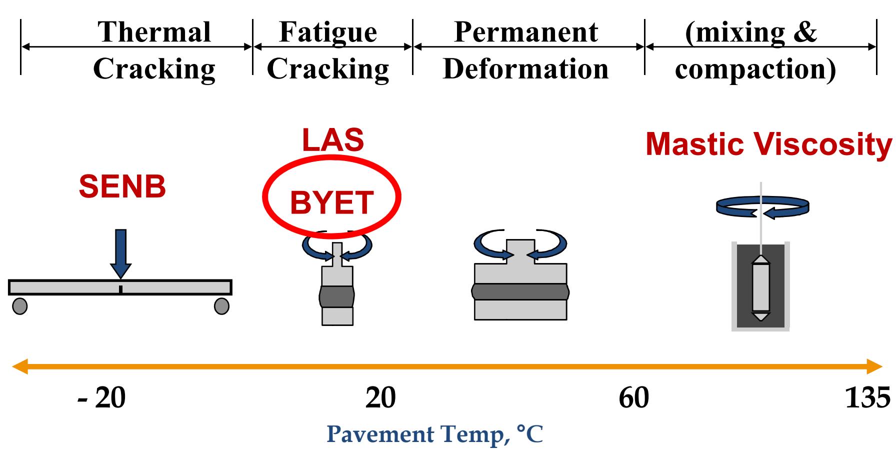
MODIFIED ASPHALT RESEARCH CENTER

ARC Asphalt Research Consortium

The BYET test as a Simpler and More Repeatable Test at Intermediate Temperatures

University of Wisconsin-Madison

ARC Binder Characterization Methods

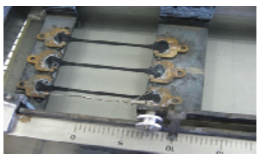


Outline

1. Review of extensional tests and failure mechanics
2. Suggested alternative tests
   a. Elastic Recovery – DSR
   b. Ductility/forced ductility – Binder Yield energy Test

What is an Extensional Test ?

- Ductility

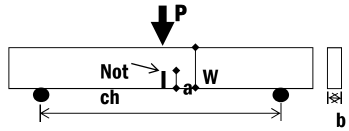


- Forced Ductility

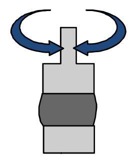
What is *not* an Extensional Test ?

- Bending – BBR- SENB





- Torsional- DSR

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Extensional Rheology and Measuring Failure

- Why are we discussing this?
  1. Ductility, Force Ductility, and DENT tests are still being used in various specification.
  2. These tests, conducted at 4, 15, and 25°C, are classified as extensional tests
  3. Failure mode is Necking, not Cohesive Fracture
     - Fracture analysis is not applicable well above Tg of amorphous material (melt condition)
  4. Extensional rheology is very complex and proper testing is very difficult

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Extensional Rheology on Melts

- Extensional characterization first performed by **Trouton (1906)** on asphalt at 15°C.
  - Used as basis for extensional rheology
- 99 years later:

"Modern" Extensional Rheology:

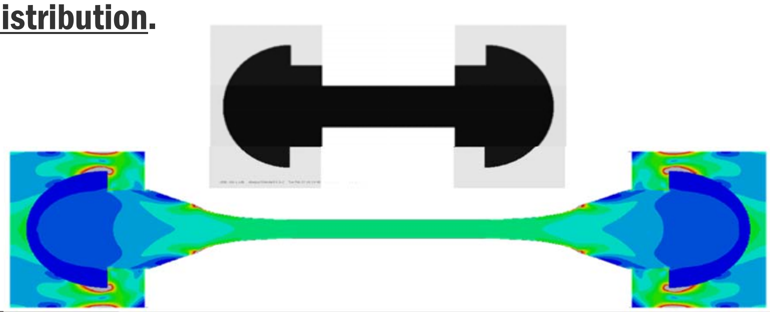
We reiterate the warning about extensional viscosity: it is fine in theory but <u>is a very dangerous idea in practice</u>, specifically when applied while <u>steady flow has not been achieved.</u>"

