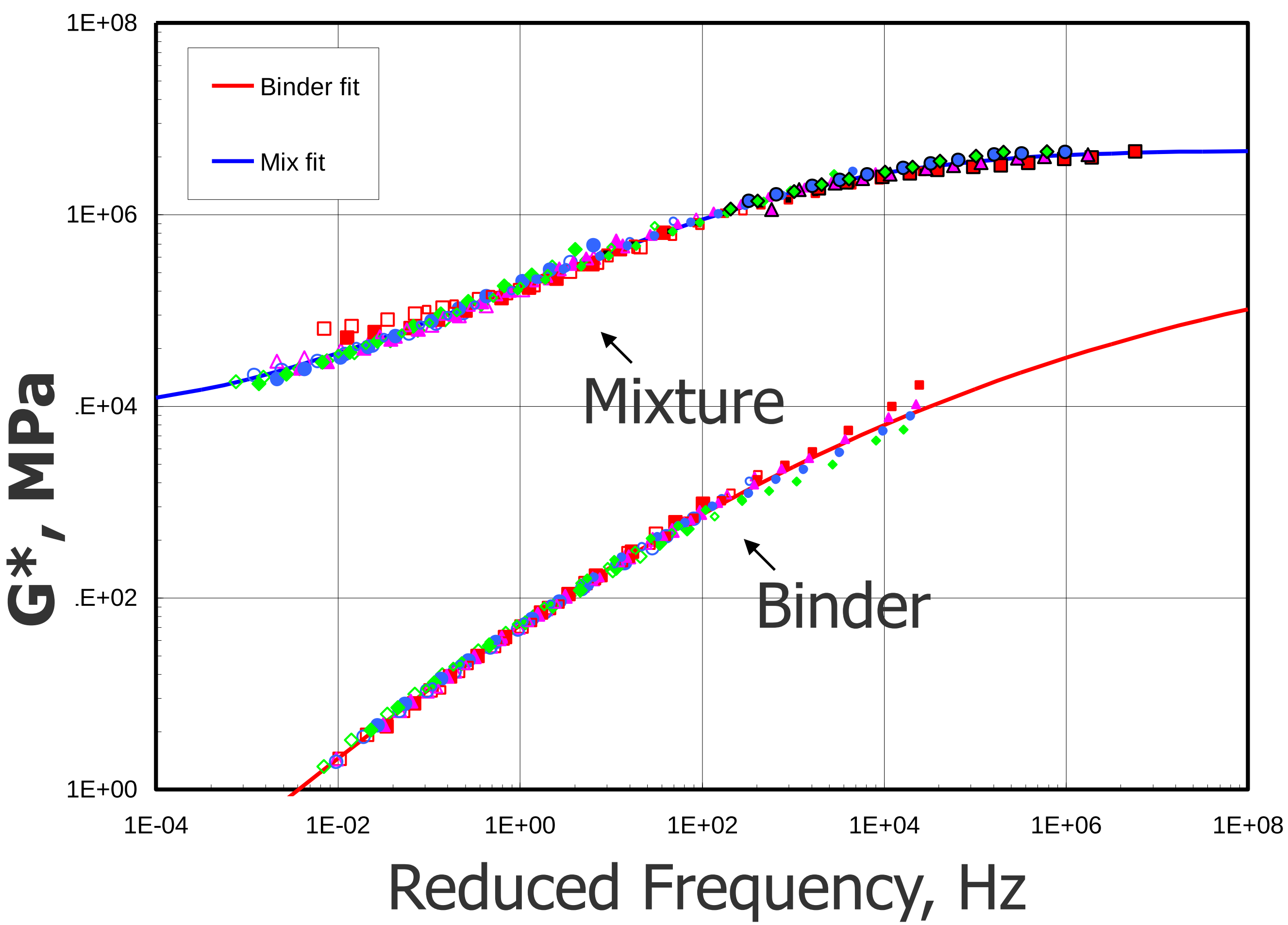
Dynamic Modulus /E*, G*/ Phase Angle, ϕ



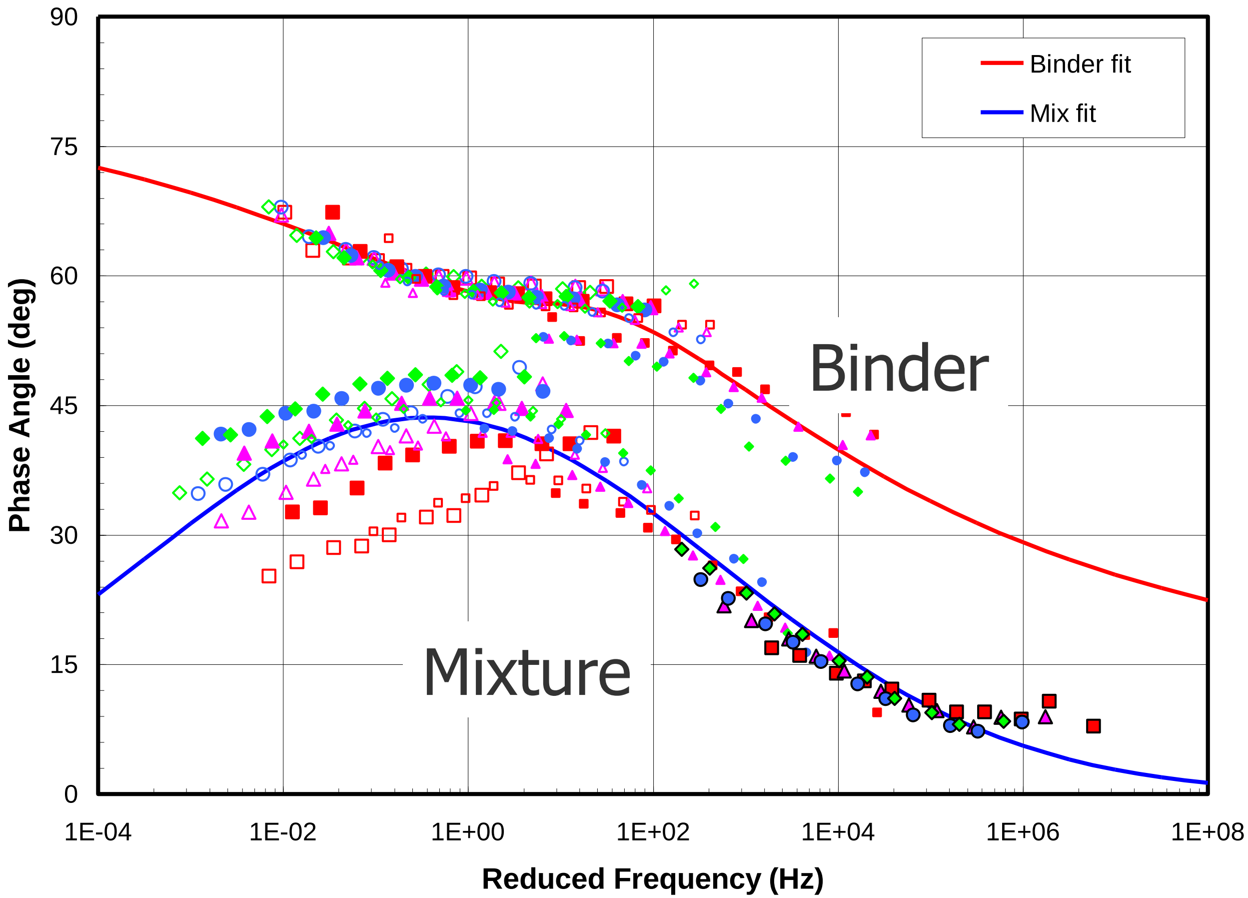
$$|E^*| = \frac{\sigma_0}{\varepsilon_0}$$

