Linear Viscoelastic Behavior of Asphalt Binders At Low Temperatures

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Outline

- Background
- Objective
- Approach
  - How?
  - Why?
- Data Collection and Analysis
- Conclusion

Objective

- To Evaluate The Linear Viscoelastic Behavior Of Asphalt Binders At Low Temperatures

Approach—How?

- Apply Different Stress Levels and Study the Effect on Relaxation Modulus
- Apply Different Strain Levels and Study the Effect on Relaxation Modulus
- Apply Different Strain Rates and Study the Effect On Failure Stress/Strain Rate

Mathematically

- Non-Linear Viscoelastic if:
  - Relaxation Modulus (Stiffness)

$$E(T) = f(t, \sigma\, or\, \varepsilon)$$

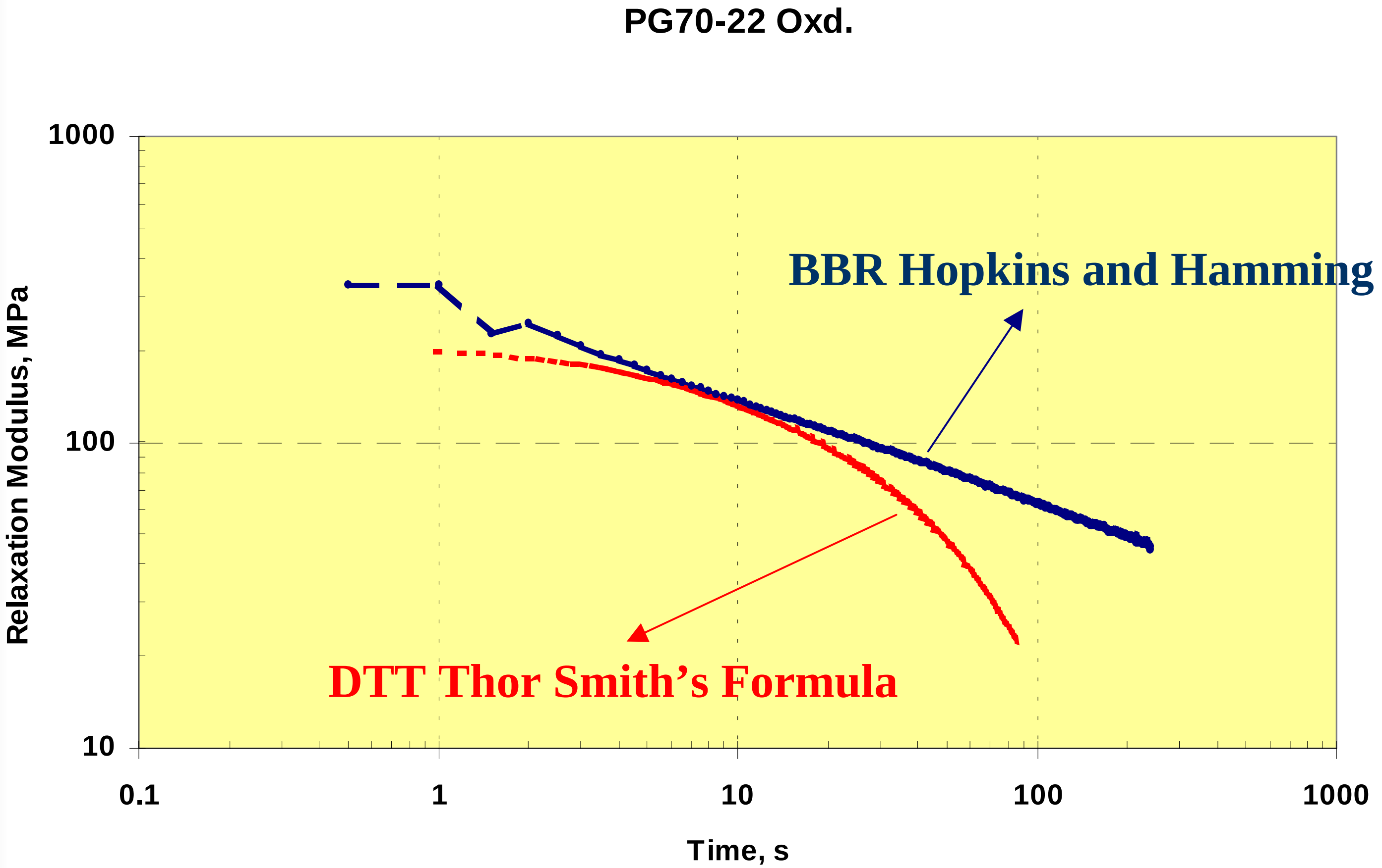
- Linear Viscoelastic if:
  - Relaxation Modulus (Stiffness)

$$E(T) = f(t)\ only$$

Approach—Why?

- To Explain:
  - Why is there a difference between the relaxation modulus calculated using the BBR compliance data and the DTT stress-strain data?
    - As Observed by Marasteanu and Anderson

Problem Statement



Thor Smith's Formula

$$E(t) = F(t)\left[1 + \frac{dLogF(t)}{dLog(t)}\right]$$

Where,

E(t) = Relaxation Modulus, MPa

F(t) = Secant Modulus, MPa = Stress/Strain

Hopkins and Hamming

$$\int_0^\infty G(t) \cdot J(t-\tau)\,d\tau = t$$

Numerical Solution Of The Above Convolution Integral

Possible Explanations

- Equipment Differences
- Numerical Errors
- Sample Geometry
- Non-Linearity
- Other

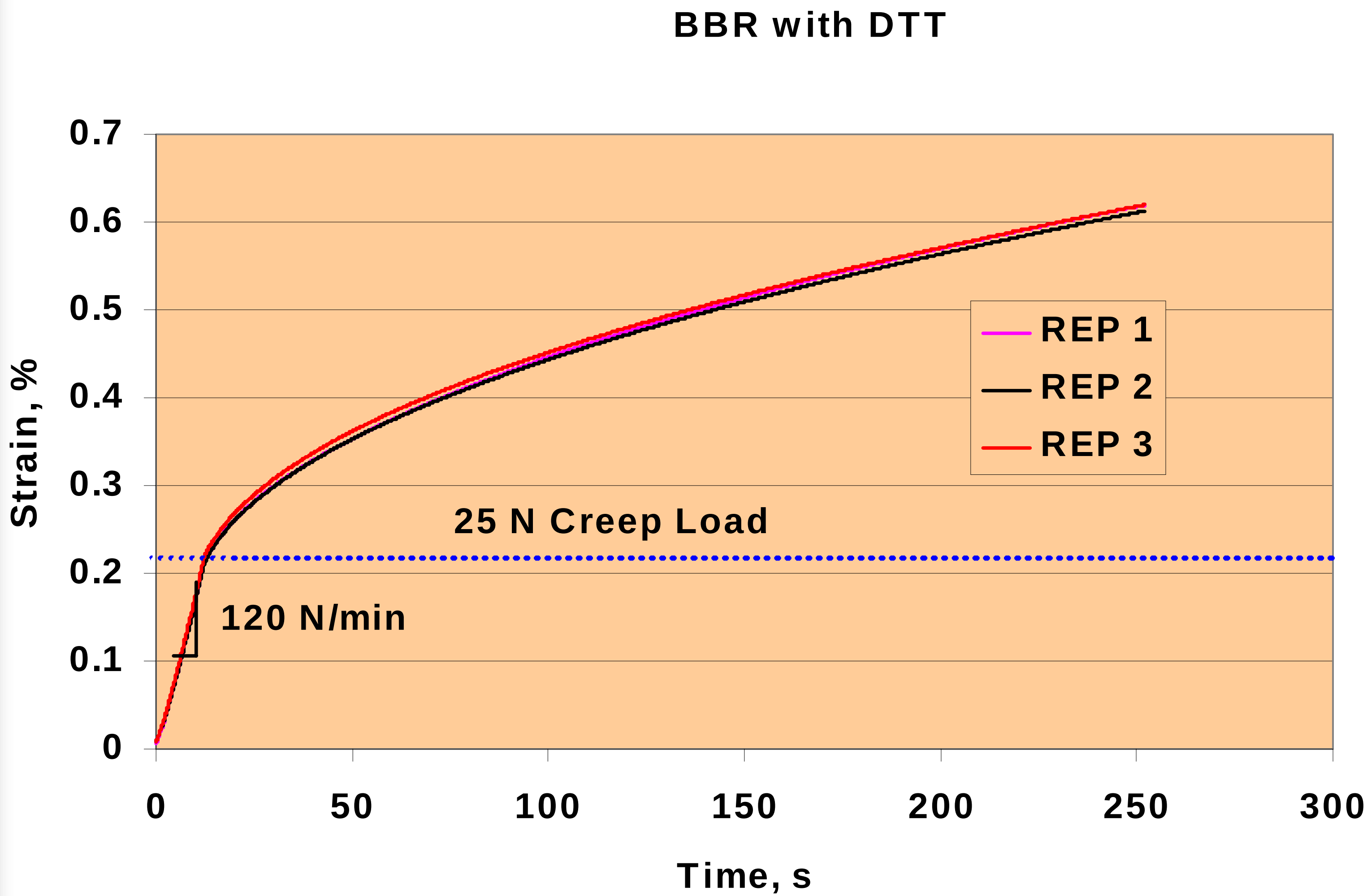
Materials and Methods

- Asphalt Binders
  - AI – Five PG 76-22 Binders
  - ALF – Styrelf, Novophalt
  - LUDO – 581 (BlackMax)
  - Lamont – Section 6
  - Oxidized PG70-22
  - SHRP Core – AAA-1 and AAM-1
- Test Temperature – PG Low Grade Temp.

