CALCULATION OF THE RELAXATION MODULUS MASTER CURVE FROM DTT TEST DATA AND THE DETERMINATION OF CRITICAL CRACKING TEMPERATURE

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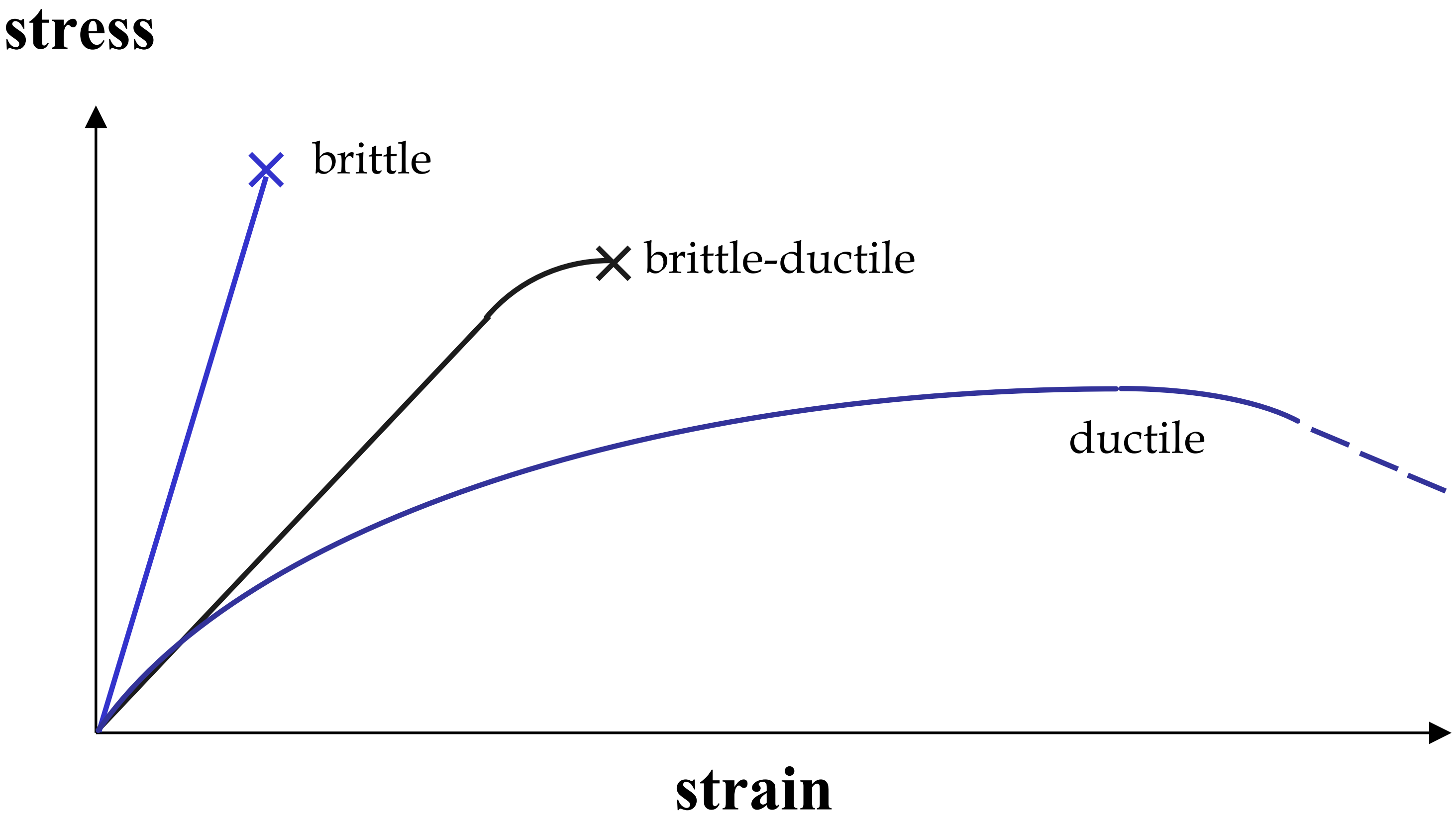
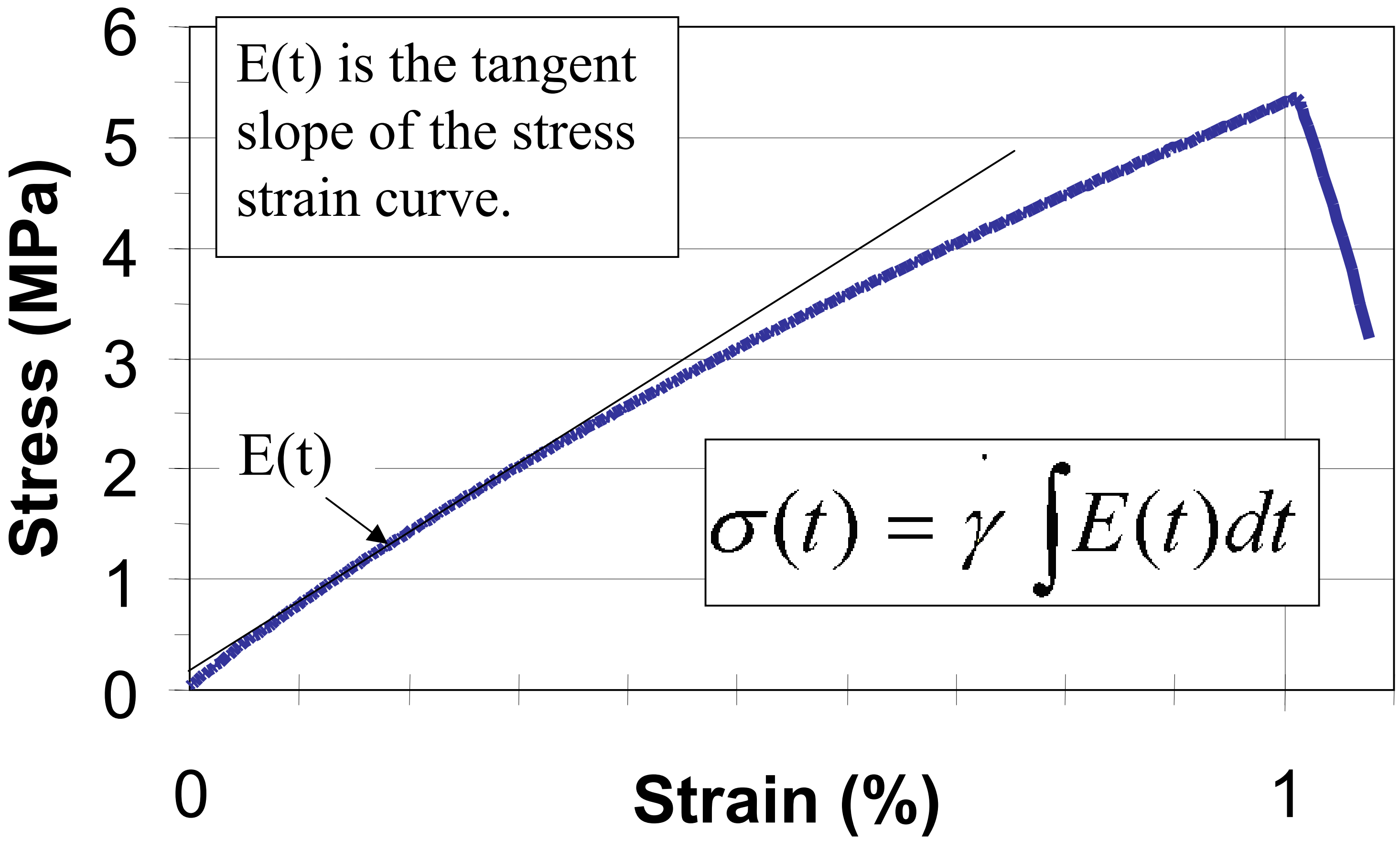
Objectives

- To improve procedures for the definition of master curves from DTT testing
- To review capability of DTT for low temperature T_{crit} prediction

Typical DTT



The DTT can define rheology

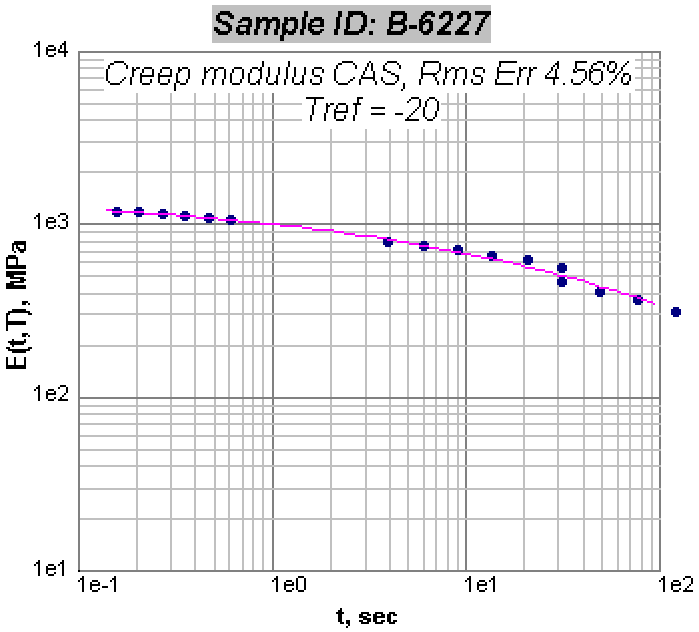


E(t) is the tangent slope of the stress strain curve.

$$\sigma(t) = \dot{\gamma} \int E(t)dt$$

Information from DTT test

- Master curve of relaxation modulus from DTT
- Initial work presented at binder ETG – April 2001 in Phoenix



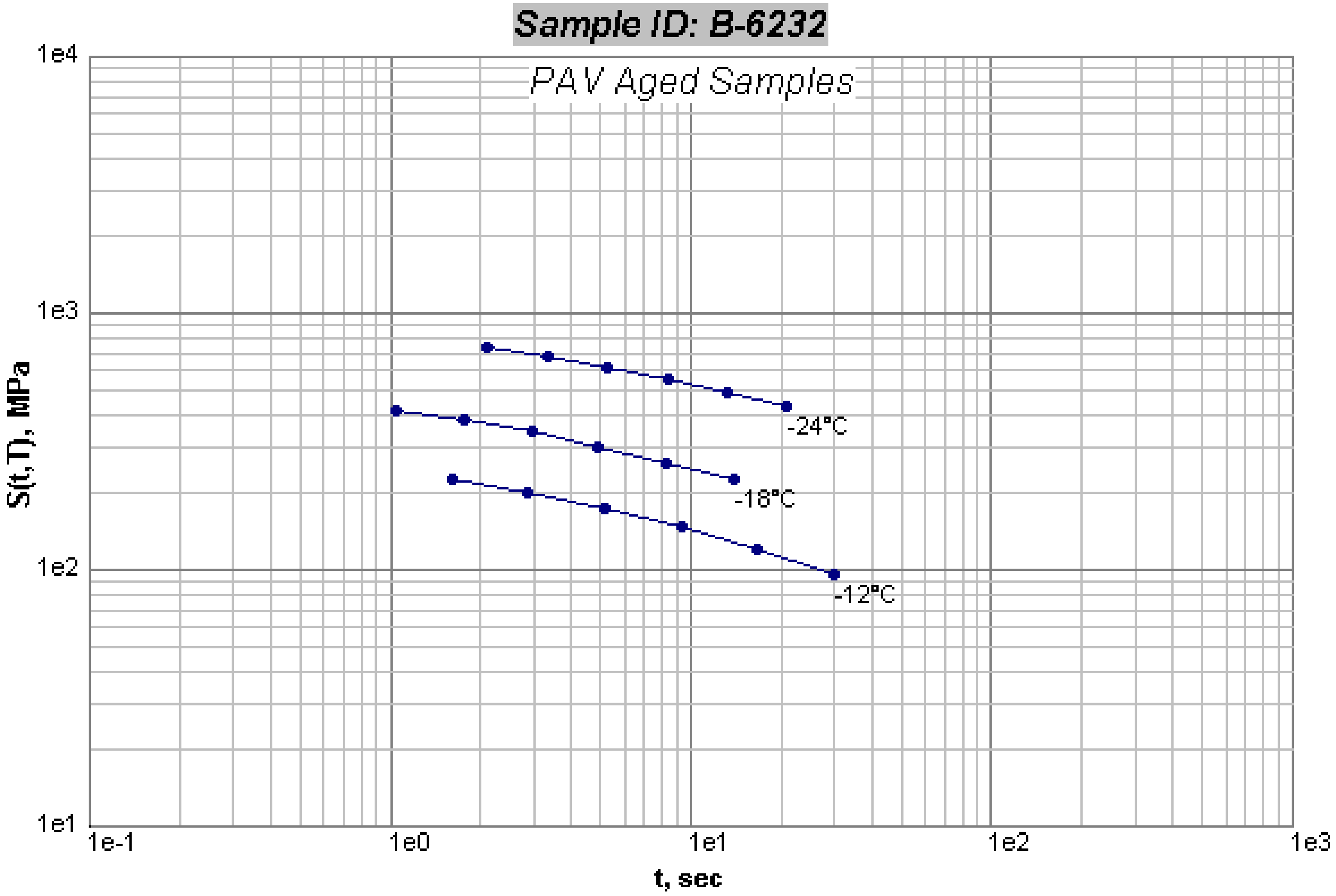
Development of Master Curve

How good is the DTT at defining the low temperature rheology?

