ARC Project Emulsion Task Force Update

Improvement of Emulsions' Characterization and Mixture Design for Cold Bitumen Applications

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Outline

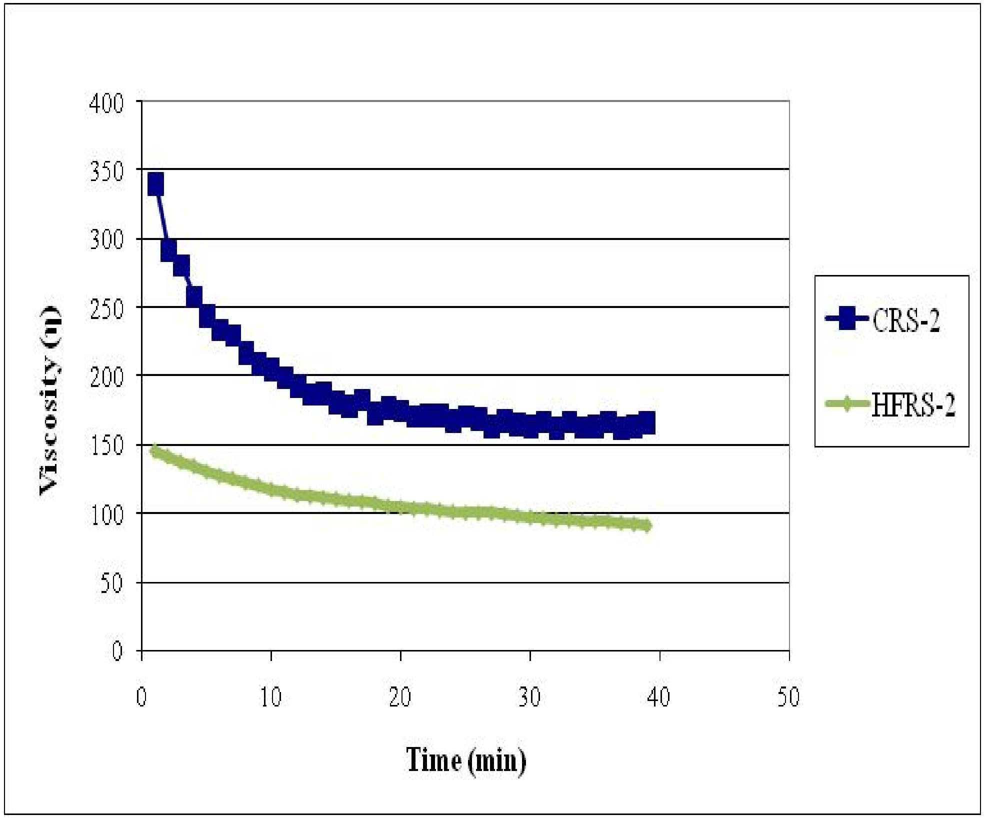
- Construction Properties - BBS and RV
  - Emulsion Viscosity in the RV
  - Bitumen Bond Strength Testing
- Residue Evaluation - DSR
  - Aging Considerations
  - Performance Testing
- Year 4 Work Plan Focus Areas

Pertinent Construction (Emulsion) Properties - Chip Seals

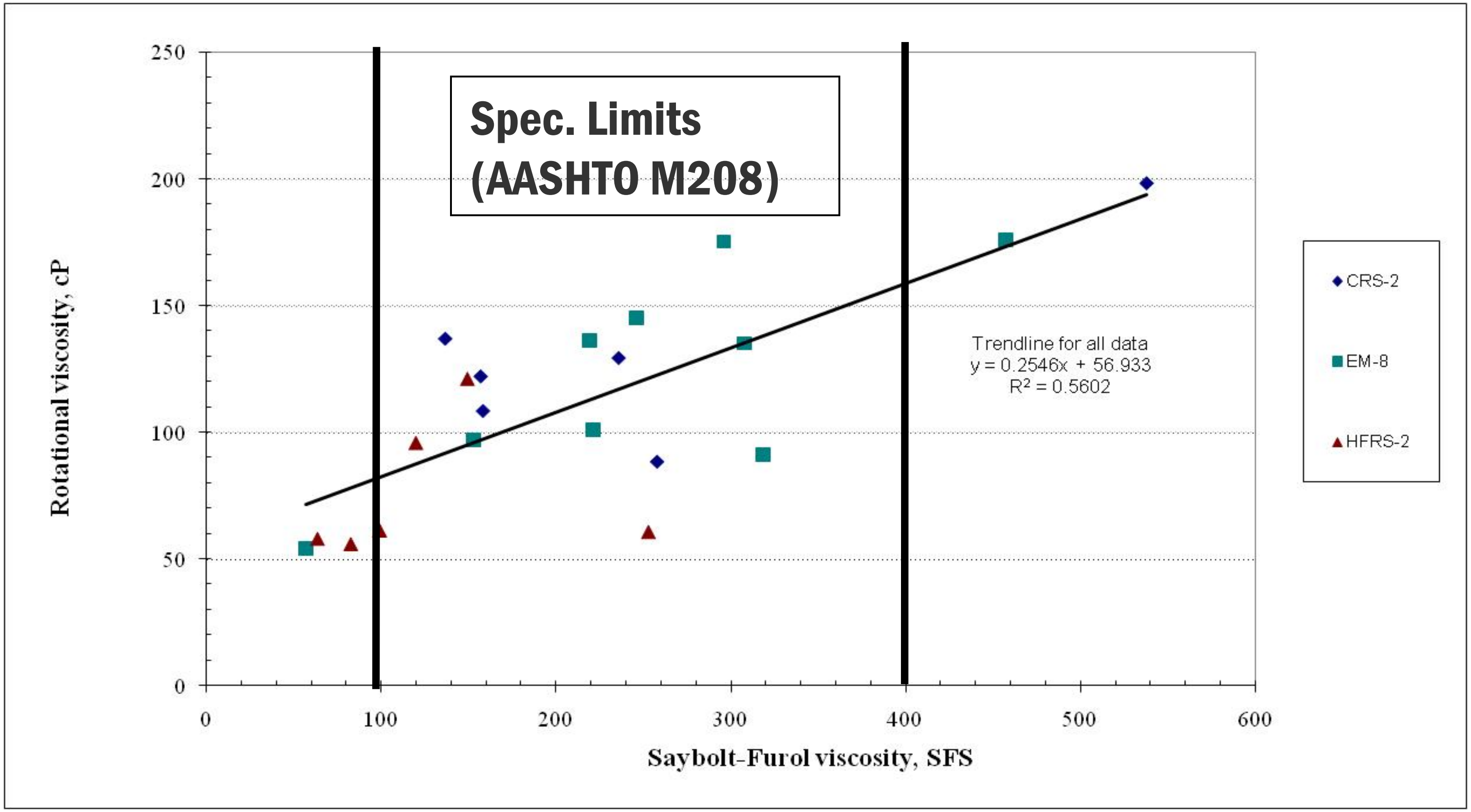
Engineering Property	Parameter(s) Measured
1. Construction Properties	
1.1 Storage Stability	Difference in residue - top and bottom of storage vessel - 24 hrs.
1.2 Spray-ability and Drain Out	Viscosity @ application temp. Shear rate to simulate pumping and placement
1.3 Breaking / Setting Rate	Change in bond strength with time.
1.4 Early Raveling	Bond Strength at a given curing time.

Use of RV to Measure Emulsion Viscosity

- Evaluate *steady state* viscosity using RV
- Testing conditions
  - 50 °C, 50 RPM, # 21 spindle
- Relationship to current methods
  - Compare to Saybolt-Furol viscosity



Preliminary Results – RV (50 RPM) vs. SFS



Concepts for Evaluation of Viscosity

- Vary Shear Rate to simulate field conditions
  - Spray-ability – η at ***high*** shear rate
  - Drain Out - η at ***low*** shear rate
  - Can RV producing a shear rate that simulates spraying?
- Relationship to Saybolt-Furol Viscosity
  - How relevant is it?

Challenges – Based on Discussion with ARC Advisory Group

- Steady Shear Viscosity
  - Is large drop in η recoverable? Or does it reflect damage in the material during initial testing?
  - Initial results show this is <u>not</u> recoverable.
- Thermal History – Disconnect between lab and field.
- Effect of Shear Rate
  - Define effect of shear rate on steady state viscosity.
  - Test must simulate field conditions.