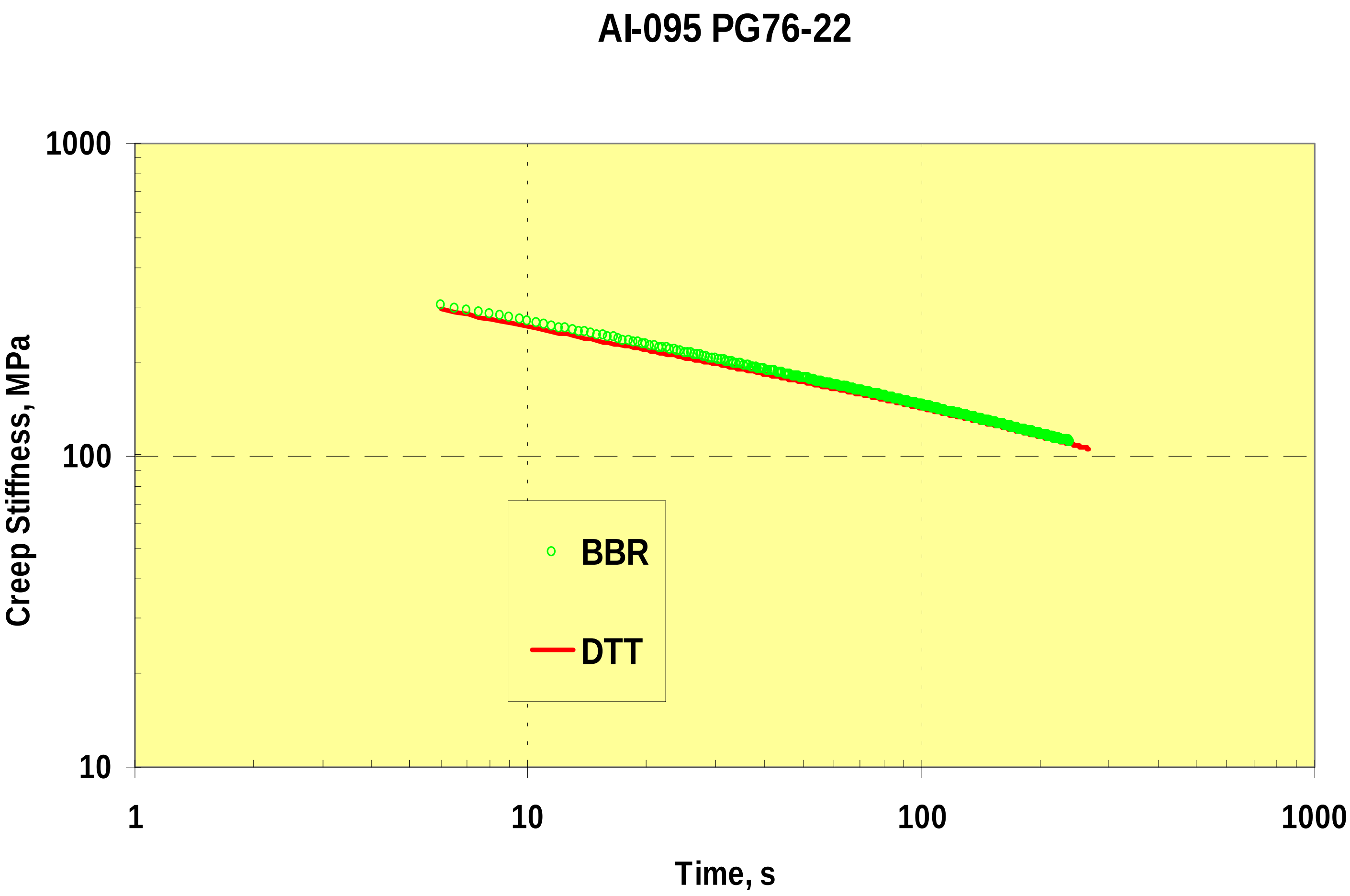
Test Methods

- BBR
  - Creep Compliance Measured
  - Relaxation Modulus Computed Using Improved Hopkins and Hamming Method
- DTT
  - Creep Compliance Measured
  - Relaxation Modulus Measured
  - Failure Data (Stress Strain Curve) Measured
  - Relaxation Modulus Computed Using Thor Smith's Formula