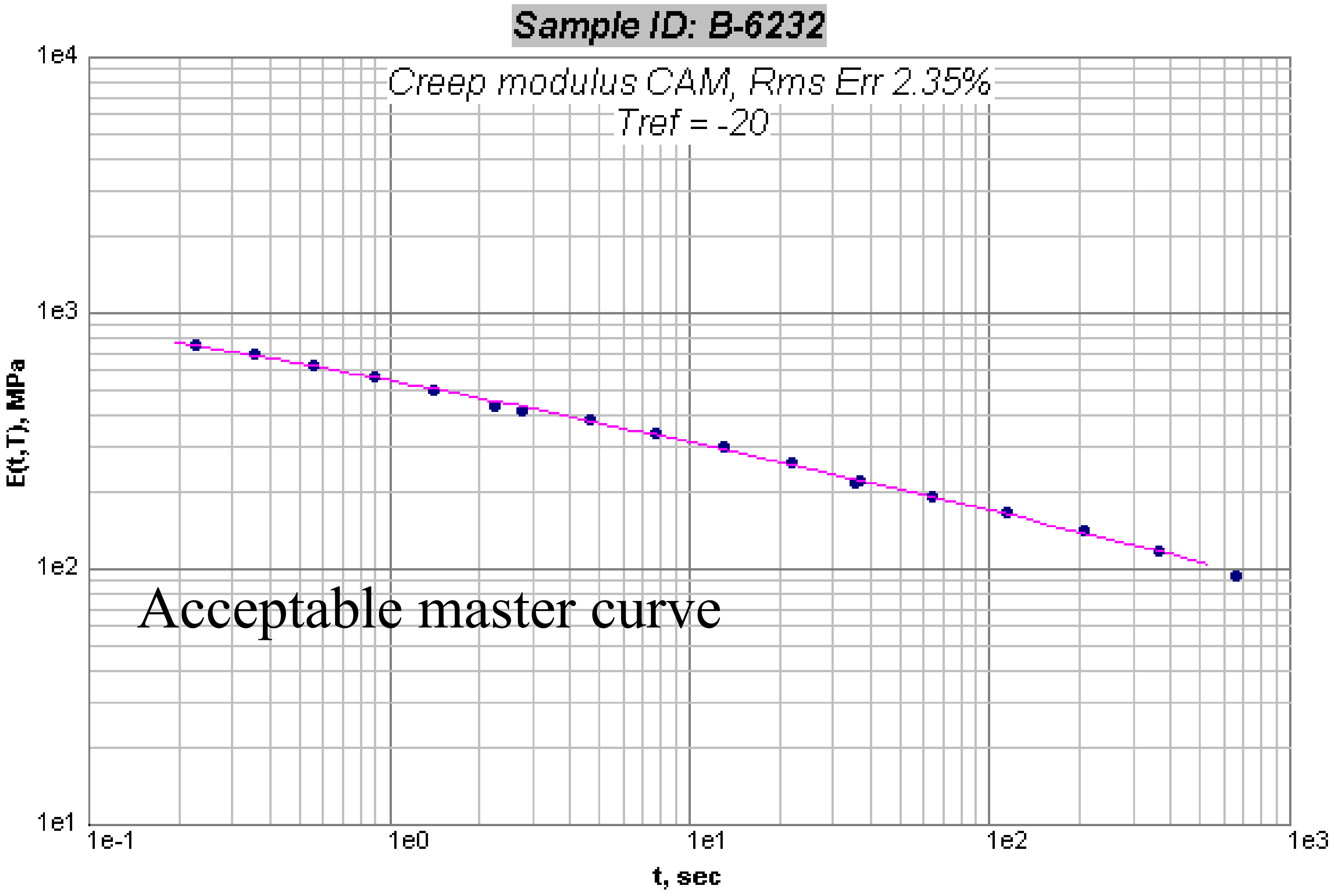
Determination of E(t)

- Initial scheme involves fitting tangent modulus to data from curve
- Several schemes being evaluated
  - Numerical averaging
  - Thor-Smith method
  - CAM model
- April 2001 - numerical appears to be more robust
- Start of test often results in early part of isotherm being rejected

Isotherms of E(t)

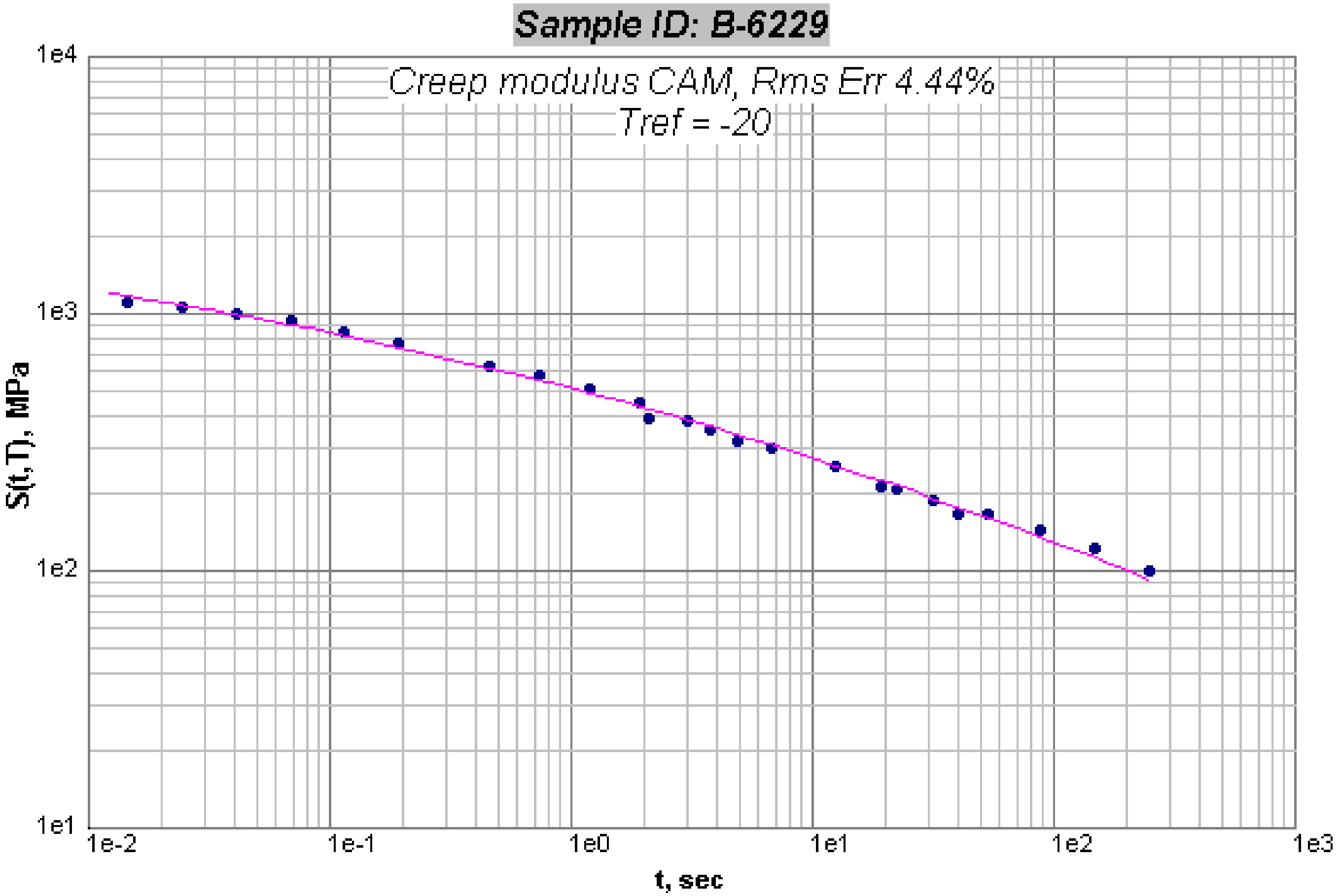


Master Curve E(t)



Acceptable master curve

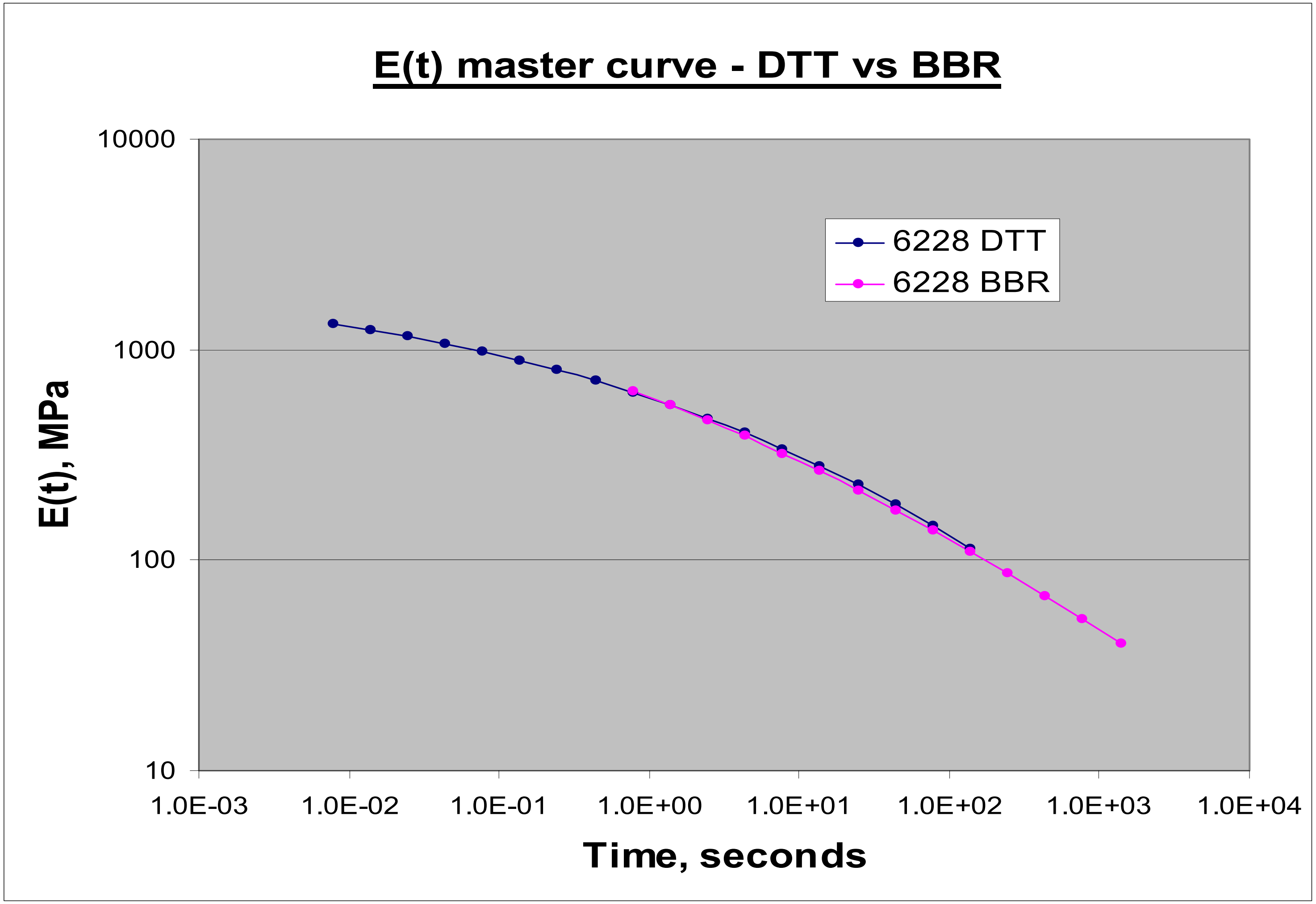
Unacceptable master curve



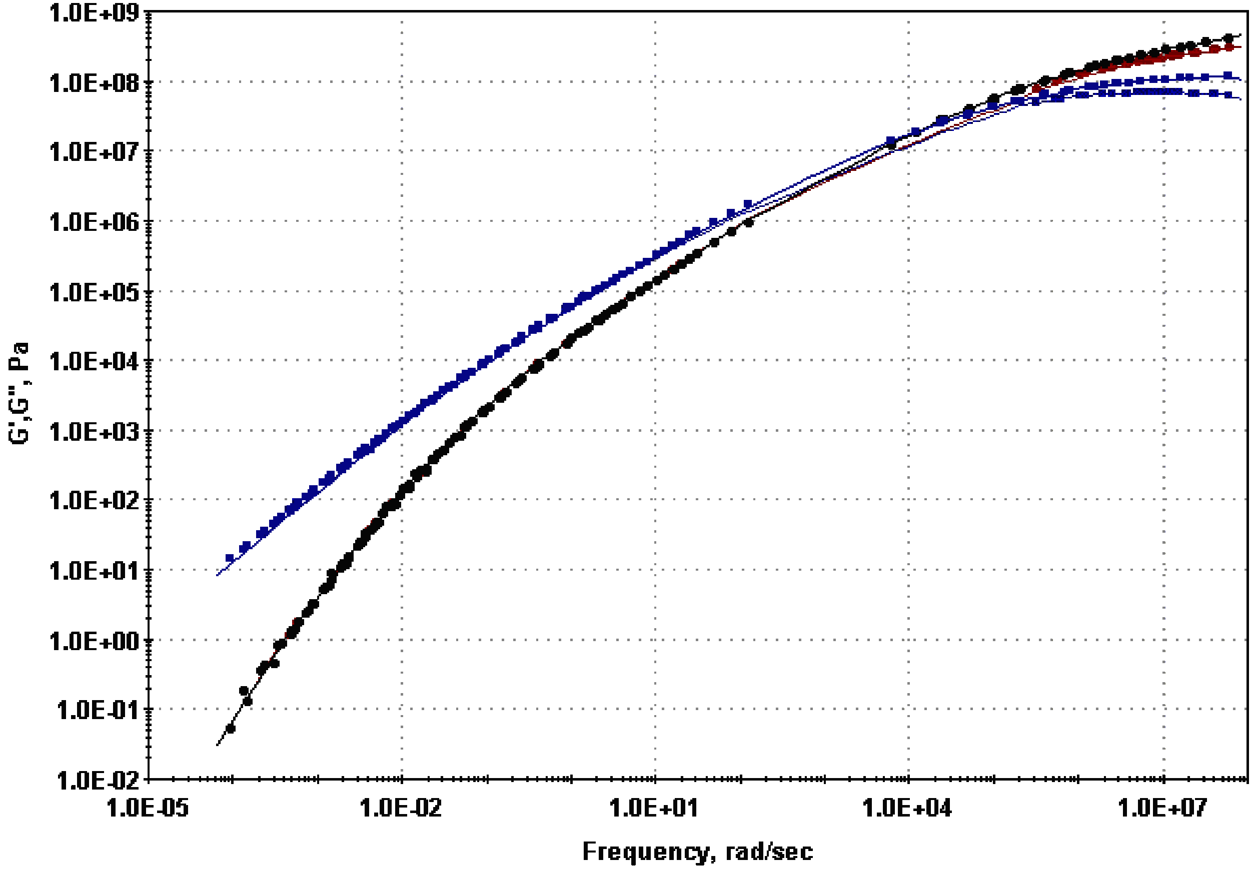
Development of visco-elastic behavior

- Numerical analysis used to convert data
  - Hopkins and Hamming used with BBR to convert S(t) to E(t)
  - DTT yields E(t) direct
  - Spectra fitted to data – used to convert between time and frequency domains
  - Comparisons of visco-elastic properties