$$\phi = \omega t_i$$

Rheology of Binder and Mixture

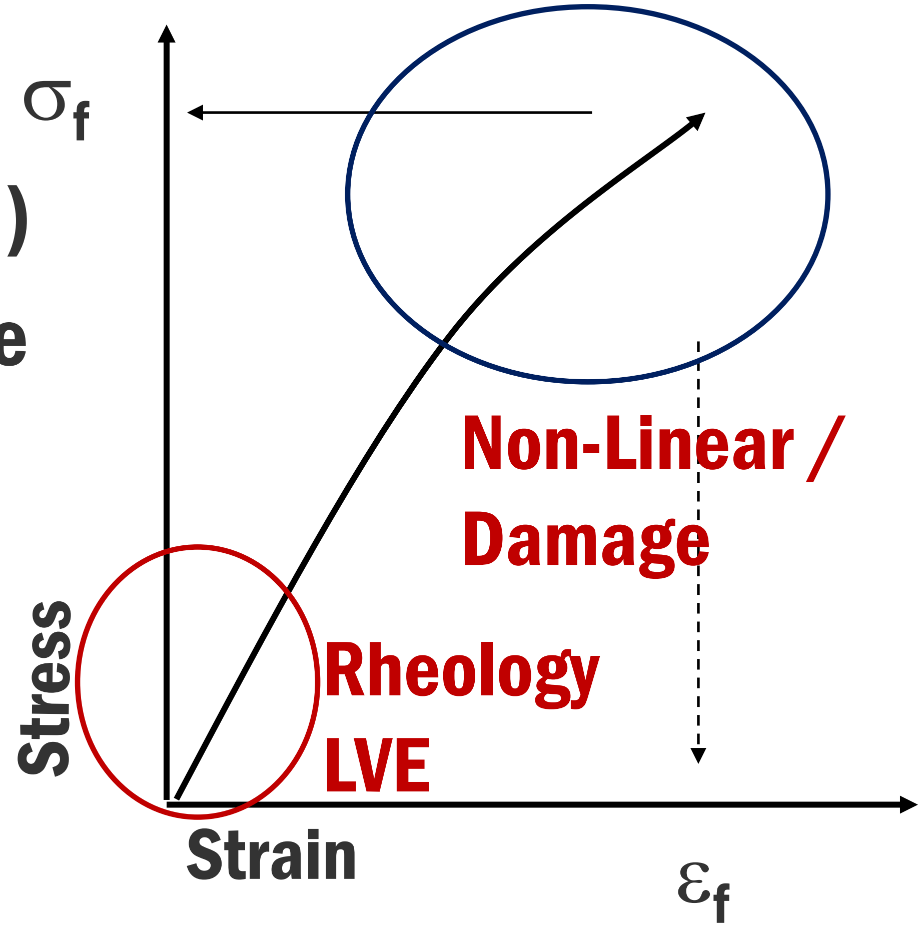


Rheology of Binder and Mixture

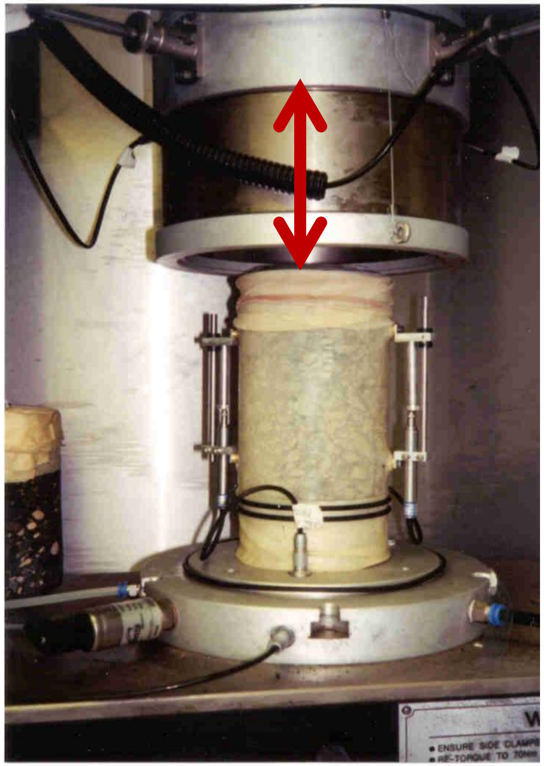


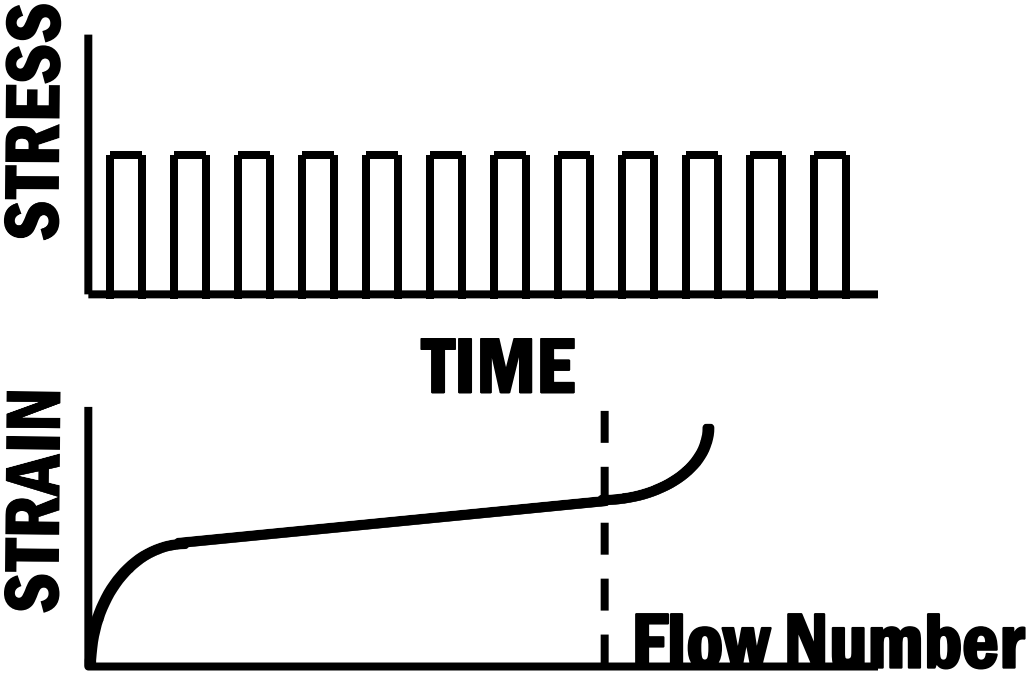
Need for Bitumen Damage Resistance Characterization

- Linear VE (Small strain) is not sufficient (NCHRP 9-10)
- Bitumen damage resistance is very important
- Modified bitumen best in damage resistance