(Ninety-nine years of extensional Flow; Petrie, 2006)

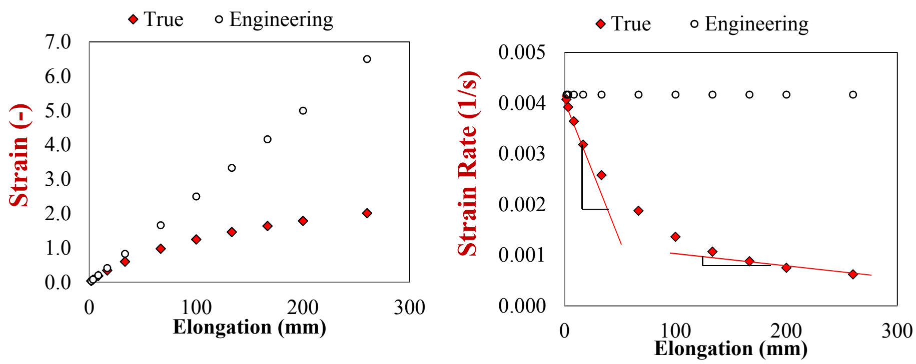
Analytical and Numerical Analysis

(Amir Arshadi, Hassan Tabatabaee)

- Analytical and numerical study of <u>strain and stress conditions</u> in Ductility Bath sample performed.
- <u>Finite Element</u> used for in depth analysis of <u>stress-strain distribution</u>.



Strain Rate in Ductility Bath Test



- **<u>At constant crosshead speed</u> 'engineering strain' rate is constant but 'true strain rate' varies significantly.**

True Strain Rate

- **Ductility bath test has <u>continuously and non-linearly decreasing</u> true strain rate with elongation.**
- **Viscoelastic failure properties are <u>strain-rate dependent</u>**
- **Effect on failure properties:**

<u>Decreasing Strain Rate = Increasing Temperature</u>

Conclusions of Part 1:

- According to principals of Extensional Rheology, testing asphalt at 4 to 15°C (as in the ductility)_does not cause "fracture".
  - Failure is through necking.
- Asphalt extensional testing (ductility and force ductility) does not satisfy requirements well known to make tests meaningful.
- Special conditions needed to perform meaningful extensional tests on melts and taking into account the necking (change in shape) during testing.

Part 2:

EVALUATION OF ALTERNATIVE TEST: BINDER YIELD ENERGY (BYET)

Binder Yield Energy Test (BYET)

- Proposed originally as part of ARC project for VECD analysis (Wen, Johnson, 2009)

Standard Method of Test for

Measuring Asphalt Binder Yield Energy and Elastic Recovery Using the Dynamic Shear Rheometer

AASHTO Designation: T XXX-13

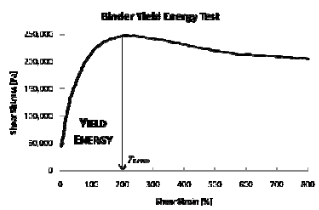
1. SCOPE

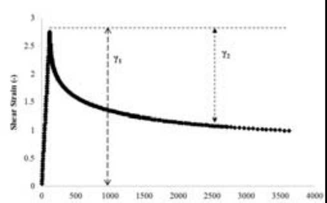
1.1. This test method covers the Binder Yield Energy test (BYET) for evaluation of asphalt binders' resistance to yield-type failure under monotonic constant shear-rate loading using the Dynamic Shear Rheometer (DSR). This test procedure can also be adapted for performing surrogate test procedure using the Dynamic Shear Rheometer (DSR) in place of the conventional ductility test (AASHTO T 51), and the Elastic Recovery test (ASTM D 6084). The test method can be used with unaged material and material aged using AASHTO T 240 (RTFOT) and/or AASHTO R 28 (PAV) to simulate the estimated aging for in-service asphalt pavements.