Next Steps for Viscosity

- Address Comments provided by Advisory group.
- Based on results develop testing procedure
  - Steady state viscosity at low shear rate, then high shear rate on the same sample.
- Testing Conditions for initial evaluation
  - Temperature: 50°C, 65 °C, 80 °C
  - Shear Rates (RPM): 1, 5, 20, 50, 150

Adhesion Testing

- Chip seal performance **highly dependent on development of adhesion** between emulsion and aggregate chips.
  - Current test is qualitative – ASTM D244 Coating Ability
- Concept is to develop a simple test to measure:
  - Bond strength, development of adhesion
  - Aggregate / emulsion compatibility
- Validation – Test Entire System
  - Sweep Test (ASTM D7000) – Aggregate Loss

Early failures due to lack of adhesion and climate effects

Bitumen Bond Strength Test (BBS)

- Test Method Development
  - Procedure
  - Equipment
  - Factor Screening Experiment
- Relationship to Chip Seal Performance
  - Correlation with Sweep Test
- Draft AASHTO Procedure – For ETF Review

BBS Procedure

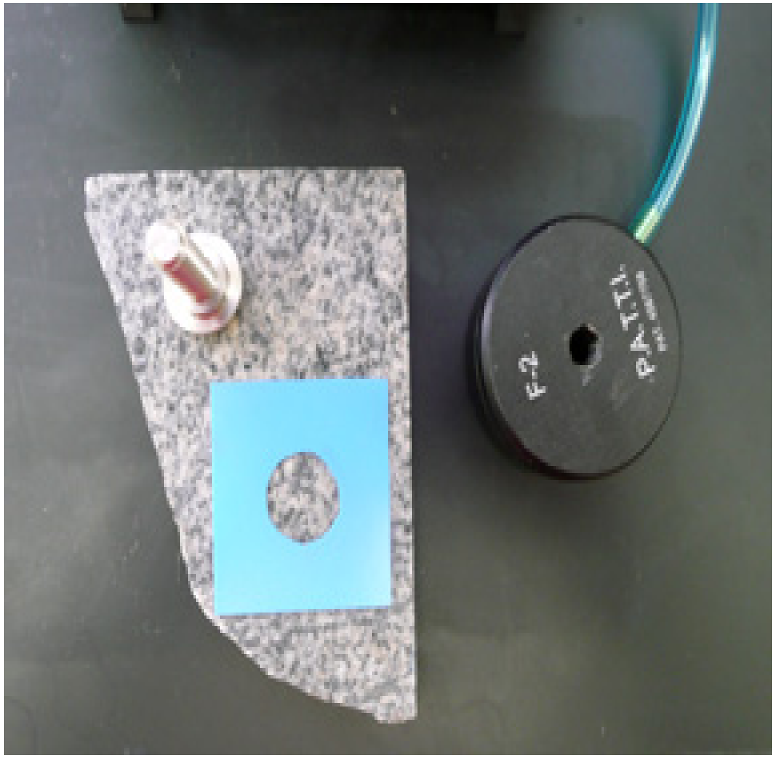
- Aggregate Plate Preparation
  - Sawing parallel faces, lapping
- Emulsion Application and Curing
  - Sample weight: 0.4 – 0.5g. Curing controlled in environmental chamber.
- Apply Stub and Acclimate to Laboratory Conditions (1 hr).
- Testing

BBS Procedure (cont)

- Data Analysis and Interpretation
  - Pull Off Tensile Strength
  - Ensure consistent loading rate
  - Examine/Image Failure Surface
    - Adhesive Failure
    - Cohesive Failure
- Detailed steps provided in draft AASHTO standard.

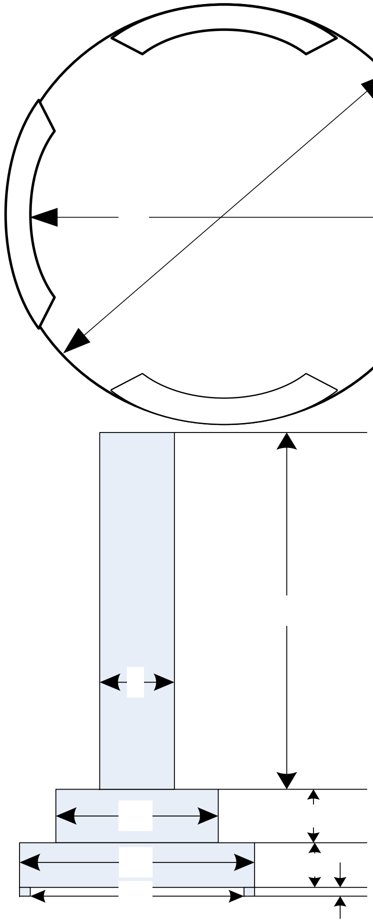
Adhesion Testing – PATTI Quantum Gold Testing Set up

Aggregate Plate and stub.
Digital display gives POTS.

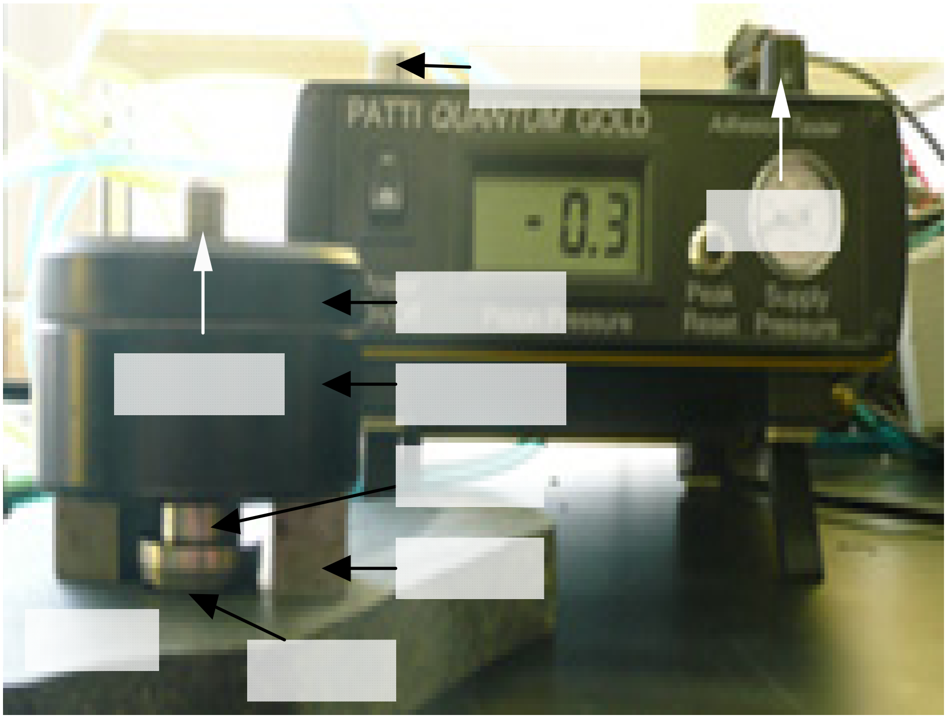


Loading plate and materials used in test preparation.