Rutting: Repeated Load Permanent Deformation Test

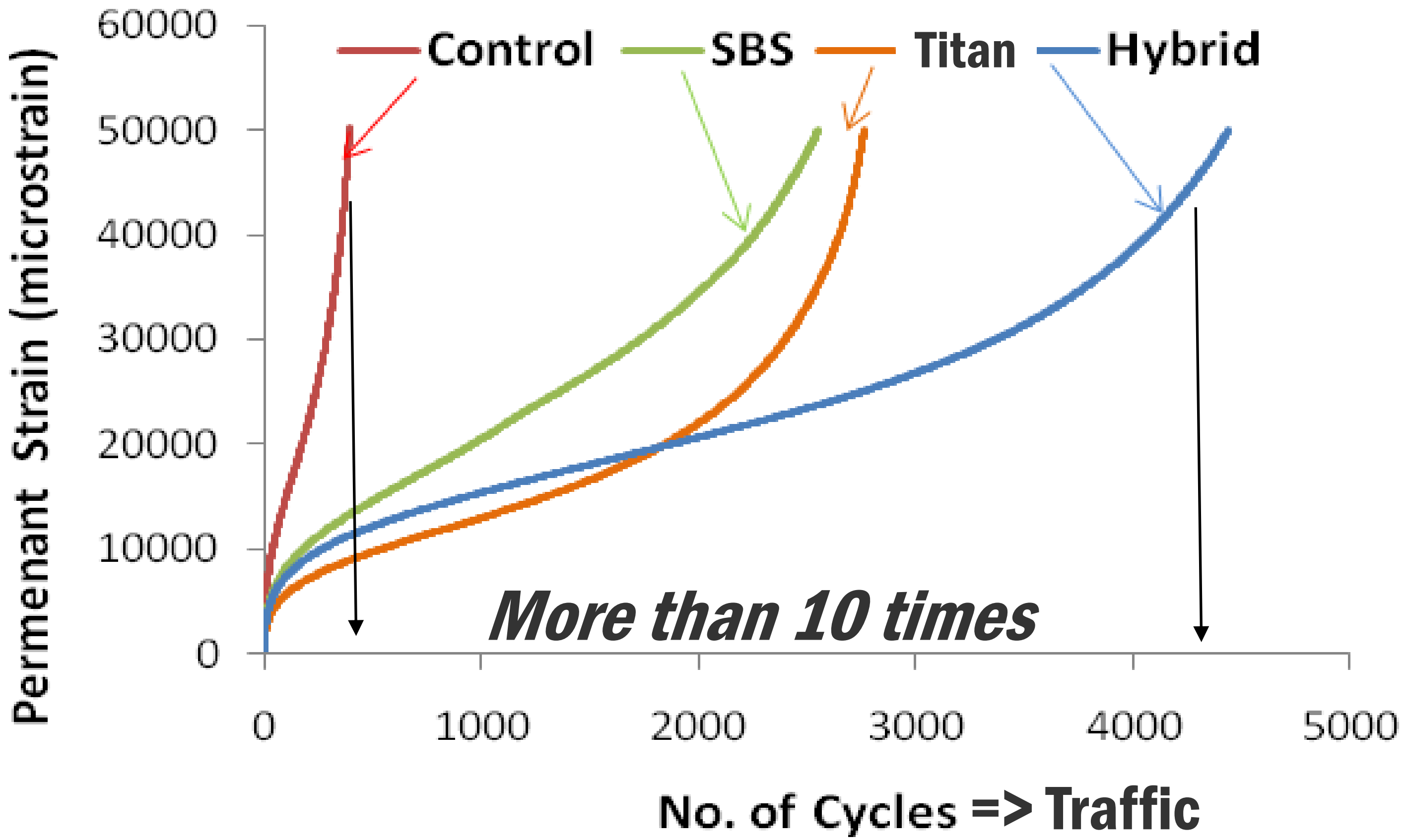


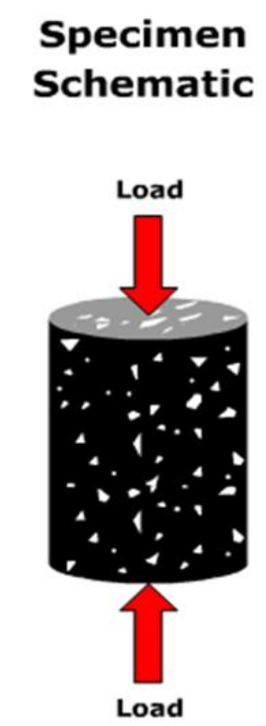


- **Creep rate:**
  - **Flow Number (FN)** at High Temp

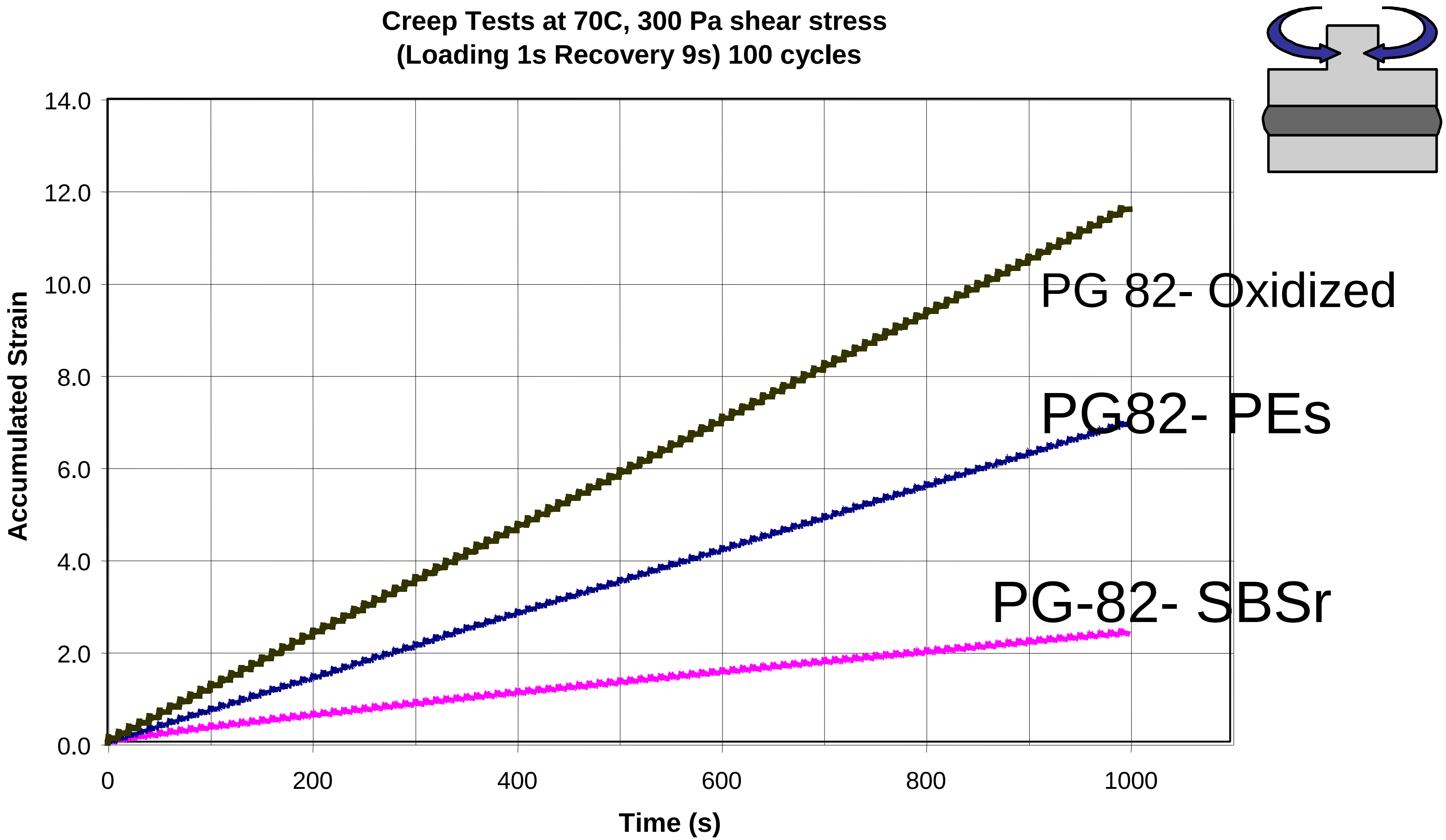
Mixture Rutting Resistance

Same mix different Binders: SBS, FPE, Hybrid

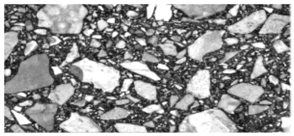




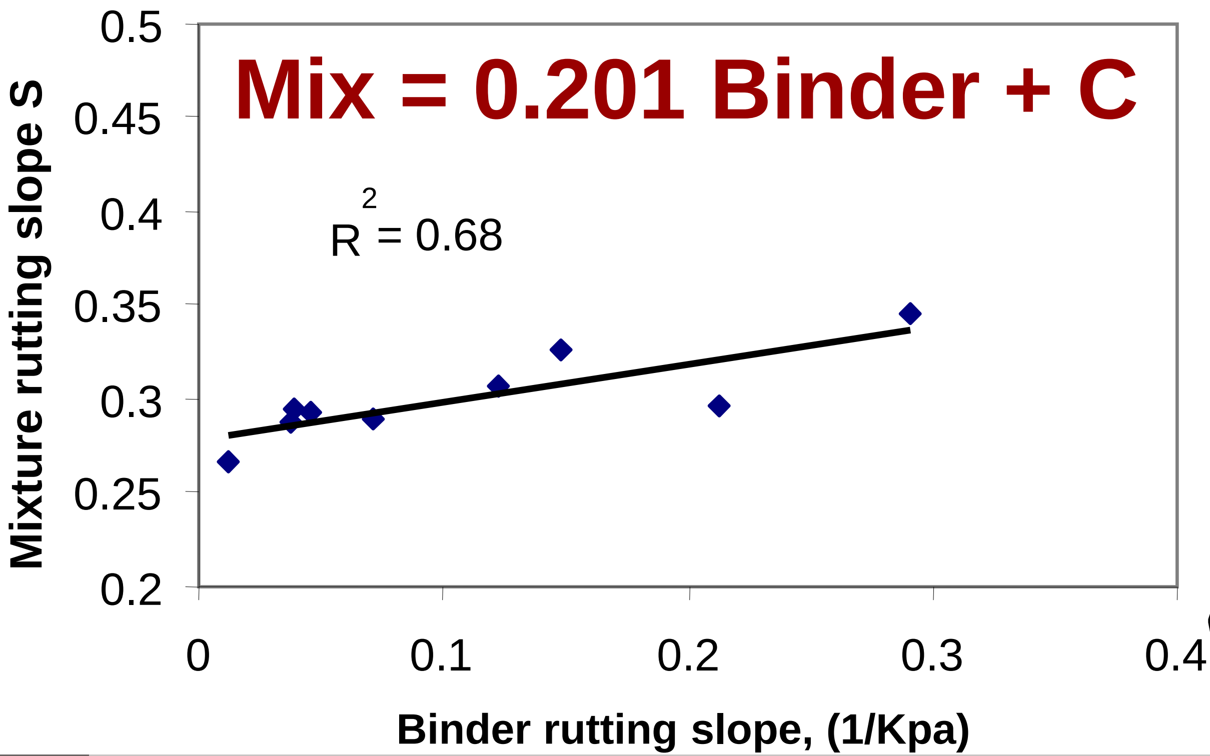
Binder Rutting Testing – Creep and Recovery

