Use of the Zero Shear Viscosity as a Parameter for the High Temperature Binder Specification Parameter

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Objectives

- Determine procedure for estimation of ZSV
- Determine correlation with pavement properties
- Investigate how ZSV would be used in specification

Outline

- Definition and determination
  - Relaxation spectra
  - Asymptotic method
  - Errors
- Validation
- Grading of binders
- Summary

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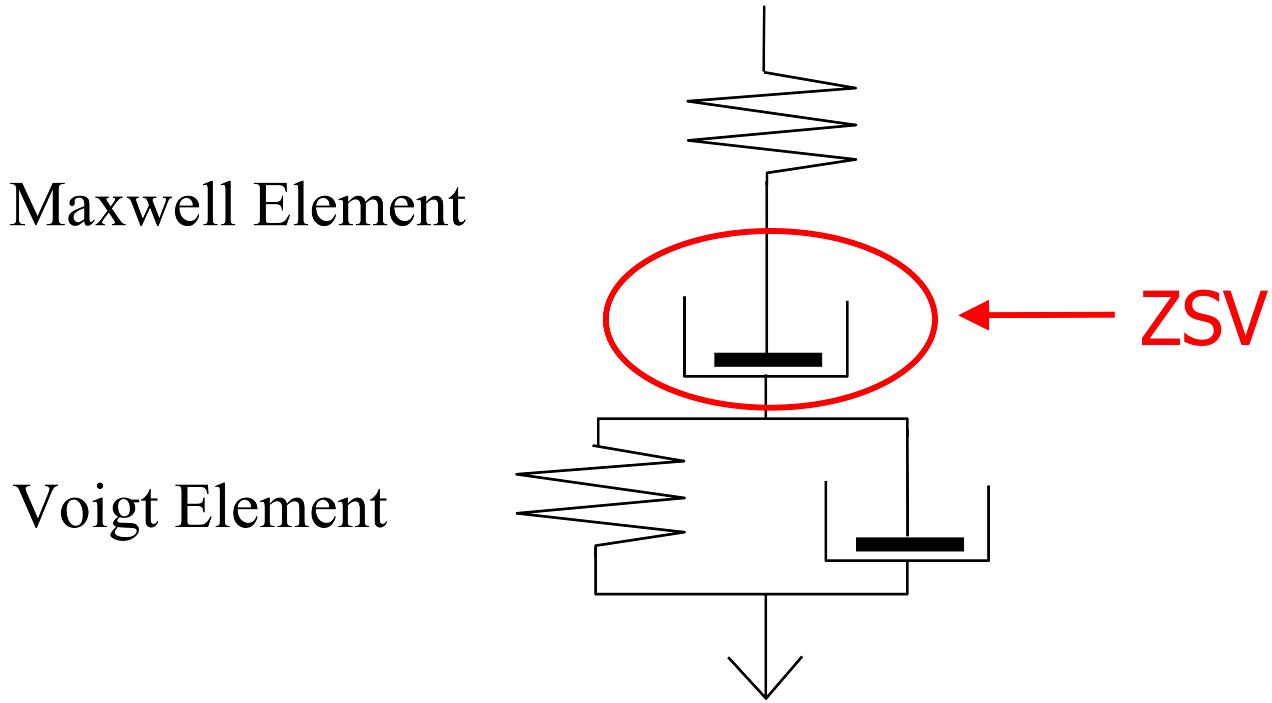
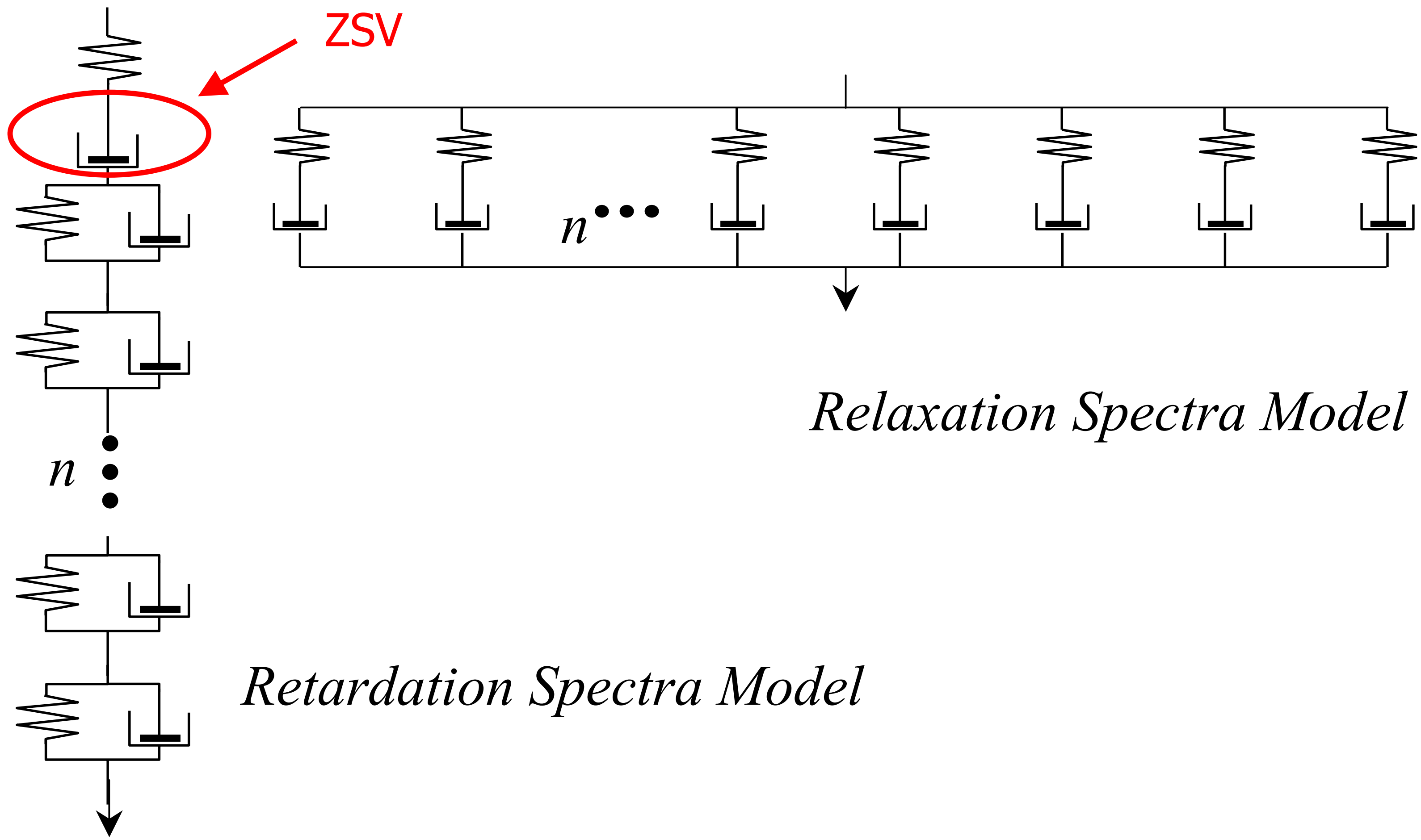
Simple visco-elastic model



Basic Visco-Elastic Model - The Burgers' Model

Spectra determinations



Spectra determinations

- Relaxation spectra fitted

$$G''(\omega) = \sum_{i=1}^{\infty} \frac{G_i \omega \tau_i}{1 + (\omega \tau_i)^2}$$

$$G'(\omega) = G_0 + \sum_{i=1}^{\infty} \frac{G_i (\omega \tau_i)^2}{1 + (\omega \tau_i)^2}$$

Determination of ZSV from Asymptote

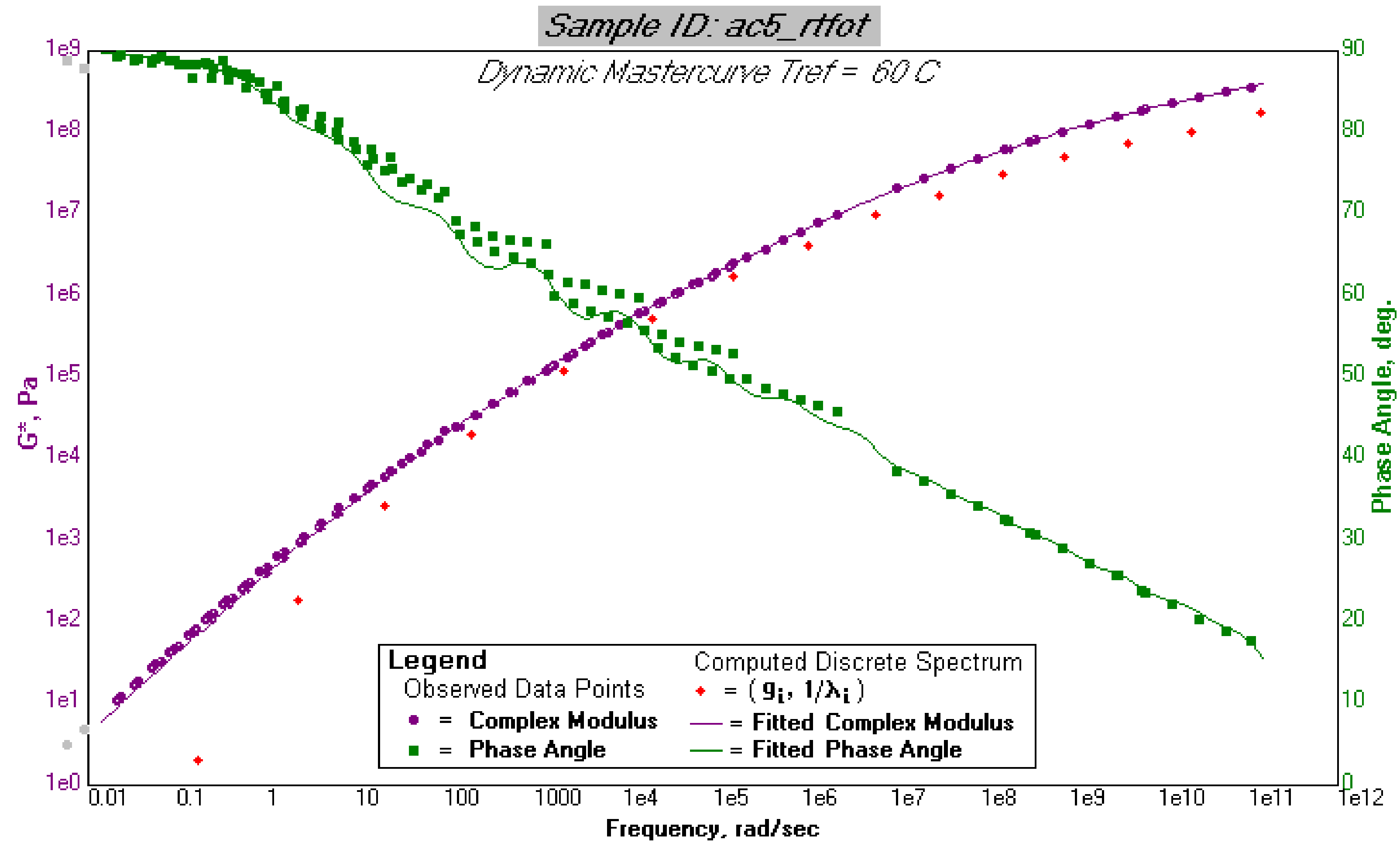
- ZSV or steady state viscosity defined as

$$_0 = \lim_{\omega \to 0} \left(\frac{G''}{\omega} \right) = \lim_{\omega \to 0} (\eta')$$