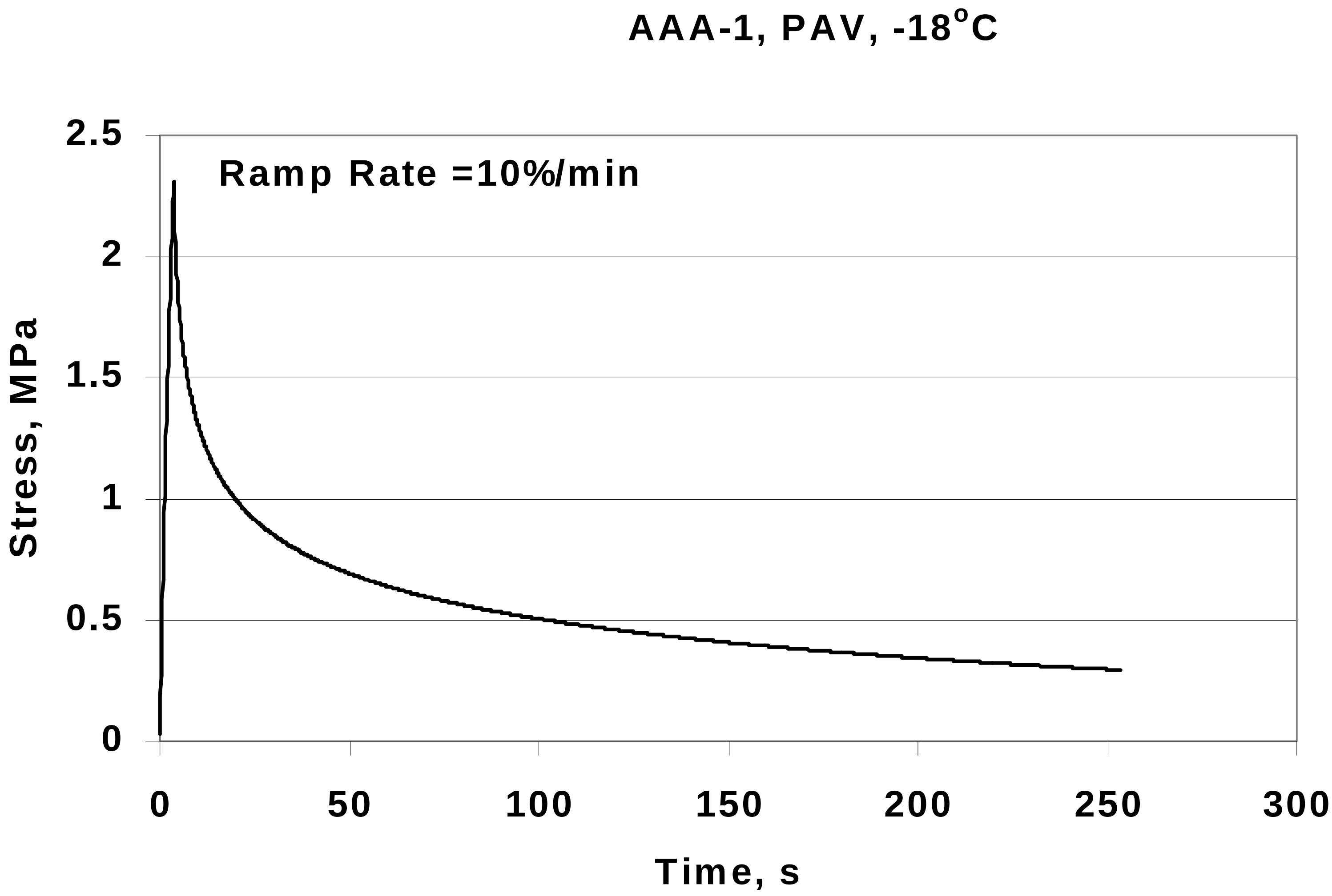
Typical BBR with DTT - Creep



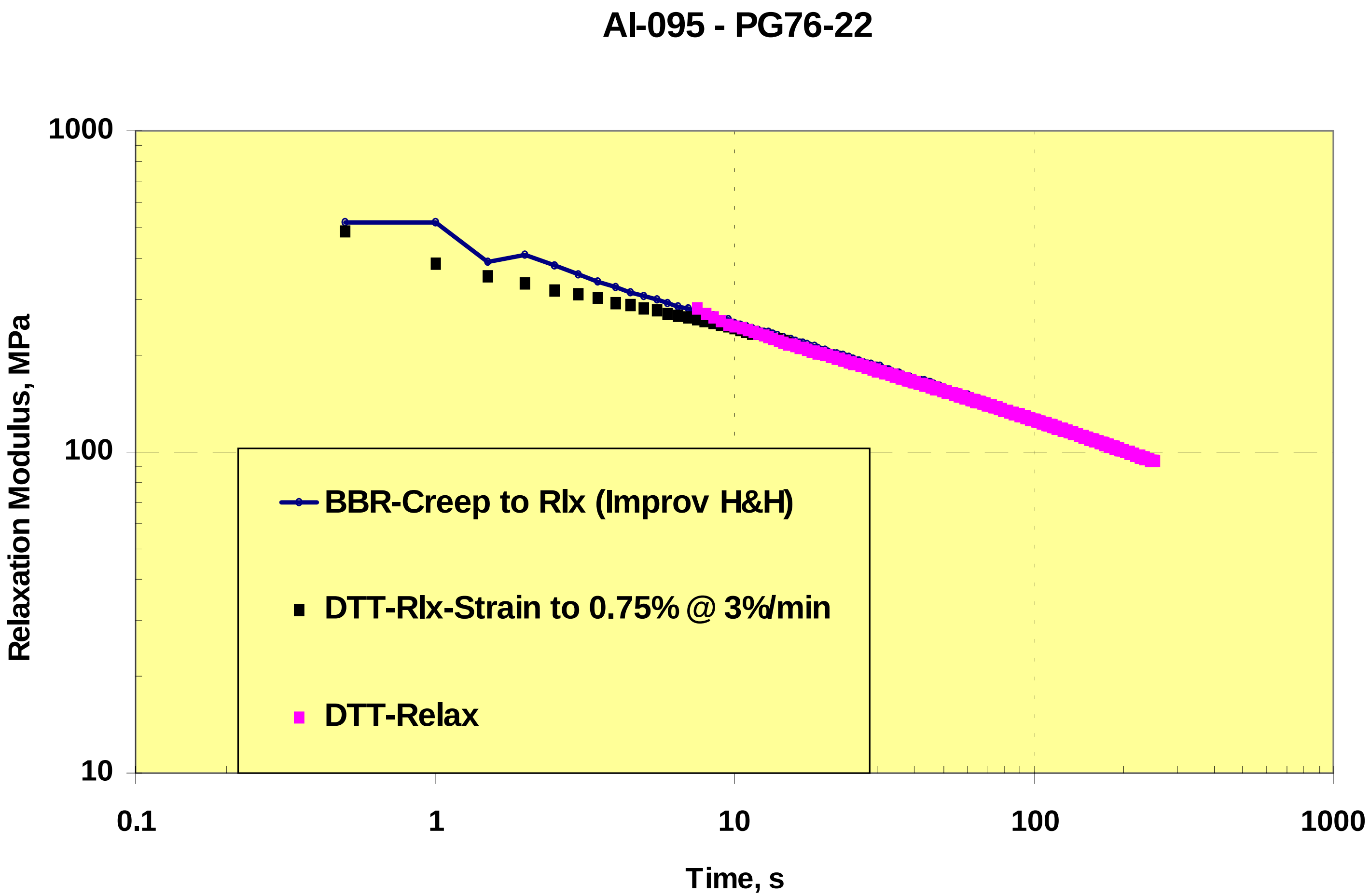
BBR Vs. DTT – Creep Data



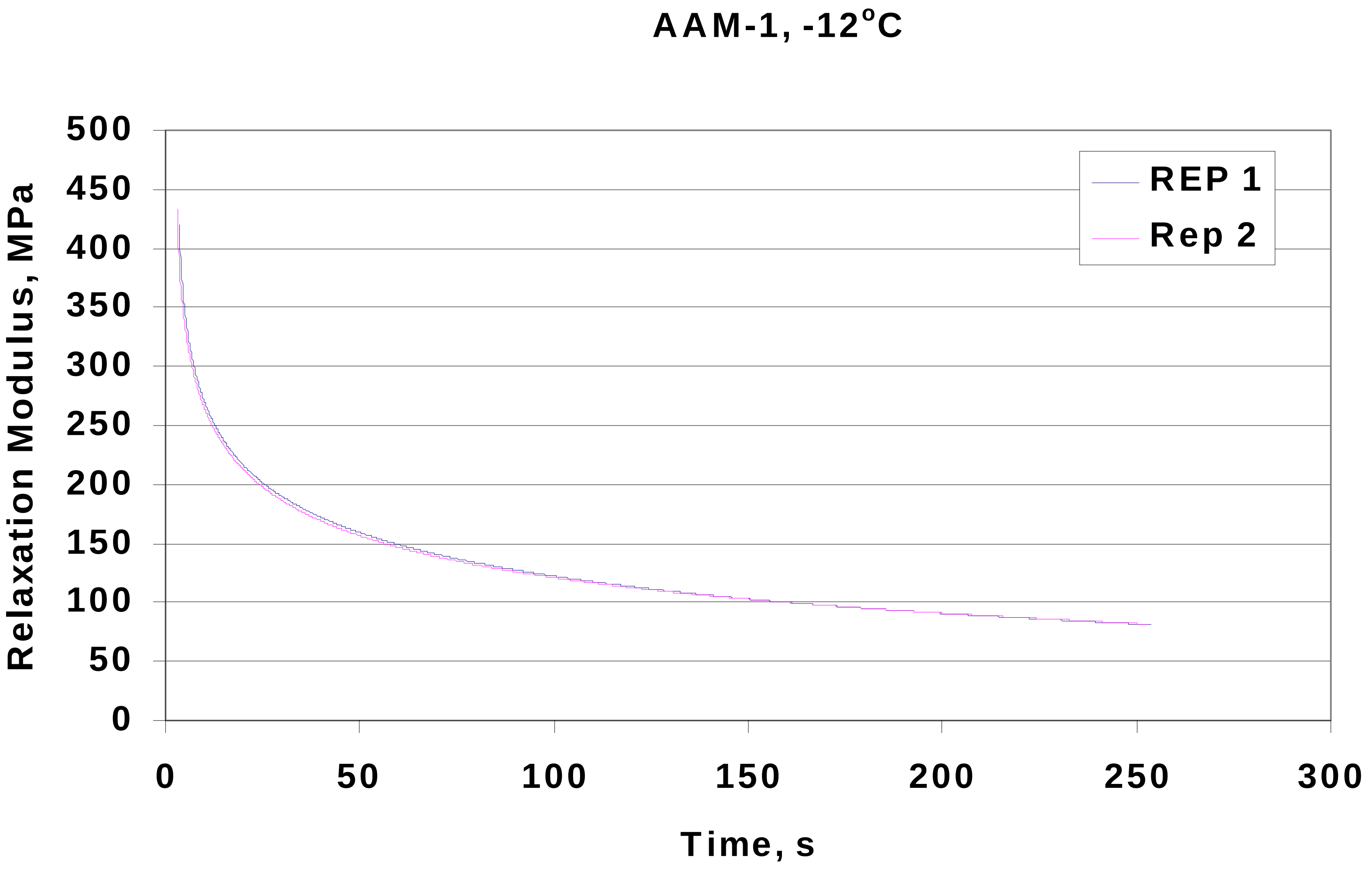
Typical Stress Relaxation - DTT



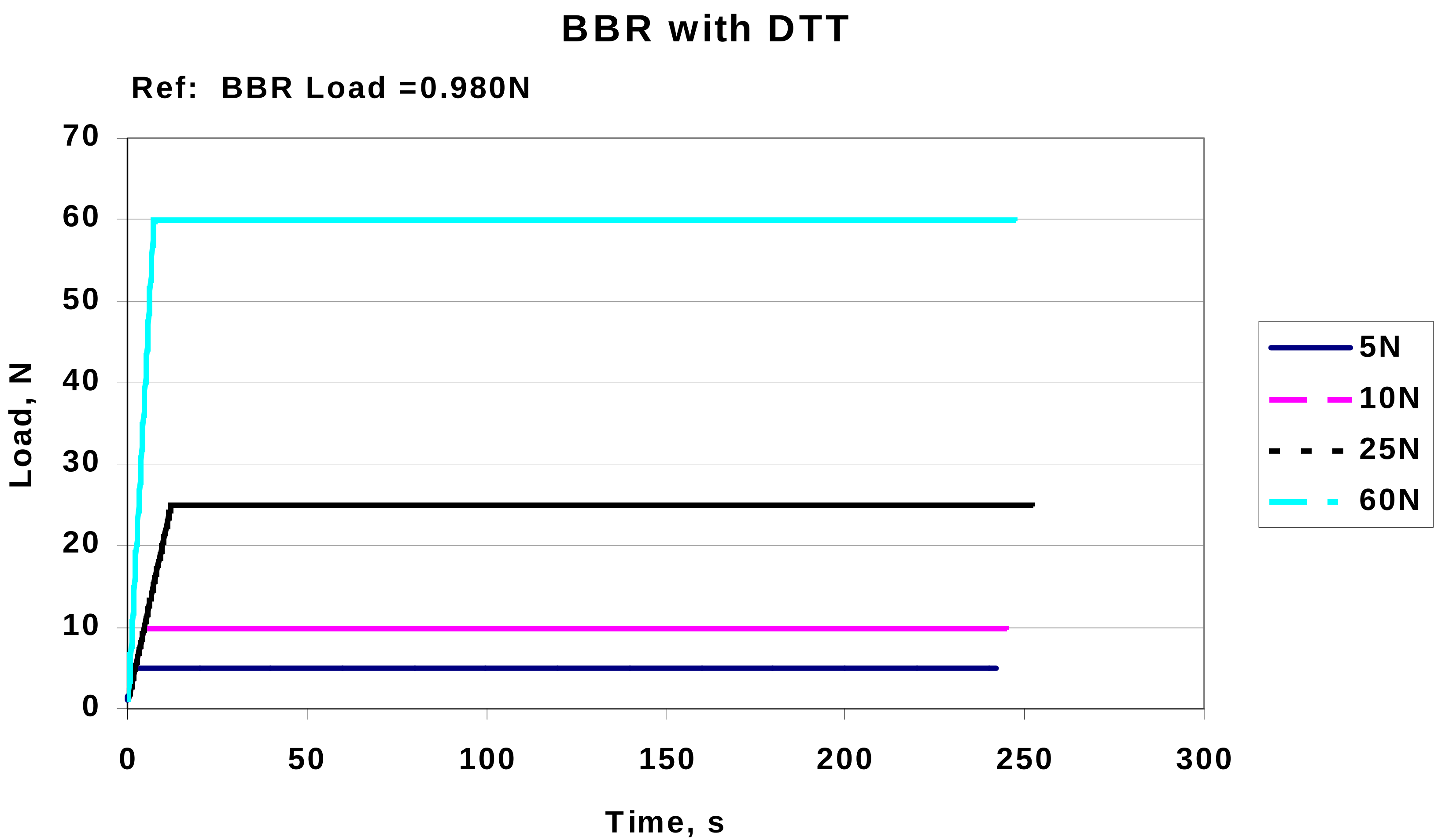