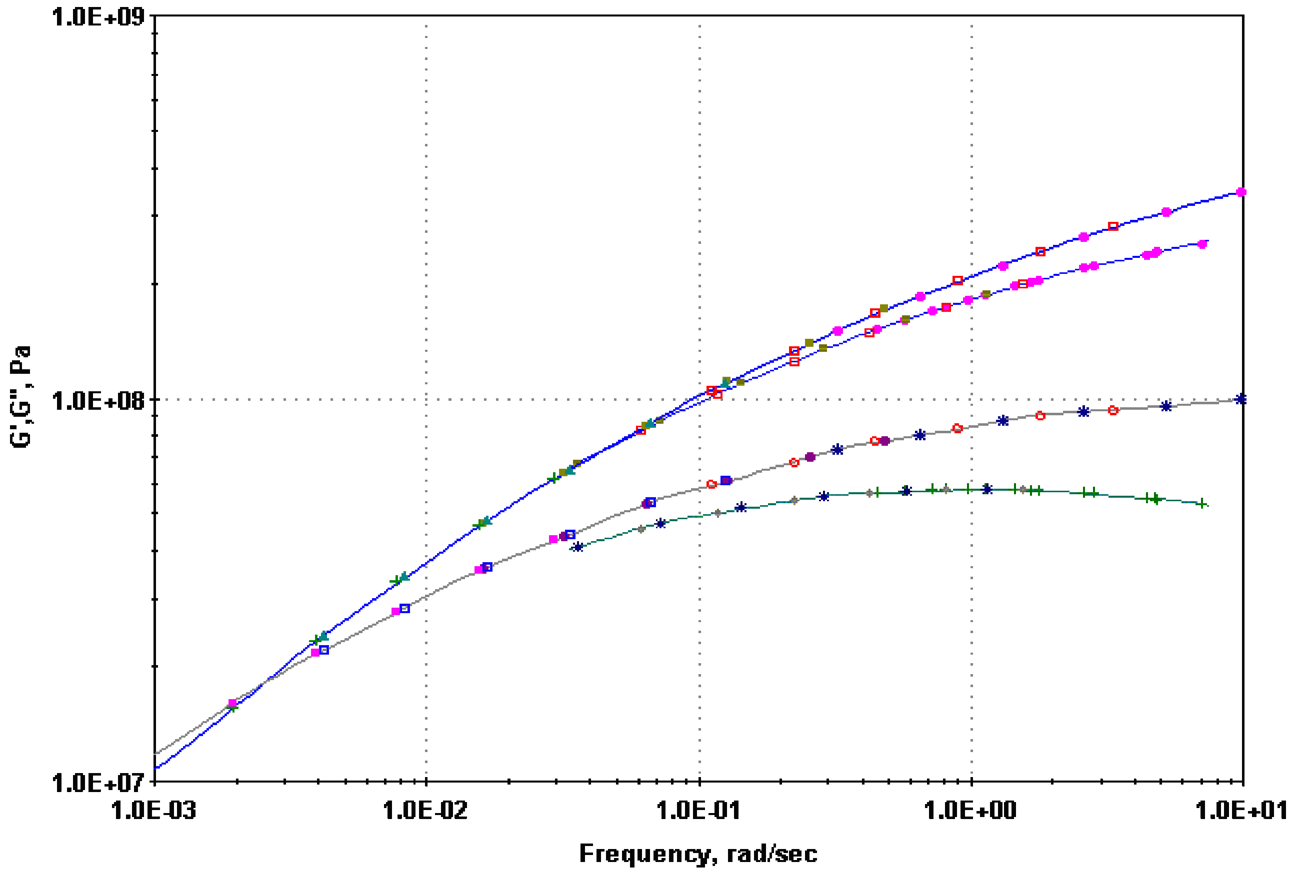
Comparison of master curves



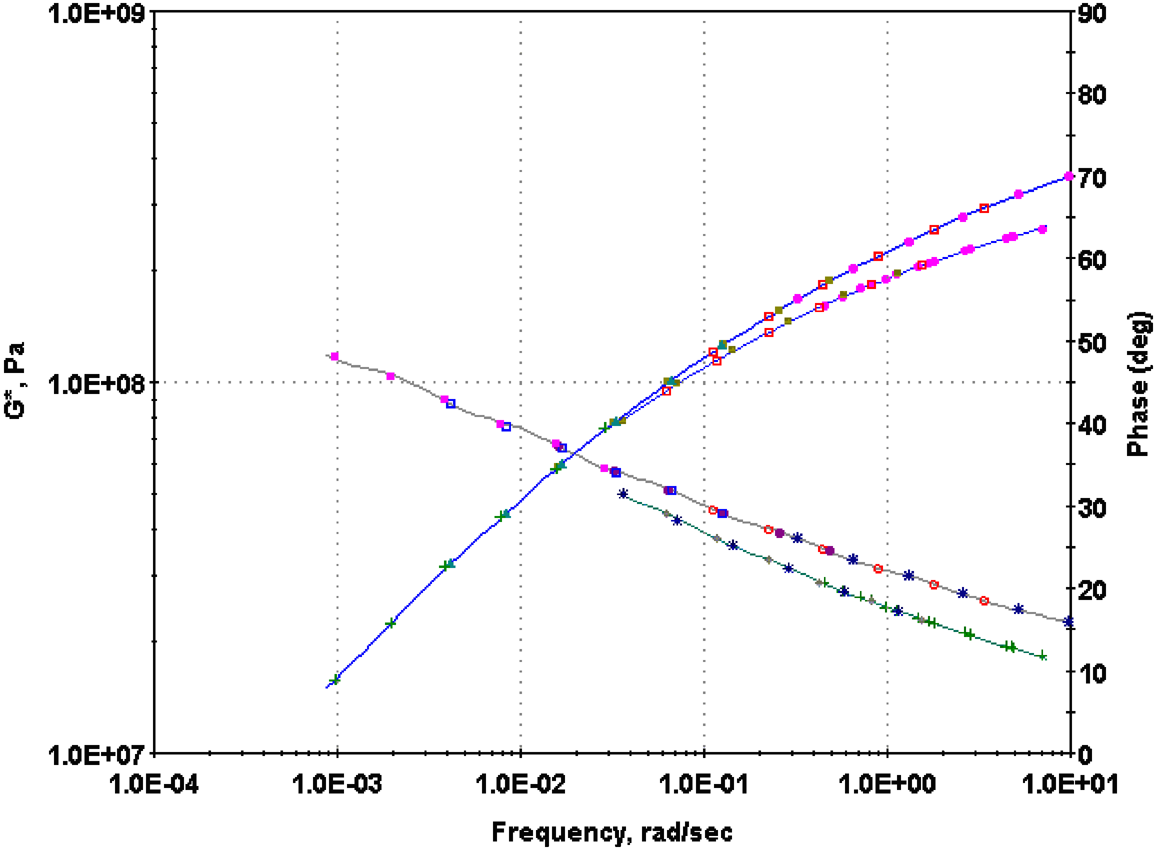
Overlaid Master Curves



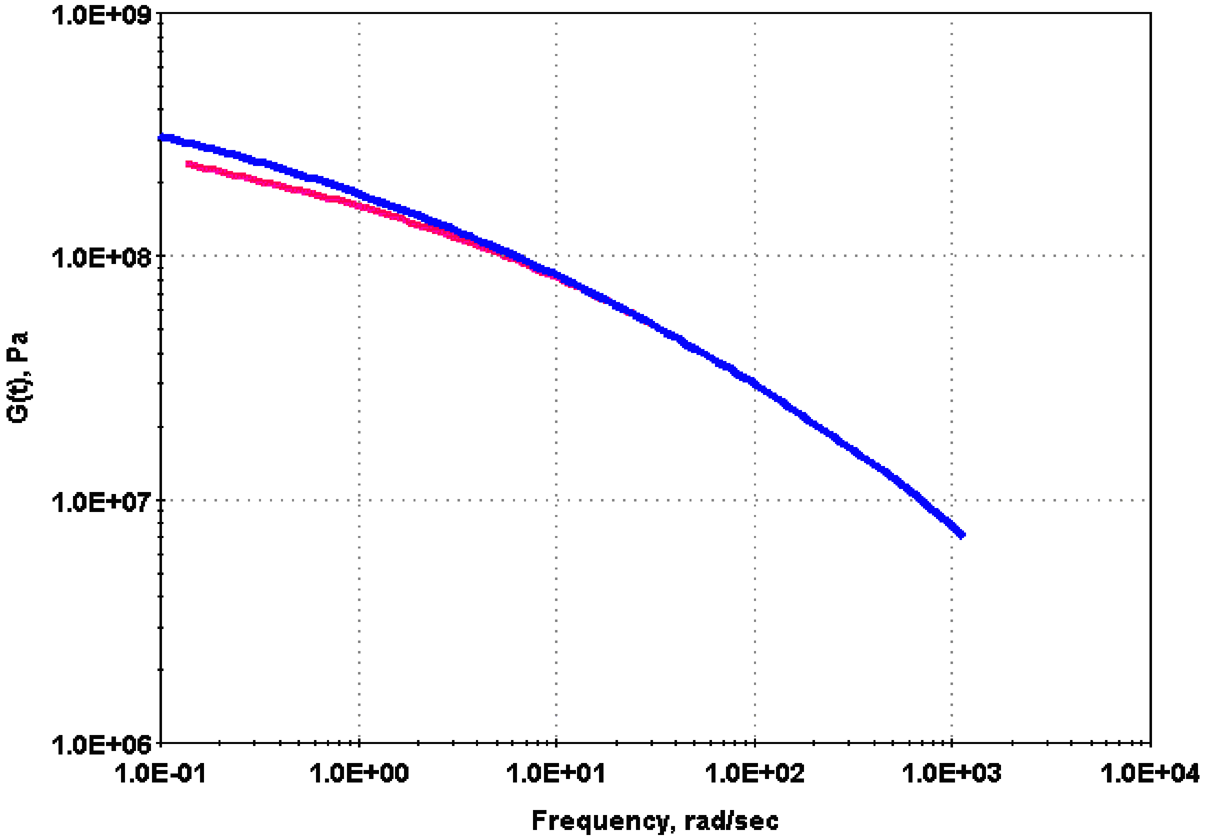
Overlaid Master Curves – Expanded Cold Region, G′ & G″



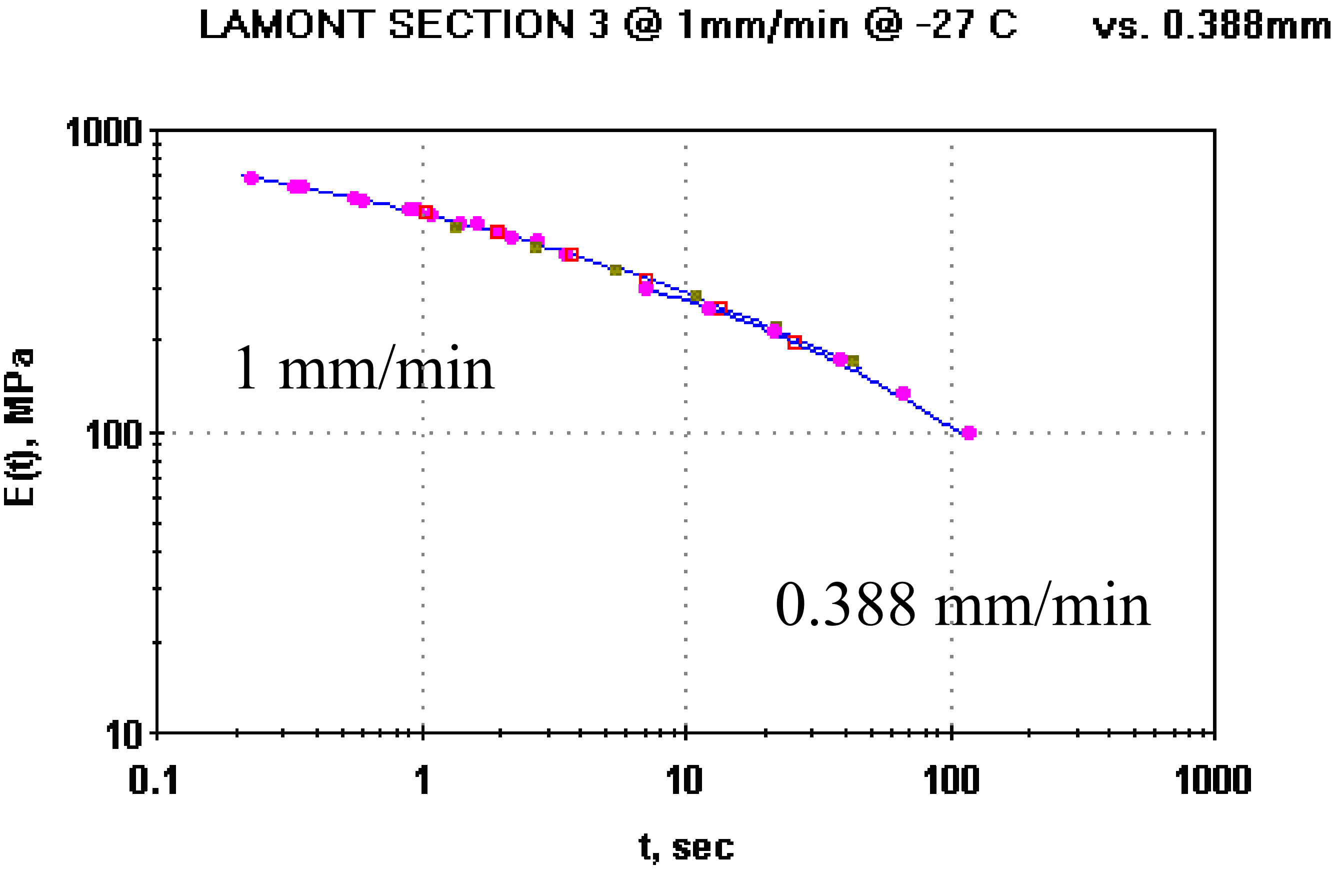
Overlaid Master Curves – Expanded Cold Region, G*, Phase Angle