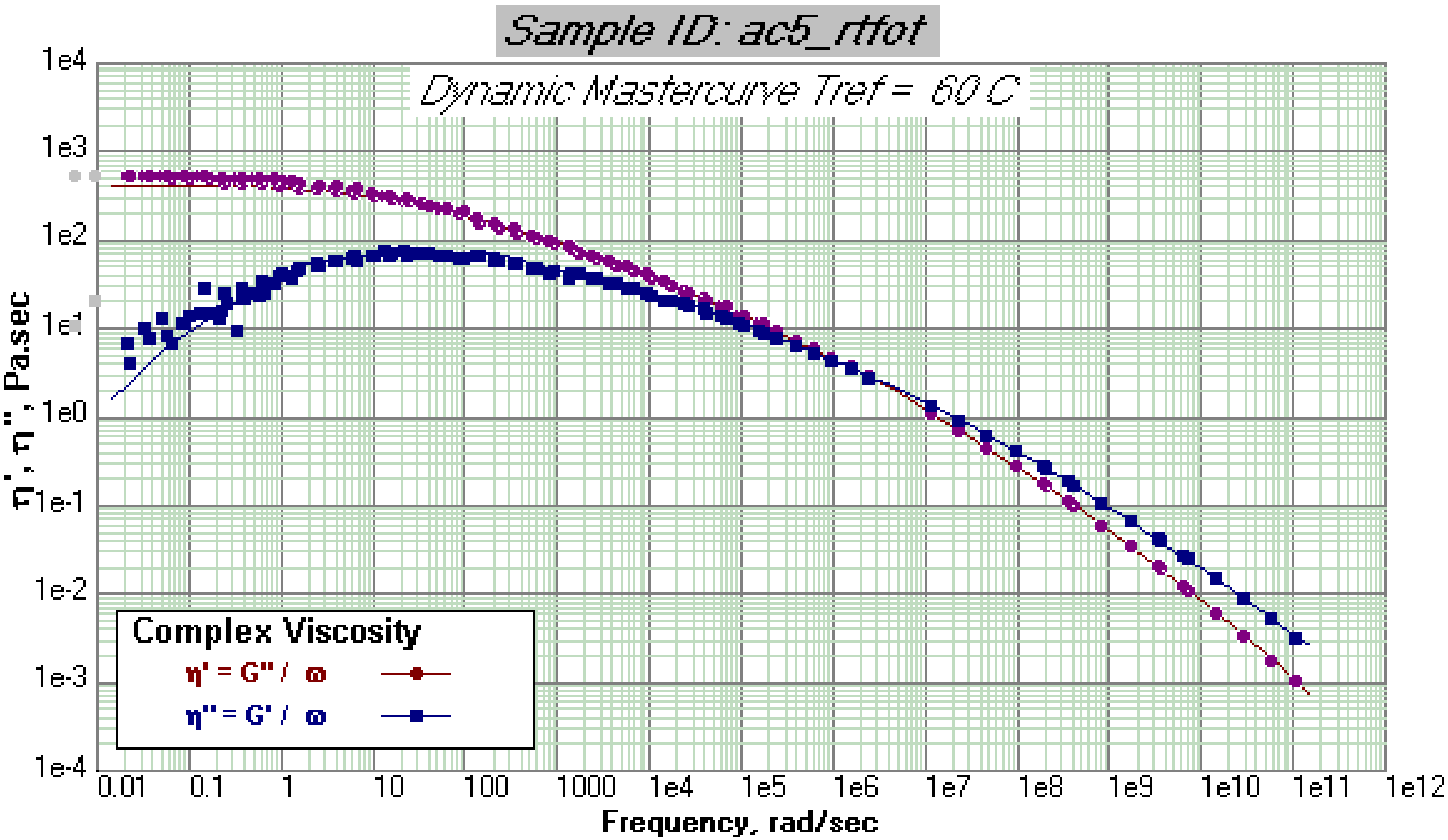
$$G'' = G^* \sin \delta$$

- At asymptotic behavior the ZSV is strongly controlled by G*

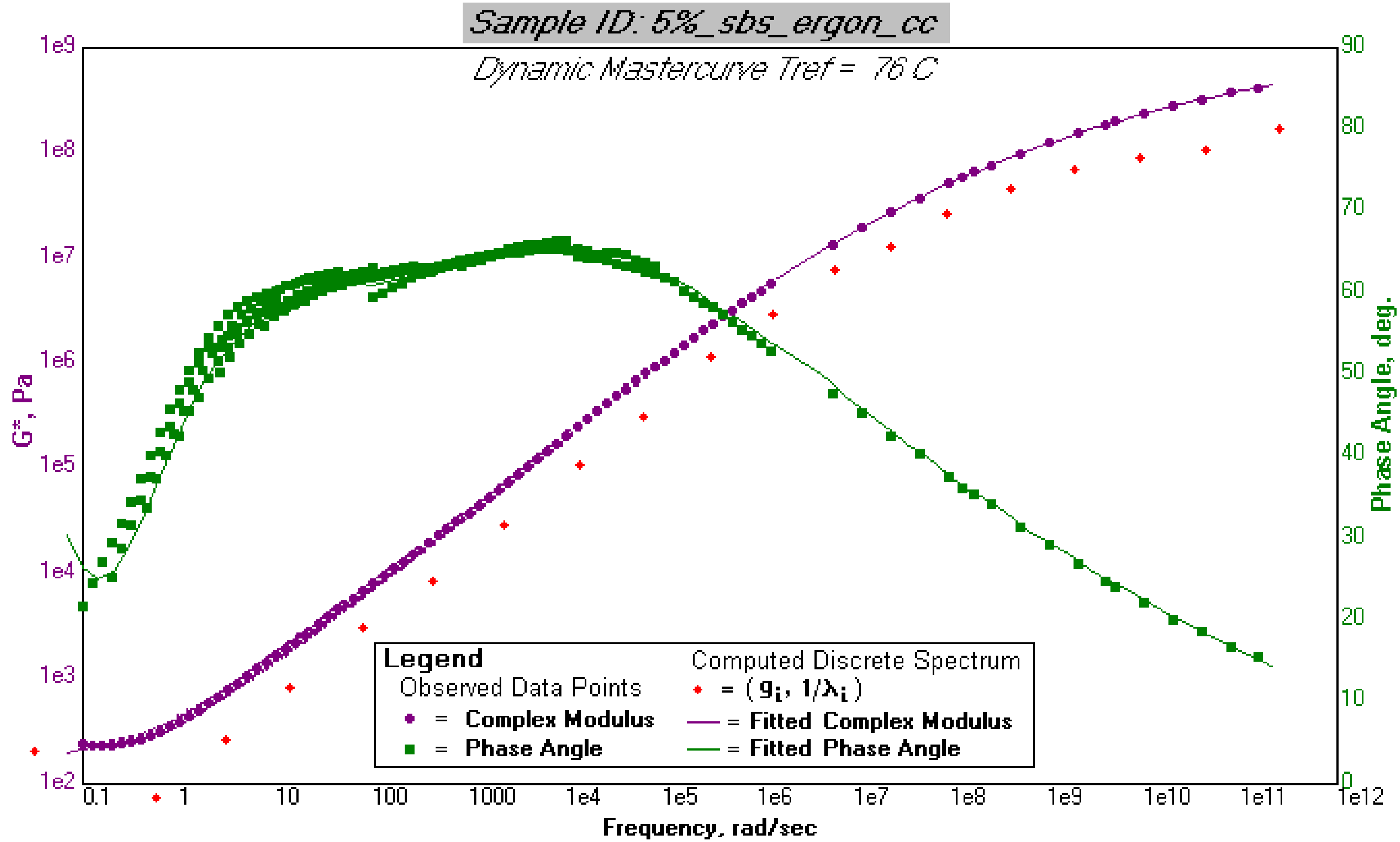
E* and δ – ALF AC-5



Dynamic viscosity – ALF AC-5

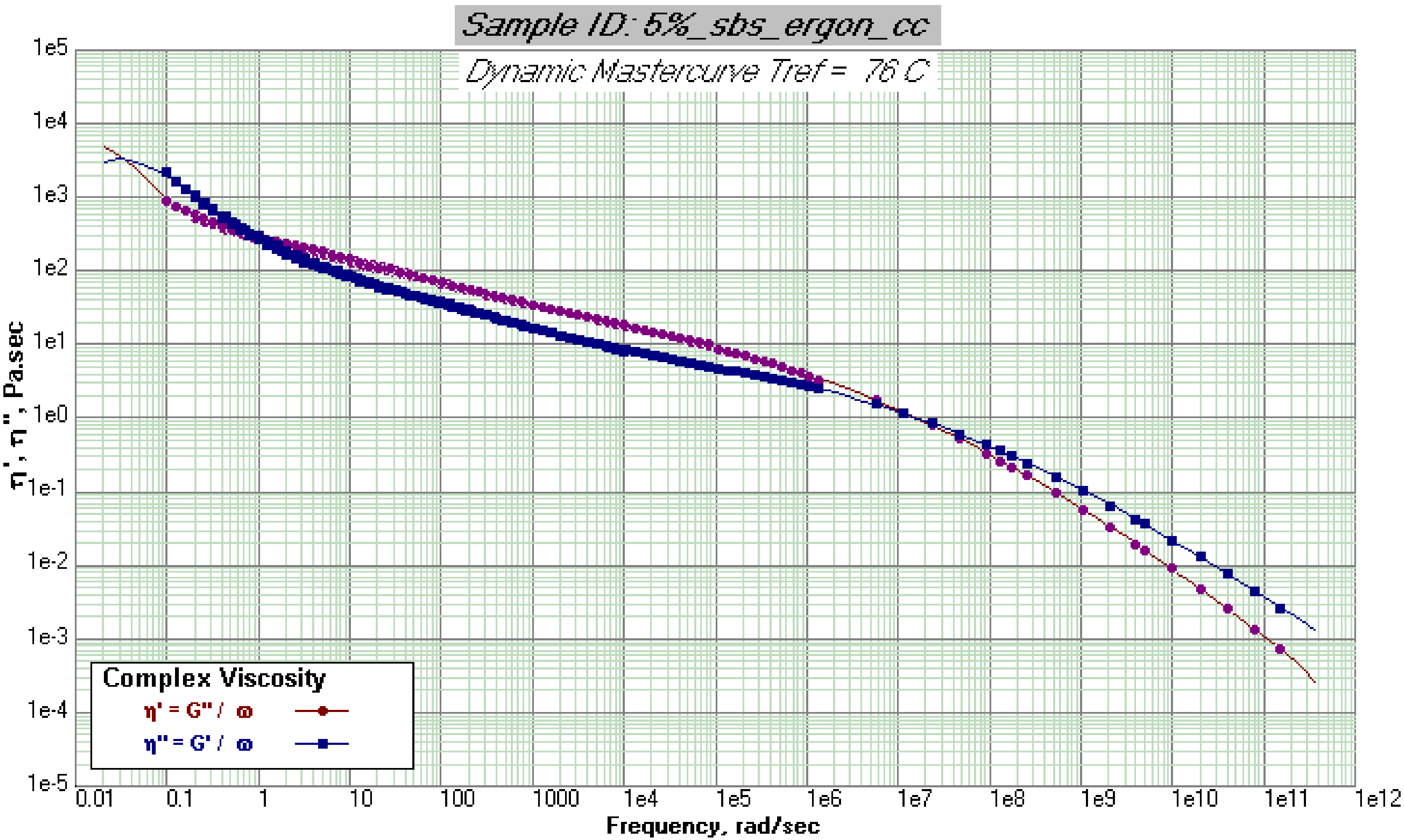


G* and δ – 5% SBS

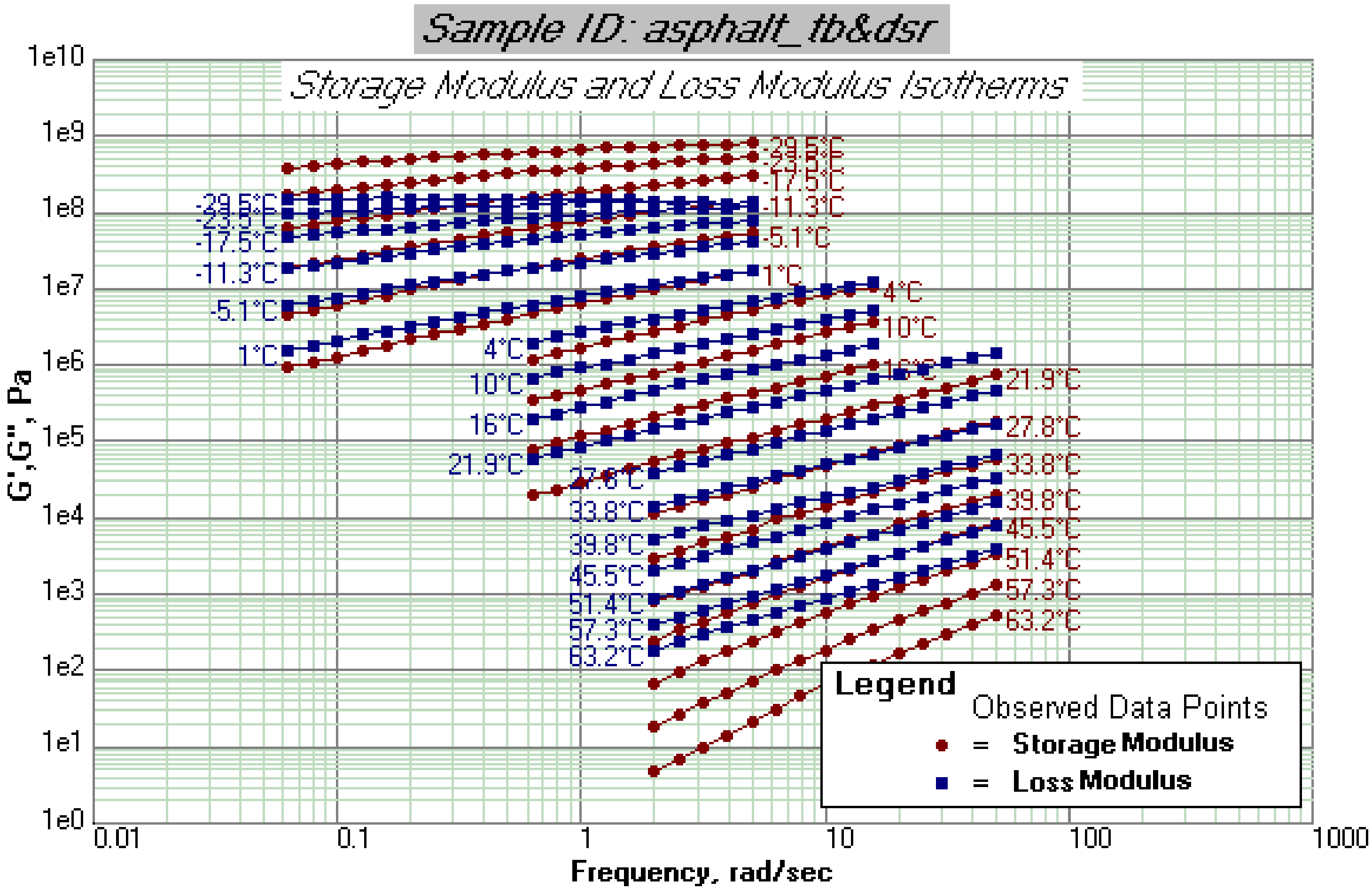


Sample ID: 5%_sbs_ergon_cc
Dynamic Mastercurve Tref = 76 C
G*, Pa
Phase Angle, deg.
Frequency, rad/sec
1e9
1e8
1e7
1e6
1e5
1e4
1e3
1e2
90
80
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
1e4
1e5
1e6
1e7
1e8
1e9
1e10
1e11
1e12
Legend
Observed Data Points
= Complex Modulus
= Phase Angle
Computed Discrete Spectrum
= (g_i, $1/\lambda_i$)
= Fitted Complex Modulus
= Fitted Phase Angle