BYET Revised AASHTO Draft

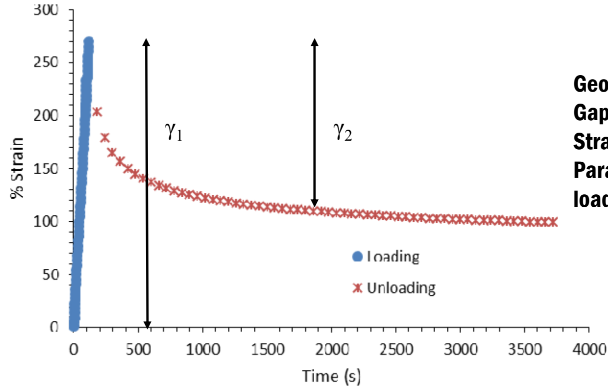
2 procedures described in document:

1. **Binder Yield Energy test**
   - 30 minute monotonic shearing
   - Shear rate is matched either to 0.01 1/s or ductility test procedure (0.023 1/s)
2. **DSR-Elastic Recovery**
   - 2 min monotonic shearing + 30 minute recovery
   - Elastic recovery calculated from response





ER-DSR Test Conditions



Geometry: 8 mm
Gap: 2 mm
Strain Rate: 0.023/s
Parameter: % Recovery 1800 s after loading

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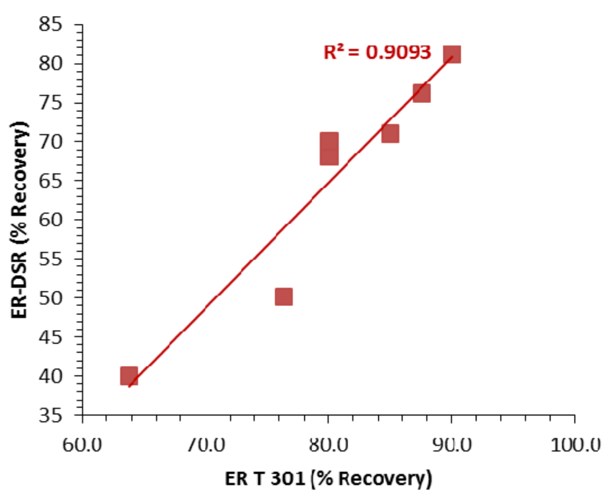
PG-PG+ Correlations: *ER-DSR vs. ER T301 (2013-2014 Binders)*



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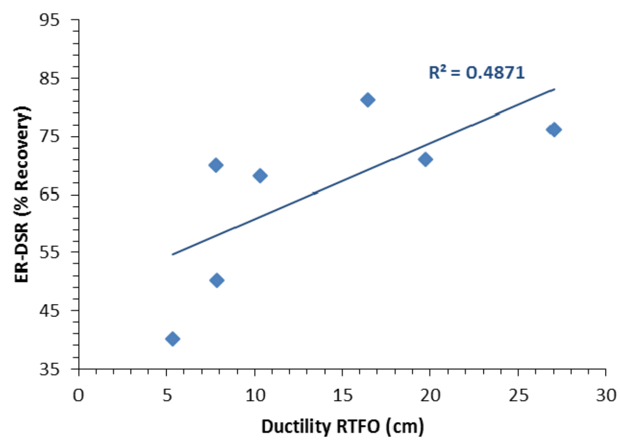
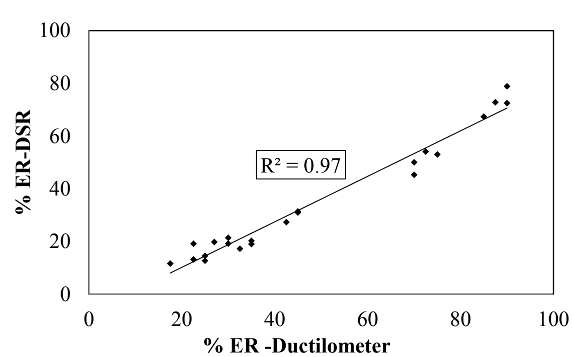
PG-PG+ Correlations: *ER-DSR vs. Ductility 4° C(2013-2014 Binders)*



Comparison to Conventional Tests

- ER-DSR simulates ductilometer extremely well.