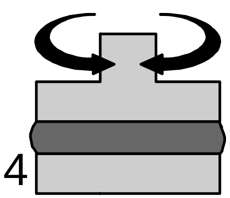


Mixture Model for *Rutting*



Average of All Aggregates



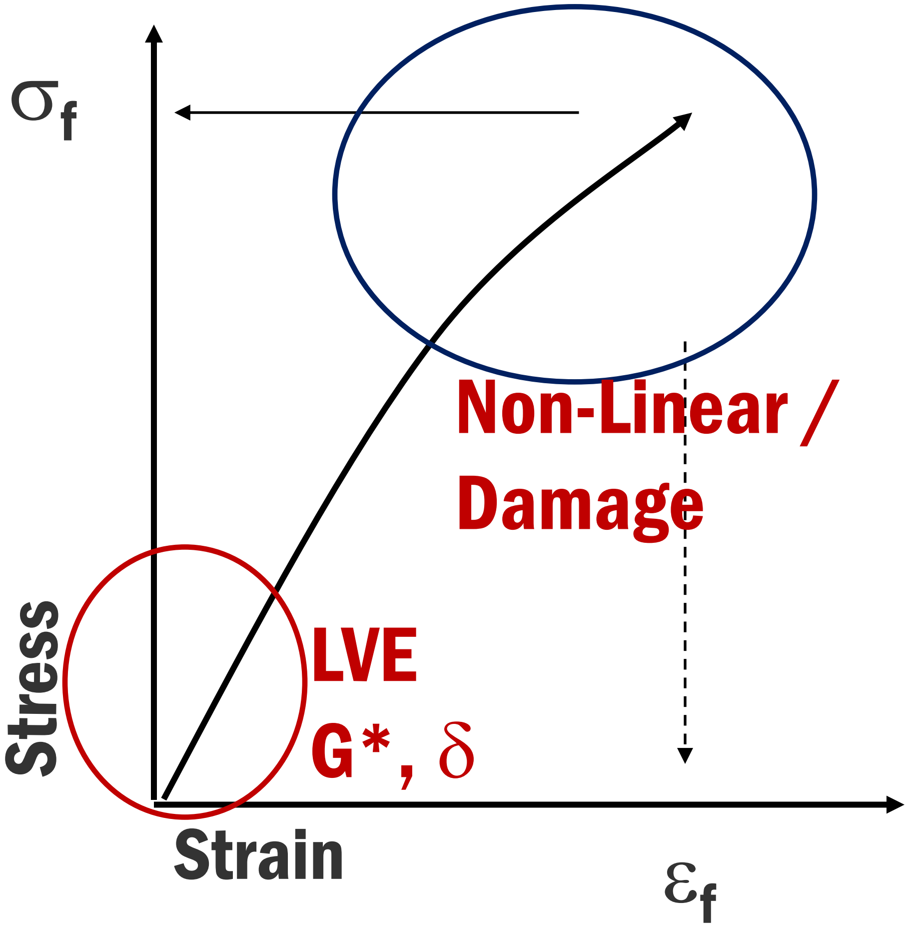


Binder
Damage Resistance

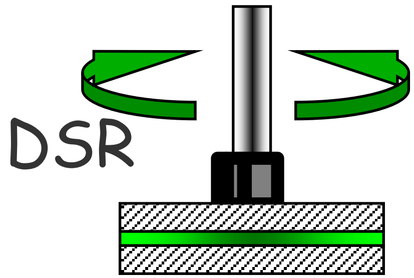
Role of Binders and how to test them

Need for Bitumen Damage Resistance Characterization

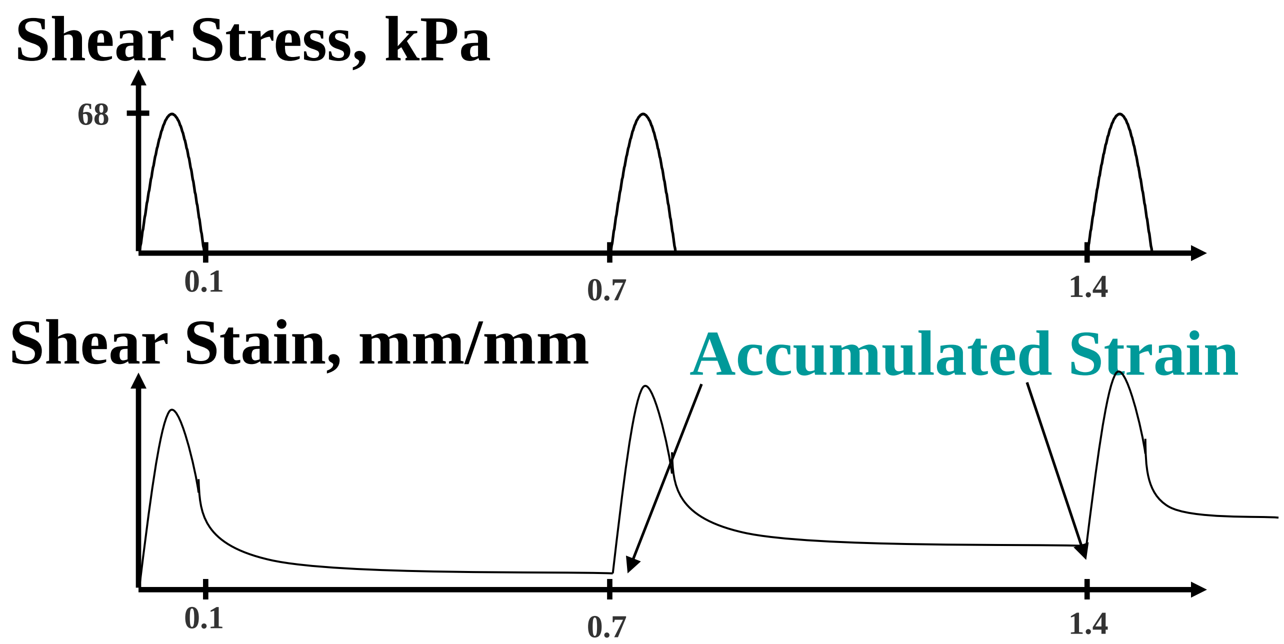
- Linear VE is not sufficient Bitumen damage resistance is very important
- Modified bitumen best in damage resistance



The new tests : Creep and Recovery
(Multiple Stress Creep & Recovery- MSCR)

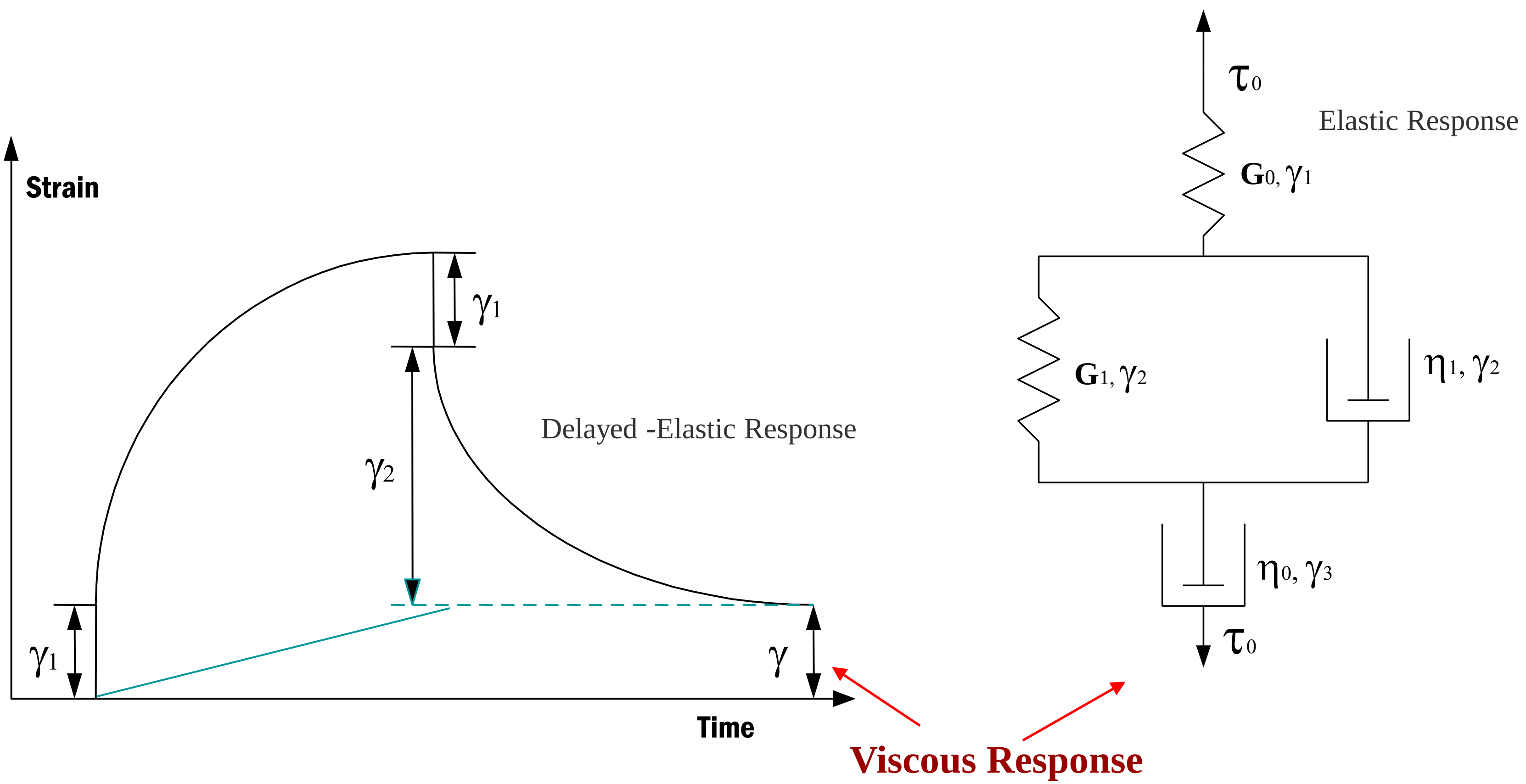


Dynamic Shear Rheometer

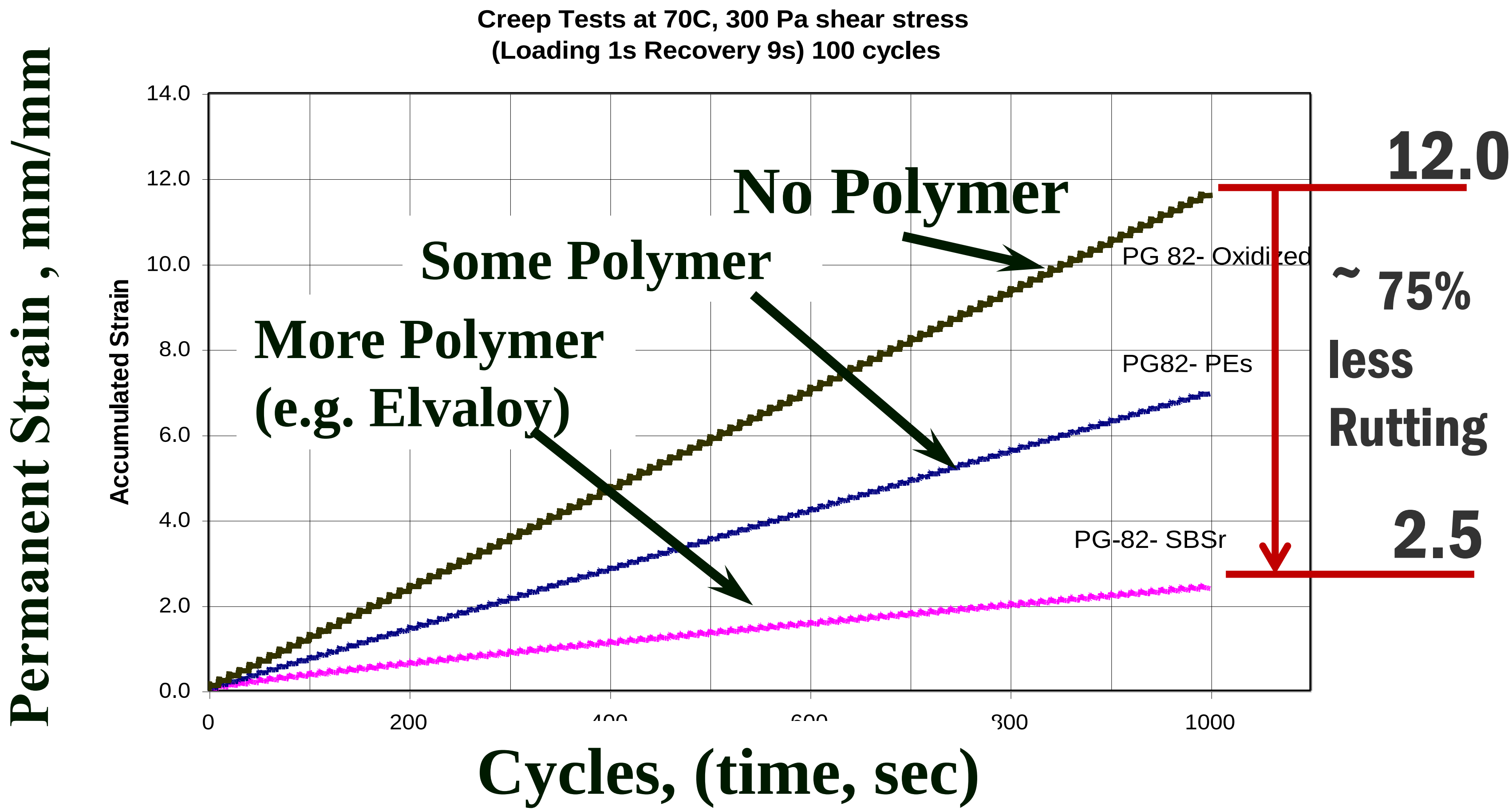


To Separate Non-Recoverable Response (Jnr)

Four-Element (Burgers) Model



More viscous (non-recoverable) = more rutting
Polymers Can Reduce *Rutting Damage*



Using Burgers Model to Estimate Jnr

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

$$= \frac{1}{G_0} + \frac{1}{G_1}\left(1 - e^{-tG_1/\eta_1}\right) + \frac{1}{\eta_{ss}} t$$