Dynamic viscosity – 5% SBS



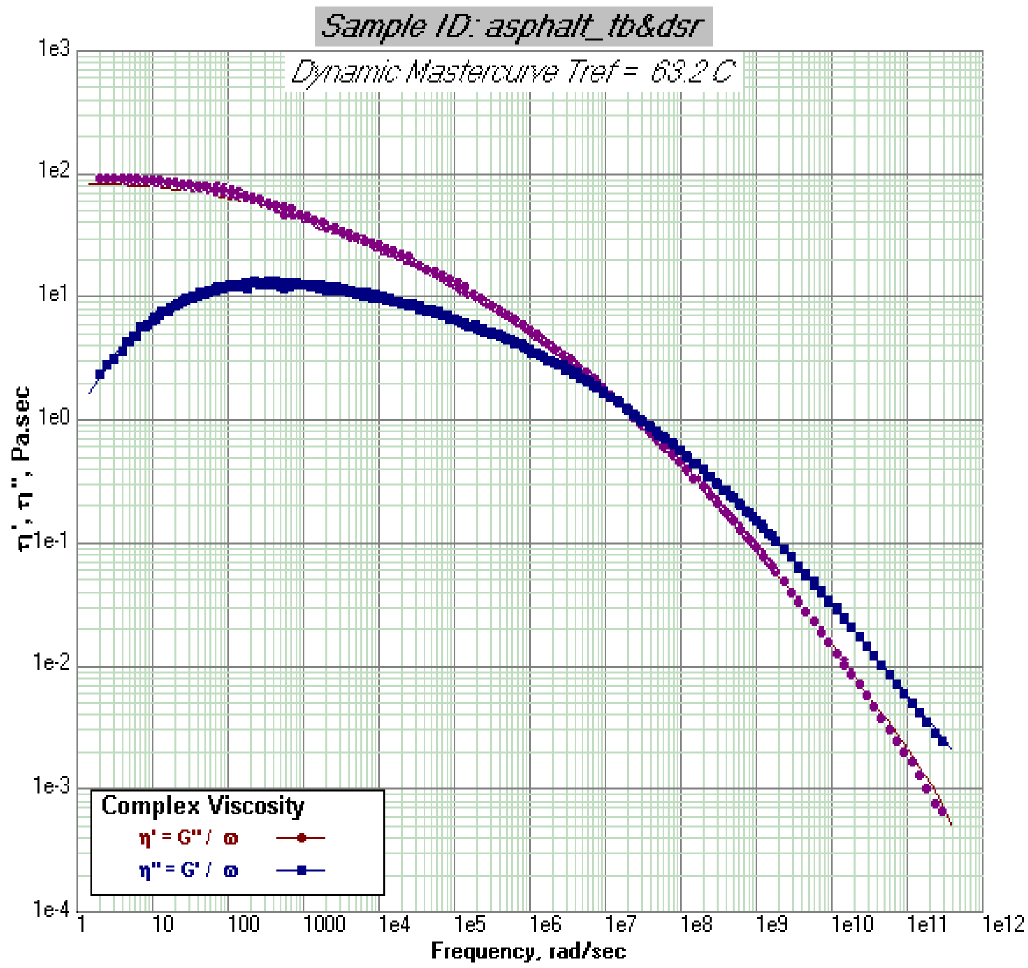
Isotherms



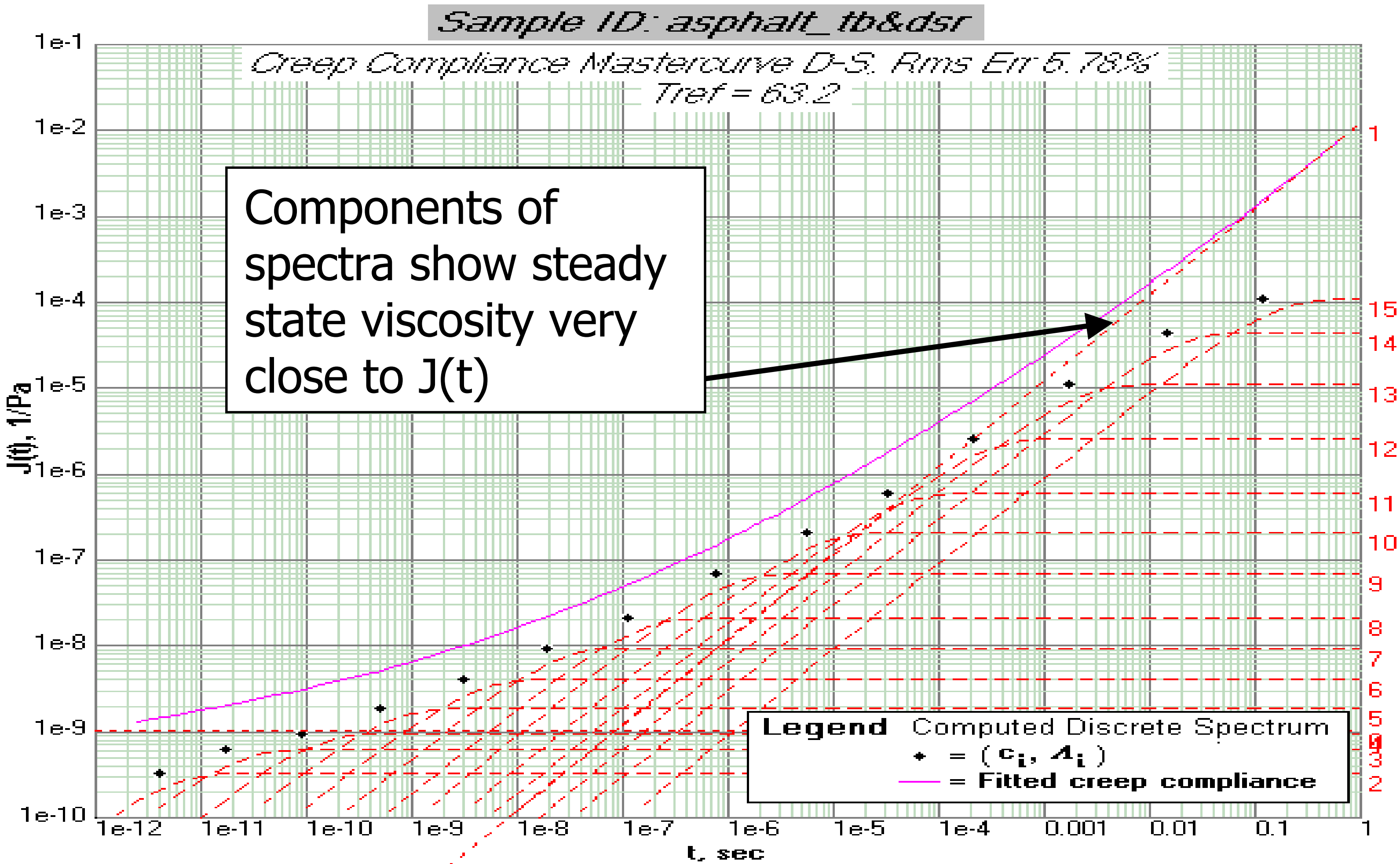
Sample ID: asphalt_tb&dsr
Storage Modulus and Loss Modulus Isotherms
G',G", Pa
Frequency, rad/sec
Legend
Observed Data Points
● = Storage Modulus
■ = Loss Modulus

Dynamic viscosities

- Standard binder used in RHEA for analysis
- Since we have an asymptote we will have a good assessment of ZSV

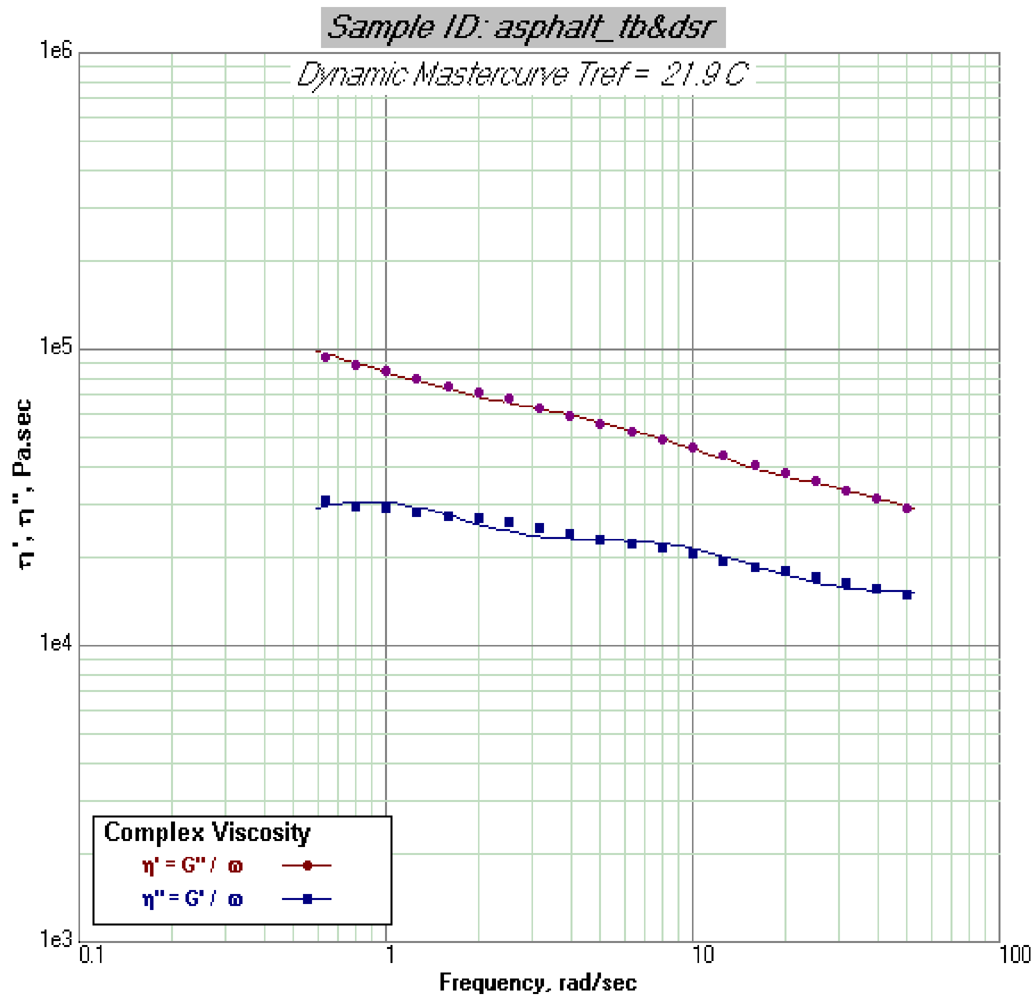


J(t) versus time



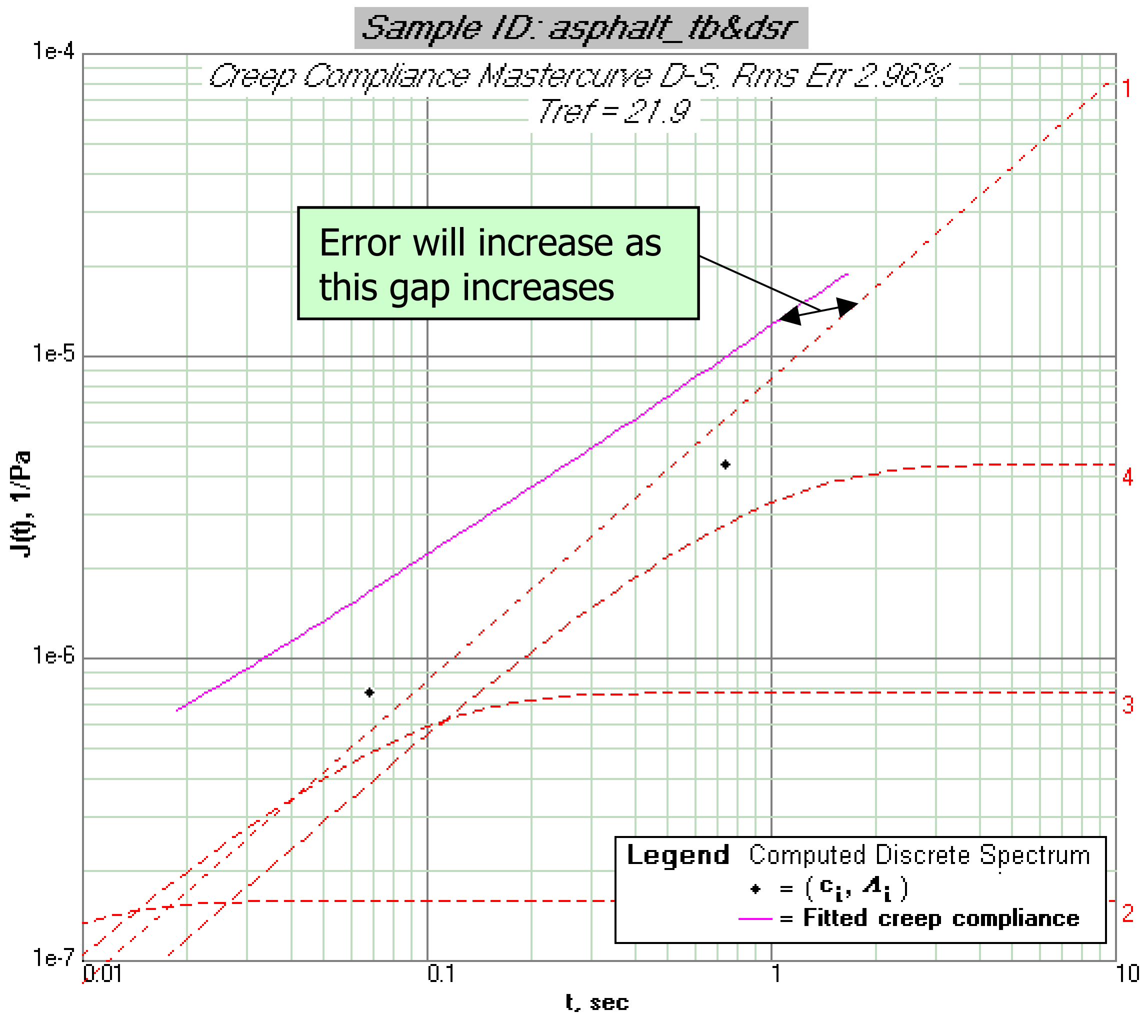
Dynamic viscosities, 21.9 C isotherm

- Standard binder used in RHEA for analysis
- Since we have **<u>no asymptote</u>** we will have a some error in assessment of ZSV