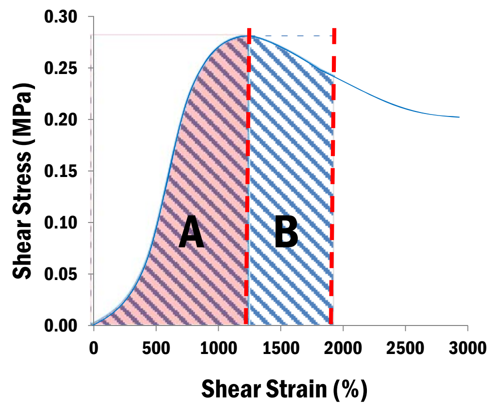
BYET New Analysis
Not Using VECD - Area under Curve as Index

- Two energy parameters are calculated for the BYET:

A. "Yield" Work (W_Y)
   - Area under curve up to peak

B. Total Work (W_T)
   - Area under peak up to equivalent max DENT/Ductility stroke

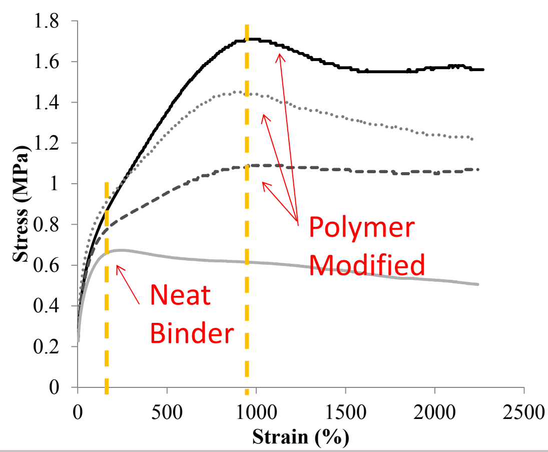
$$W = \int_0^{\gamma_n} \tau d\varepsilon \cong \sum_{i=1}^{n} \tau_i \Delta\gamma_i$$



BYET using DSR

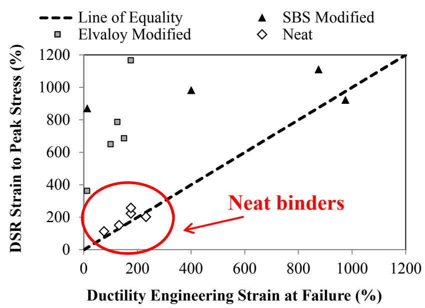
- Tested using DSR with same rate and temperature as DENT/Ductility
- DSR testing eliminates necking and strain rate variation issues of DENT/Ductility
- Very controlled conditions and easy preparation
- Very Repeatable:

C.O.V. < 3.0%



Comparison to Conventional Tests

- BYET simulates ductility for unmodified binders and gives a better indication of ductility for modified binders.



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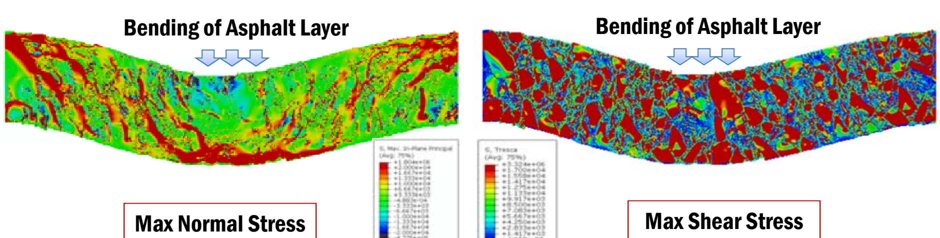
Stress State of Binder in Pavement