BBS Stub Geometry



Testing Apparatus

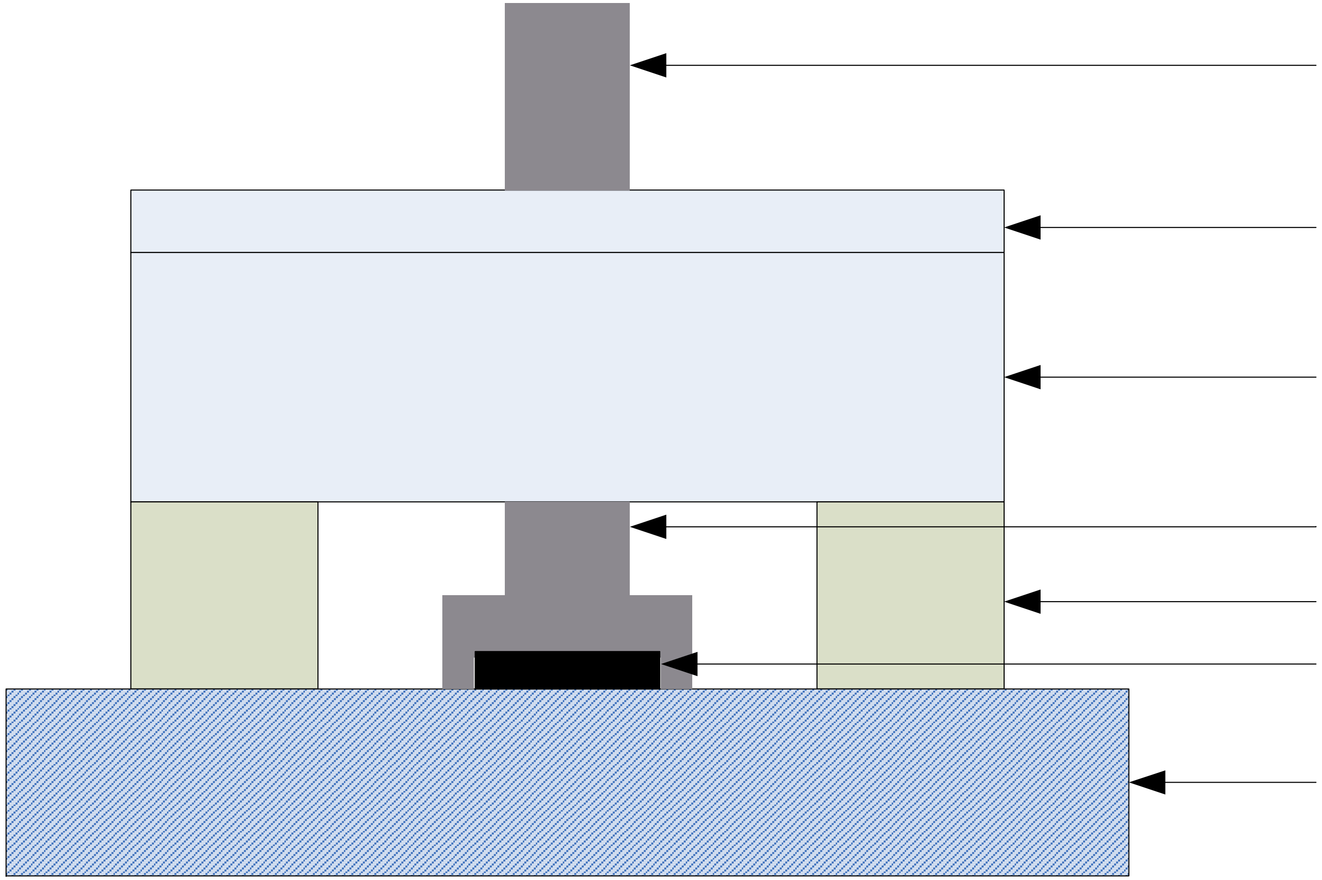


Graded Scale for Air Flow Control

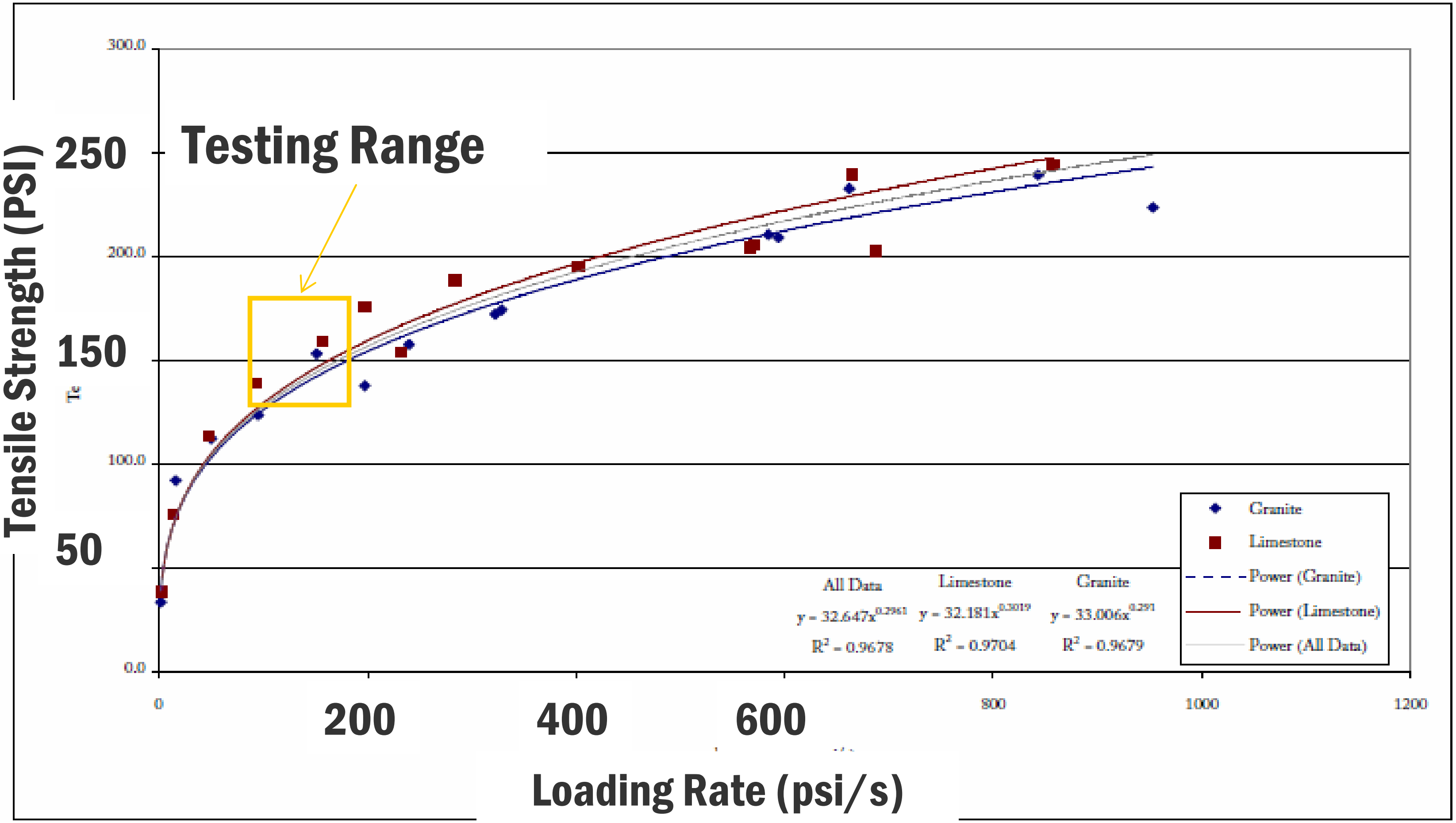
Test Button

Pressure Plate

Schematic of Complete Testing Assembly



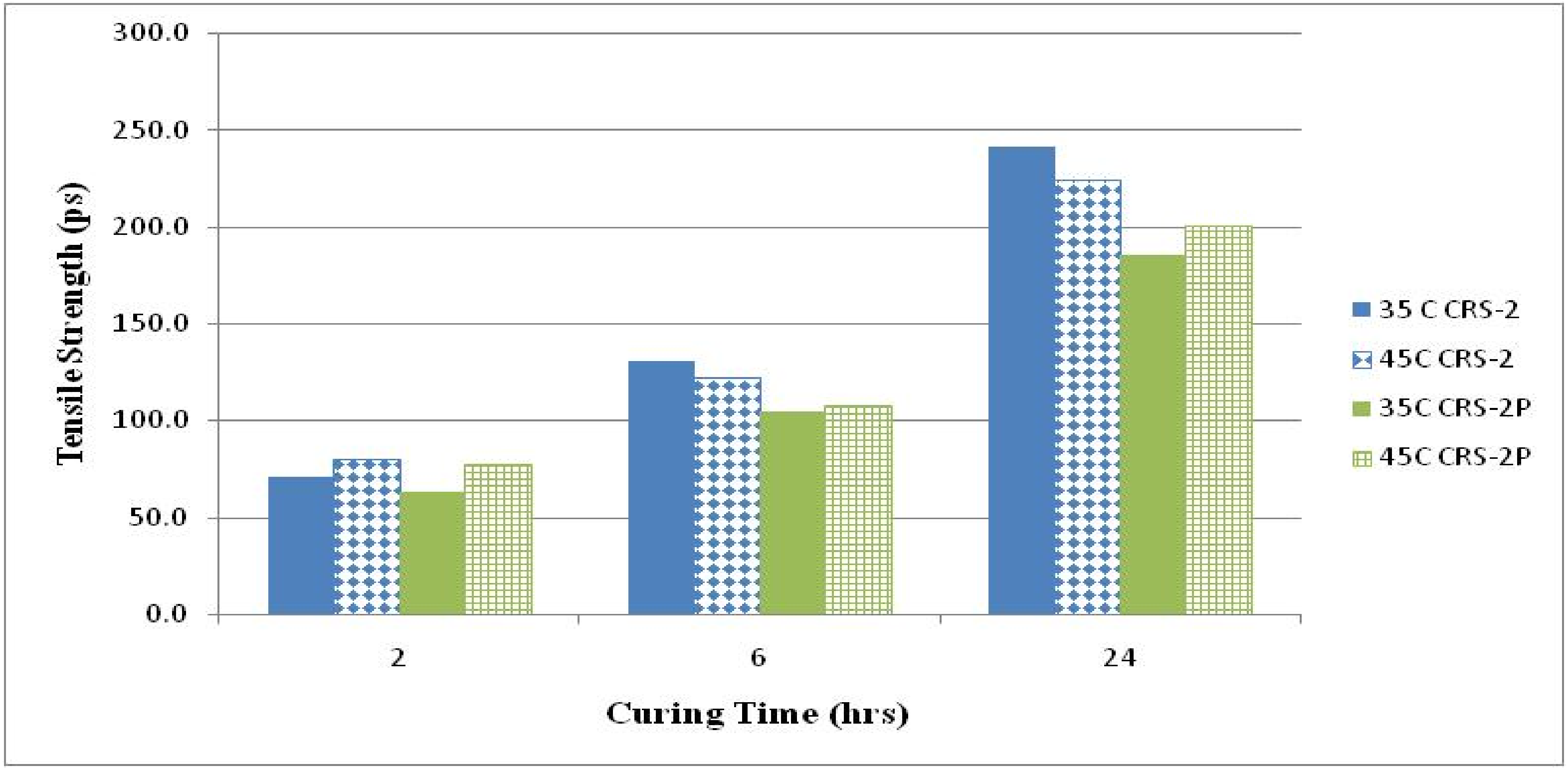
Is Control of Flow Rate Important? Yes



BBS Identification of Significant Factors

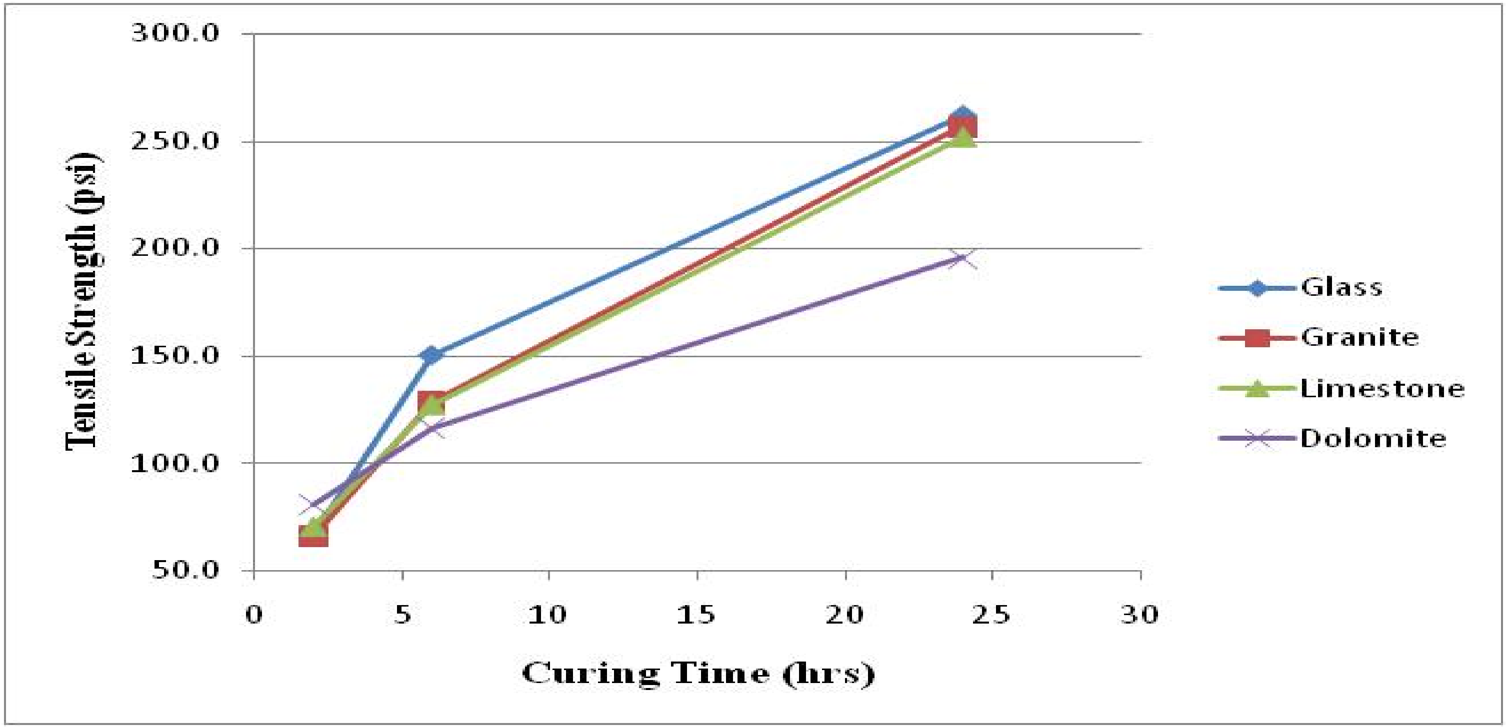
- Environmental Conditions
  - Control Humidity – 30% RH
  - Temperature (°C) – 35, 45