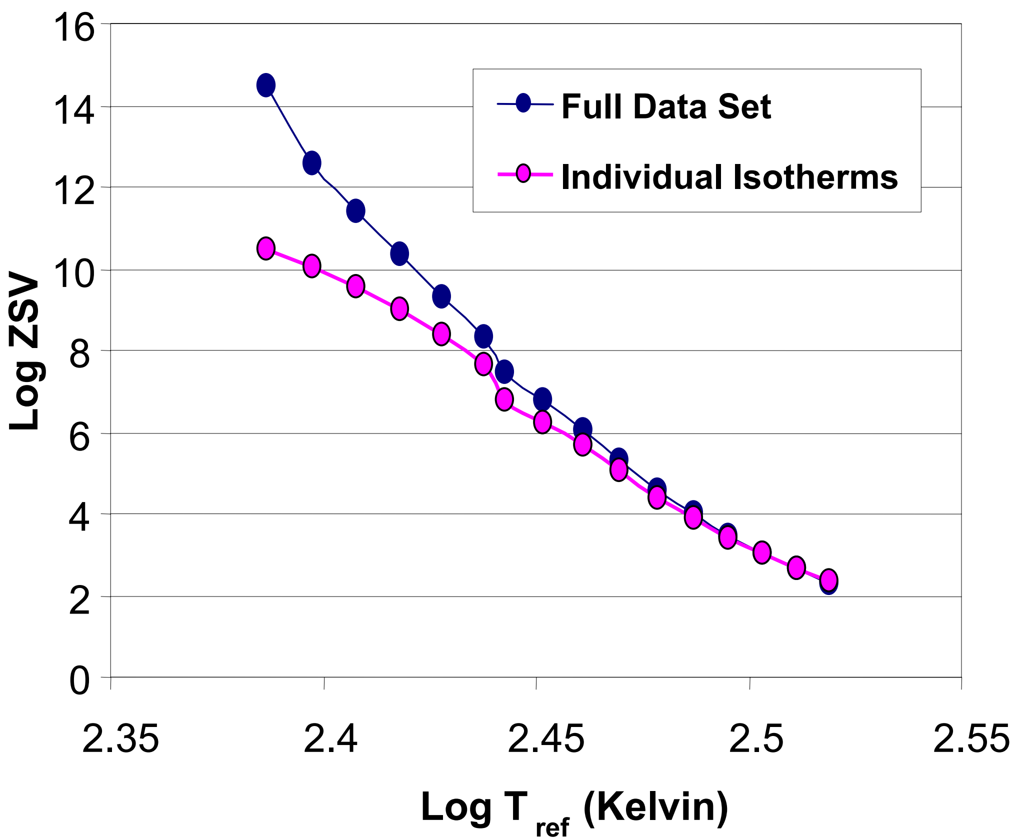
J(t), 21.9 C isotherm

- At the stiffer conditions the steady state viscosity behavior is further away from the measured conditions and consequently the estimation is more prone to error
- This is not rms error of fit



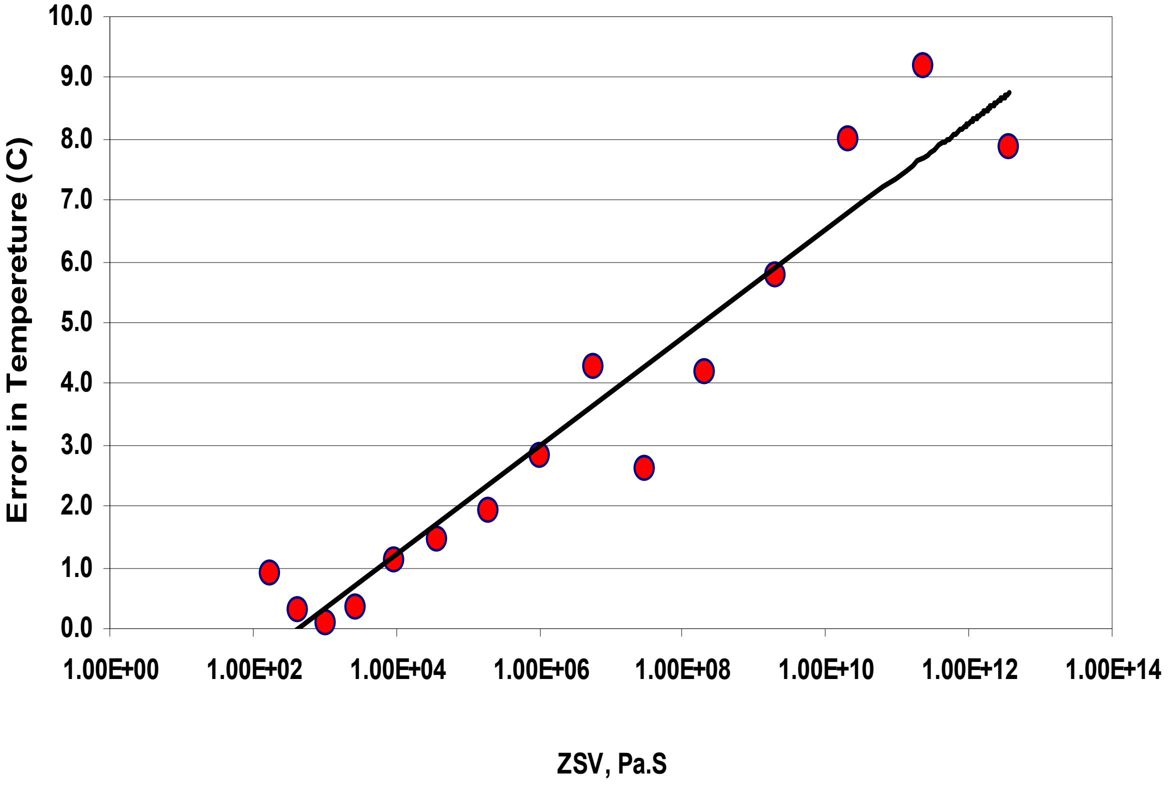
Error in determination of ZSV

- At each temperature the isotherm is used to determine ZSV
- At each temperature the full master curve is used
- The full master curve is anticipated to be accurate
- The error in ZSV reduces as the value of ZSV drops
- Critical value is around 10,000 Pa.s



Error in determination of T_{crit}

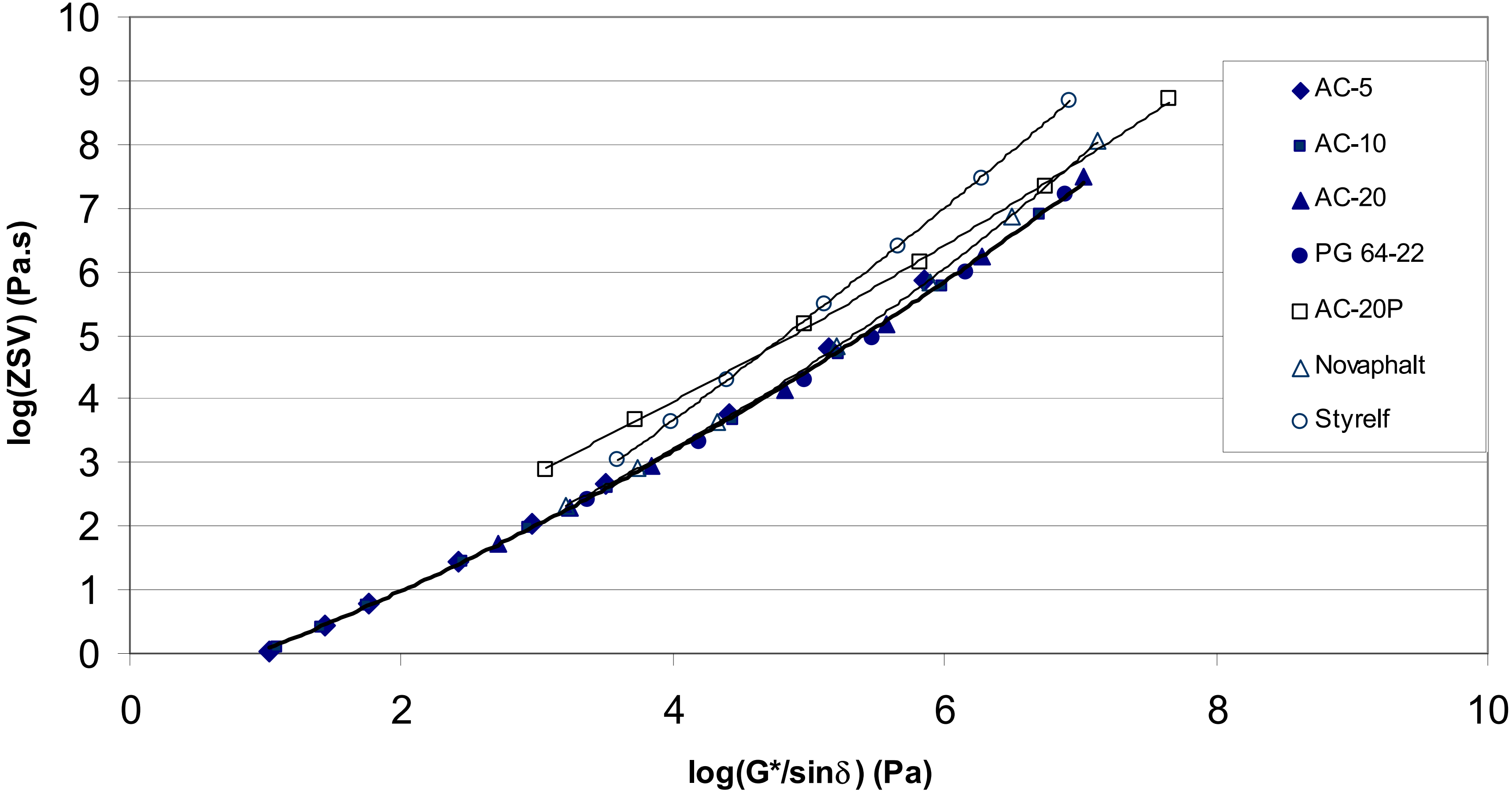
- Error in numerical value of ZSV translates into less than 1^{o}C if ZSV is less than 10,000 Pa.s



ZSV versus temperature

- For non-modified ZSV versus G*/sin δ forms/approximates single relationship
- This allows existing MP1 parameters to be obtained at equivalent conditions thus making use of original SHRP validation
- Polymer modified binders deviate from single relationship