Steady State Viscosity

where

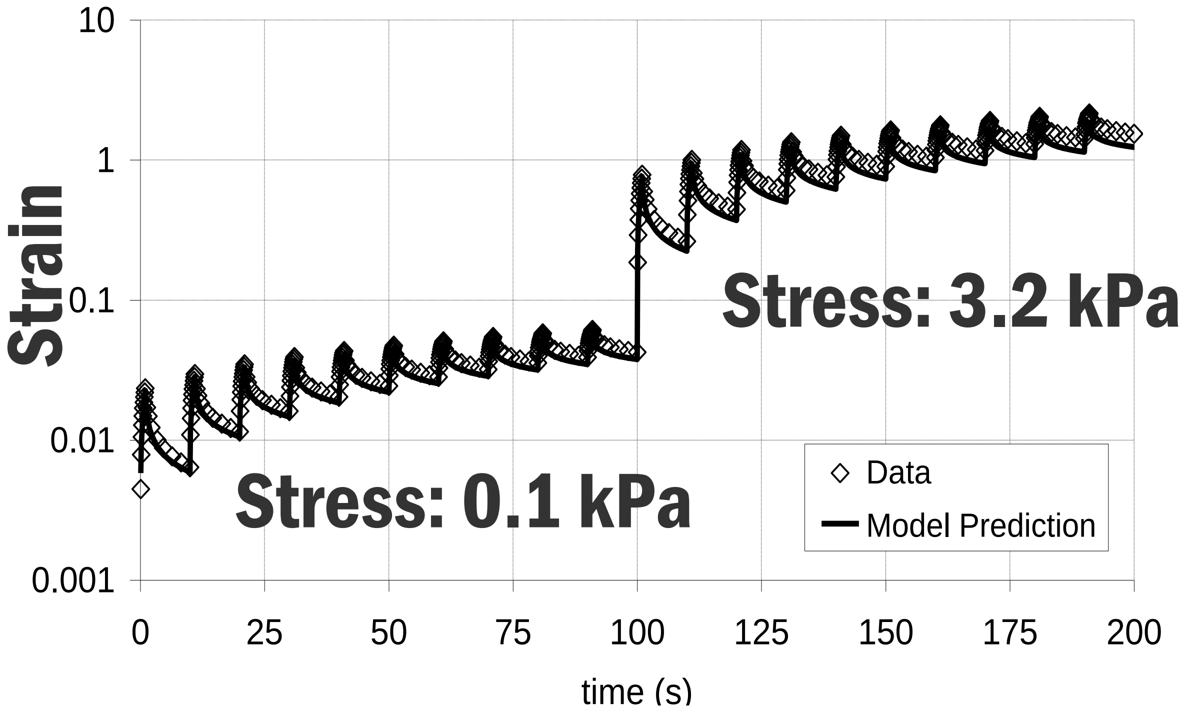
J_e = elastic compliance,

J_{de} = delayed elastic compliance, and

J_v = viscous compliance => Jnr

Multiple Stress Creep and Recovery (MSCR) - ASTM 7045-10, AASHTO TP70

- Creep stress:0.1 kPa, 3.2 kPa
- 10 cycles
  - 1 sec constant creep stress
  - 9 sec zero stress
- Output: **Creep compliance (Jnr) and Percent Recovery (%R)** at 0.1 kPa, and 3.2 kPa



The New Bitumen Grading System- M332 – PG xx(z)-yy

1. *Climate: xx-yy*
2. *Traffic conditions- Trucks (S,H,V,E)*
3. *Reliability , and*
4. *Modification*

Traffic
Volume & Speed

PG 64(V)-10

Performance Grade

Summer
Average 7-day max pavement design temp

Winter
Min pavement design temp

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Advanced Performance Grading System for Qatar – AASHTO MP19

- Direct and effective consideration of Traffic

Traffic Volume Design ESALs[a] (Million)	Adjusting the Jnr limits Measured at Environmental Grade		
	Traffic Speed - Load Rate		
	Standing[b]	Slow[c]	Standard[d]
0.3 to < 3	H	Standard	S
3 to < 10	V	High	H
10 to < 30	E	Very high	V
≥ 30	E	Extremely high	E

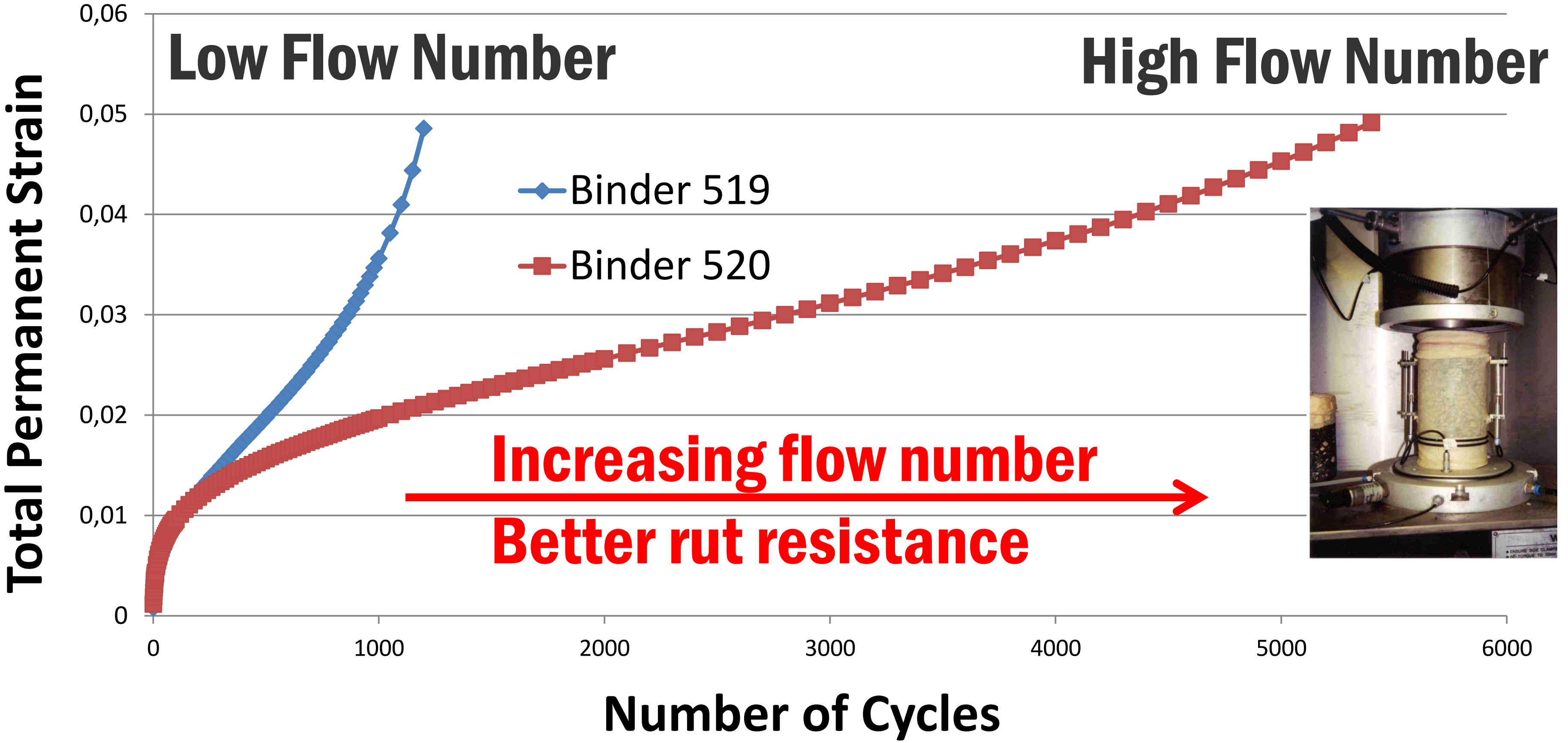
b-Standing Traffic—Average traffic speed is < 20 km/h. [c] *Slow Traffic*—Average traffic speed >20 to <70 km/h, [d] *Standard Traffic*—average traffic speed is > 70 km/h.