- Aggregate Type
  - Glass (reference), Granite, Limestone, Dolomite
- Emulsion Type
  - CRS-2 vs. CRS-2P
  - Same Base Binder

Typical Results – Effect of Curing Temperature



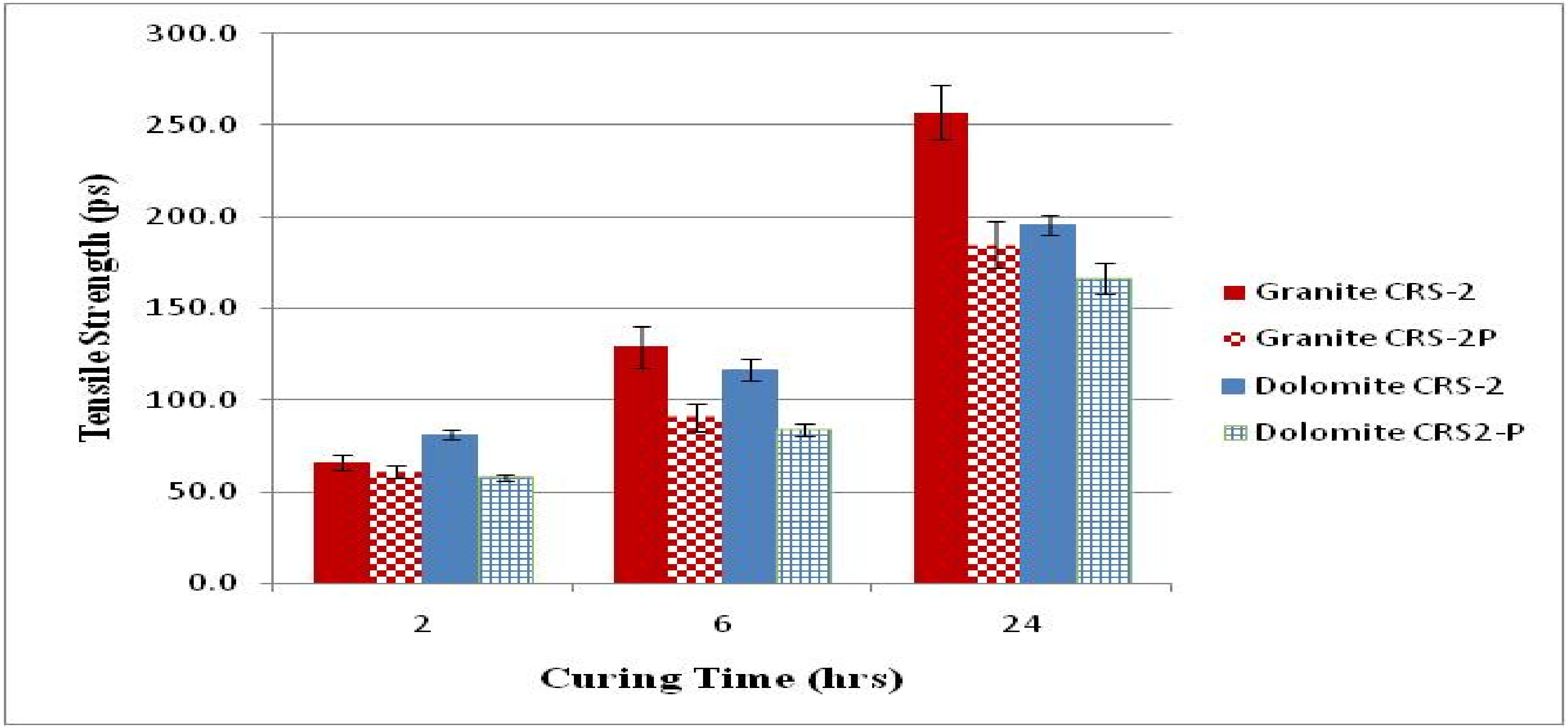
- No effect of curing temperature for either emulsion.
- Skinning at 45C? Select 35°C for further testing

Typical Results – Effect of Substrate – CRS-2



- Further investigation needed for performance of dolomite. Freshest surface – effect of surface charge?