ZSV versus G*/sin δ



ZSV values corresponding to G*/sinδ of 1.00 kPa and 2.2 kPa

G*/sinδ (kPa)	ZSV (Pa-sec.)
1.0	104.8
2.2	252.7

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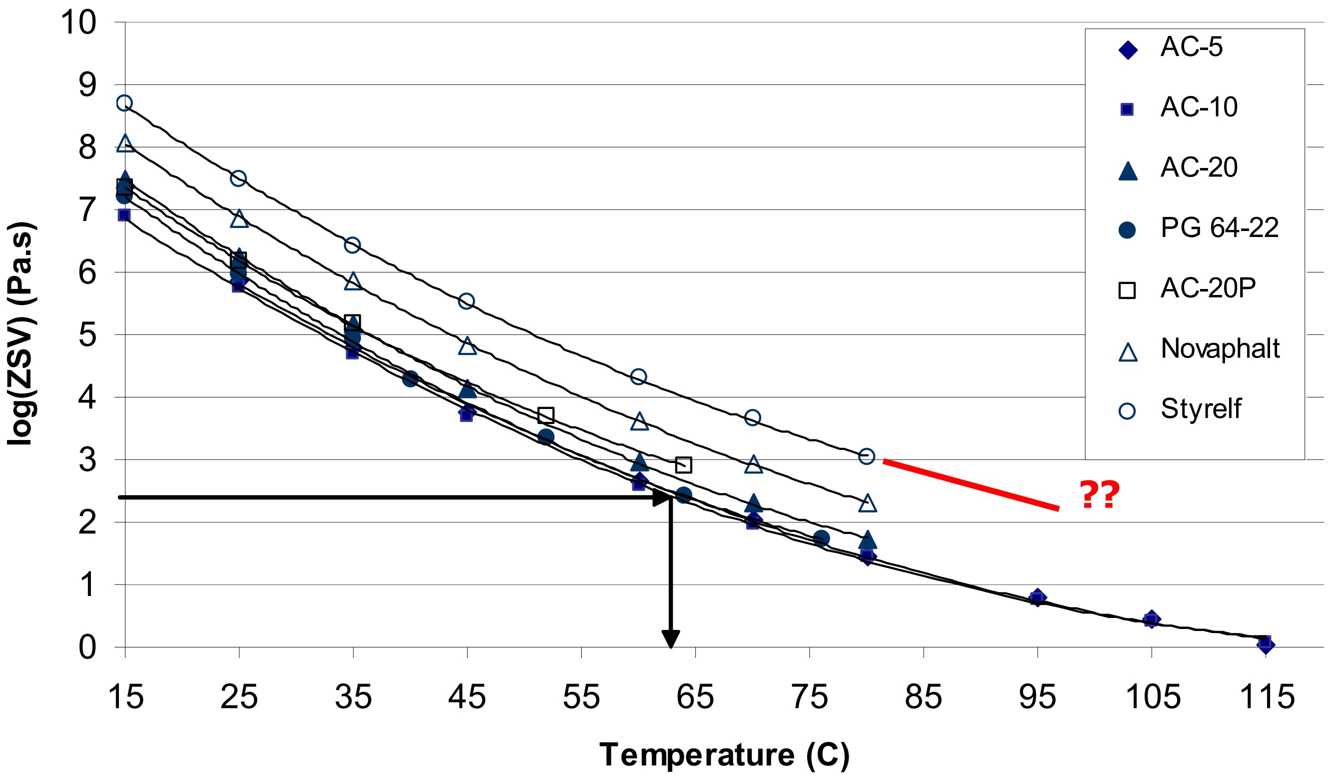
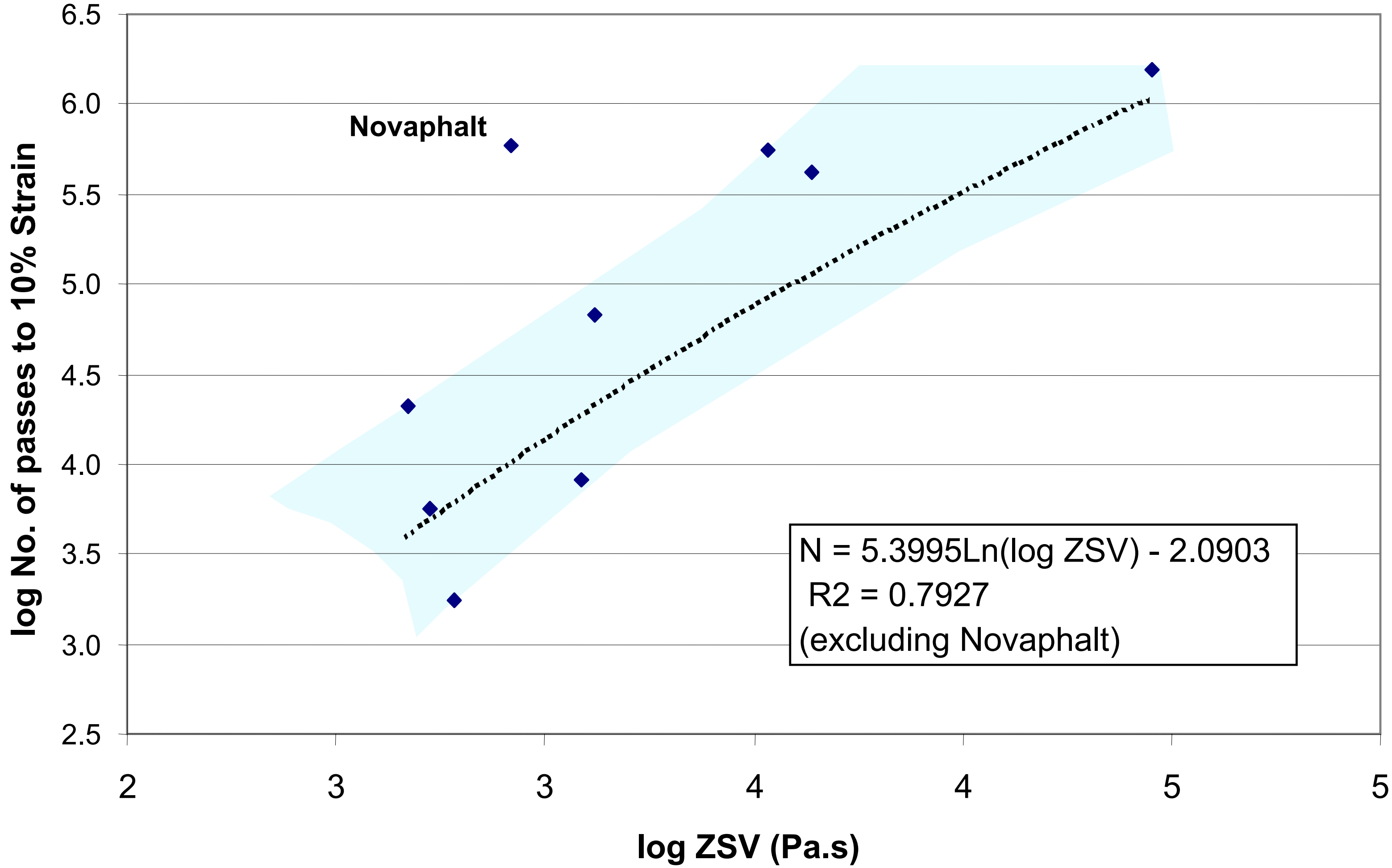
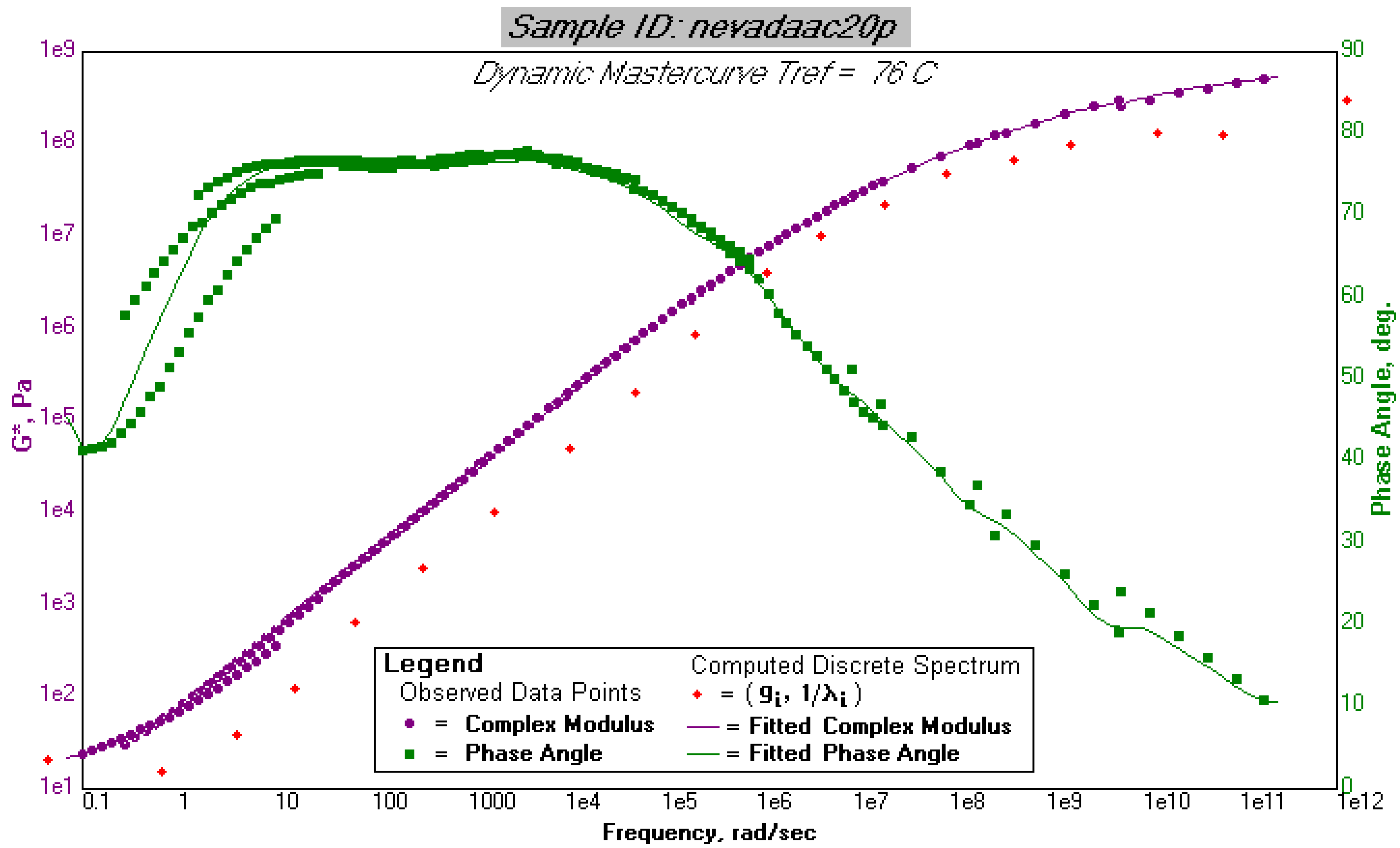
Variation of ZSV with Temperature