- Asphalt binder **between aggregates** are under **multi-axial stress** states; Shear in binder is never without a normal stress in pavement
- Realistic representation of binder **requires both shear and normal stress components.**
- **Cannot be achieved** in ductility or extensional tests



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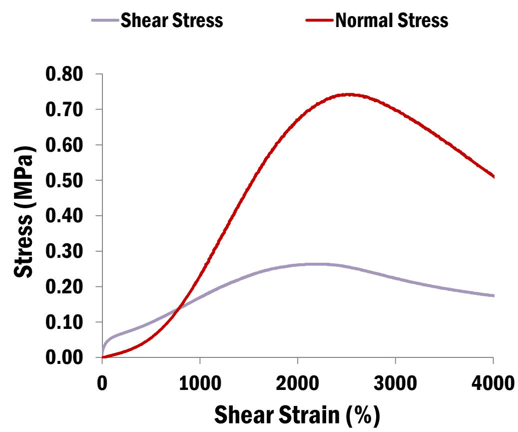
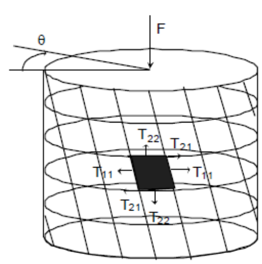
BYET Provides Multi-axial Stress State:

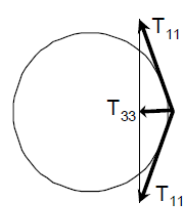
- BYET sample is under multi-axial stress
  - Both normal and shear components
  - Believed to more realistic representation of binder in pavement



Why is normal force formed?

Circumferential (hoop) Stress: Weissenberg Effect





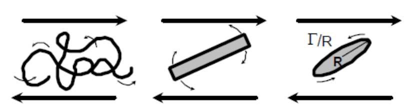
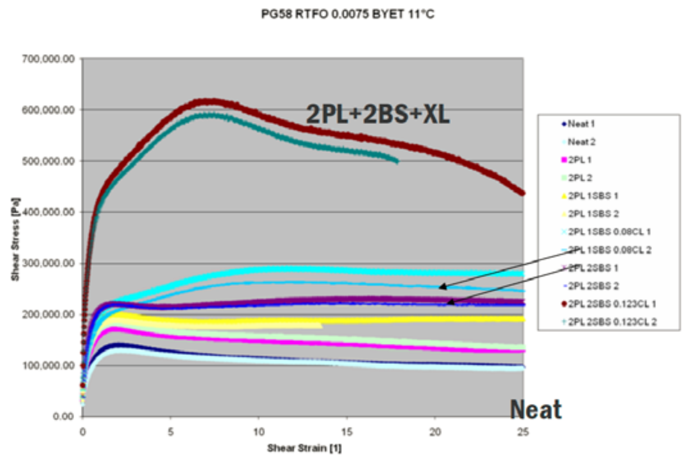


Figure 6:. Normal stresses arise in shear flow of a) polymer coils and b) rod-like particles due to Brownian motion and in c) liquid drops due to interfacial tension, G

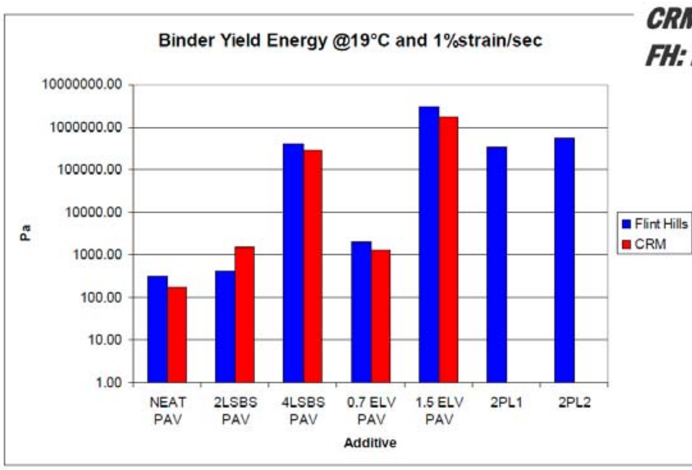
- In cross linked samples torsion causes particles or coils to orient or untangle in direction of flow, especially on flow lines along surface.
- Brownian motion (higher entropy) mobilizes incremental tension on surface toward establishing previous random arrangement.
- Force is dependent on degree of cross-linking and average molecular weight. (Franck, 2007)
  - Very high in high cross linked SBS modification.