Typical Results – Effect of Modification – CRS-2 vs CRS-2P

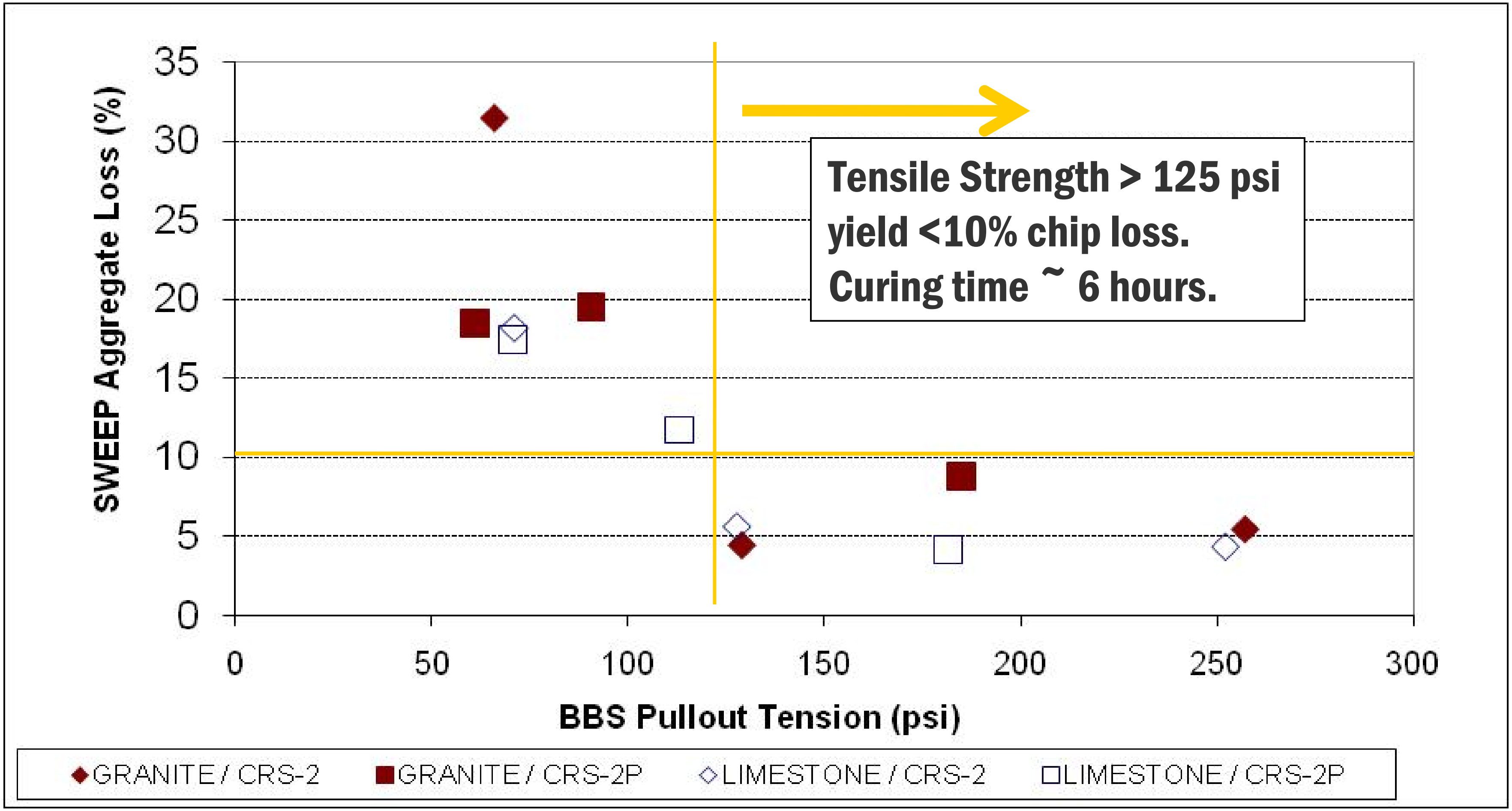


- **CRS-2>CRS-2P in all cases. Why? Demuls/Viscosity, extra curing time needed?**

Adhesion Testing – Completed & Next Steps

- Screening Experiment (ANOVA) – 90% Confidence Level
  - Curing Conditions Significant
  - Aggregate Type must be considered
  - Aggregate Moisture (dry vs. SSD) and Surface Roughness (insignificant)
- Define “Optimum” Loading Rate – Replicated ANOVA @ 6 hrs cure.
- Evaluate effect of curing time at selected loading rate
  - 2 hrs
  - 24 hrs
- Relate to Sweep Test

BBS Relationship to Performance



BBS Test – Next Steps

- Relationship to Performance
  - Continue comparison to Sweep Test
  - Comparisons to Field Performance
- Test Method Evaluation
  - Continue to conduct test on various emulsions/substrates
  - Collaboration with Stellenbosch
- Finalize Draft Standard and establish precision/bias.

Discussion Points

- More ideas for new tests of emulsions using existing PG equipment. Is there a need for an adhesion test?
- Surface Treatment Performance
  - How do we define it? What are important factors (Traffic, Climate, Materials)?
- Are modified emulsions worth it? Develop database to quantify effects of modification on performance.

Emulsion Characterization - Residue Aging

Construction Properties

Un-aged → Emulsion → Adhesion – BBS; η – Brookfield RV

Performance Properties

Short Term Aged → Residue (Rec.) → DSR

Long Term Aged → Residue (PAV) → DSR

Proposed Residue Evaluation Framework

Property	Aging Level	Testing Temperature	Proposed Procedure	Potential Evaluation Criteria
6.1. Resistance to Bleeding	Recovered Residue	High Surface Temperature	MSCR (100 kPa/3200kPa)	**Jnr** **Stress Sensitivy**
6.2. Resitance to Early and Late Raveling	Recovered Residue PAV Residue	TBD	Strain Sweep	**Strain at 50% Reduction in G***
6.3 Fatigue Cracking	PAV Residue	TBD	Frequency Sweep	**TBD**
6.4 Thermal Cracking Resistance	PAV Residue	10°C	Frequency Sweep	**Estimates of BBR Properties S(60) and m(60)**
6.5. Polymer Identifier	Recovered Residue	25°C	Elastic Recovery DSR Procedure MSCR	**%ER - DSR** **% Recovery**

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Emulsion Residue Aging – Short Term

- ASTM Evaporative Residue Recovery Method
  - Residue Rheology ~ Properties of RTFO aged base materials
  - Preserves Effects of Modification
- Research Challenges
  - Establish relationship to field
  - Reduce 48 hour recovery time

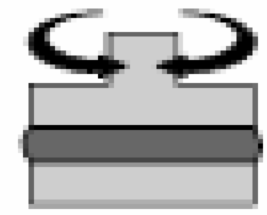
Kadrmas – TRB 2009 Session 791

Emulsion Residue Aging - PAV

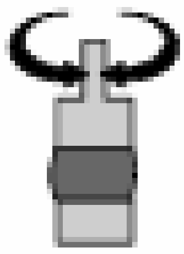
- Available Procedure: PAV for Hot Binders
  - Aged at 90 – 110°C at 300 psi for 20 hours
- Challenges in applying PAV procedure to emulsion
  - PAV Temperature > Softening point of emulsion residue (40 - 60 °C)
  - Effect: Latex structure in emulsion residue could be compromised
- Previous work: PAV at 85°C for 65 hours (Guiet, et. al)
  - Microscope images showed presence of polymer (SBS), however
  - Cohesion and ER greatly reduced – inconsistent with field performance.
- Propose PAV at 60°C for 120 hours
  - Very long aging time – but insight into rheology is needed.

Residue Performance Characterization – Concepts and Examples

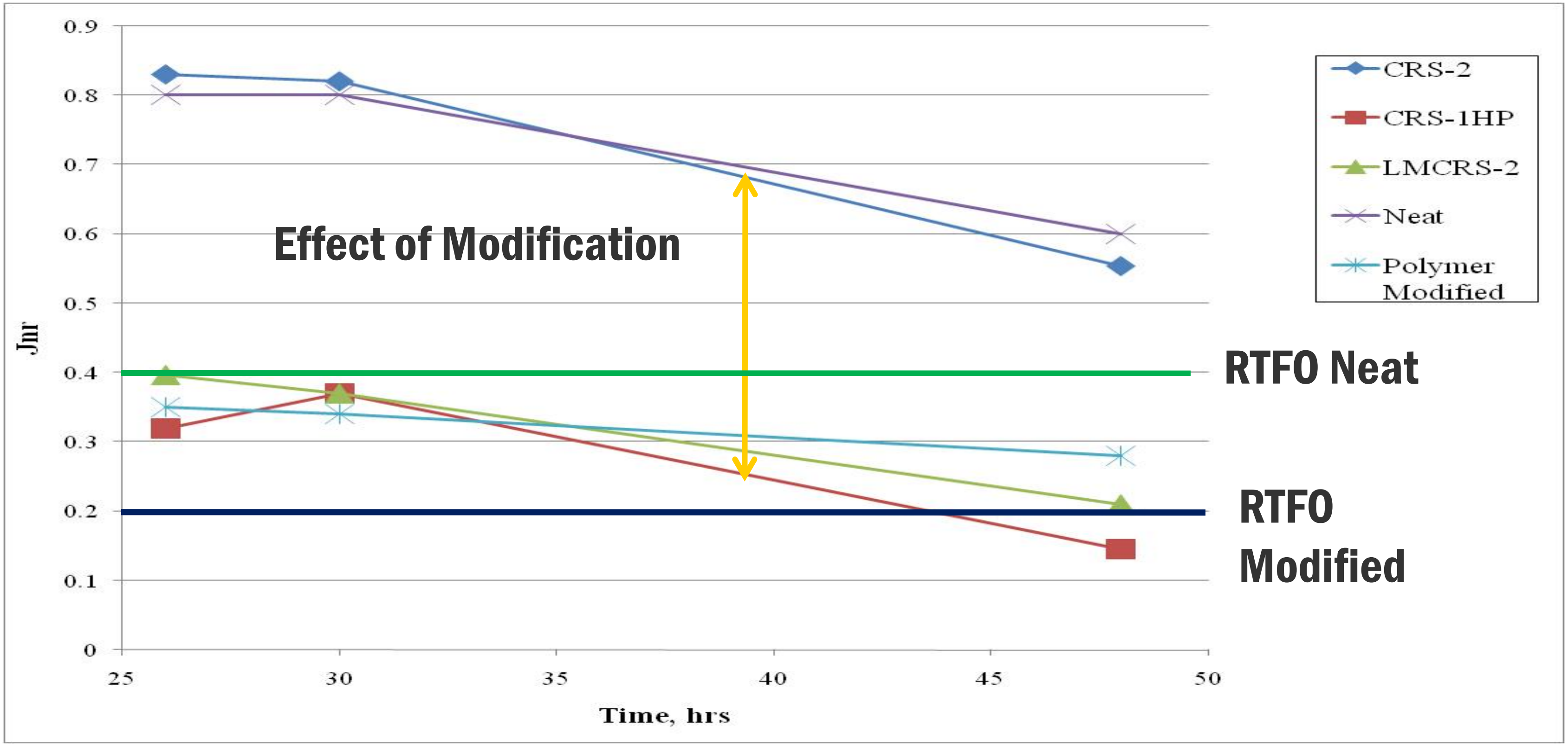
- Previously Presented Tests
  - High Temp. – MSCR: Jnr
  - Polymer Identifier – MSCR: % Recovery
  - Intermediate – Strain Sweep: Failure Strain