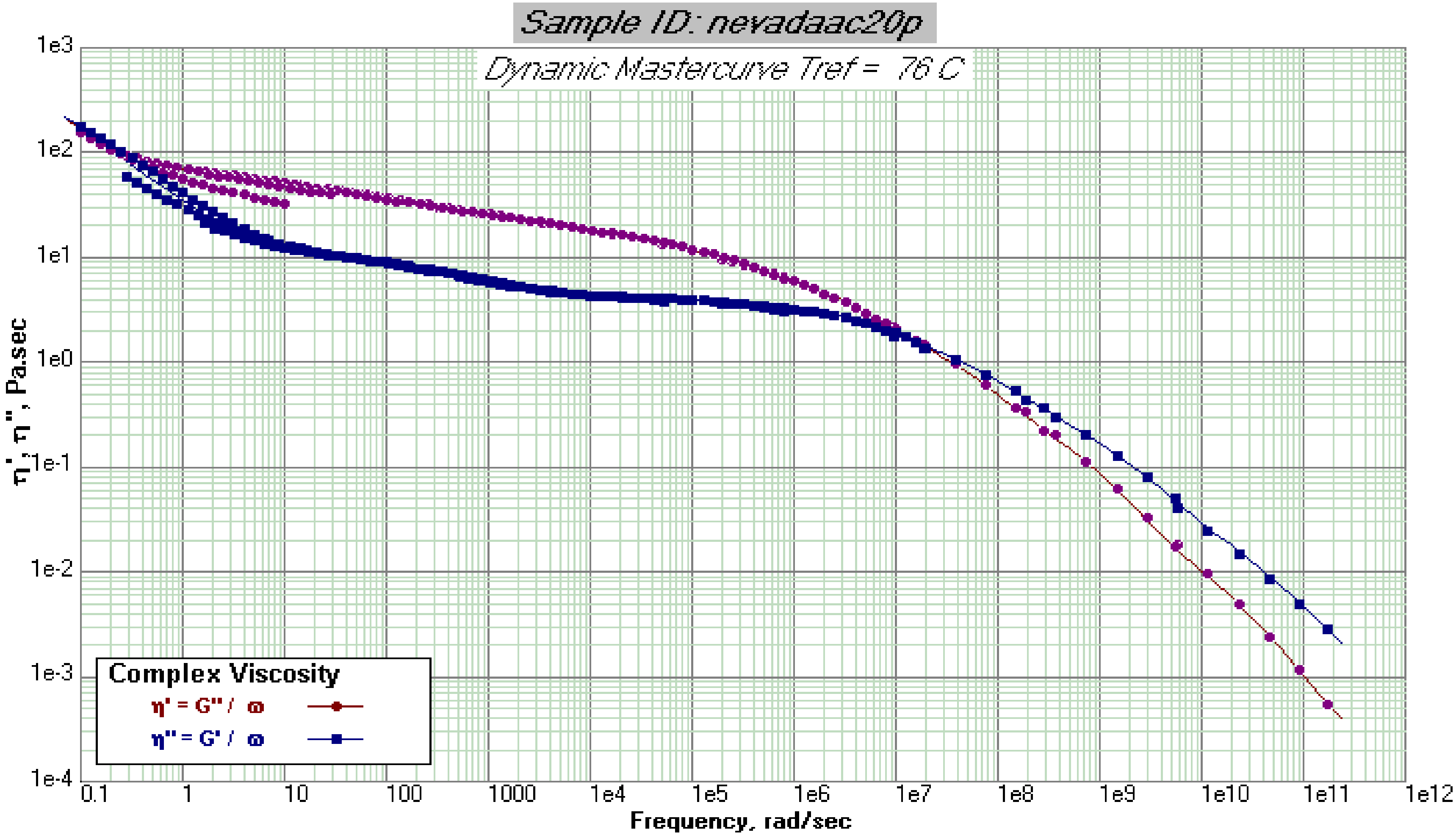
Deformation versus ZSV from ALF Test Site



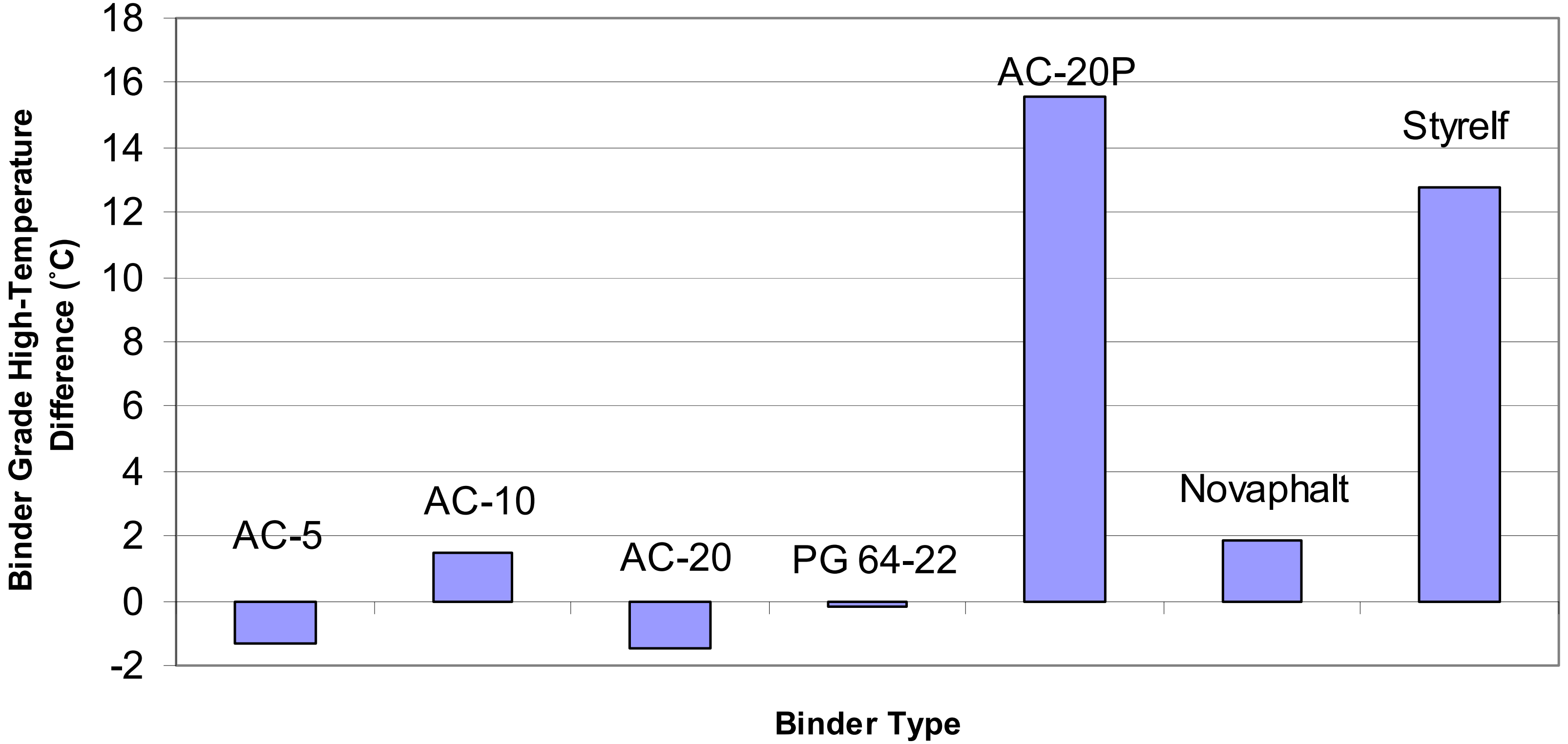
E* and δ – Nevada AC20P



Dynamic viscosity – Nevada AC20P

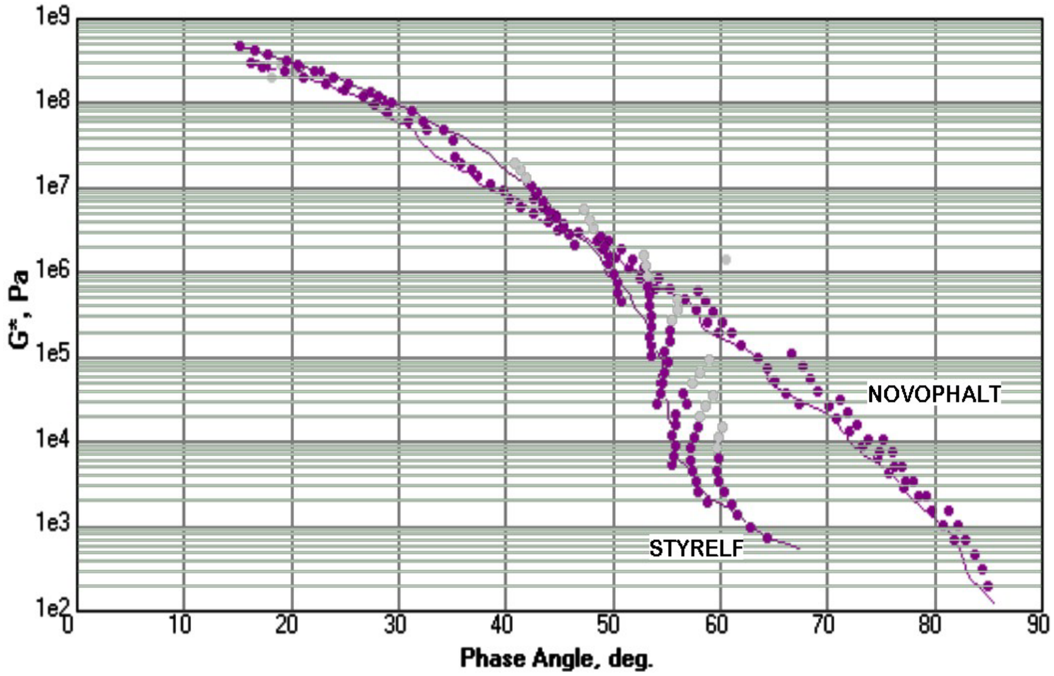


Binder High-Temperature Grade Difference



ZSV

- Is significantly effected by network structures – e.g. polymer modification



Other validation work

- Work on going by others to look at ZSV

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Testing schemes

Lab	Test Frequencies used in range
A (0.1 to 10 rads/sec)	0.1, 0.12589, 0.15849, 0.19952, 0.25118, 0.31622, 0.39809, 0.50116, 0.63092, 0.79427, 1, 1.25891, 1.58487, 1.99521, 2.51178, 3.16211, 3.98083, 5.01147, 6.30896, 7.94238, 10
B (0.1 to 10 Hz/sec)	0.1, 0.1334, 0.1779, 0.2371, 0.3162, 0.4217, 0.5625, 0.7498, 1, 1.333, 1.779, 2.372, 3.163, 4.216, 5.625, 7.498, 9.997