Overlaid Master Curves, G(t) – Shear Relaxation Modulus



Effect of Loading Rate on DTT MC


LAMONT SECTION 3 @ 1mm/min @ -27 C   vs. 0.388mm

Master Curves

- Reasonable agreement on master curves is obtained
- The data from the DTT appears to define a glass transition at a lower temperature based upon a peak in G″
- More work was needed to look at numerical procedures

Problems found

- Data sets contained fanned data
- Start up – zero condition not well defined if using DTT as rheometer
- Errors in DTT master curve greater than BBR

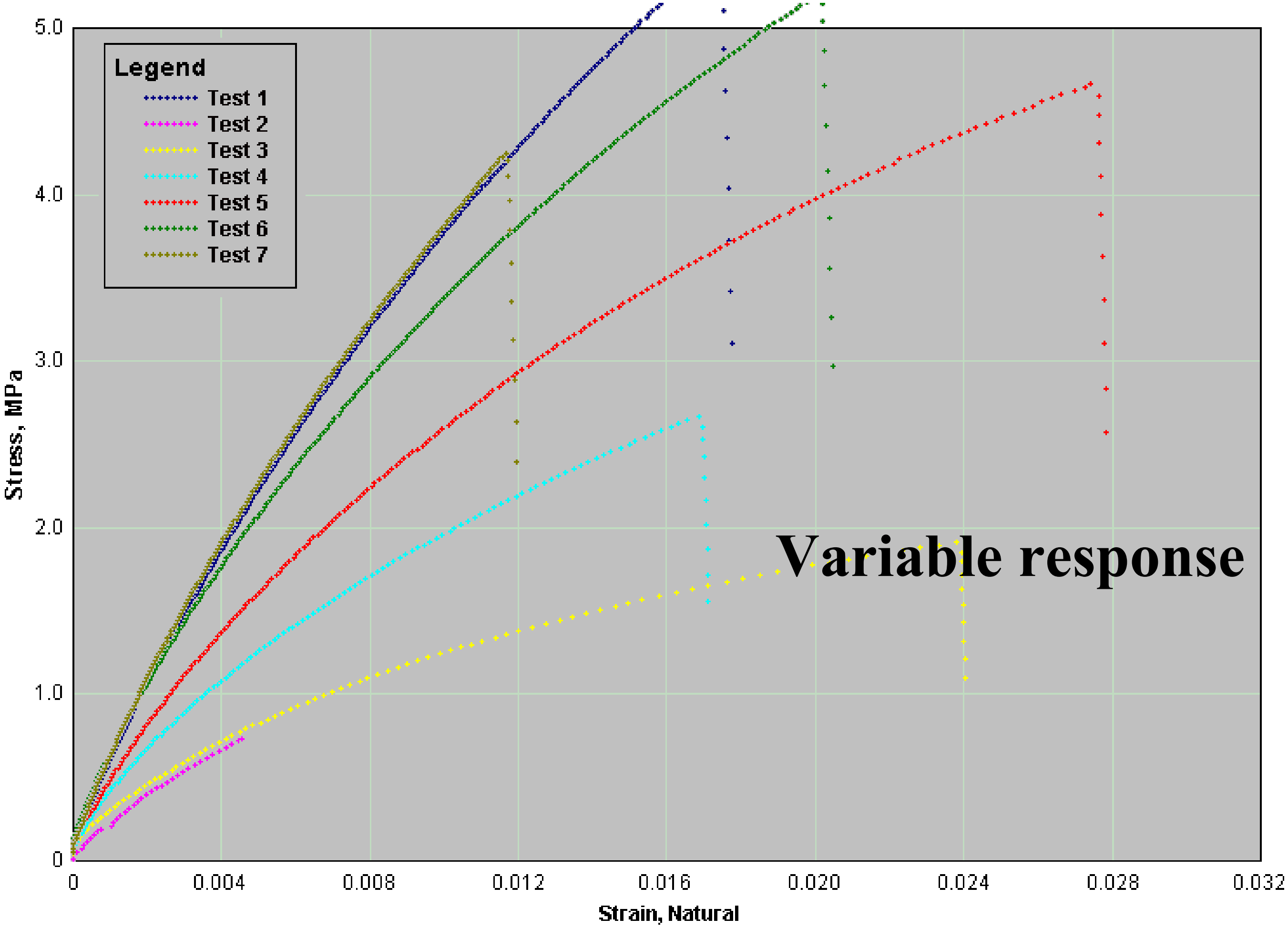
Low temperature cracking

- Removal of fanned data sets
- Adjustment of start conditions
- Work with binders tested at Calgary

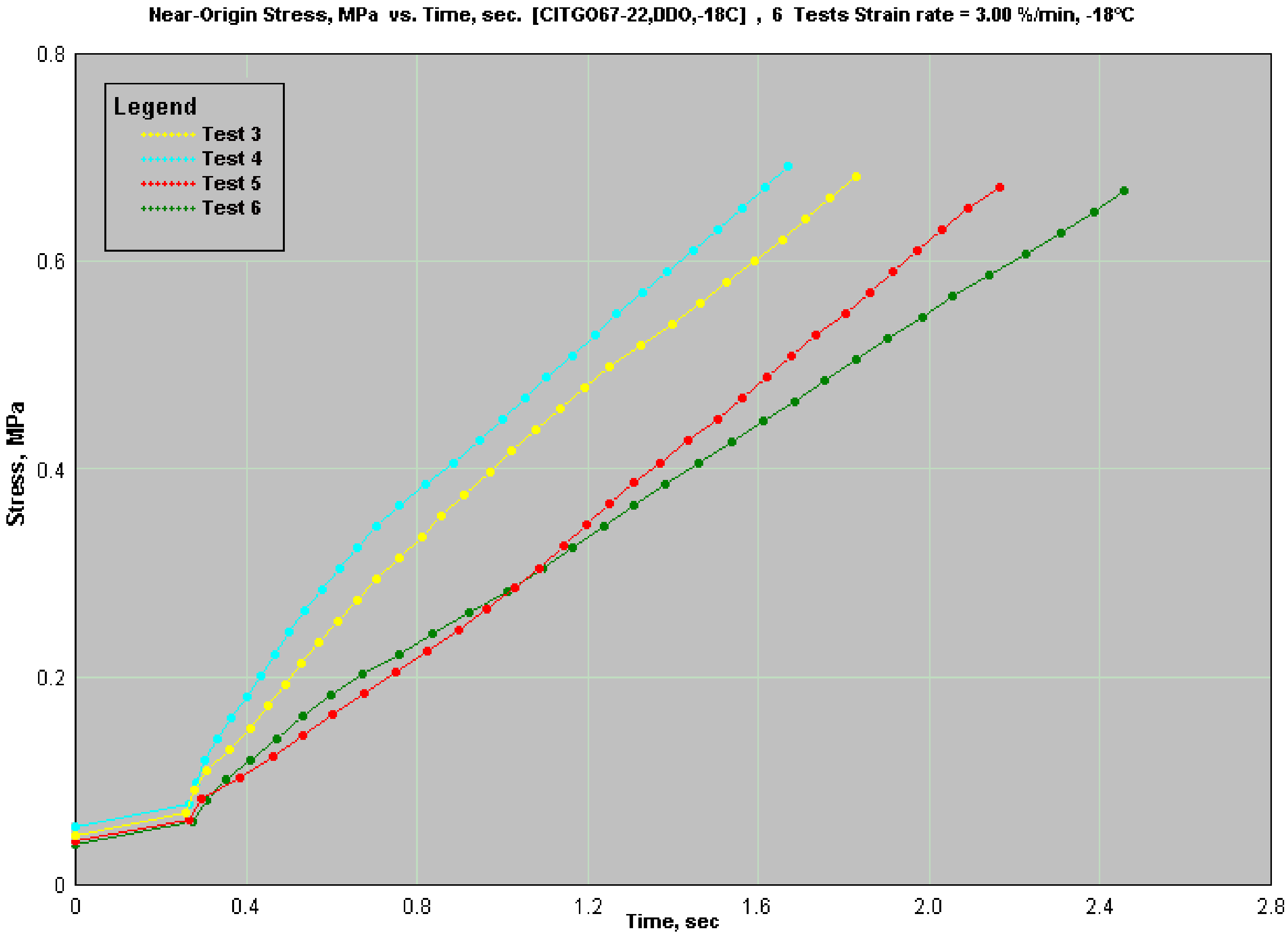
Fanned data

- Removal of fanned data sets is required to ensure that data is compatible
- Fanned data is generally a result of poor sample preparation
- Fanned data is identified by inspection of E(t) criteria