- Newly Developed Tests
  - Elastic Recovery in DSR
  - Low Temperature – DSR to estimate BBR Performance

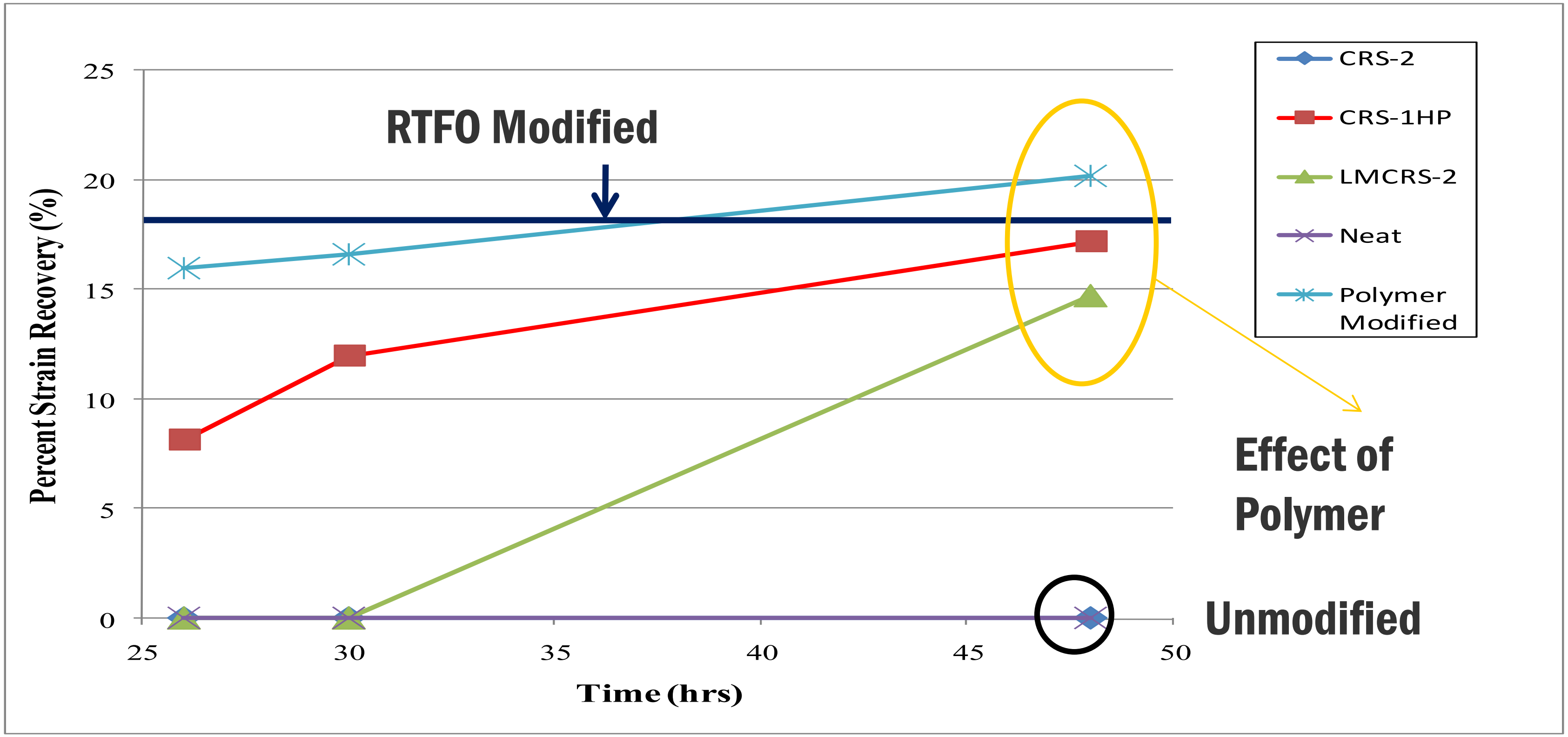


High Temperature Evaluation - MSCR

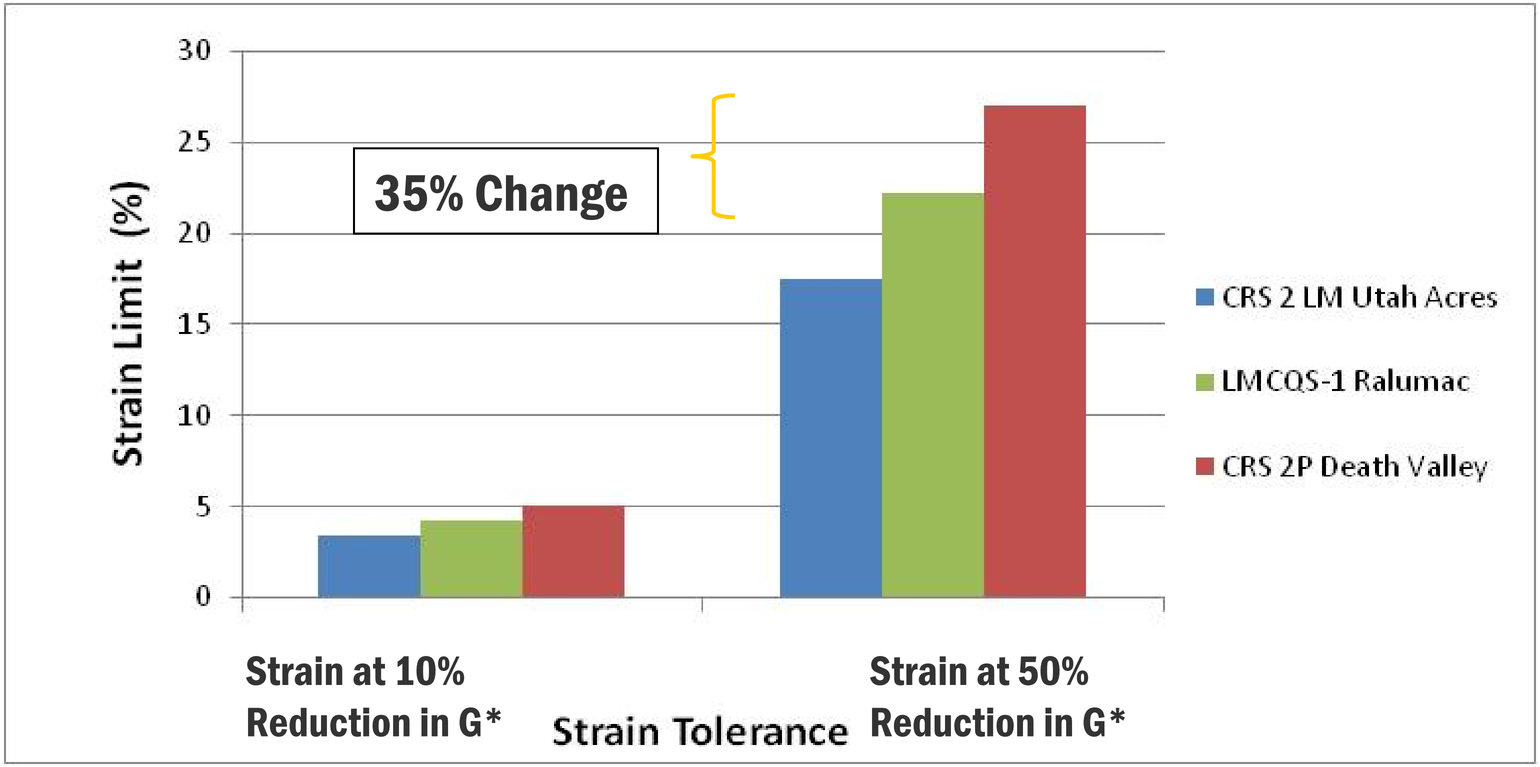


Displays effect of modification and curing time on Jnr.