BBR Vs. DTT – Relaxation



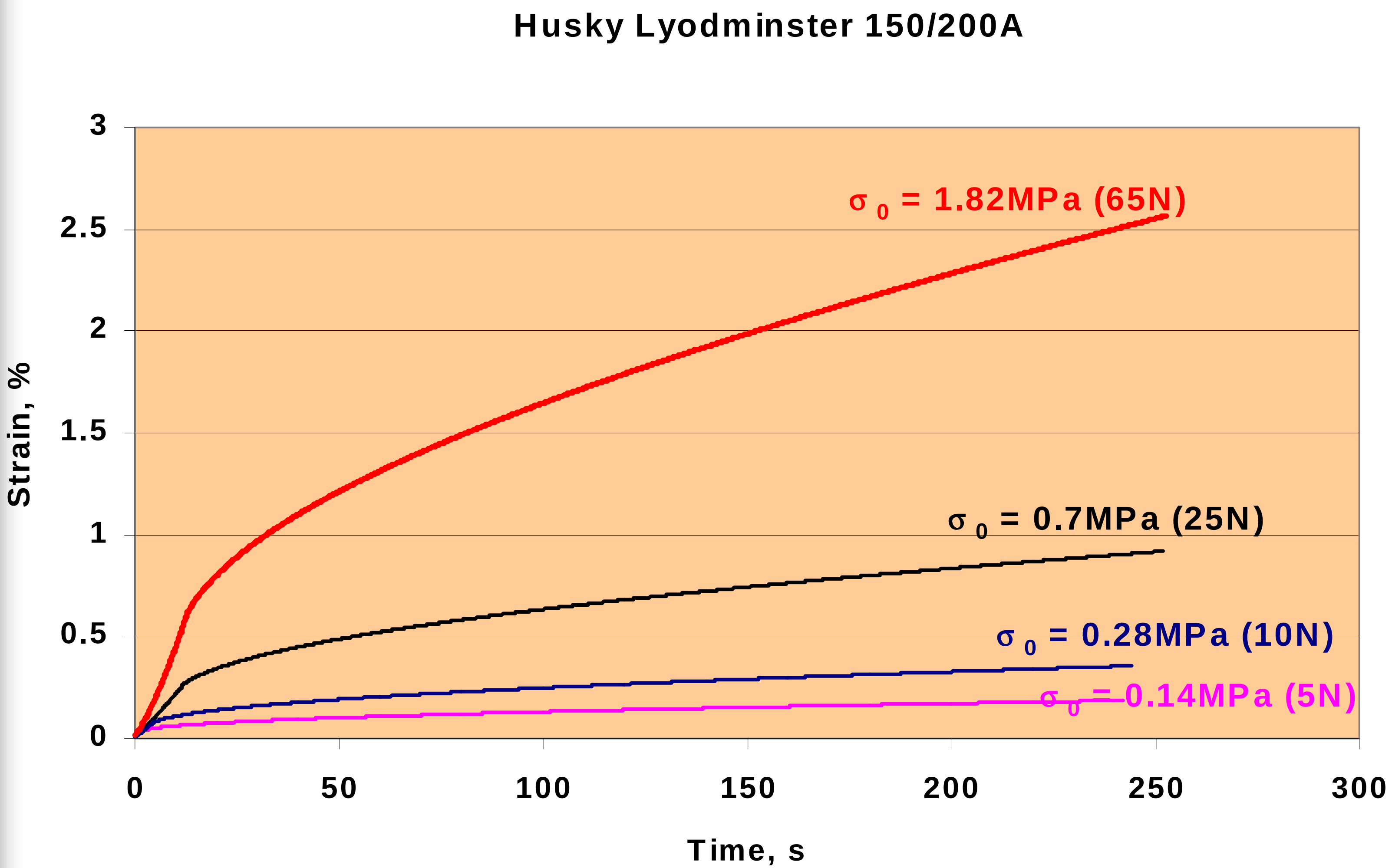
Repeatability



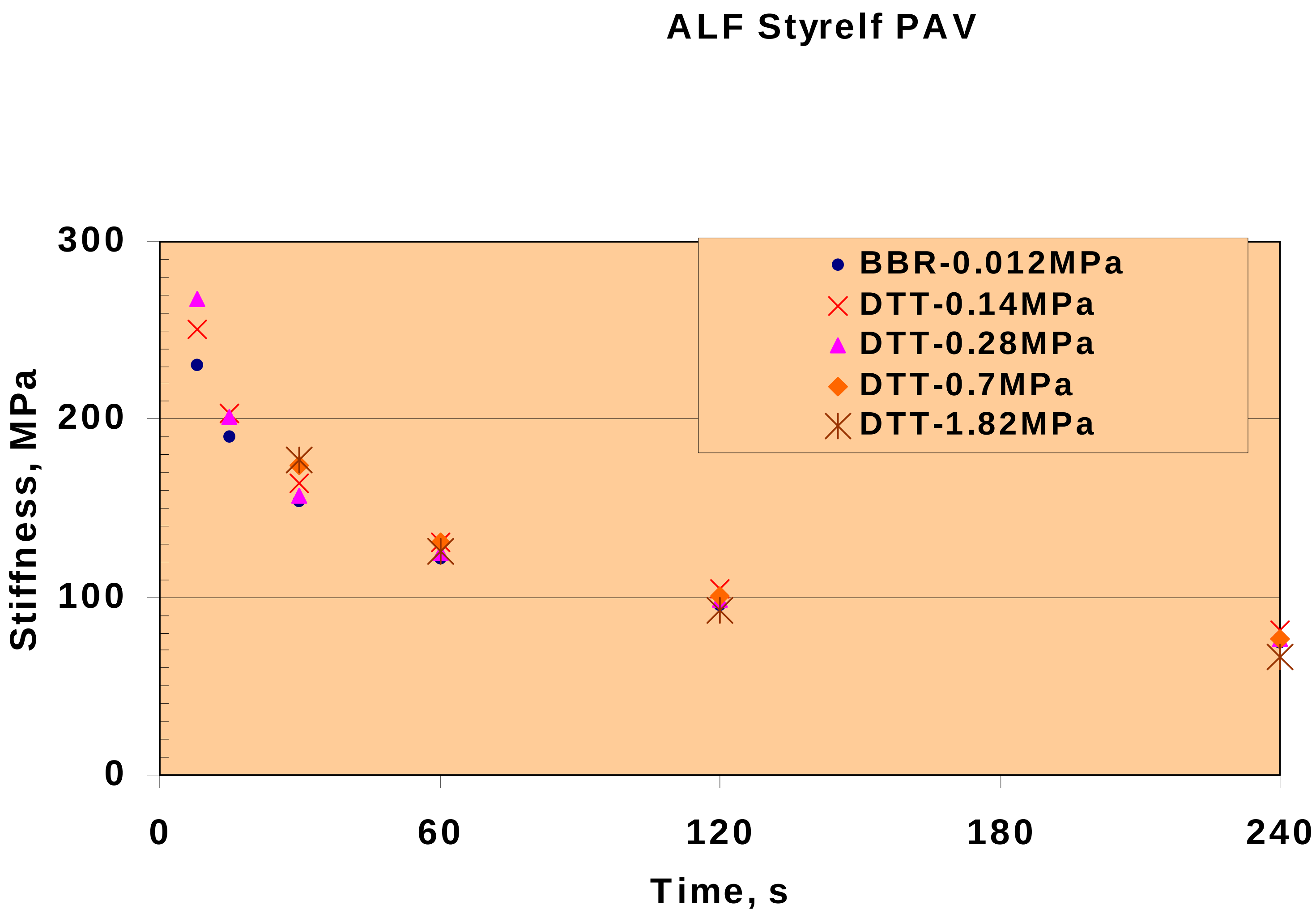
Linearity Check – Creep Loads



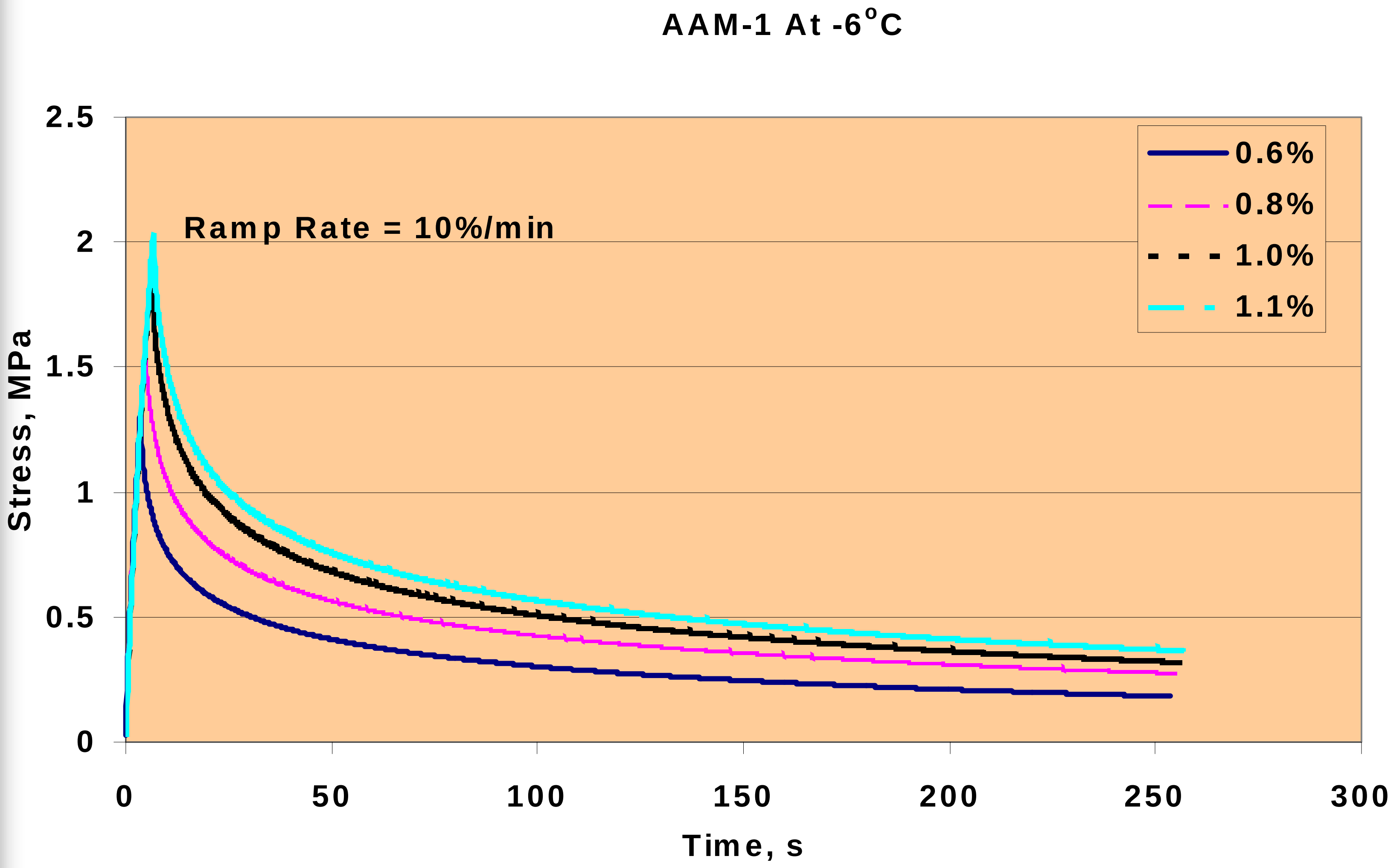
Linearity Check – Creep Loads