Variable data from DTT



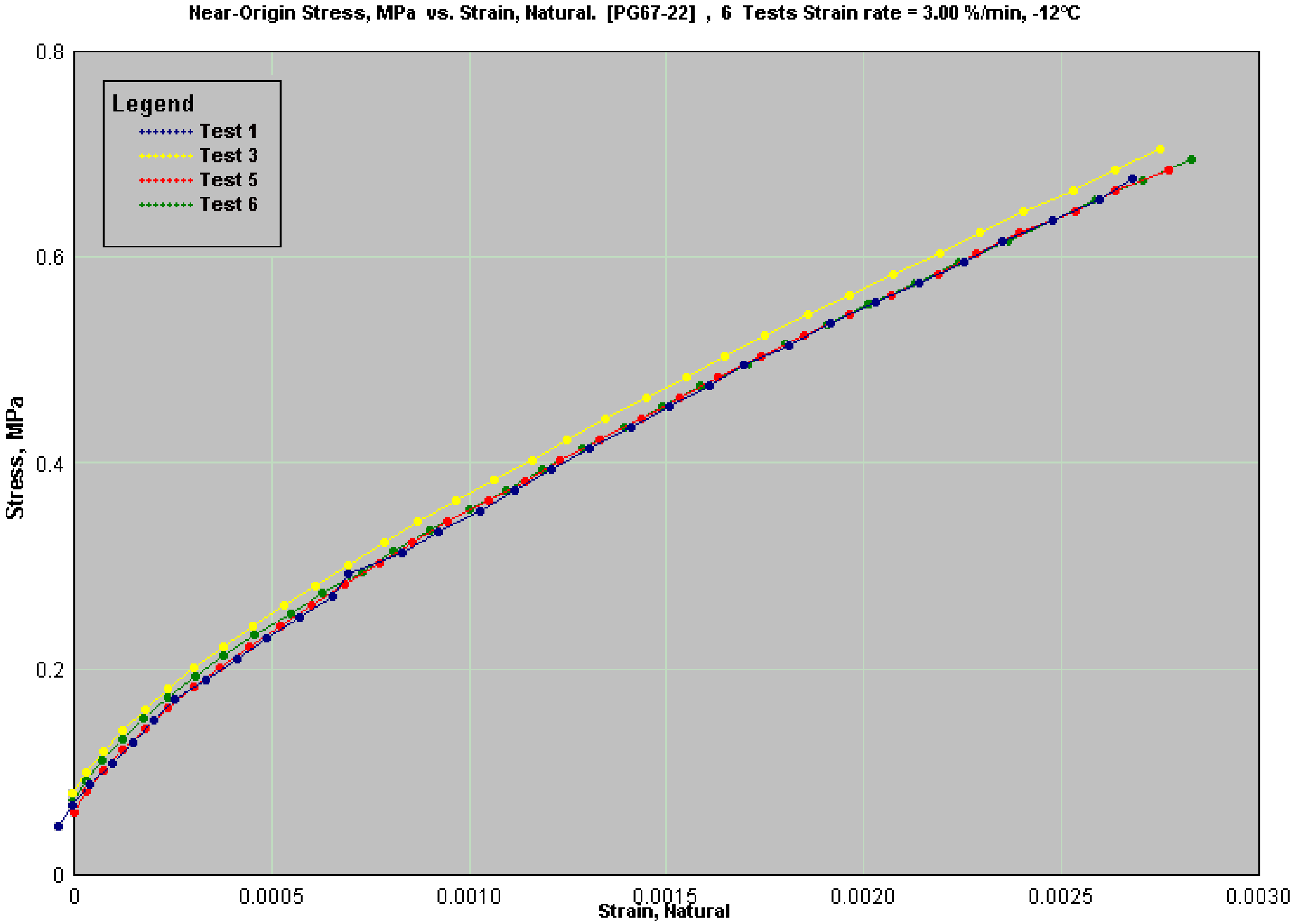
Start up errors – different slopes



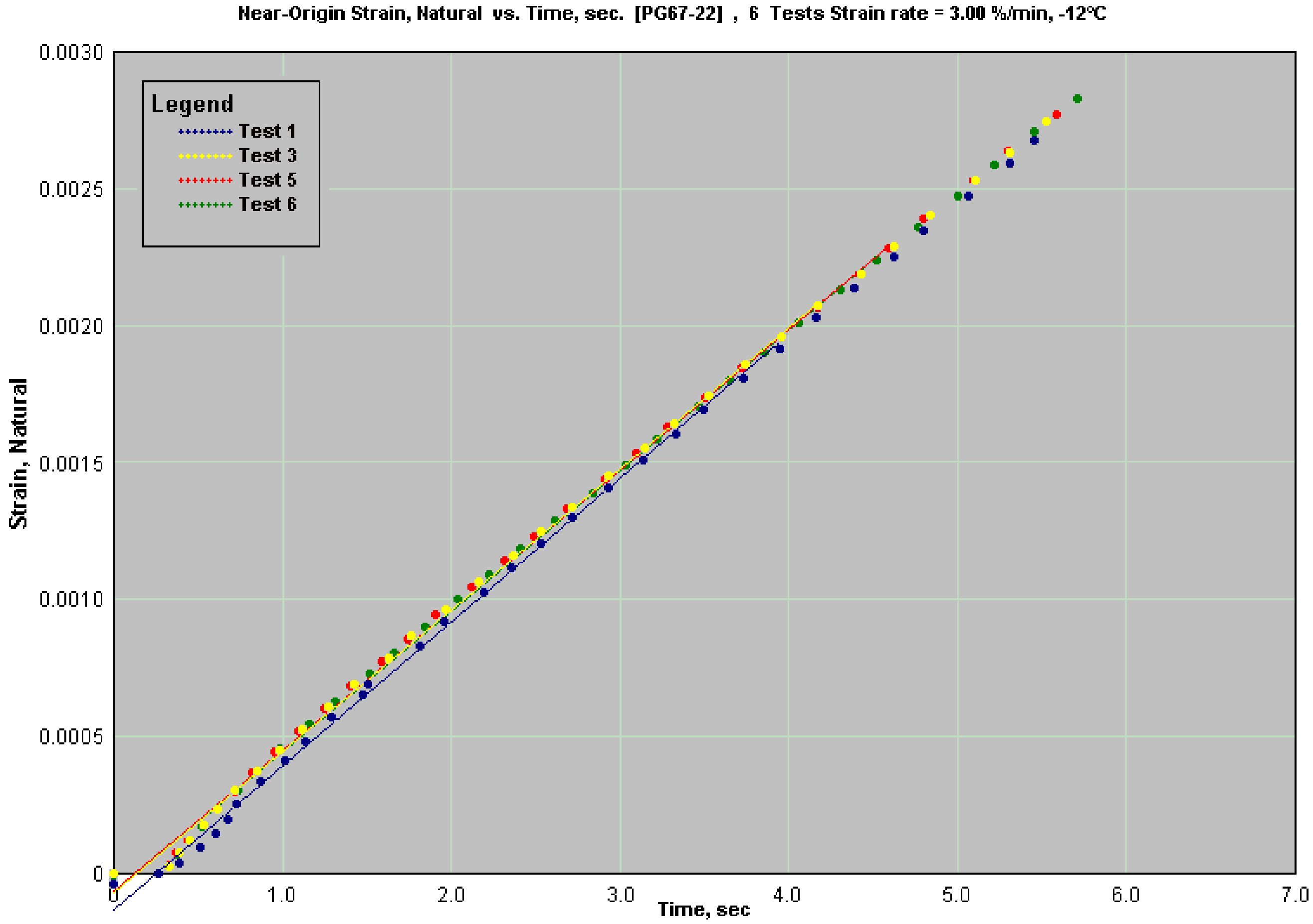
Start-up errors

- As control is passed from analogue to digital control some difficulties are always obtained at start conditions
- Strain rates cannot be applied in a infinite time
- Result is some error in the initial start conditions

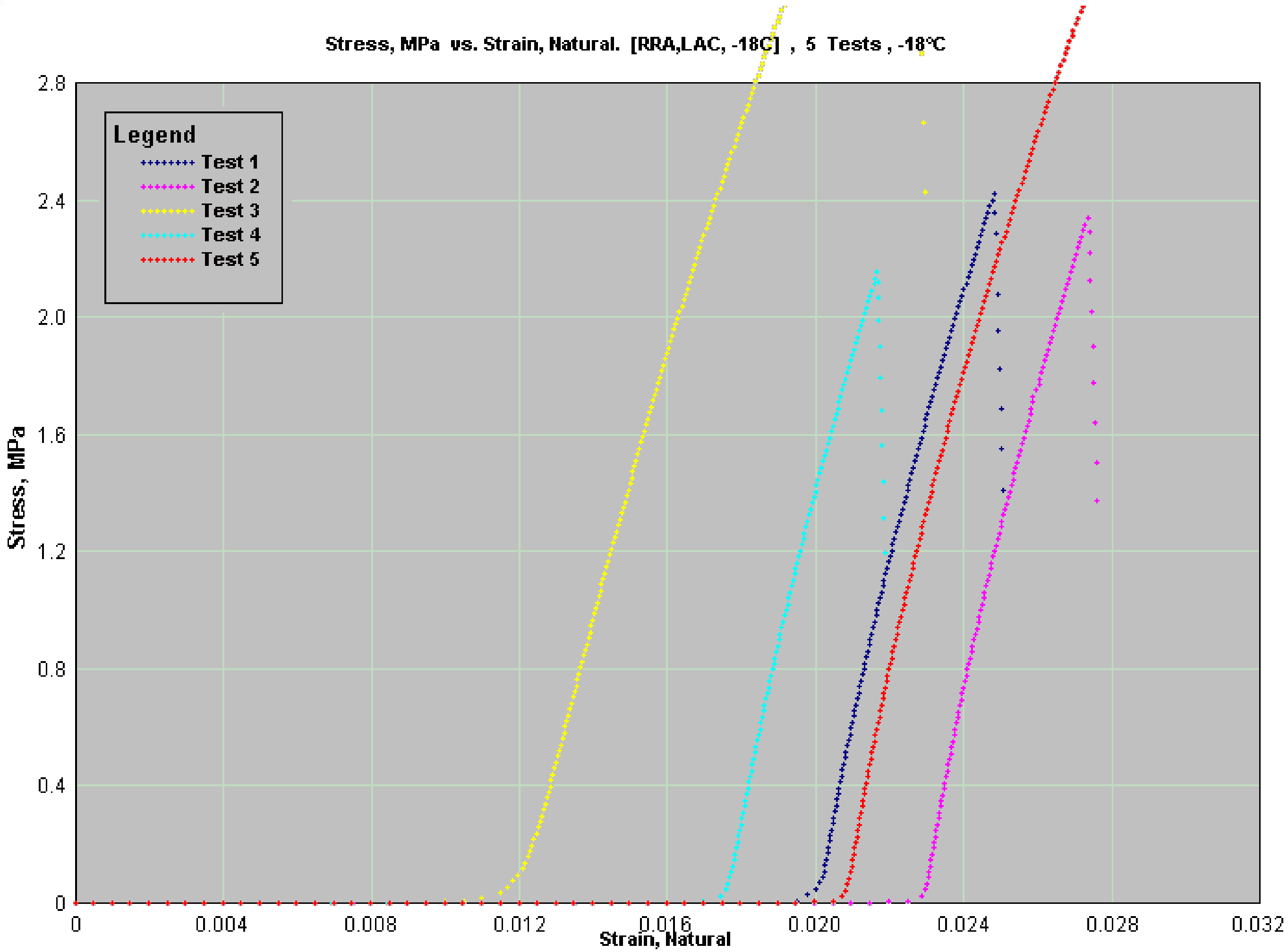
Start up errors – stress vs. strain



Start up errors – strain vs. time



Start up errors – non-zero corrections



Definition of binder stiffness, E(t)

- Binder stiffness estimated from fitting model to DTT data

$$S(\xi) = S_{glassy}[1 + (\xi/\lambda)^{\beta}]^{-\kappa/\beta}$$

S_{glassy}, λ, β and κ are fitted.

- Model then used to obtain binder stiffness at time associated with failure

Adjustments to start up

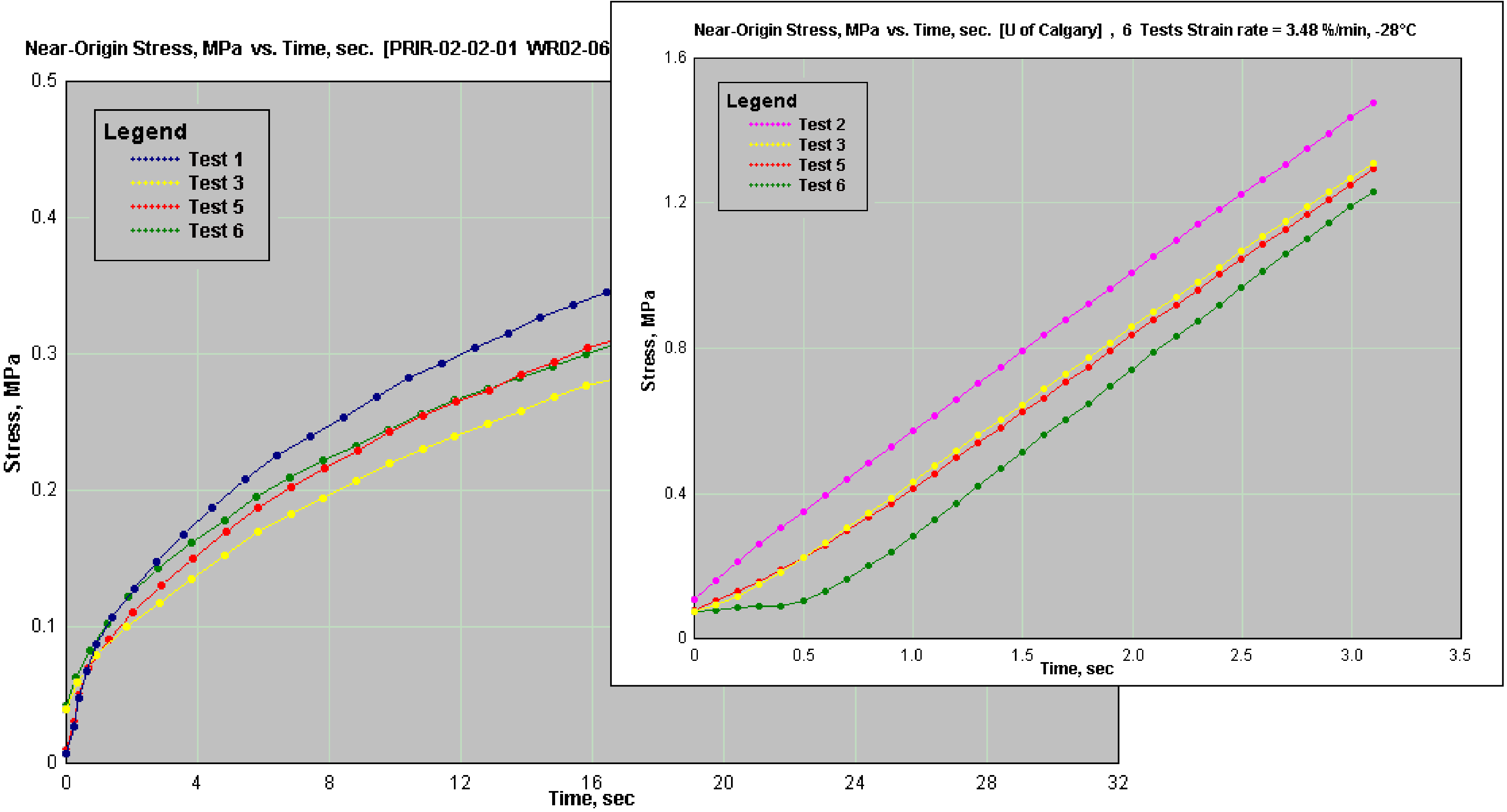
The derived form of CAM equation (with usual three parameters, say A, B, C) is as follows:

$$\sigma(t) = 3000 \times t.\dot{\varepsilon}\left[\left(1+\left(\frac{t}{A}\right)^{B}\right)^{\left(\frac{-C}{B}\right)}\right]$$

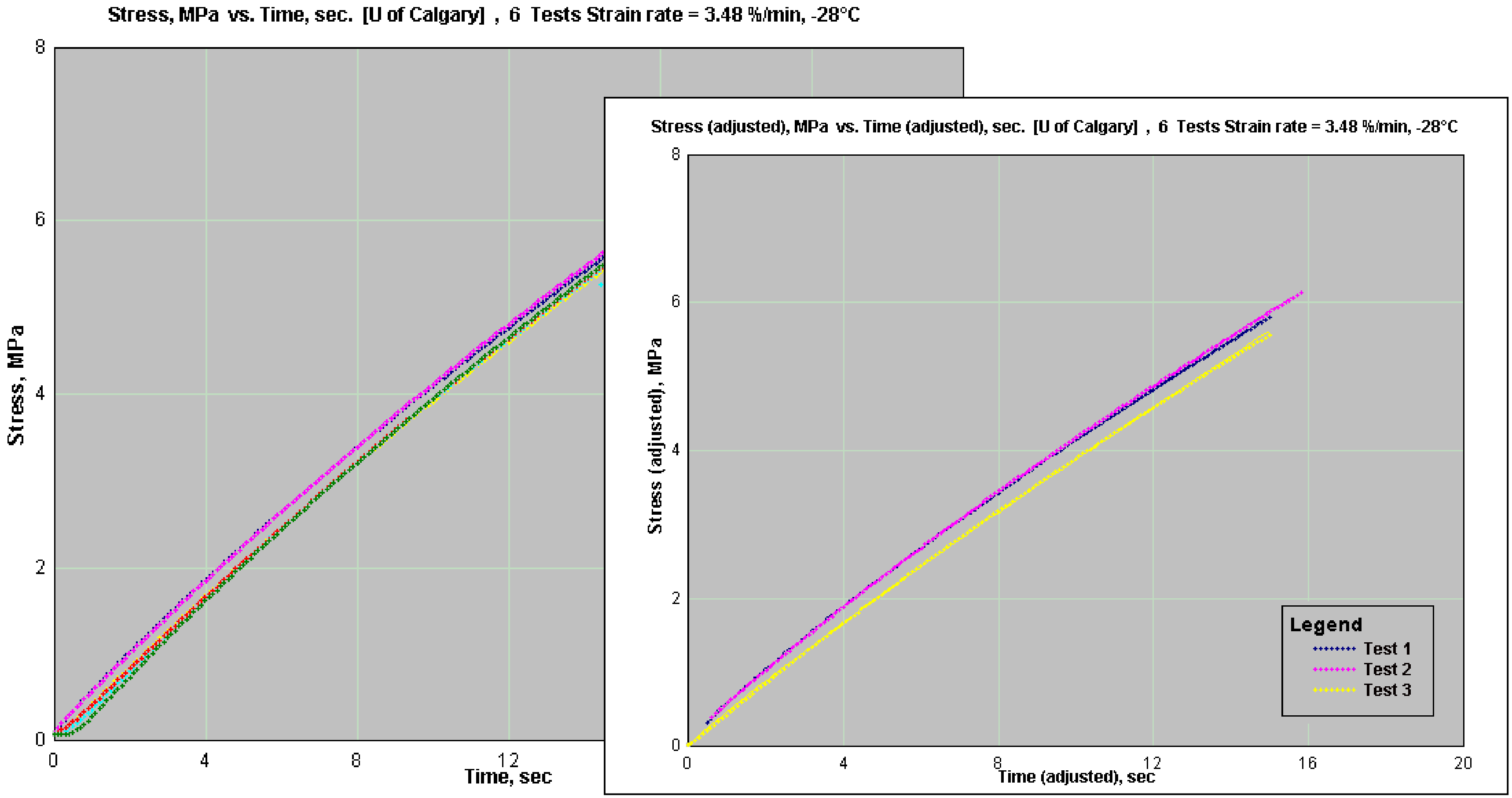
Two additional unknowns D, E must now be introduced so that this equation can be applied to the actual raw data that doesn’t pass through the origin.