MSCR % Recovery – Effect of Modification



Strain Sweep of residue @ 25 C (PRI data) - Effect of Modification

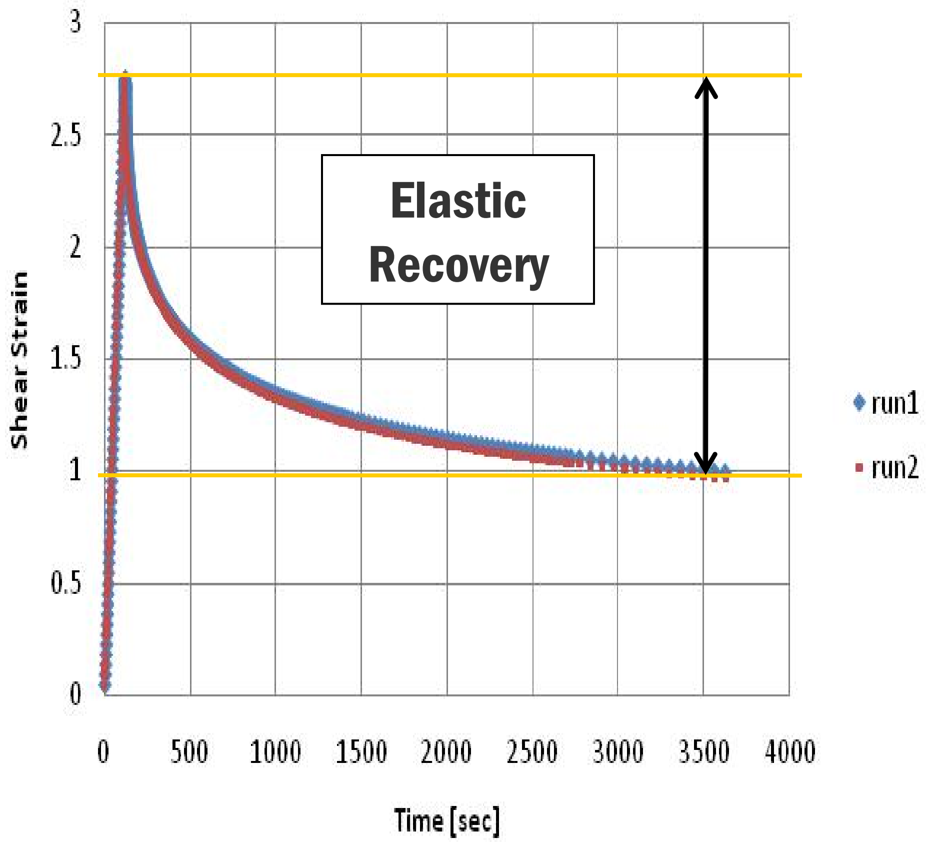


*Data obtained from FLH Project

Elastic Recovery in the DSR

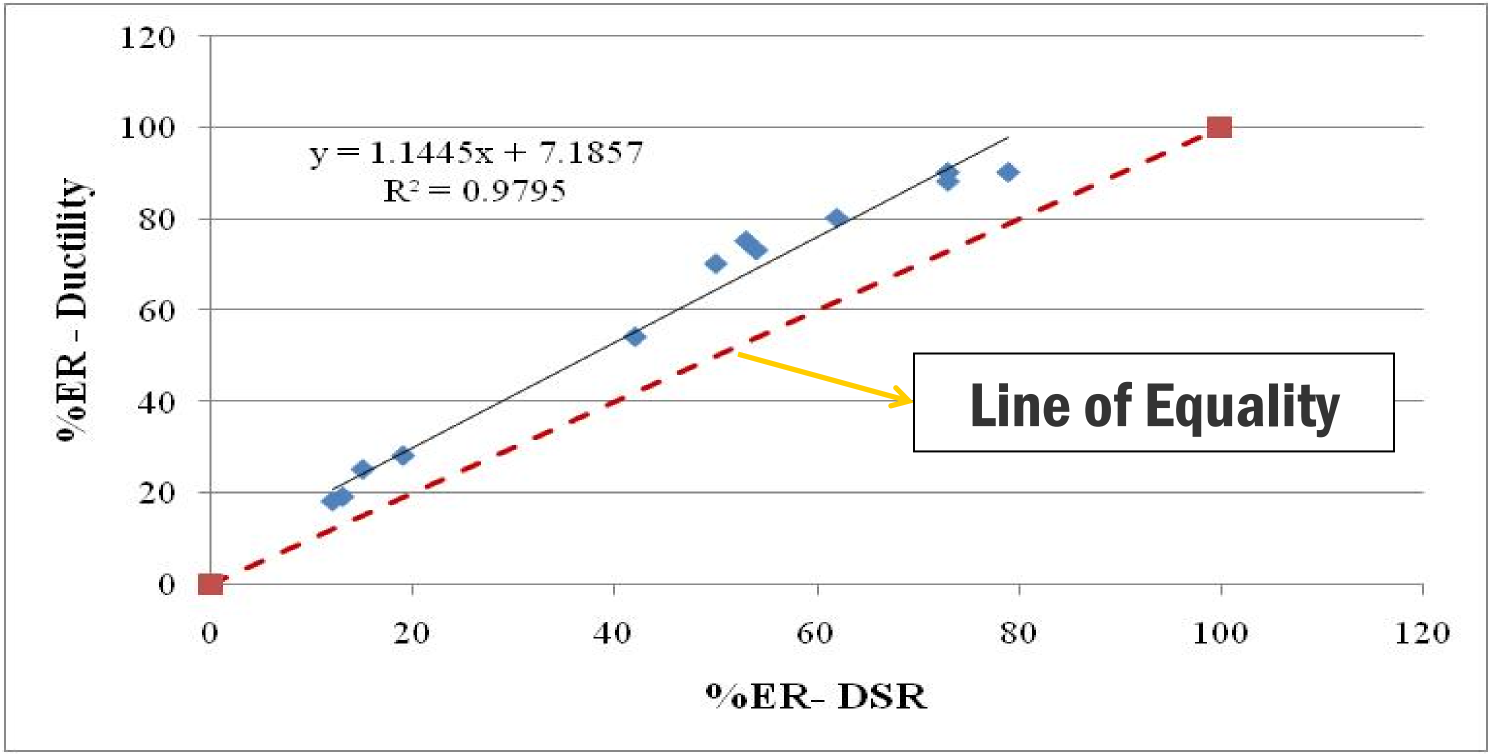
- Procedure
  - 8 mm Parallel Plate Geometry
  - Testing Temperature: 25°C
  - Step 1: Strain controlled. Imposes a strain rate of 2.32%/sec for 120 s.
  - Step 2: Control stress to 0 Pa for 1 hour.
- Strain rate and loading time defined to match conditions of current Elastic Recovery test.

Elastic Recovery in the DSR - Schematic



- Materials Tested
  - Base Binders PG 58-28 to PG 64-22.
  - Modifiers:
    - SBS
    - Elvaloy
    - PPA
  - Base binders modified 2 levels.

Elastic Recovery in the DSR - Results



- Strong relationship, but DSR test under predicts result from standard method.

Estimating BBR from DSR Data – Concepts

Comparing Dynamic and Creep Measurements – solve for ω

Equation (1): $$Td \approx \left[\frac{\frac{1}{273-Ts} - 2.303\boldsymbol{R}[\log(ts\omega)]}{250{,}000}\right]^{-1} - 273$$

Where:

Td = test temperature for dynamic testing at frequency ω, °C

Ts = specified temperature for creep testing, °C

R = ideal gas constant, 8.31 J/°K-mol

t_s = specified creep loading time, s

ω = dynamic testing frequency, rad/s

- **Equivalent DSR ω to measure S(60)/m(60) at 10°C = 20 Hz**
- **Data shows both 10Hz and 20 Hz used can be used.**

Estimating BBR from DSR Data – Concepts (cont).