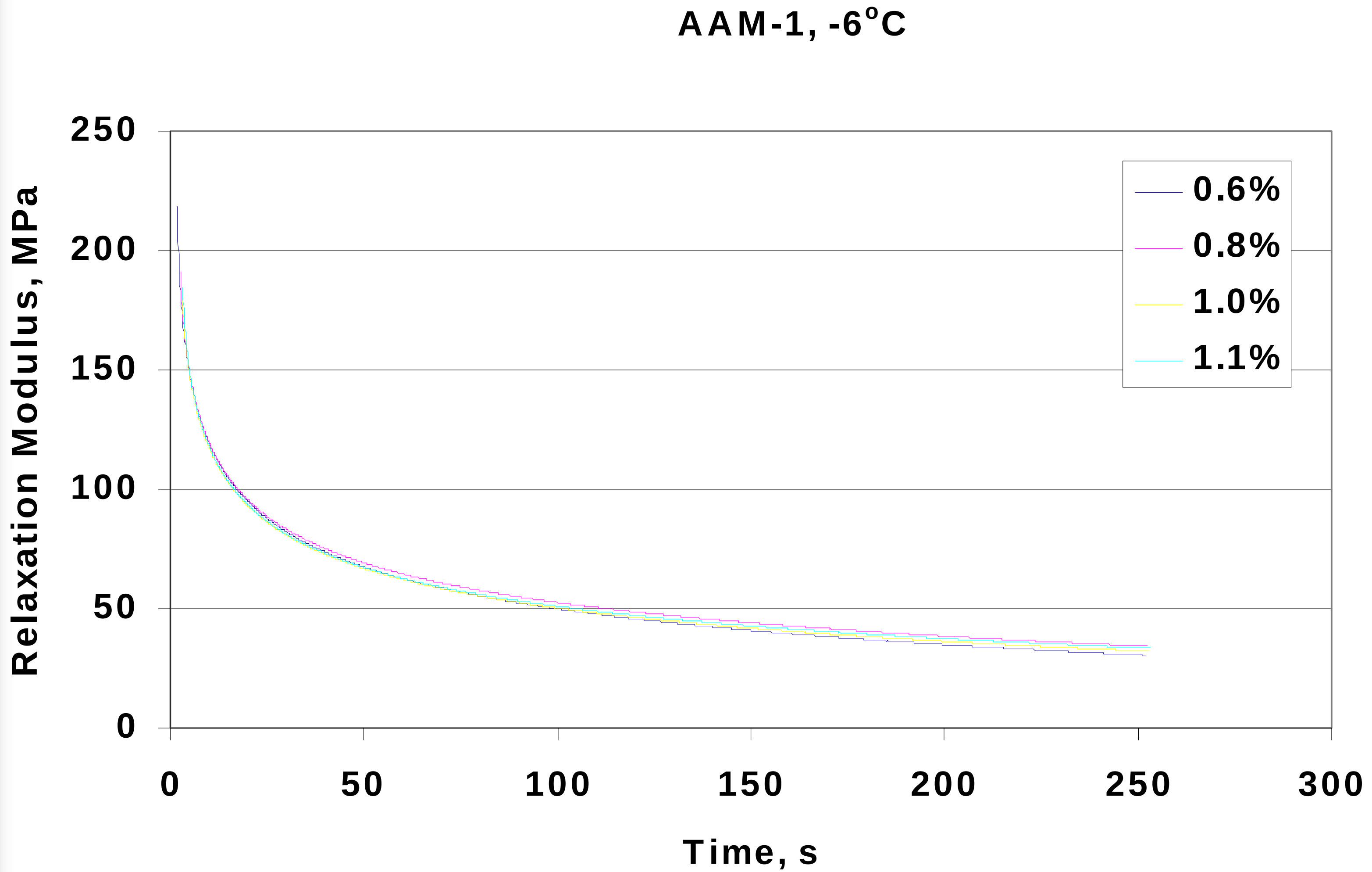
Linearity Check – Creep Stiffness



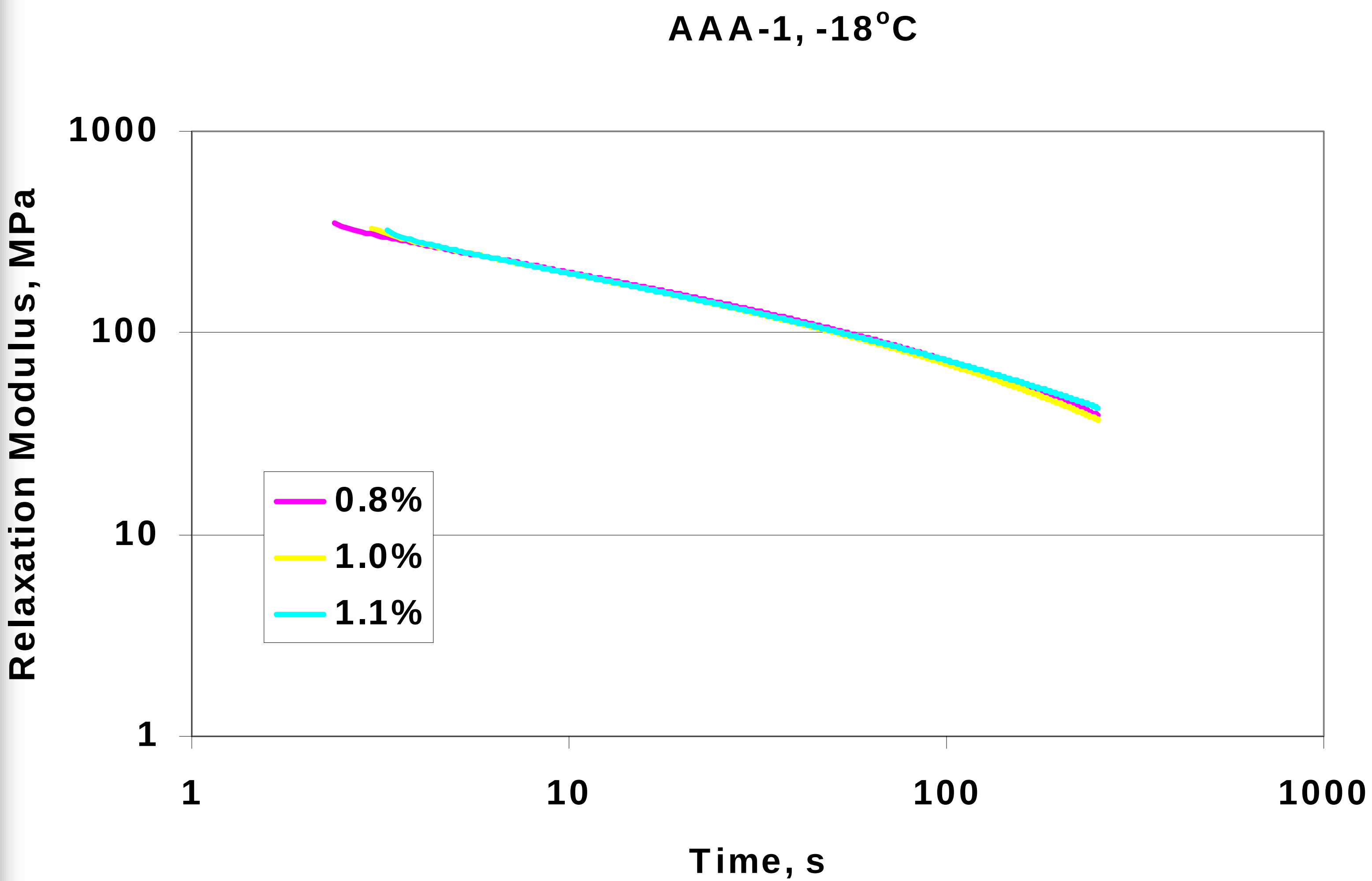
Linearity Check – Relaxation Strains



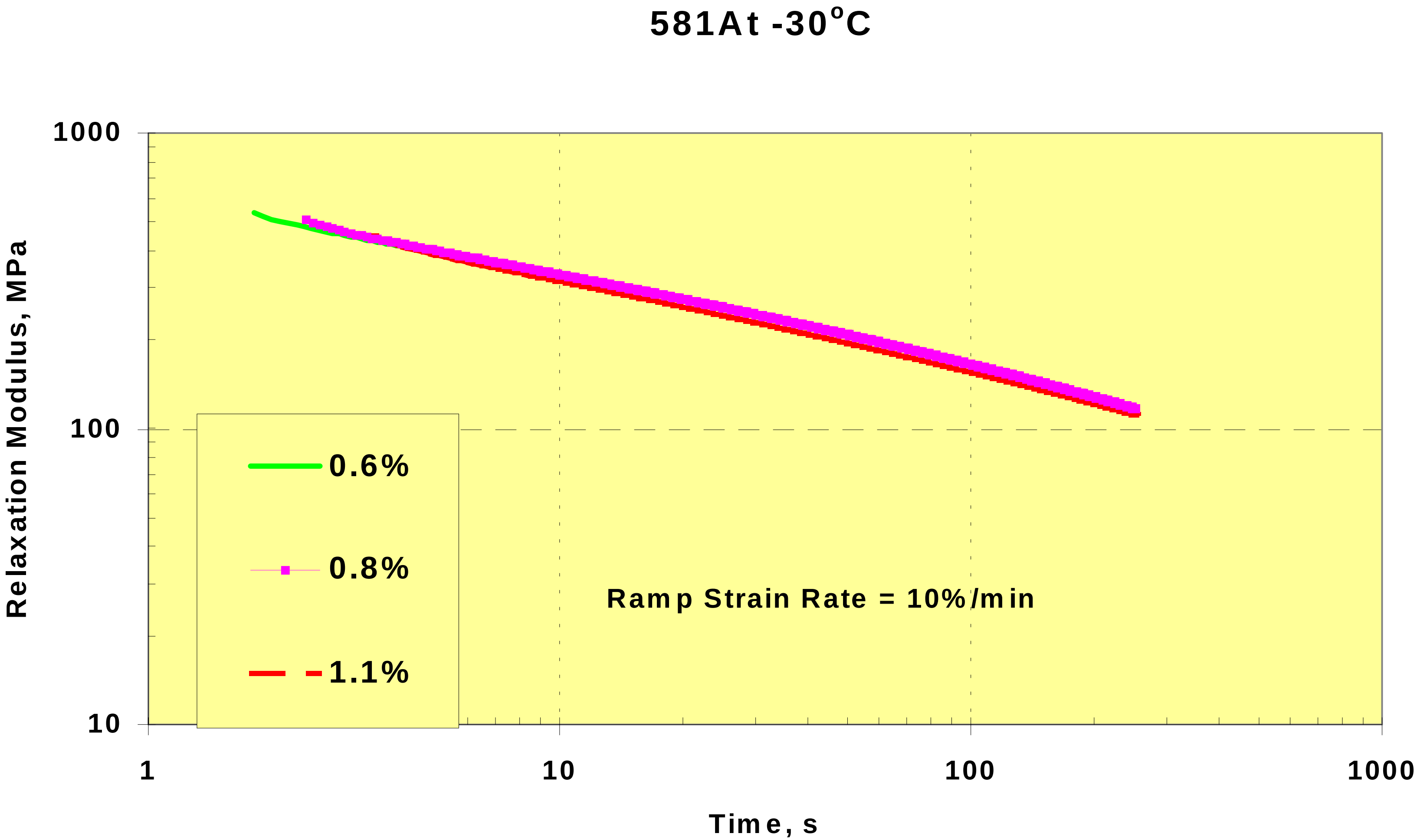
Linearity Check-Relaxation….