Used within Linear Visco-elastic limits

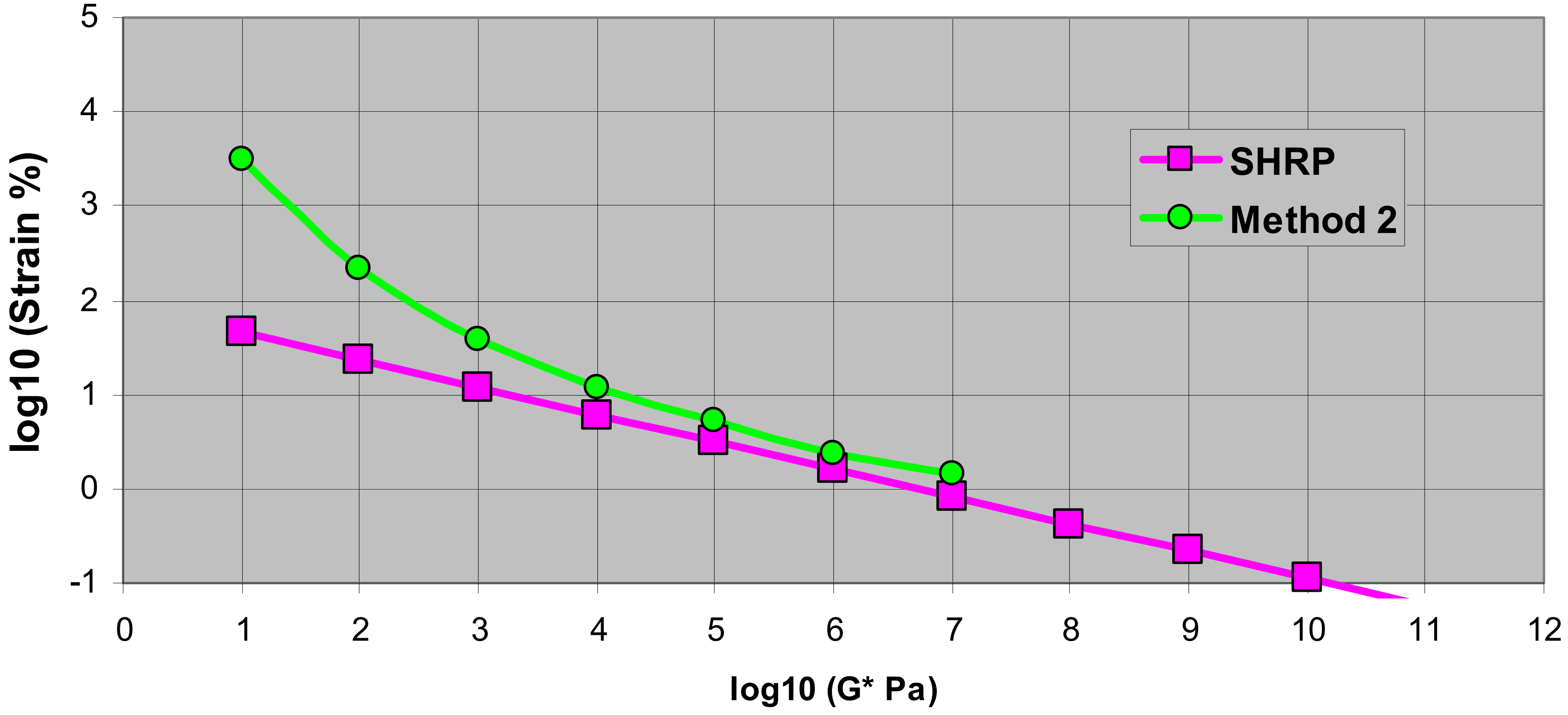
Examples of zero adjustments



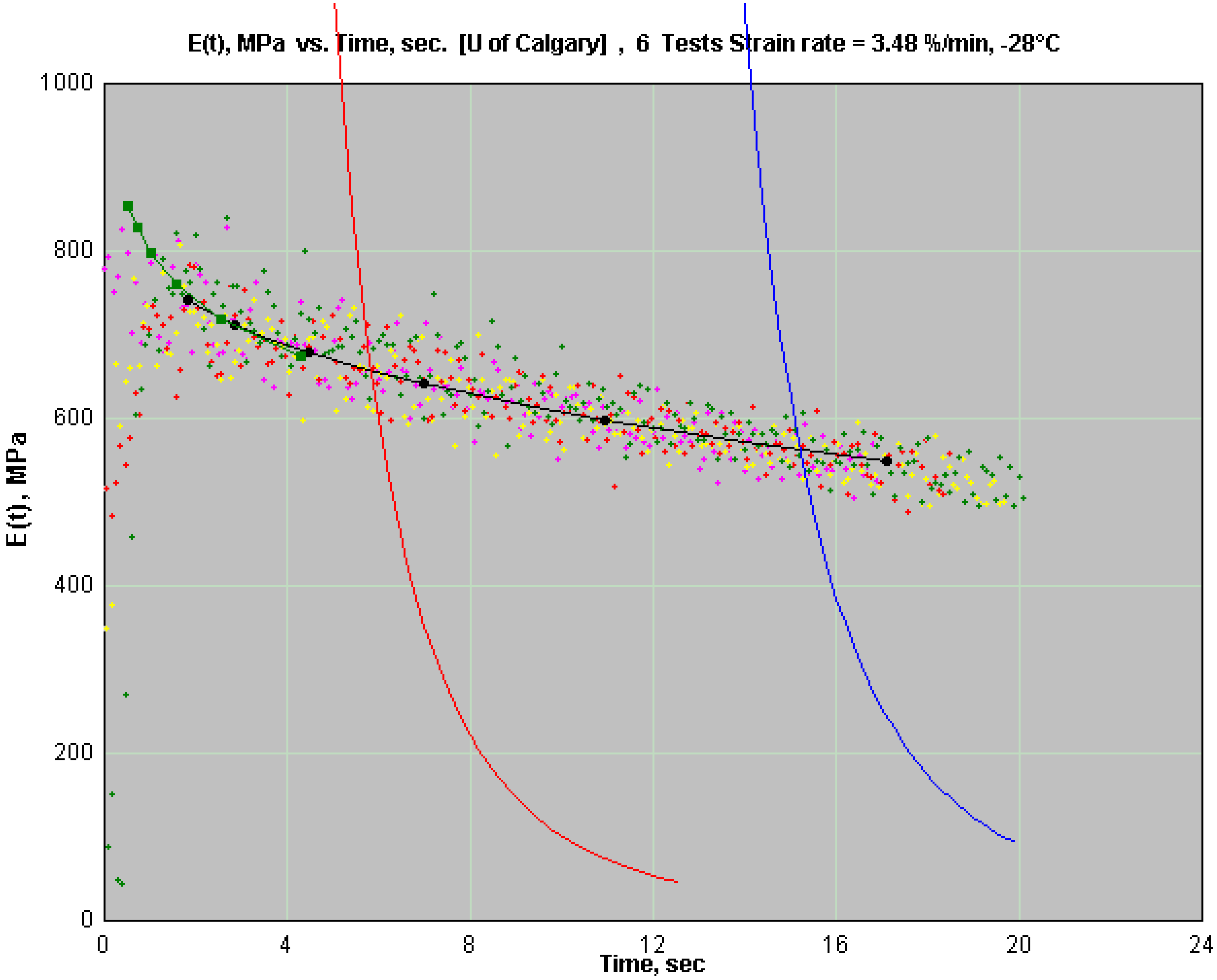
Stress adjustment for high temperature (-28 C) test, conventional asphalt