Mixture Micro-structure: Aggregate Packing effects

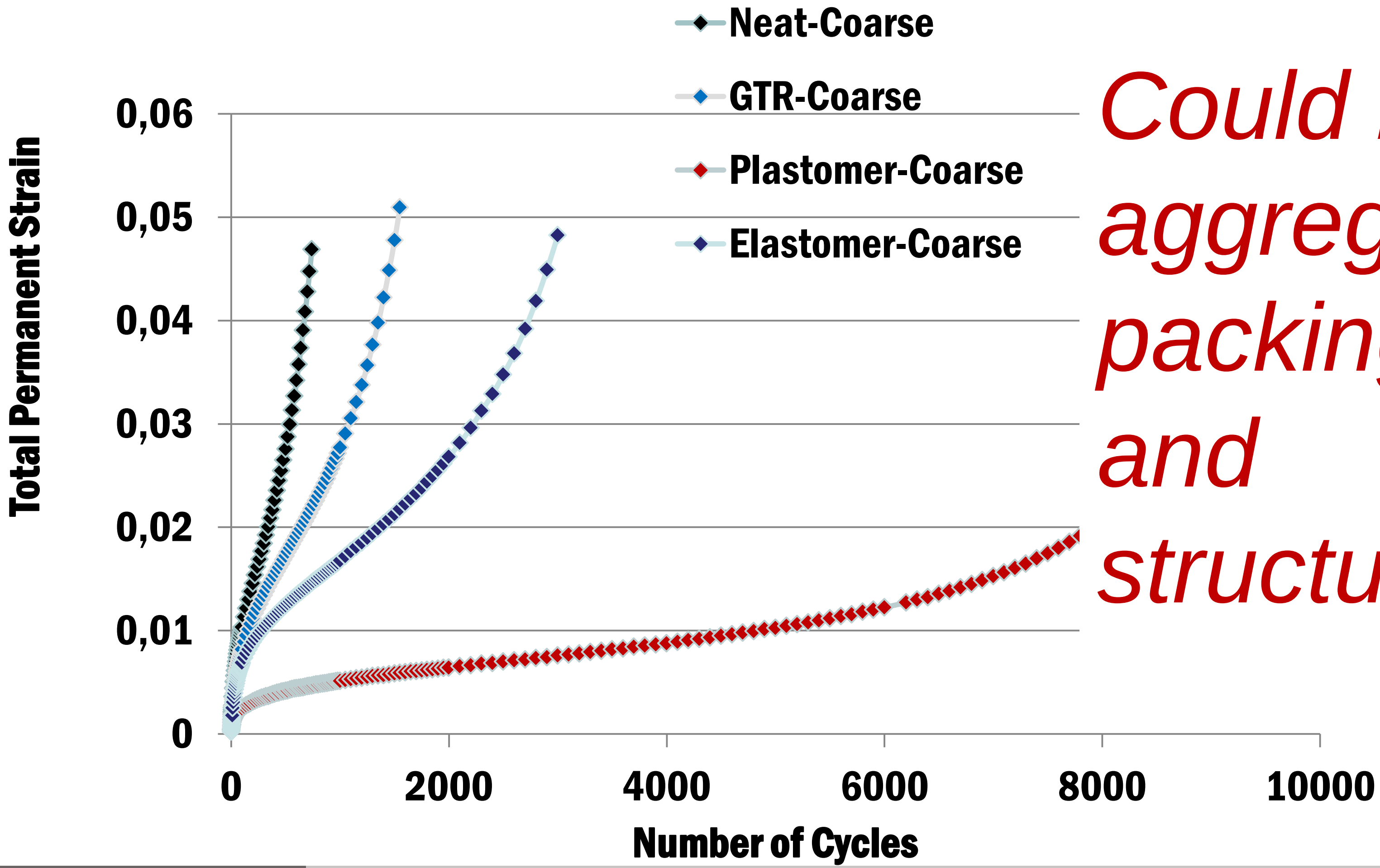
Role of Aggregates

and how to measure it

Typical Results from FN - Mixtures



Bitumen + aggregate gradation + volumetrics ≠ Performance



Could be aggregate packing and structure

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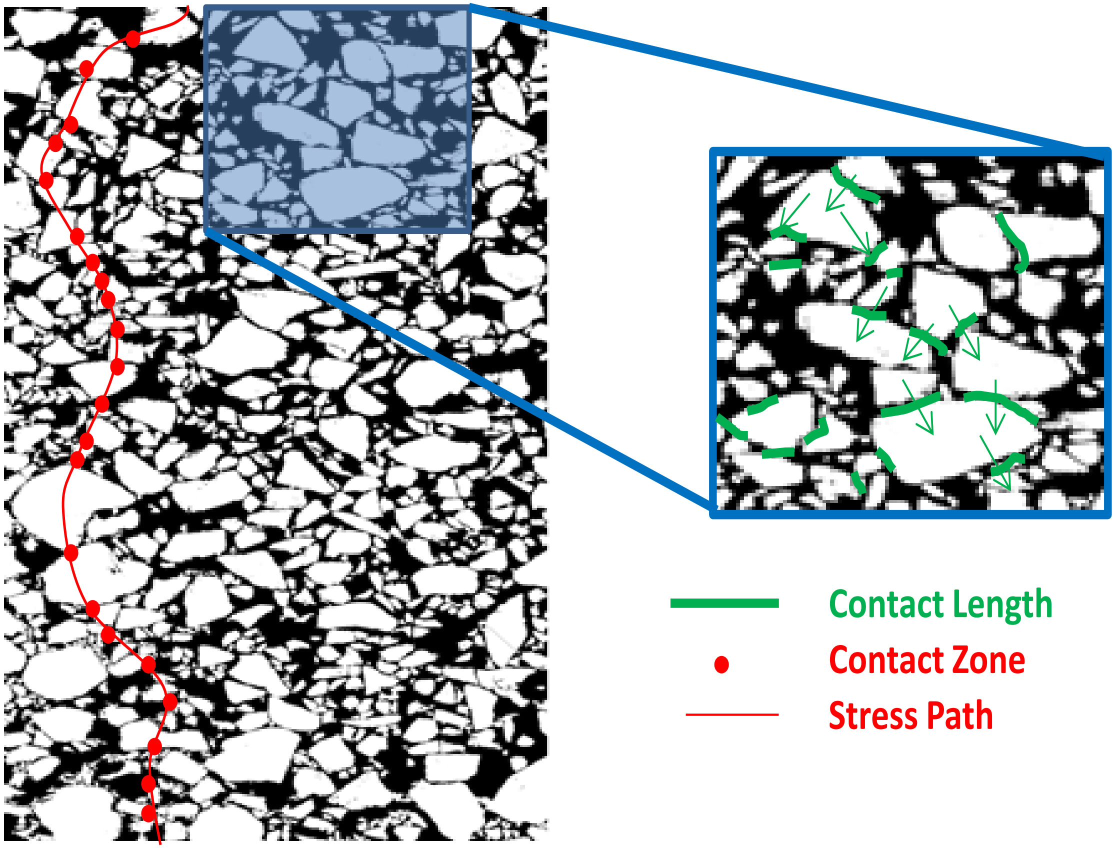
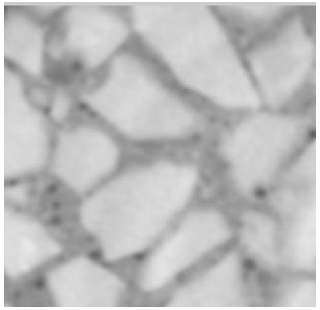
Can we Measure aggregate structure ?
iPas1 … iPas2 … (Image Processing and Analysis Software)

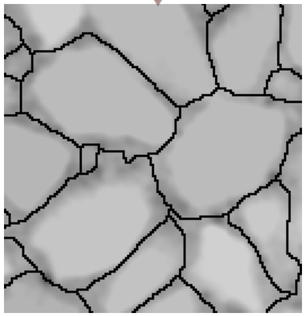
- iPas: A tool to identify aggregate structure.
- Give statistics about
  - Packing
  - Connectivity
  - Orientation
  - Spatial segregation