BYET Can Differentiate Between Modification and Cross-linking

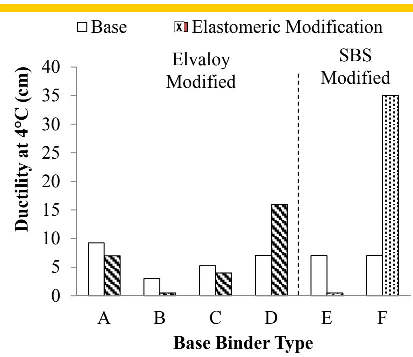


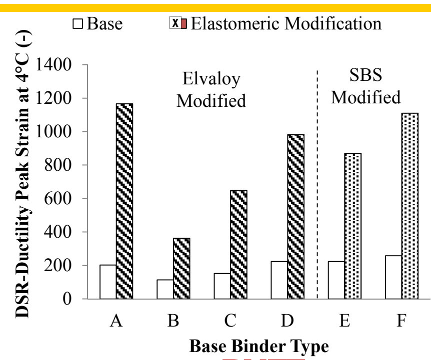
BYET Can Differentiate Between Modification and Cross-linking

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



Ductility Bath vs. BYET



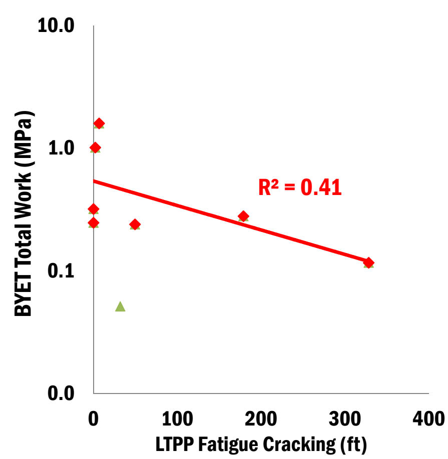


Ductility Bath → **Mixed Results**

BYET → **Clear PMA Improvement**

BYET Relates Better to Field Performance

- Using continuous shearing in DSR (BYET)
  - No necking = no strain rate changes due to no elongation
  - Better control of test conditions (temperature, geometry, etc.)
  - Better relation to performance: Logical trend: High BYET energy corresponds to low cracking



Concluding Remarks

- There are serious problems with extensional tests(Ductility, Force Ductility, and DENT).
- Problems Solved using BYET to replace Ductility:
  - Constant strain rate (fair to all materials)
  - Much better repeatability
  - Good discrimination between binders in terms of performance
  - Simple and available device with better control of test conditions (temperature, rate, geometry)

Thank You!

Questions?

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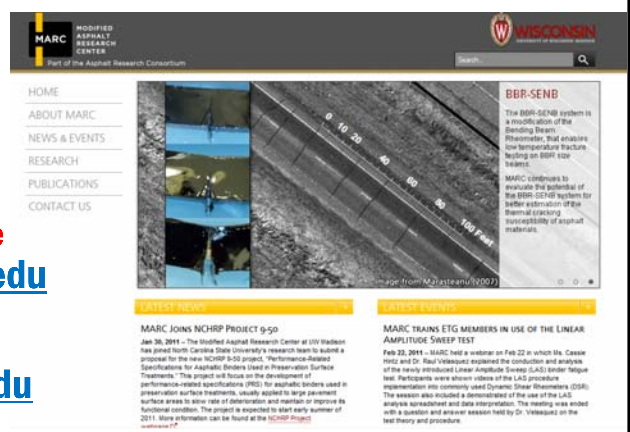

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