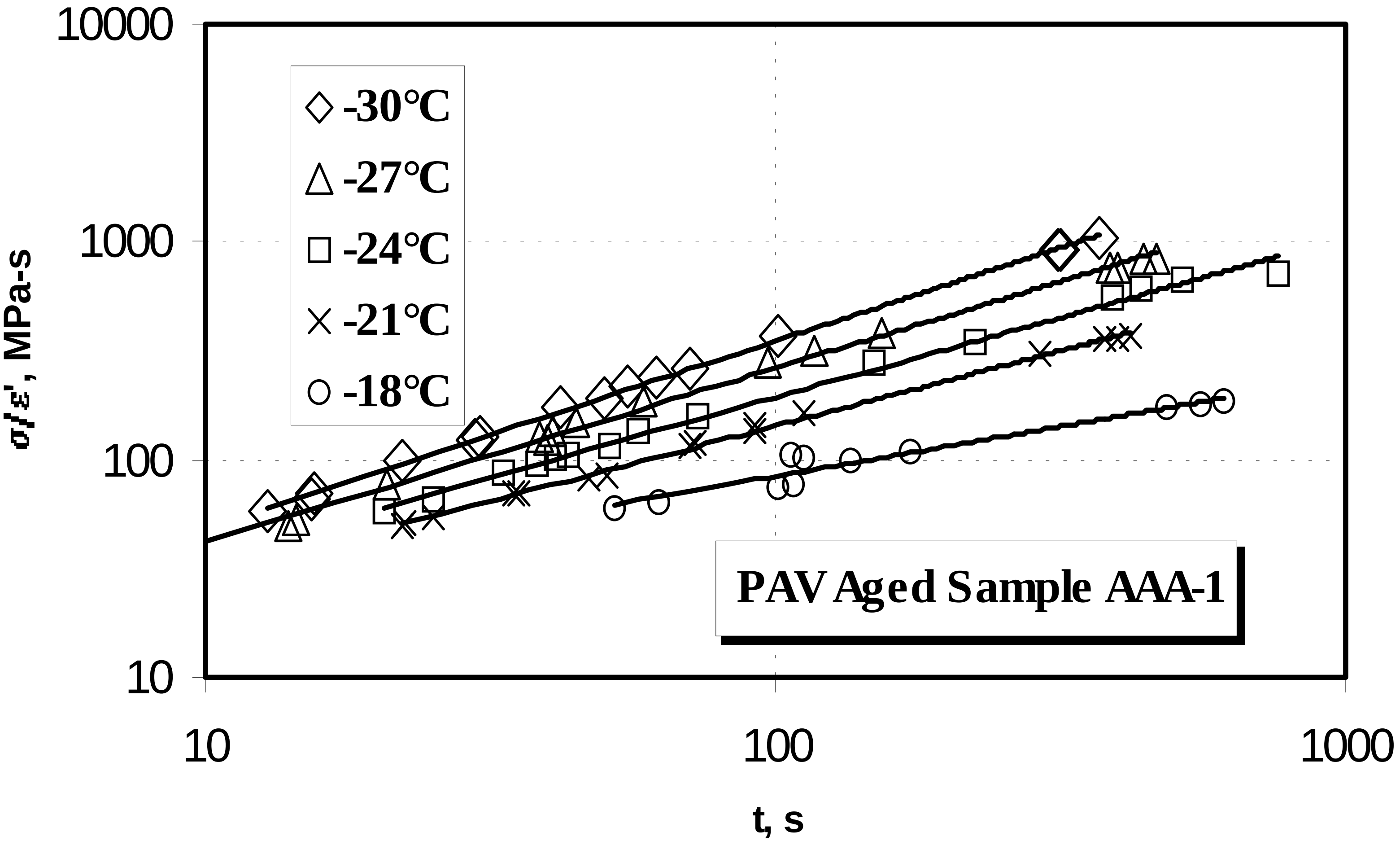
Linearity Check – Relaxation



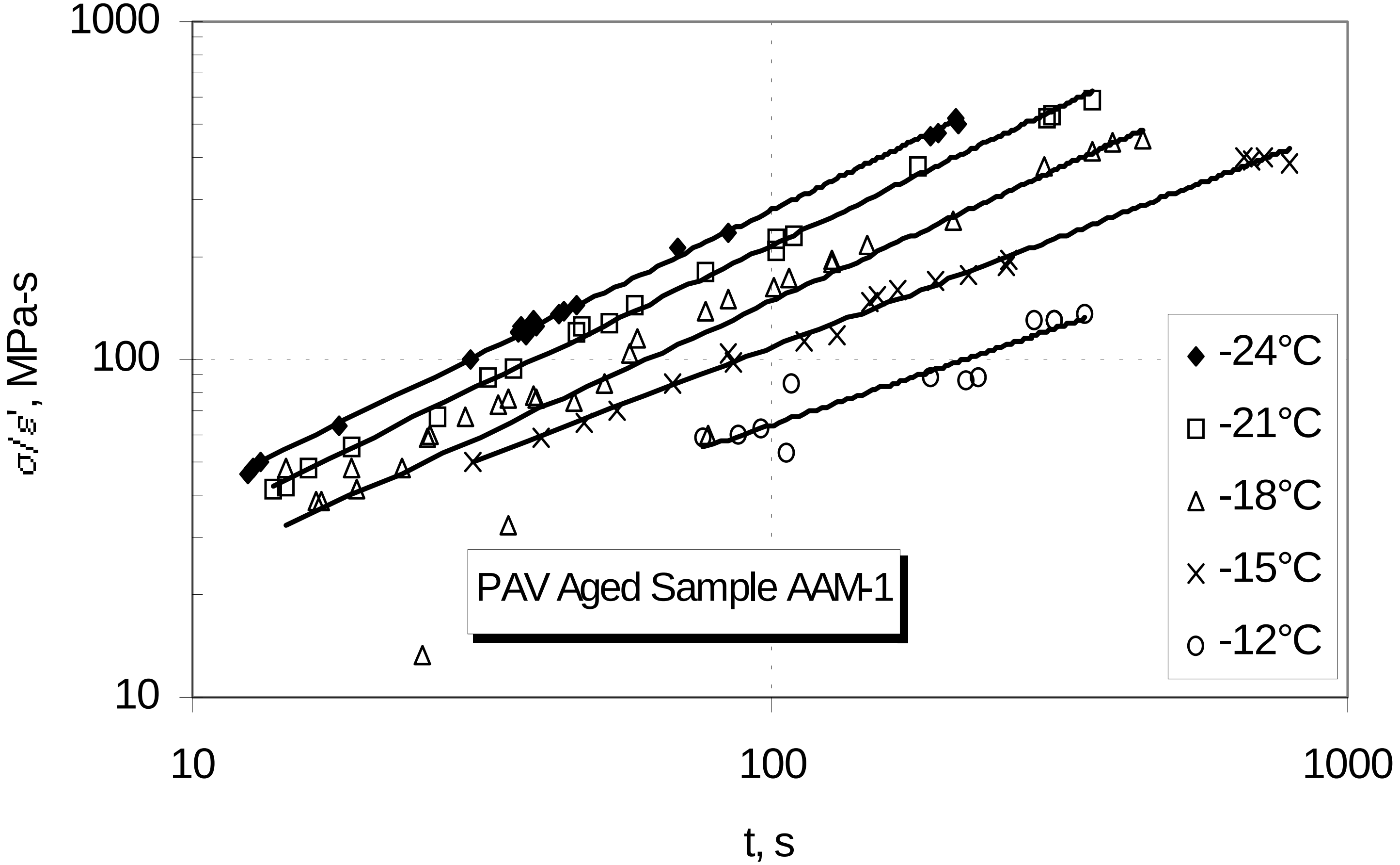
Linearity Check - Relaxation



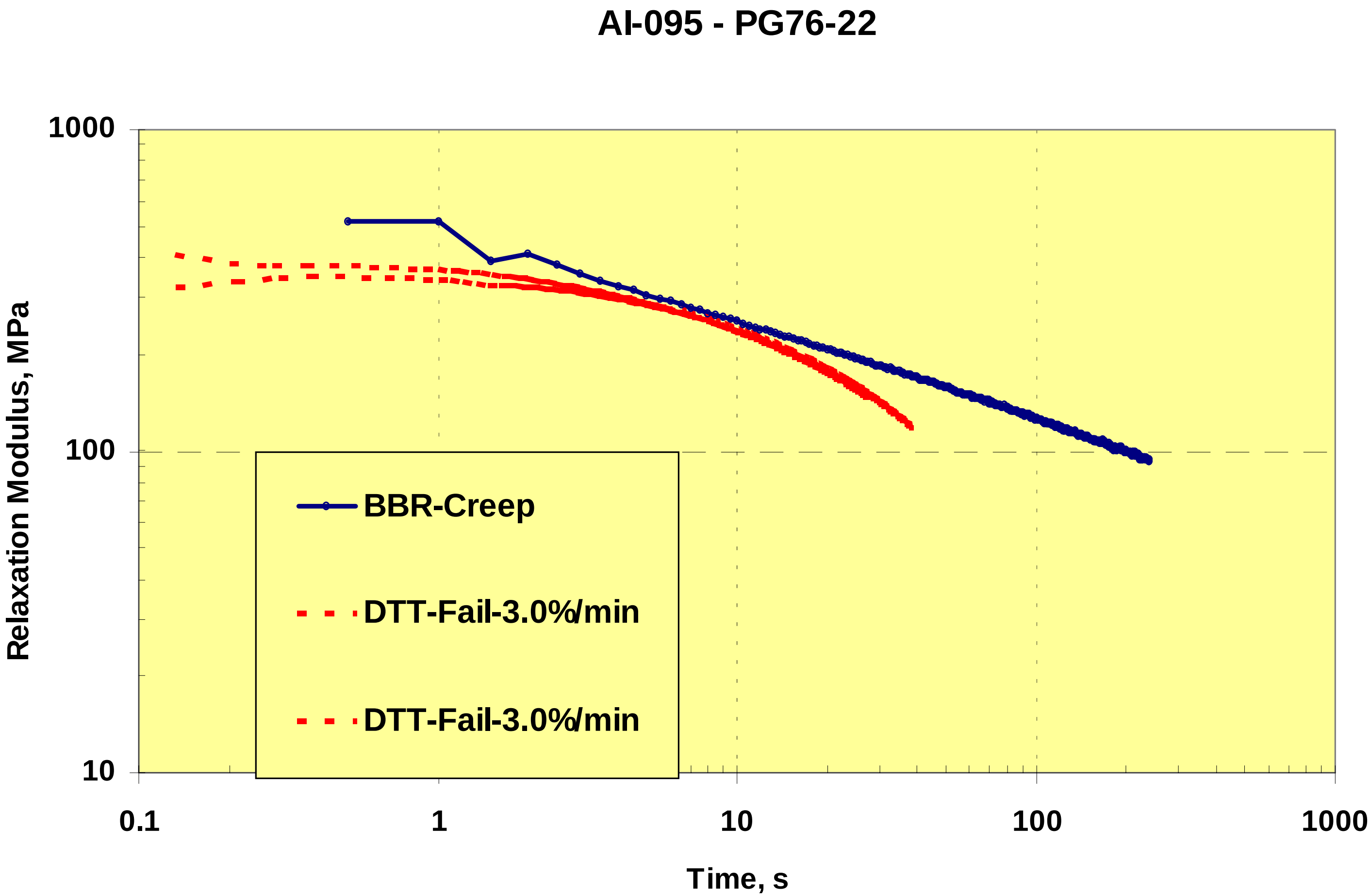
Linearity Check- Failure



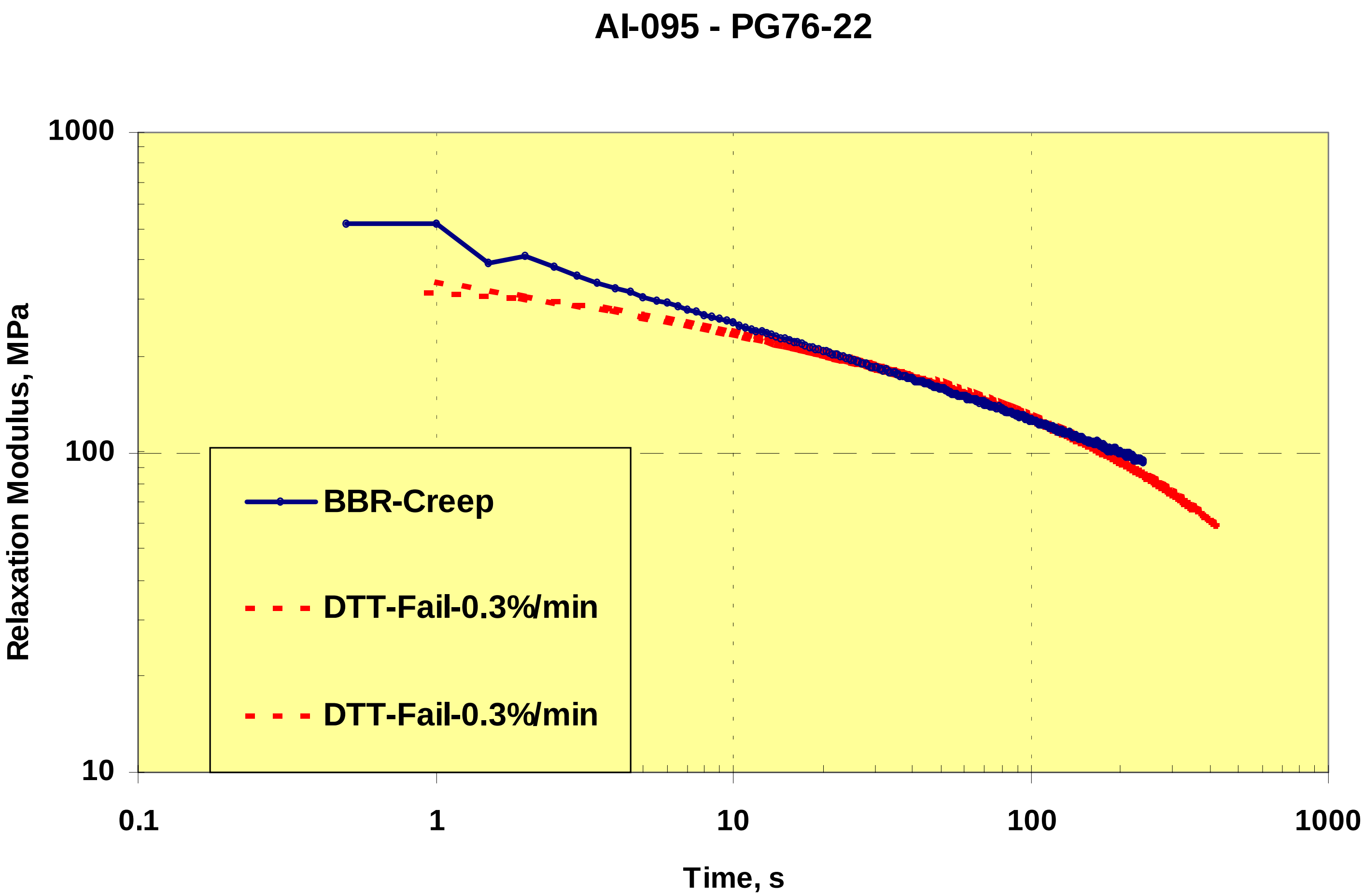
Linearity Check - Failure



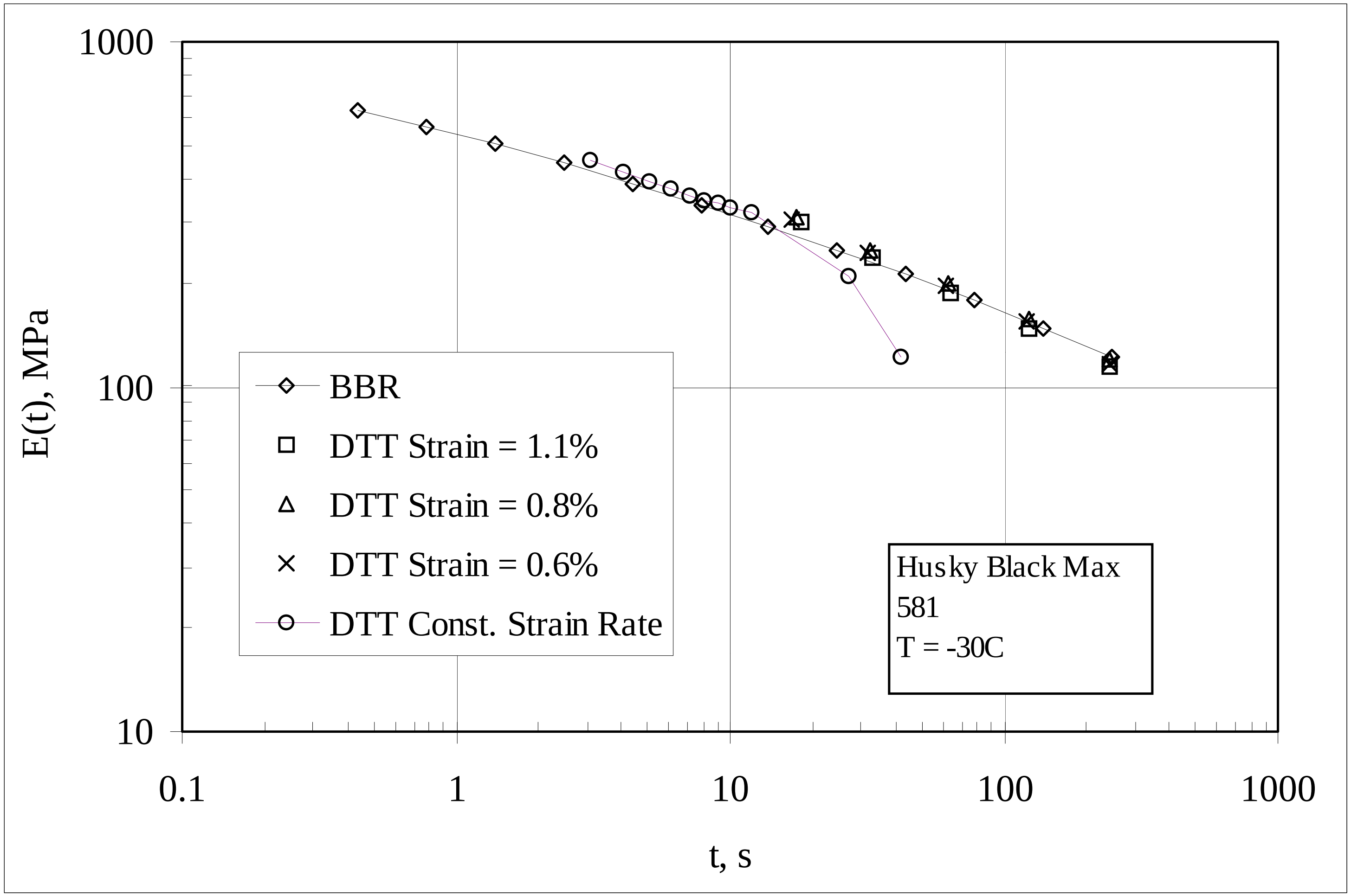
BBR Vs. DTT – Failure Data



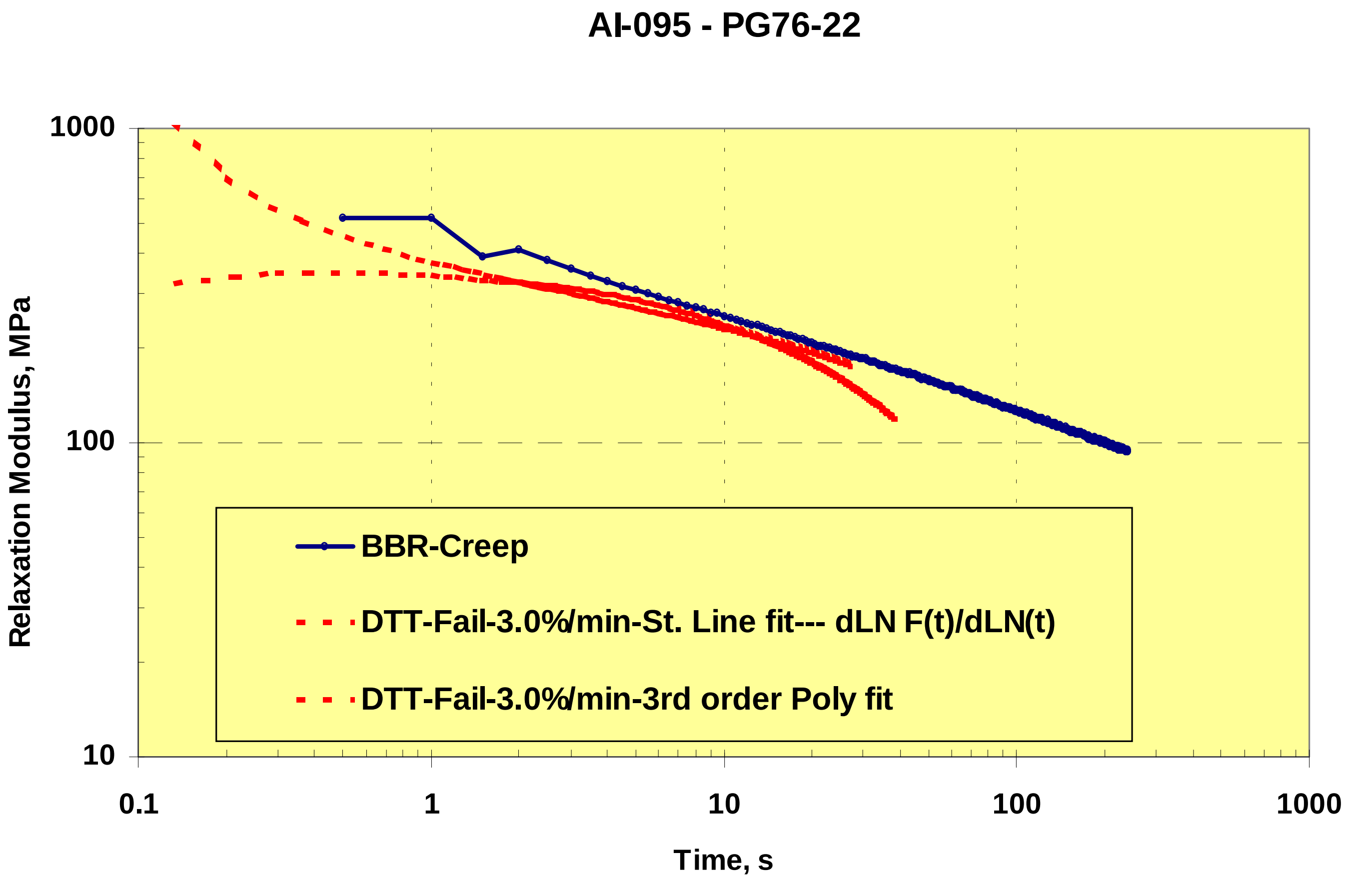
BBR Vs. DTT – Failure Data



All Combined-Summary



Other Variables



Thor Smith's Formula

$$E(t) = F(t)\left[1 + \frac{dLogF(t)}{dLog(t)}\right]$$

Where,

E(t) = Relaxation Modulus, MPa