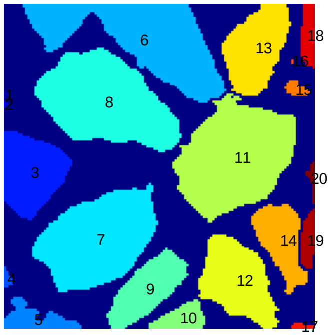


iPas software includes 2-Parts

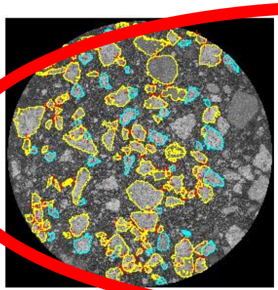
(1) Image **processing**



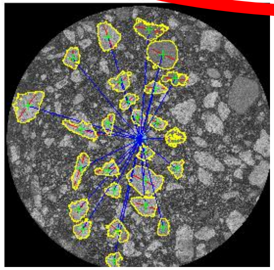




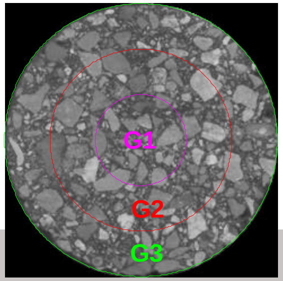
(2) Image **analysis**



Proximity points



Orientation

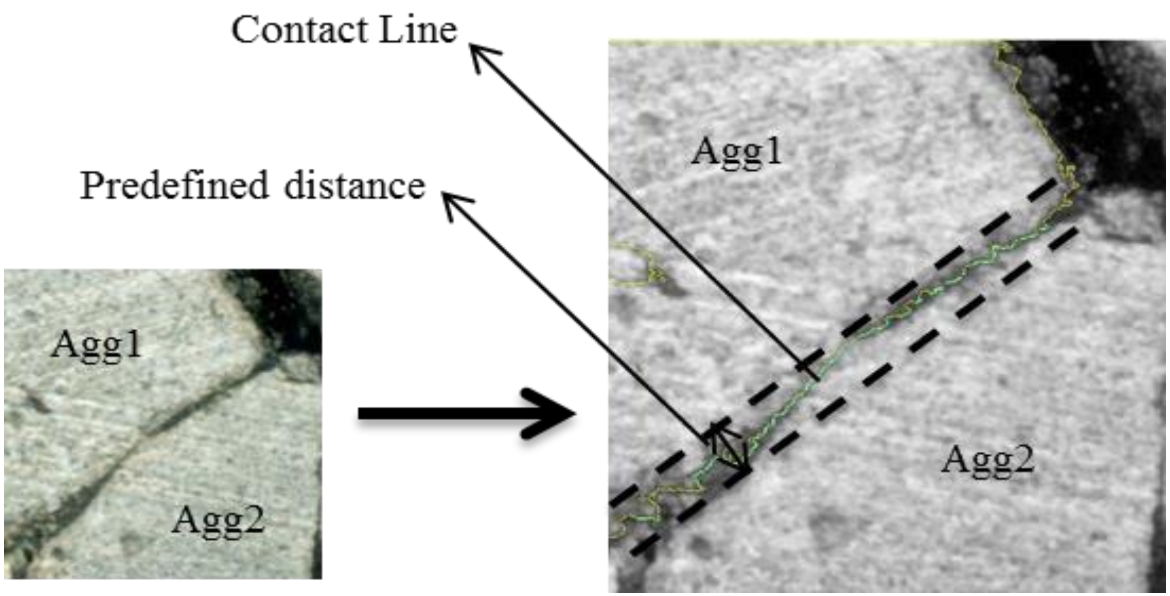


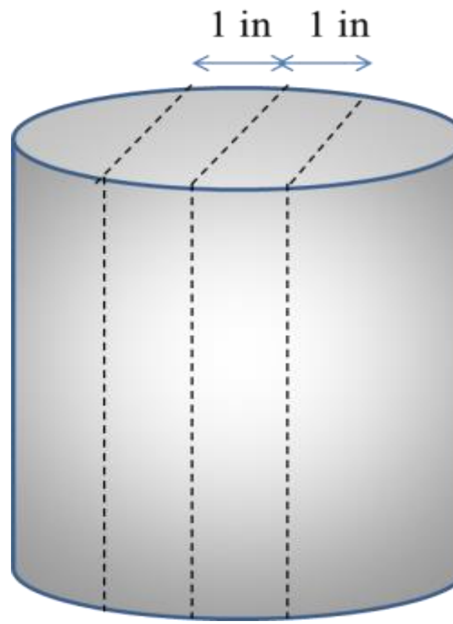
Segregation

Aggregate Packing Characterization
2D to represent 3D - Stereology

iPas output used to quantify packing: Aggr. Proximity Index

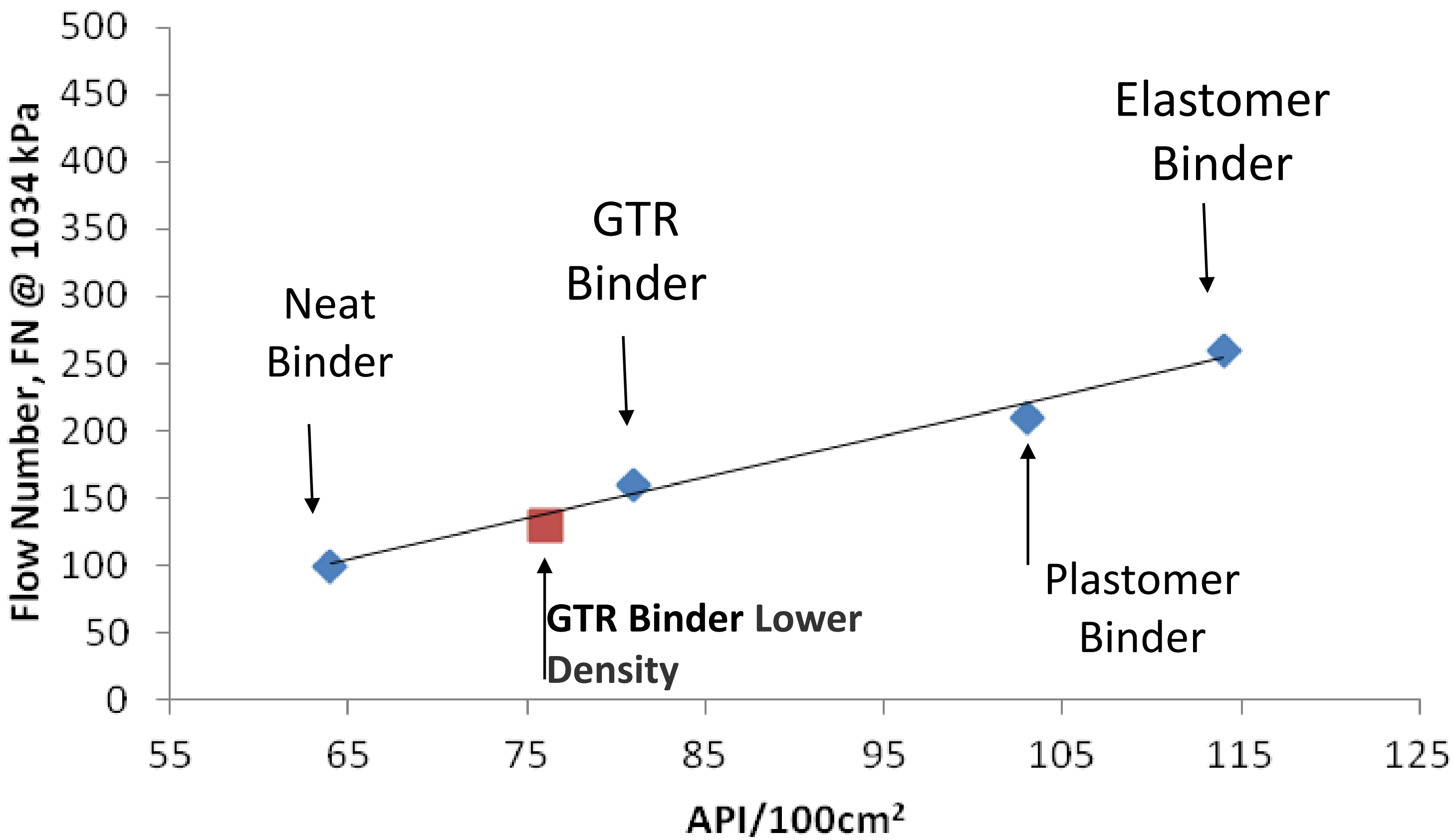
API= Total aggregate to aggregate Proximity length