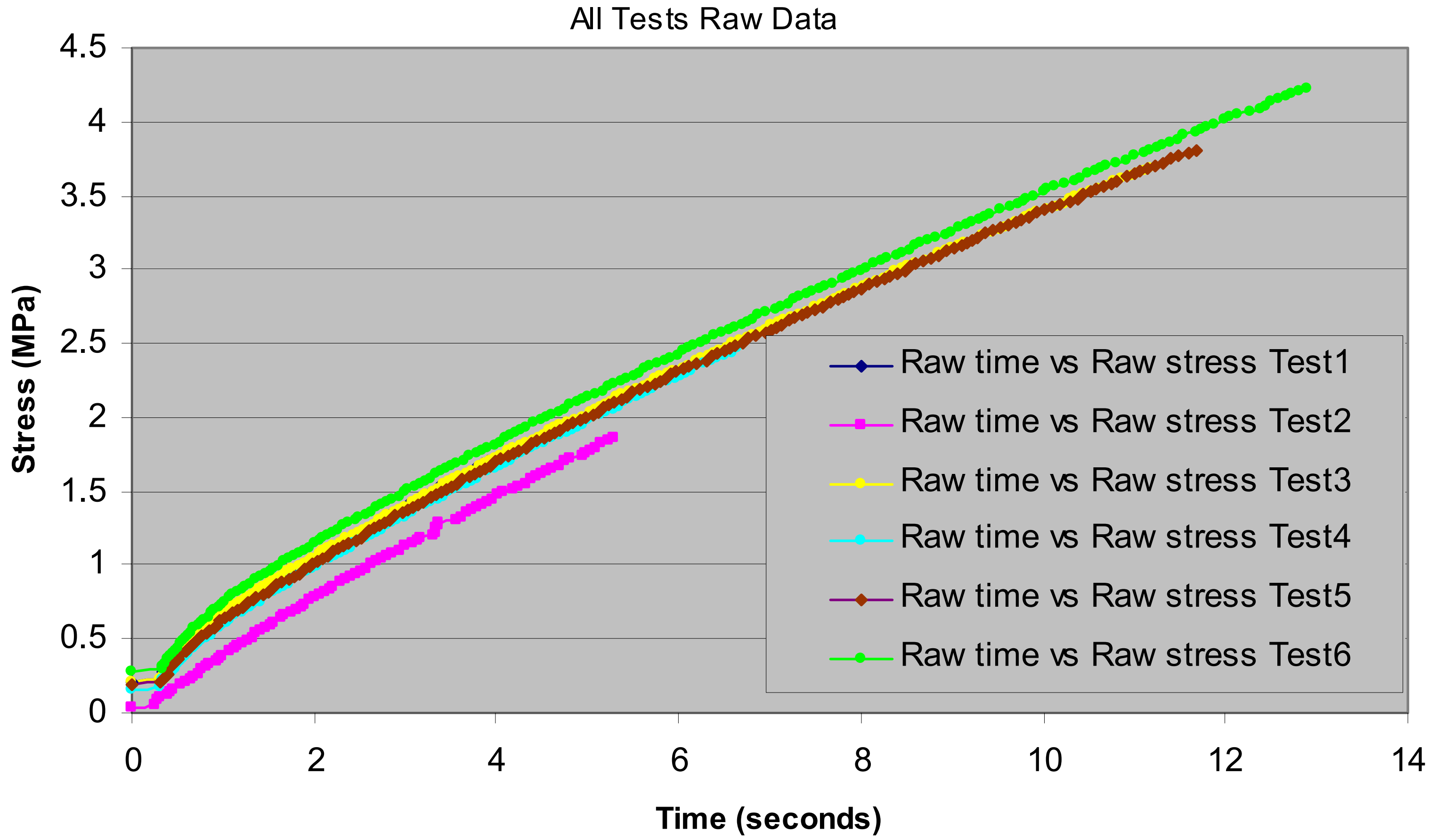
Linear visco-elastic limit



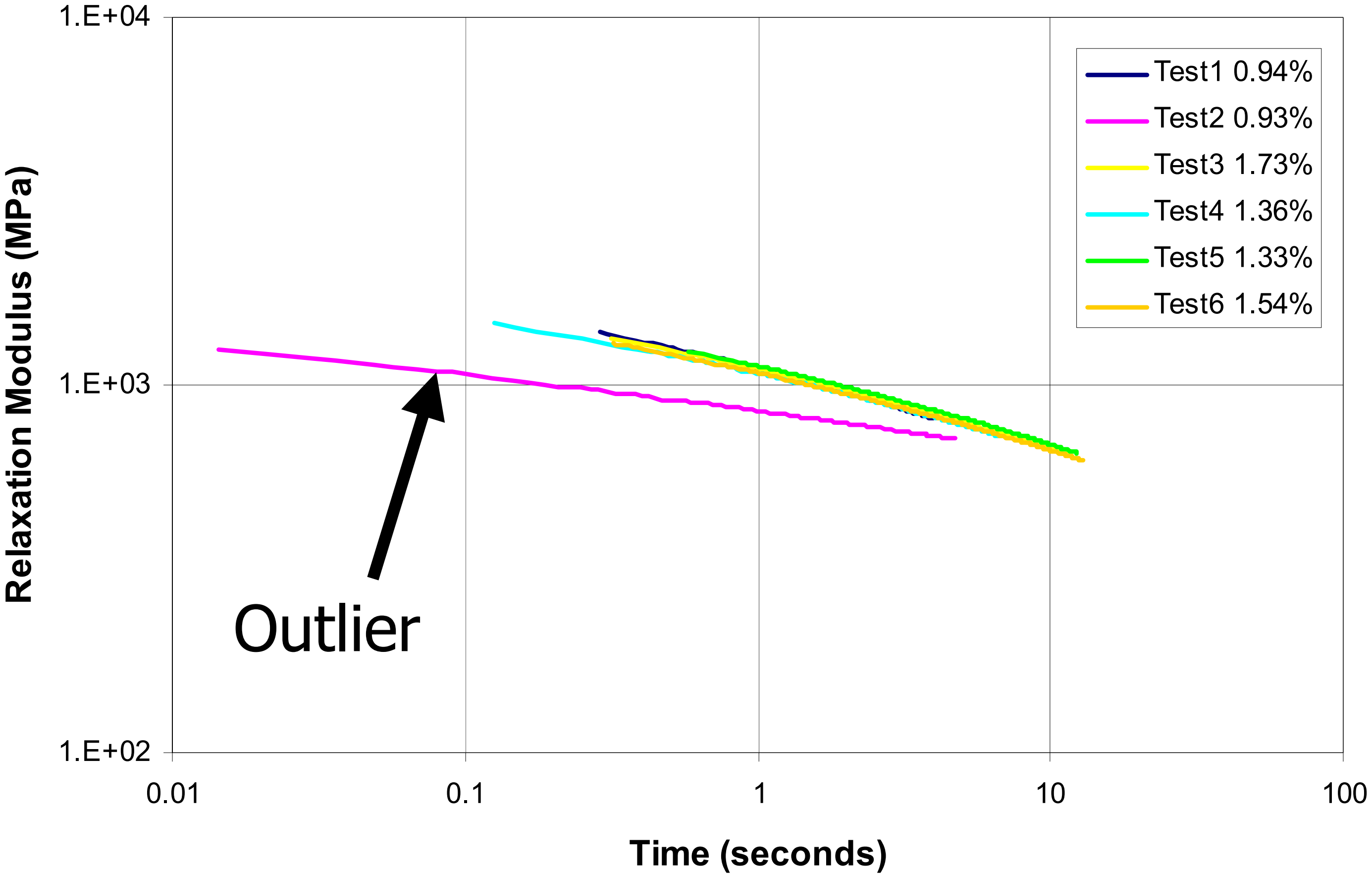
Application of VE limit to isotherm construction



Typical data set

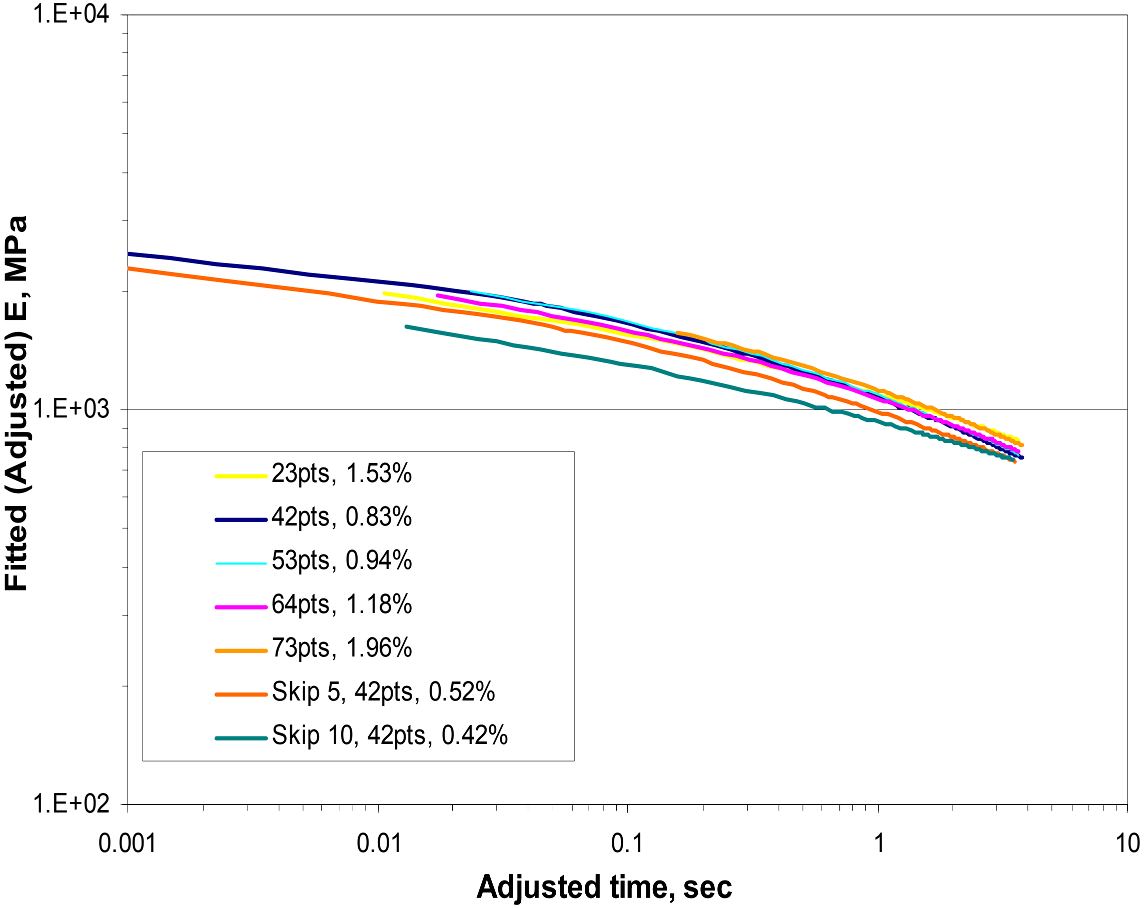


Identification of outlier using E(t) plot

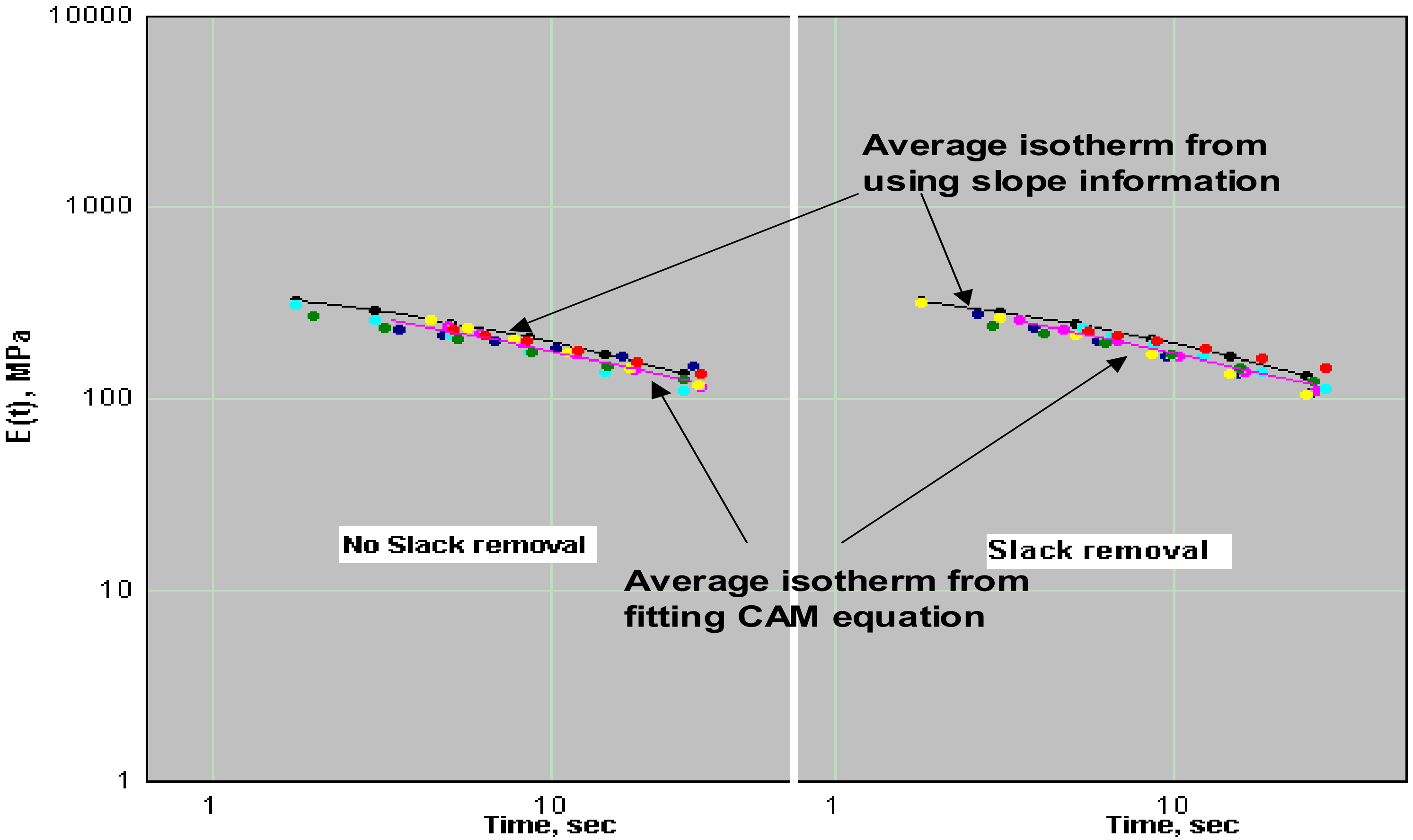


Effect of data analysis scheme

- Effect of different analysis scheme
- Removal of start-up data not useful in improving reliability of isotherm



Isotherms with and without adjustment



Average isotherm from using slope information

Average isotherm from fitting CAM equation

Analysis of Calgary Binders

Binders evaluated

- The binders used in the analysis had numerical references of 1293, 1719, 1730 and 1733
- Included highly modified and conventional binders
- Binder test data from the University of Calgary was analyzed on a “blind” basis.

DTT test results for 4 binders

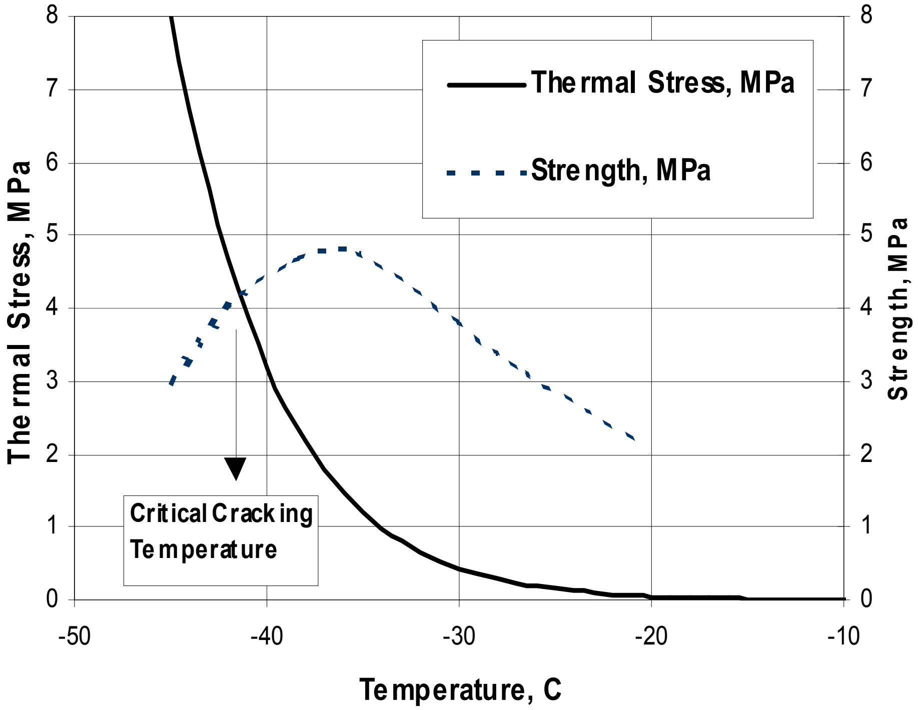
Binder Reference	Temperature (C)	Mean Stress at Break (MPa)	Mean Strain at Break (%)	Mean Energy at Break (mJ)
1293	-18	5.328	1.395	44.36
	-24	6.306	.7812	27.24
1719	-18	3.879	2.784	71.92
	-24	4.635	1.001	27.47
1730	-24	6.580	3.454	164.3
	-30	7.156	1.263	54.44
1733	-30	7.734	1.620	72.88
	-34	8.125	1.076	48.18

Critical Cracking Temperatures (T_{crit}) of 4 Asphalt Binders using MP1 Specification