F(t) = Secant Modulus, MPa = Stress/Strain

Correct Method to Convert

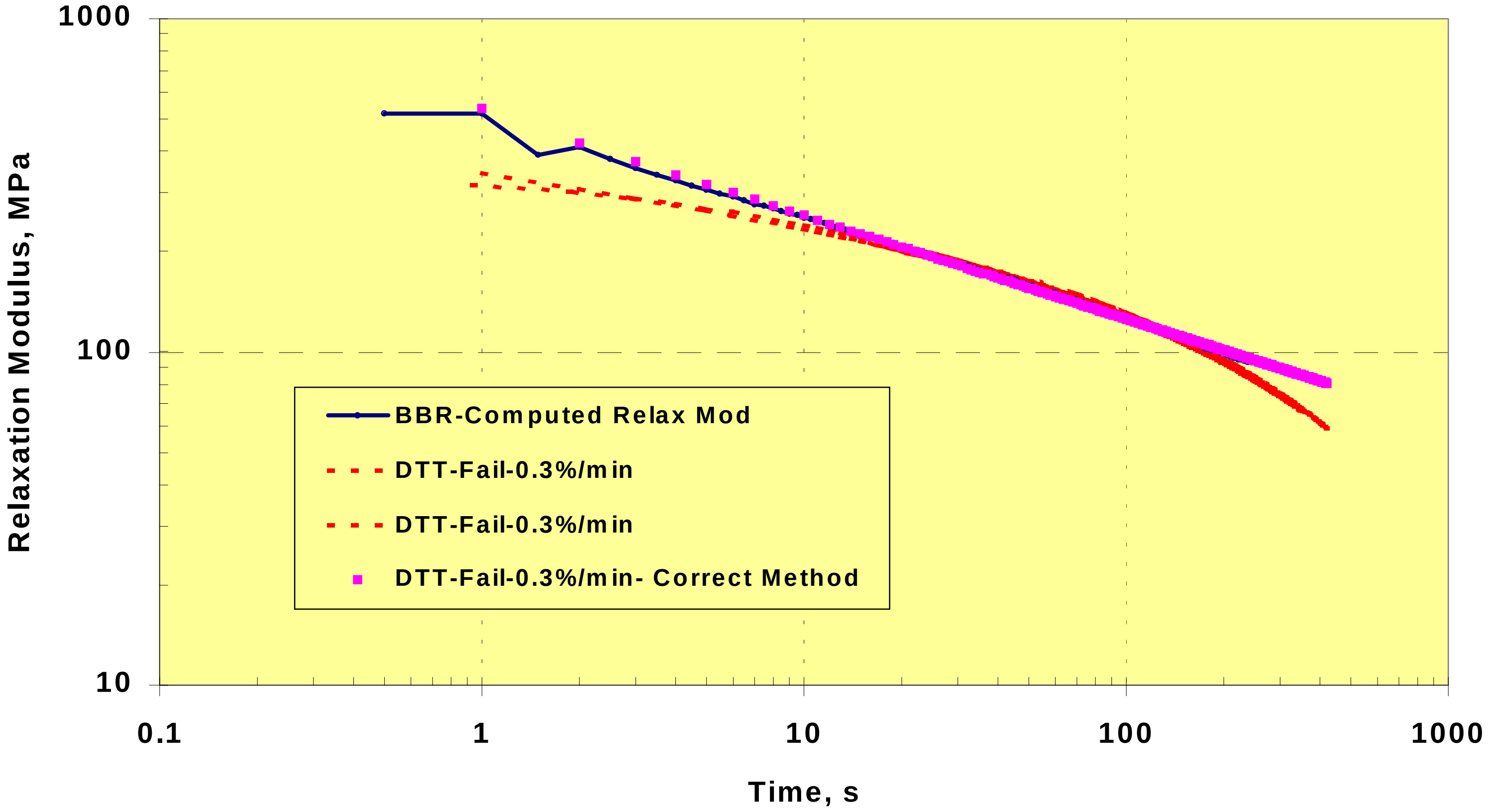
- Take the derivative of the stress-strain curve
  - Fit a Power Law to the True Stress vs True Strain Curve

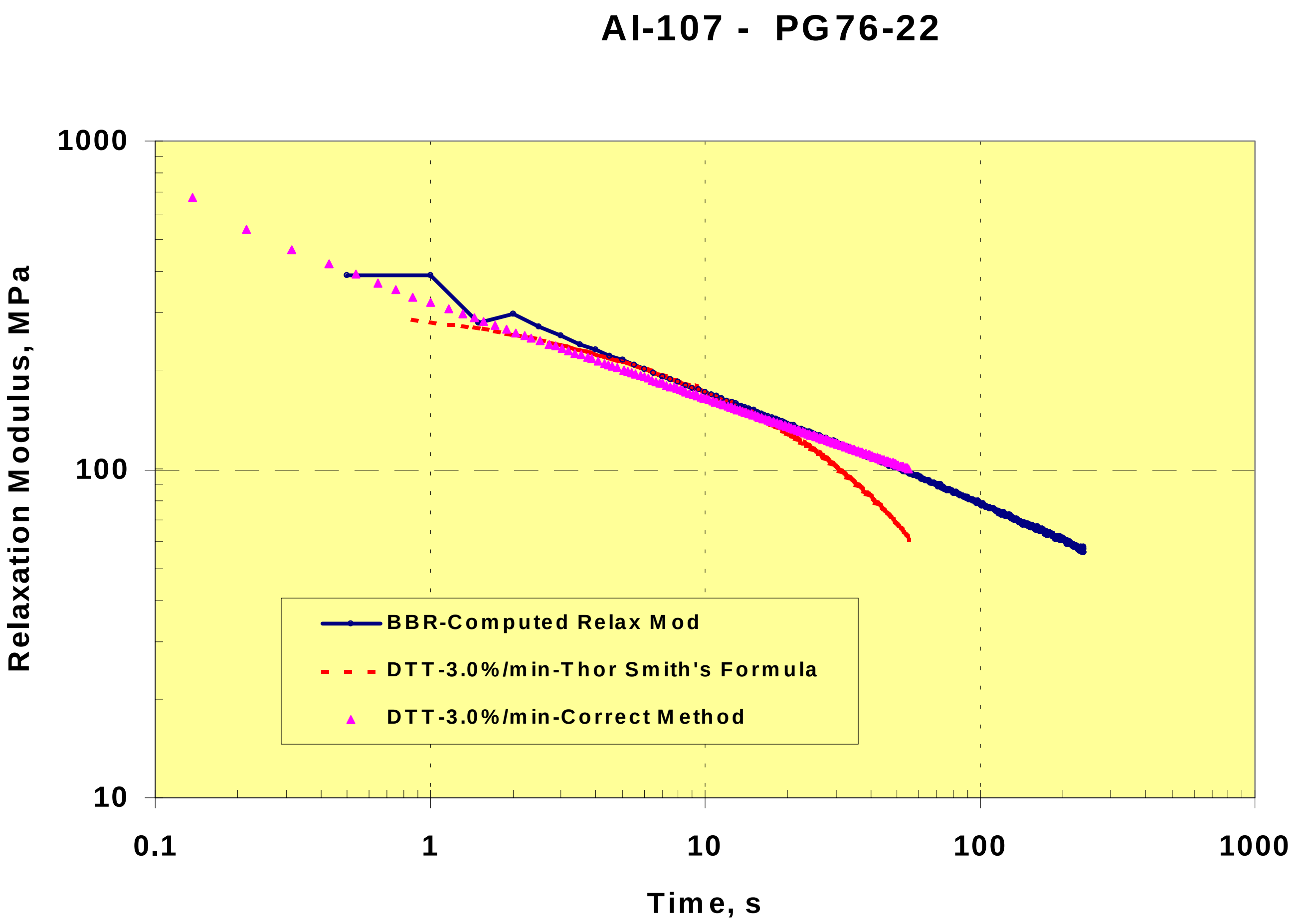
$$E(t) = \frac{d\sigma}{d\varepsilon}$$

$$\sigma = K(\varepsilon)^n$$

$$\frac{d\sigma}{d\varepsilon} = K \cdot n \cdot (\varepsilon)^{n-1}$$

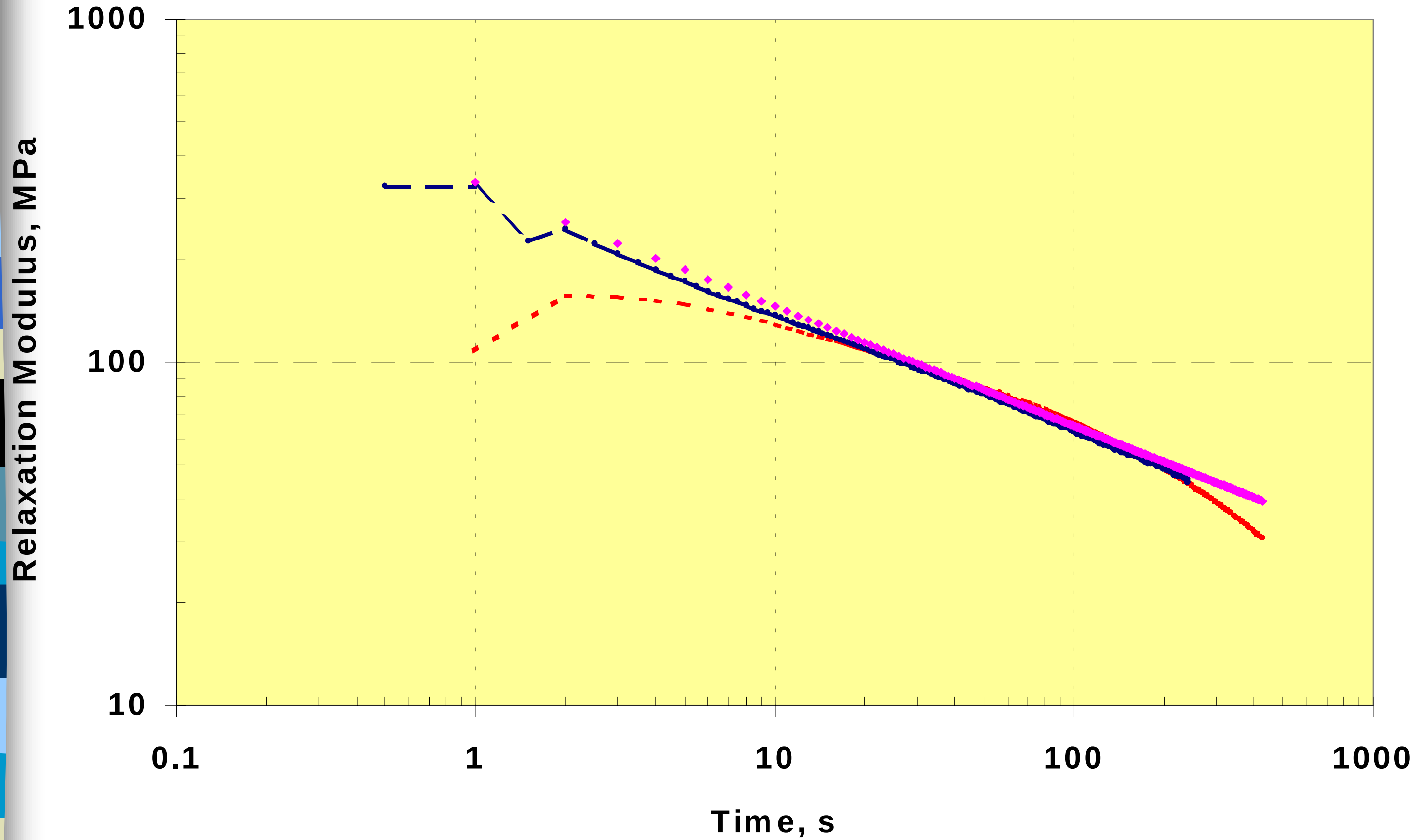
AI-095 - PG76-22





AI-107 - PG76-22
1000
100
10
Relaxation Modulus, MPa
0.1
1
10
100
1000
Time, s
BBR-Computed Relax Mod
DTT-3.0%/min-Thor Smith's Formula
DTT-3.0%/min-Correct Method

PG70-22 Oxd.



Findings

- BBR and DTT produce identical results
- Flexure and Uniaxial geometry produce the same results
- Non-Linearity was not found at the PG grade temperatures
- When Converting Stress-Strain Curves From the DTT into Relaxation Modulus
  - Use True Stress Vs True Strain
  - Use the Derivative of the True Stress vs True Strain

Test for The Audience

- What is one other thing we learned about the DTT that is not always apparent?

Acknowledgements

- FHWA-John D’Angelo and TE-39 Laboratory Staff

Thank You!