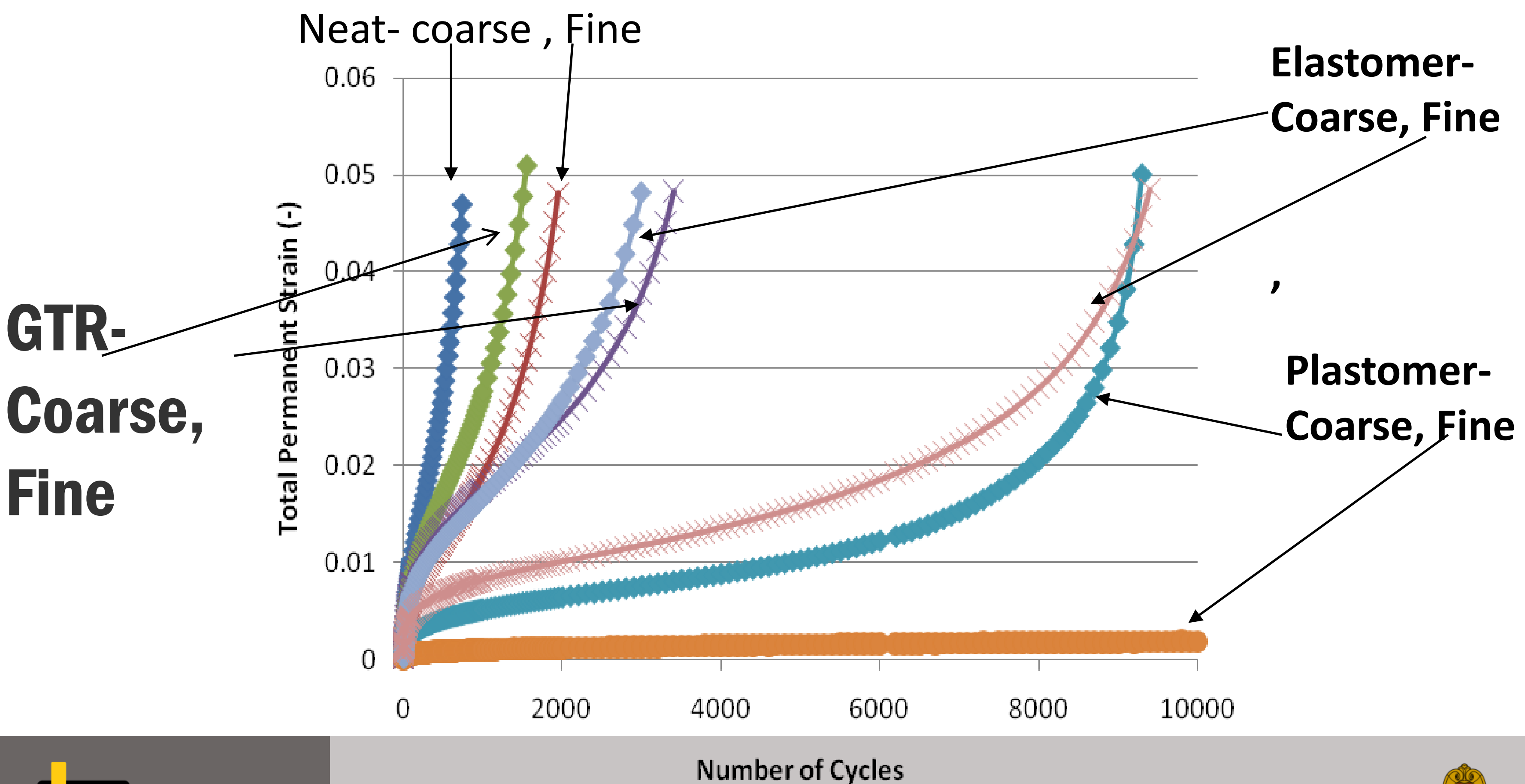


Cutting sections

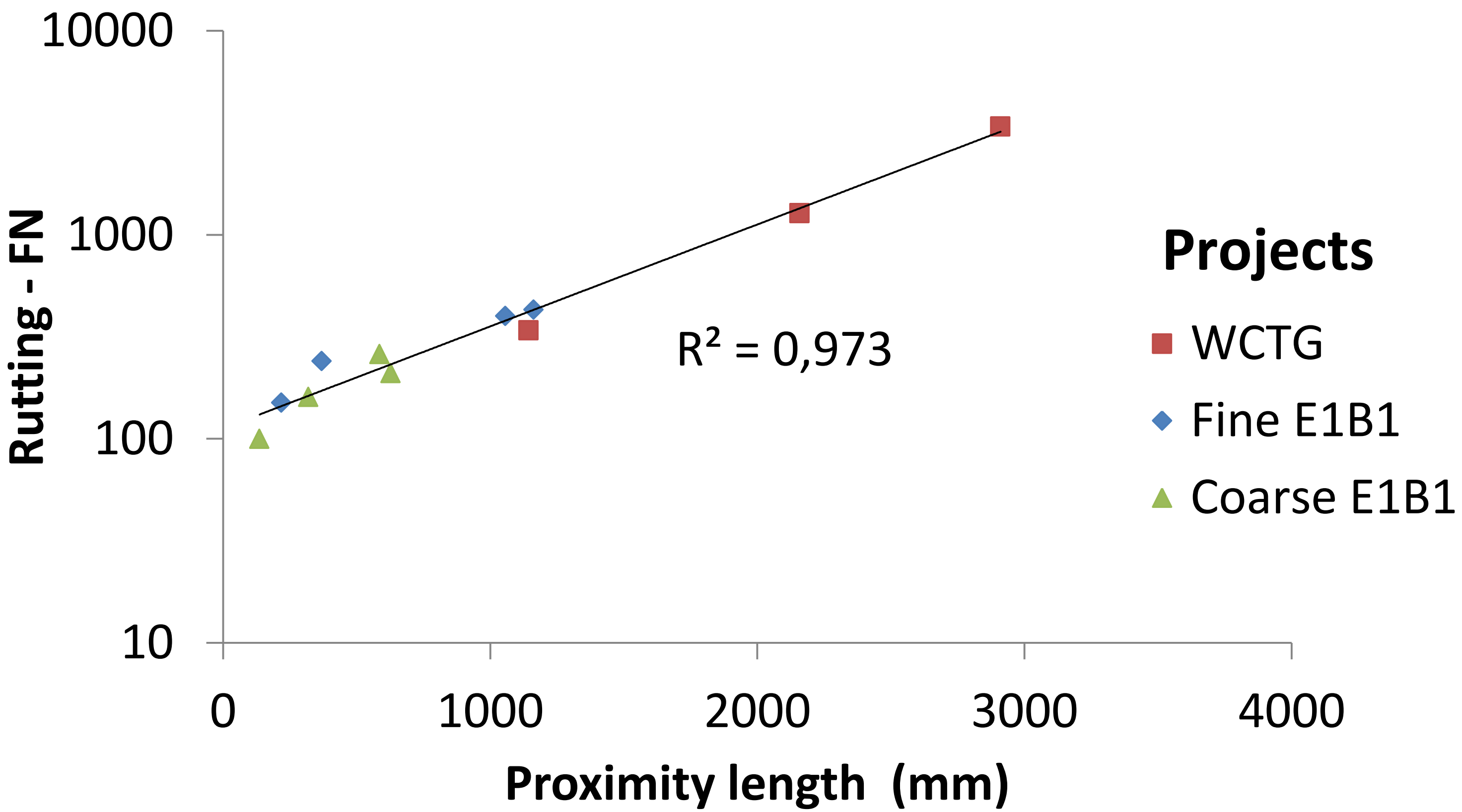
Internal Aggregate Structure (API) Can explain the differences in FN



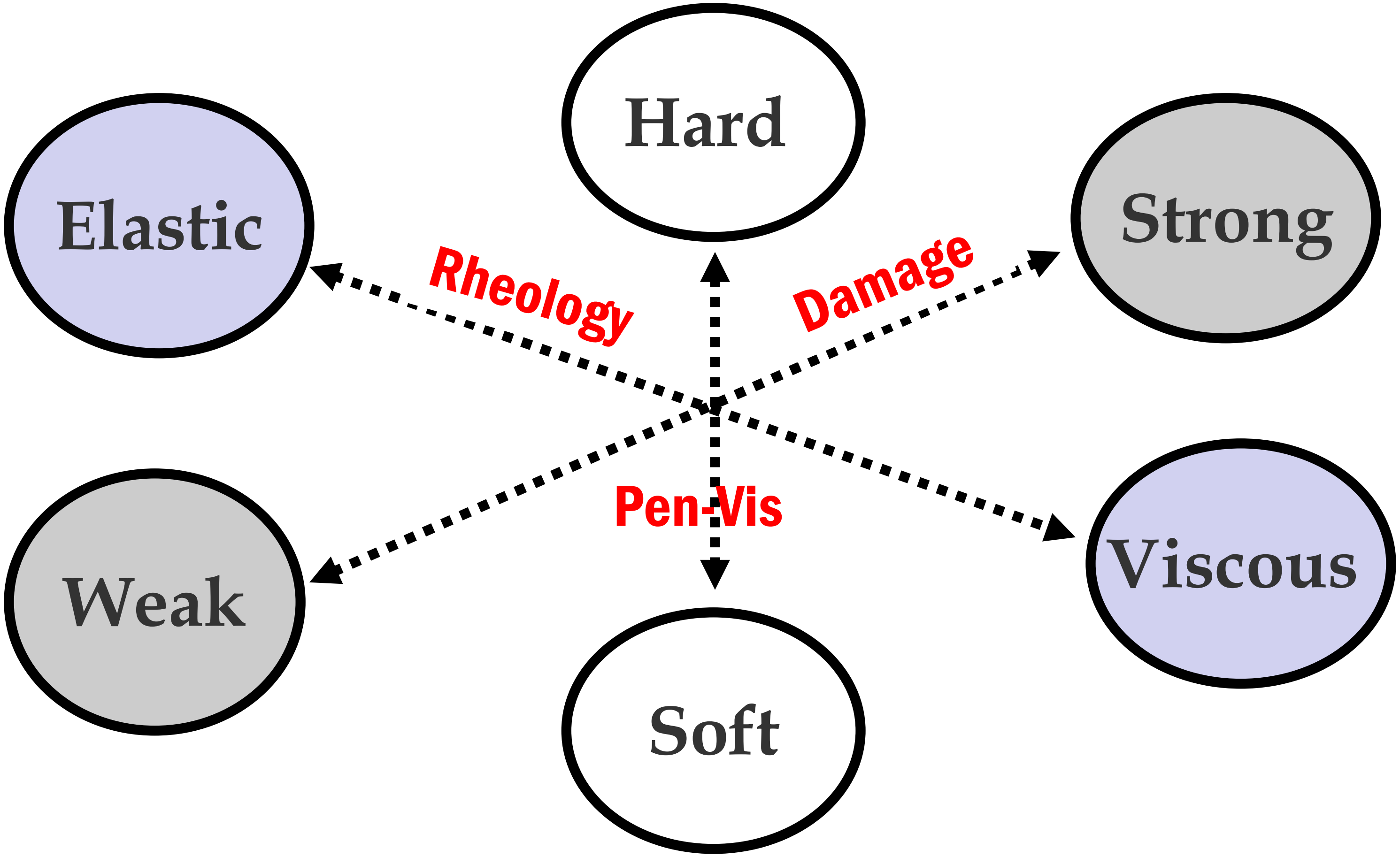
More Results of Mixture Rutting: Effect of Aggregate Gradation



Validation of Effect of Aggregate Packing and Skeleton



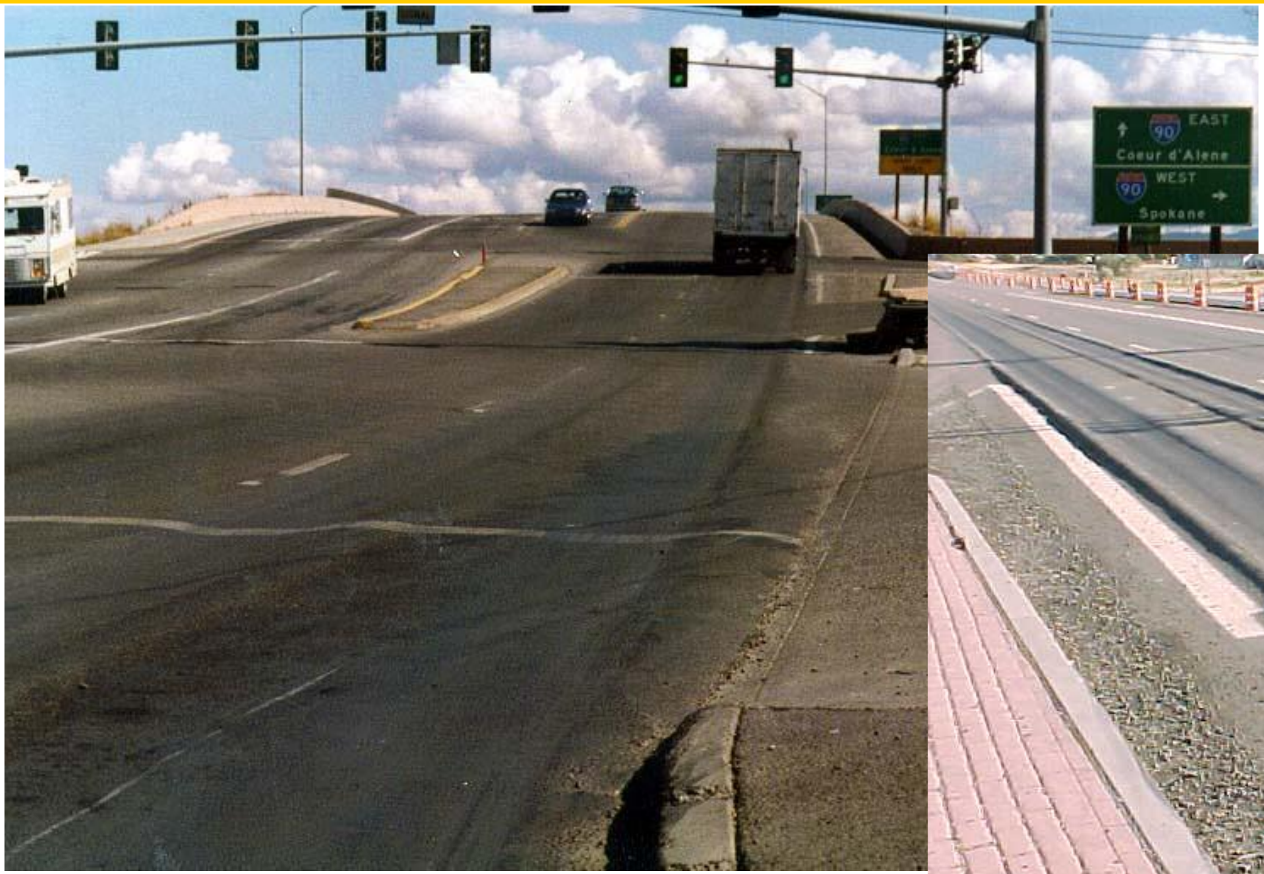
Technologies to Stop Rutting → *Damage Resistance Characterization + Imaging*



Summary

- Both Binders and Aggregates play a major role in rutting resistance
- Binder damage resistance should be measured correctly (large strain repeated creep)
- Voids can have an effect (but aggregate structure is more important
- Aggregate packing is very important
- Imaging and visualization can help

Same Problems but New Methods to Solve



Acknowledgments

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  - Argentinean Road Association
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