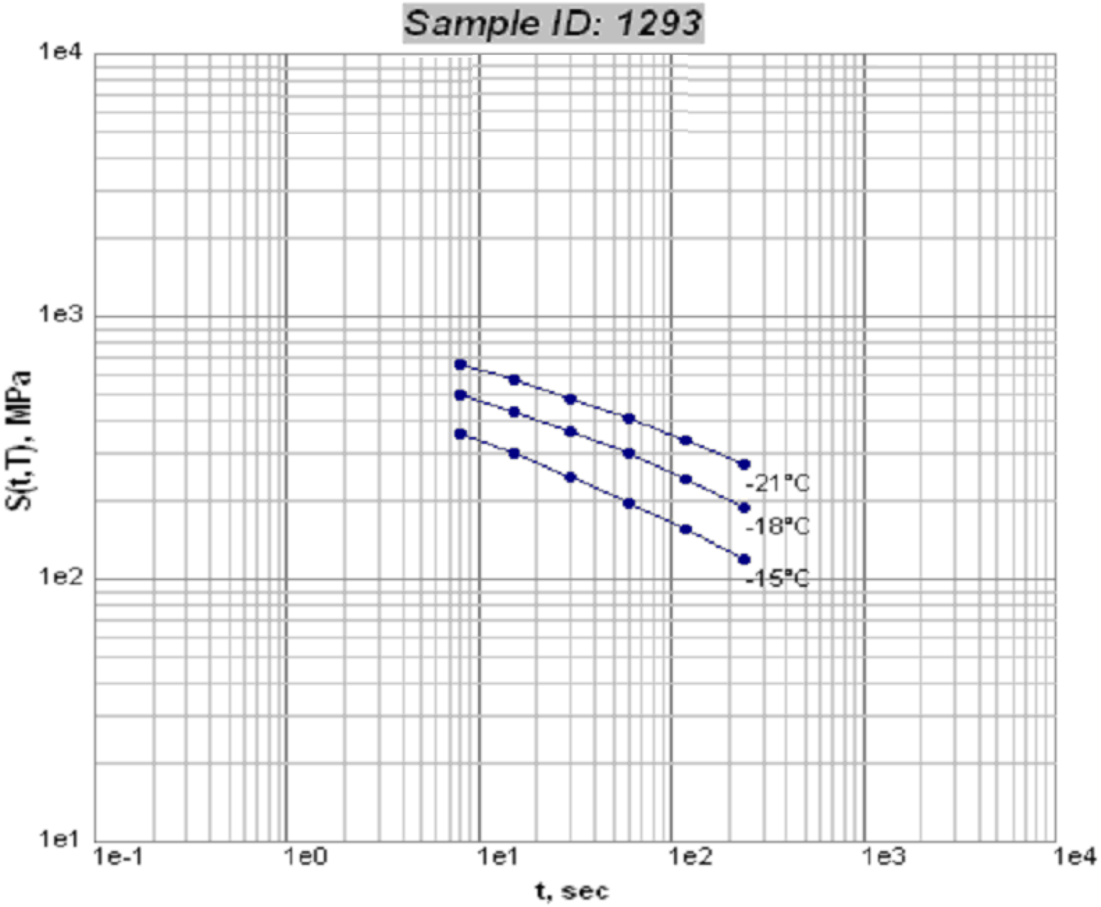
Binder Reference	T_{crit} (C)	Controlling parameter (S or m)
1293	-28.3	m
1719	-33.7	both equal
1730	-36.3	m
1733	-38.4	S

MP1a Calculation

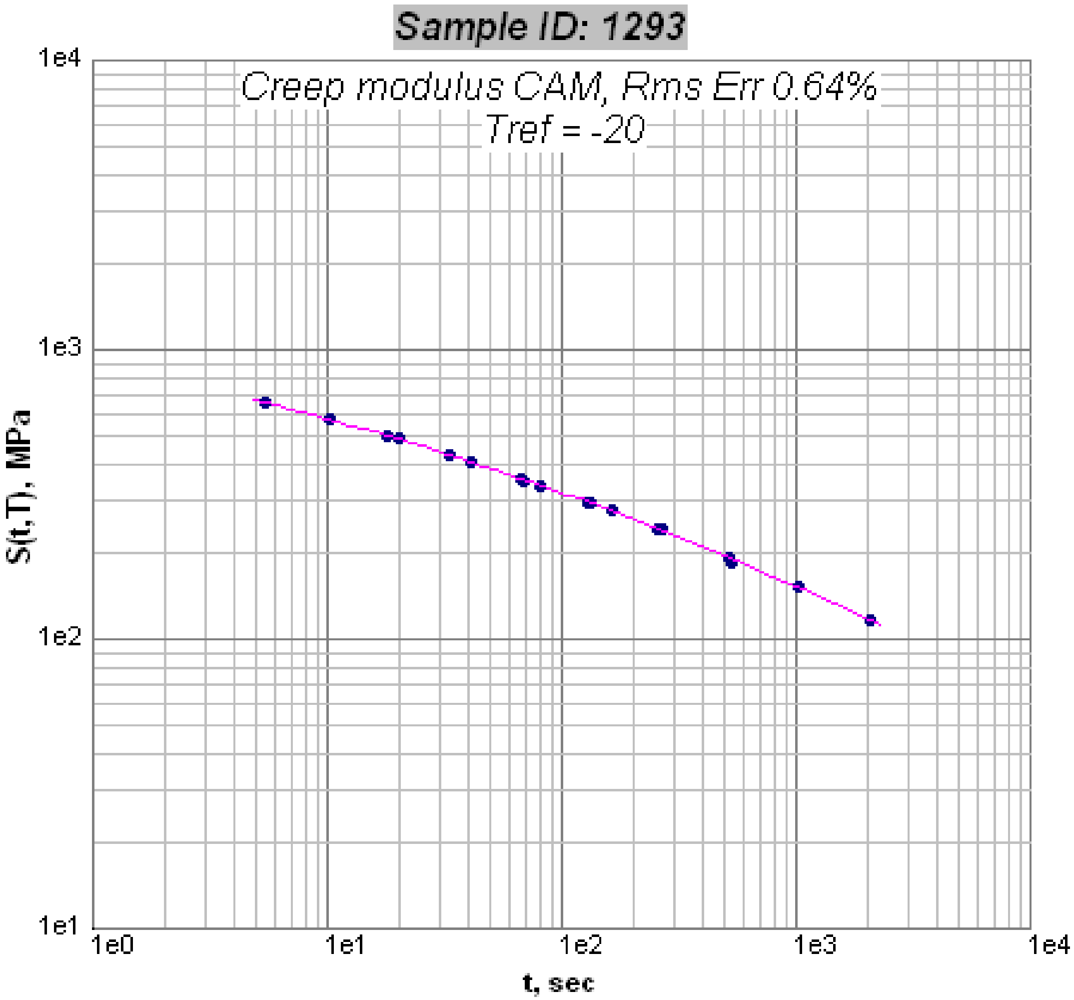
- Thermal stress derived from BBR
- In this work thermal stress was calculated from BBR and DDT



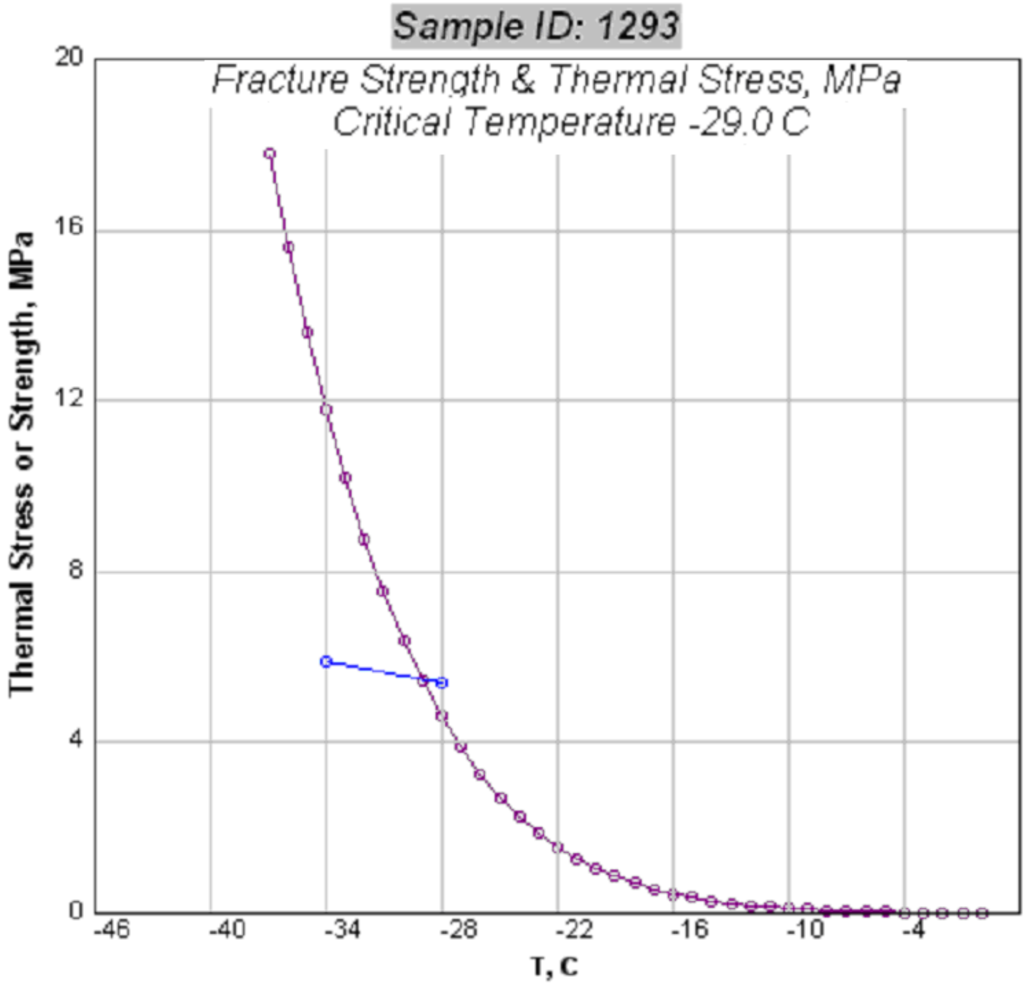
BBR isotherms



BBR master curve



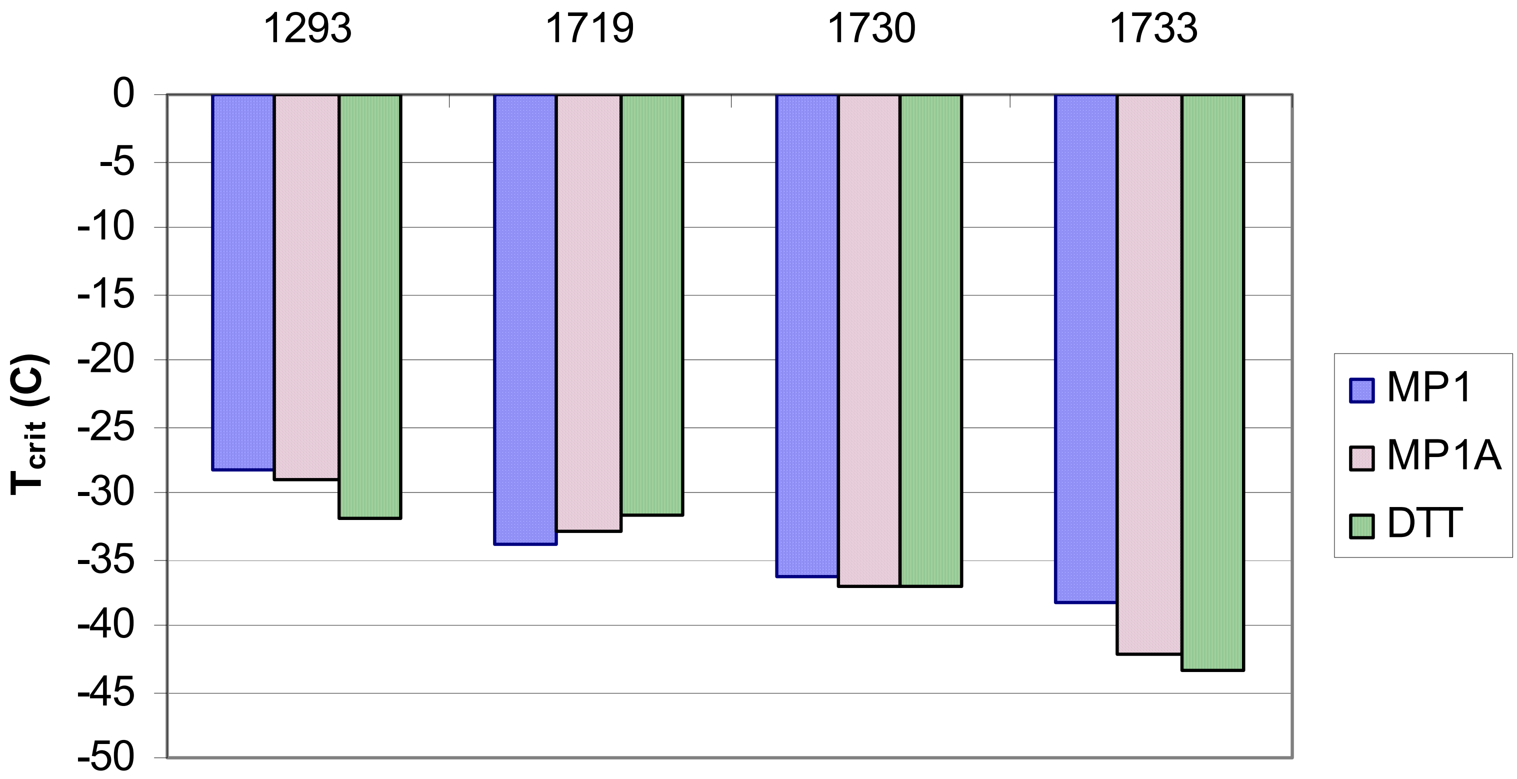
MP1a – T_{crit} calc



T_{crit} results

Binder	T_{crit}, MP1	T_{crit}, MP1A	T_{crit}, DTT
1293	-28.4	-29.0	-31.9
1719	-33.8	-32.9	-31.7
1730	-36.3	-37.0	-37.1
1733	-38.4	-42.3	-43.3

T_{crit} from different methods



Summary

- Data gives good prediction of Tcrit from just DTT
- Study needs extension with more materials
- The results show the DTT-only method calculates the critical cracking temperature within 2.9°C of the current MP1A calculated values with the results being on average 0.7°C higher.

Thank you