- **Approximation of S(t)**

$$S(t) \approx \frac{3G^*(\omega)}{[1+0.2\sin(2\delta)]}$$

$$t \rightarrow \frac{1}{\omega}$$

S(t) =	creep stiffness at time, *t*, Pa
G*(ω) =	complex modulus at frequency ω, Pa
δ =	phase angle at frequency ω, Pa

- **Approximation of m(t)**

$$m = \frac{d(\log G^*)}{d(\log \omega)}$$

Where:

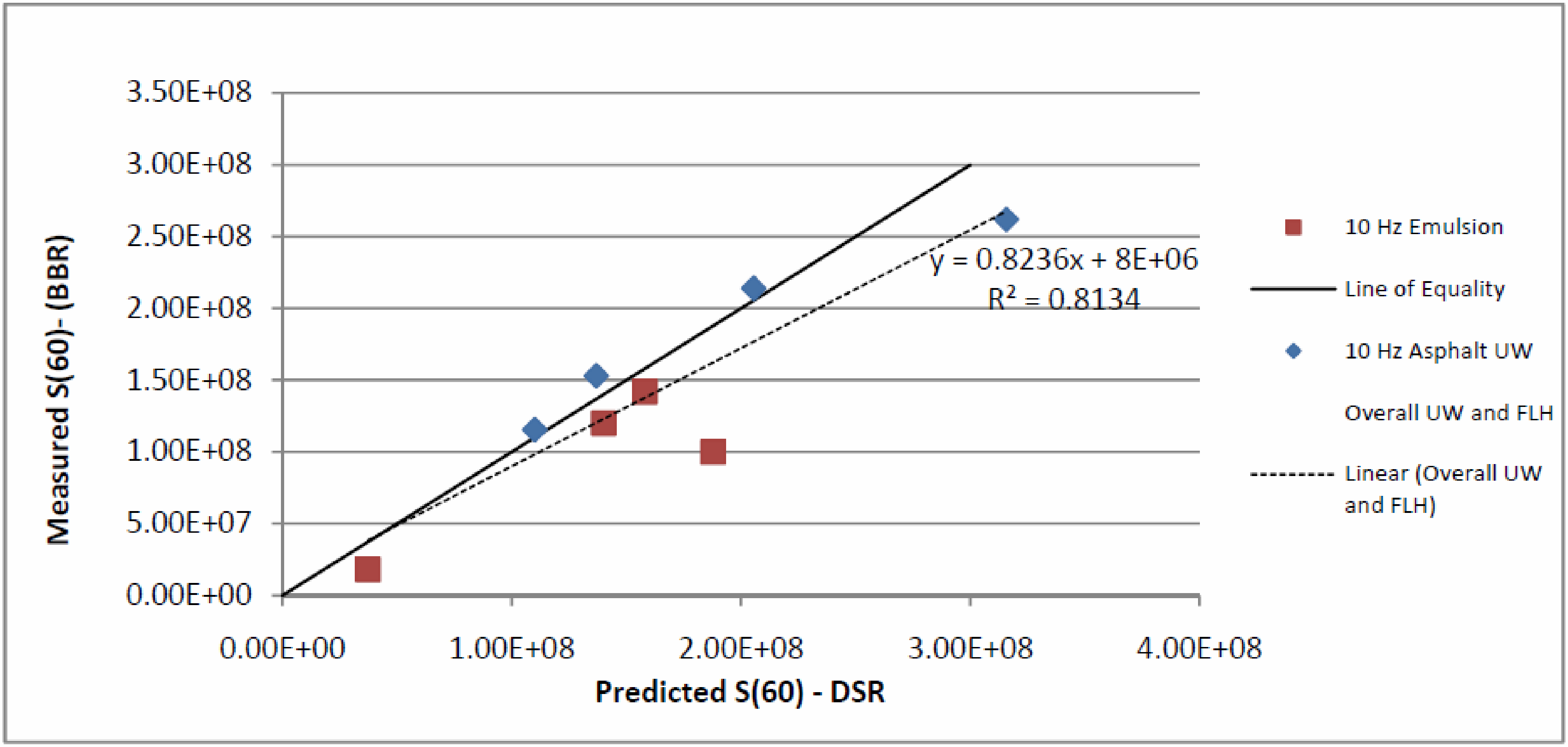
m =	slope of G* vs. Frequency plot at a given frequency
δ =	phase angle
G* =	complex modulus
ω =	frequency (rad/s)

Ferry, J.D. Viscoelastic Propertis of Polymers. Madison, WI: University of Wisconsin, 1980.

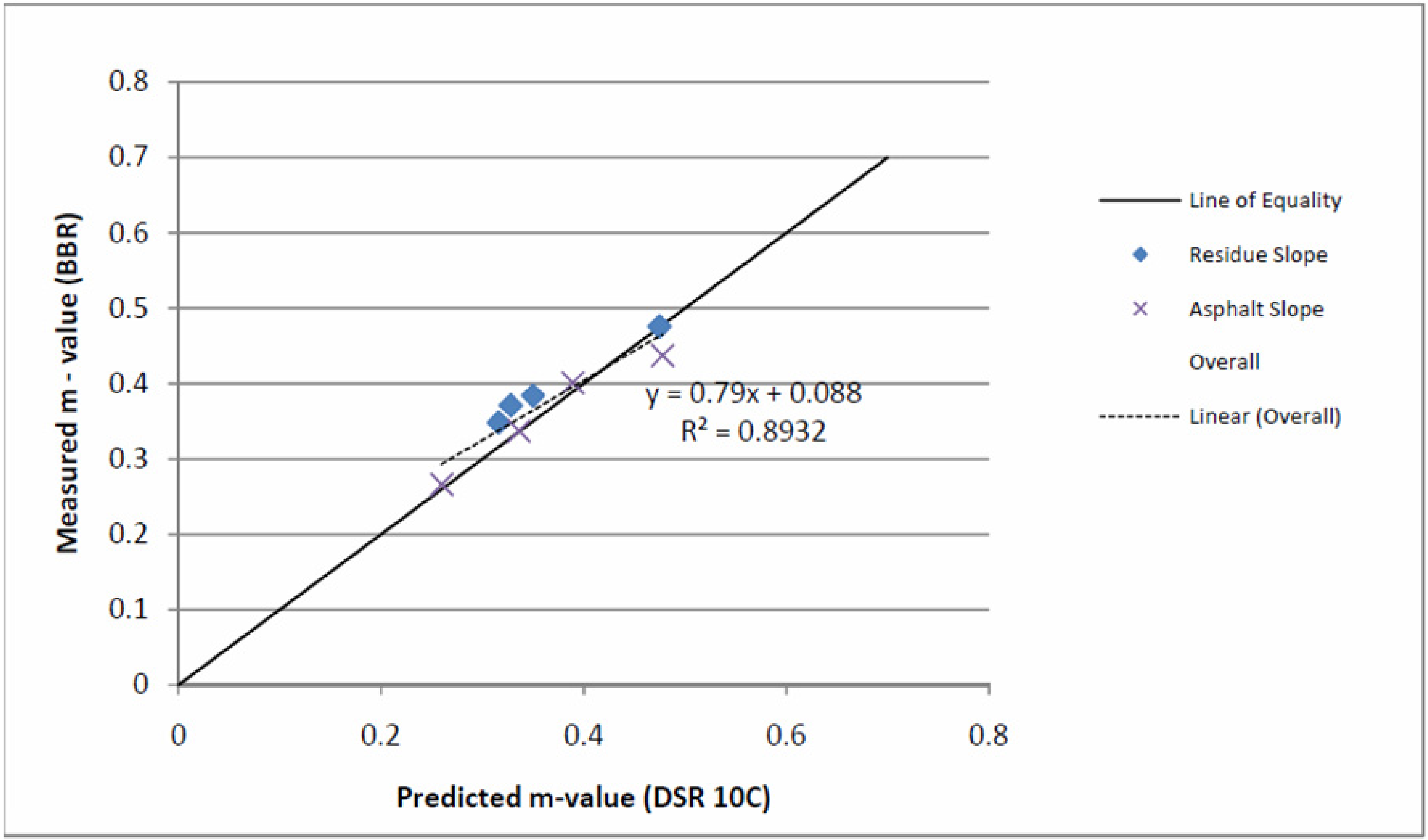
Estimating BBR from DSR Data

- Procedure
  - 8 mm Parallel Plate Geometry
  - Testing Temperature: 10°C
  - Frequency Sweep: 0.1 – 100 rad/s
- Materials Used:
  - Base Asphalt – 4 Levels of Aging (OB, RTFO, PAV, 2PAV)
  - Four emulsion residues from FLH project.
- Use G*,δ at 10Hz to conduct comparison (20 Hz) not available for all materials

Estimate of S(60)



Estimate of m(60)



Year 4 Work Plan Focus Areas

- Performance Properties of Emulsions
  - Establish range of performance for various emulsion residues.
- Improvements to the Sweep Test
  - Use as a design tool
  - Examine modifications to procedure
  - Apply to other distress modes: bleeding.

Year 4 Work Plan Focus Areas

- Field Validation
  - Construction and performance thresholds based on field performance.
  - Identify field tests to evaluate construction properties.
  - Field vs. Laboratory aging of emulsion/residue.
  - Link performance tests (DSR) to chip seal distress modes.
- Dense Cold Mixes
  - Define emulsion selection framework.
  - Develop mix design procedure and evaluation parameters.

Thank you for your time!

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