Grade acceptance

- For the grade temperature determine the values of G* and δ for the 21 frequencies specified.
  - (0.1, 0.12589, 0.15849, 0.19952, 0.25118, 0.31622, 0.39809, 0.50116, 0.63092, 0.79427, 1, 1.25891, 1.58487, 1.99521, 2.51178, 3.16211, 3.98083, 5.01147, 6.30896, 7.94238, 10 rads/sec)
- Save the data to a text file.
- Using appropriate software, calculate the value of ZSV, Baumgaertel and Winter (1989).
  - (IRIS, RHEA, RHEA ZSV, other software from equipment manufactures)
- Judge compliance with the following criteria.
  - TANK material ZSV $\geq$ 100 Pa.s
  - RTFOT, ZSV $\geq$ 250 Pa.s
- Report

Estimation of “True” PG High Temp Grade

- Determine ZSV at different temperatures
- Estimate ZSV from DS analysis
- Plot ZSV versus temperature and estimate “True” high PG temperature
- <u>PROCEDURE IS CONCEPTUALLY SAME AS CURRENTLY USED</u>

Grade bumping

- Concept based upon viscous modulus
- The effect of loading can be estimated by using traffic speed
- The effect of traffic volume is considered by linear response of strain with magnitude of loading

$$\eta_{0\ reqired} = G_V \times t$$

$$G_V = \frac{\eta_0}{t}$$

$$\log(ZSV) = k - n \log T$$

where:

k and n are regression parameters
T is temperature in degrees Kelvin

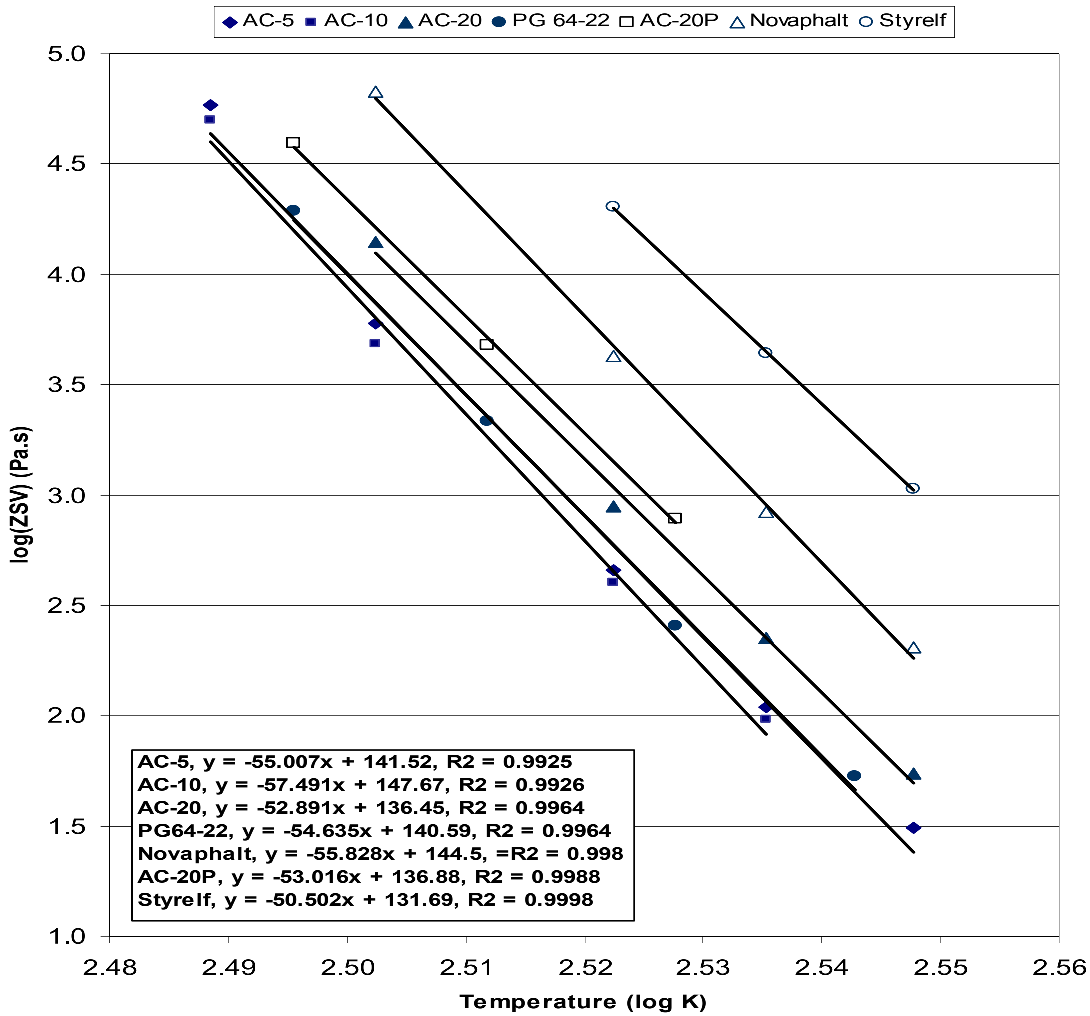
Grade bumping

- Increased values of ZSV would be effectively obtained by grade bumping
- The ZSV required can be determined for many different conditions
- Grade bumping would be determined as agency policy as current

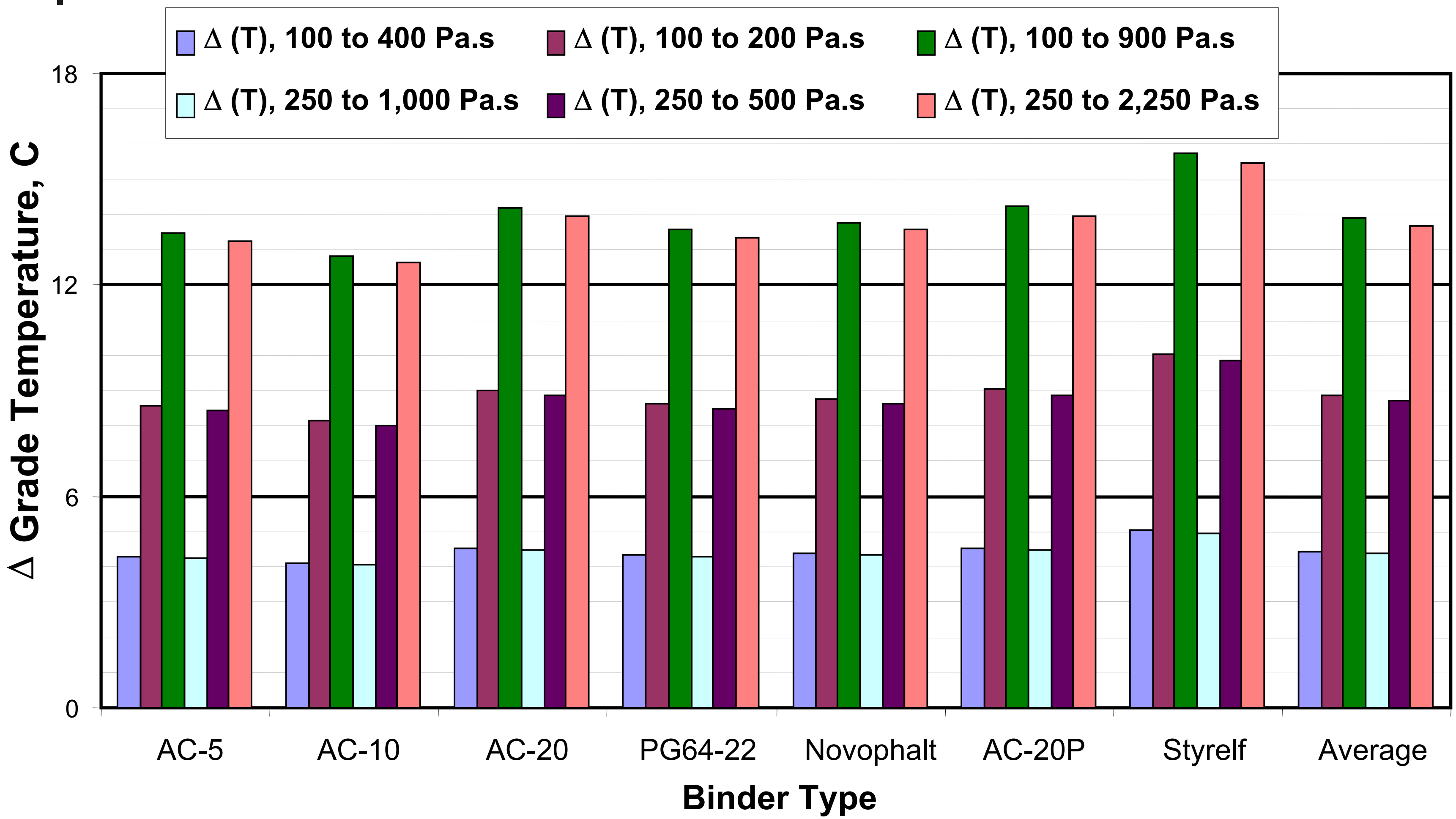
Condition	ZSV_{TANK}, Pa.s	ZSV_{RTFOT}, Pa, s
Normal free flowing	100	250
Double traffic or half traffic speed	200	500
Double traffic and half traffic speed	400	1,000
Heavy traffic (say 3 times normal) and slow (say 1/3 normal)	900	2,500

Determination of equivalent temperature to satisfy grade bump requirement

- Within the high temperature area the ZSV versus temperature relationships tend to have a consistent slope
- A consistent slope allows grade bumping based on ZSV



Effect of G_v on grade bump



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Summary 1 of 2

- A method for using ZSV to describe the asphalt high-temperature binder performance grade is proposed. This criterion was compared with the current Superpave specification to determine the difference in high-temperature binder grade computed using two methods.
  - Both methods produce similar results for the unmodified binders. However, significantly different results were produced for modified binders.
- Data from the rheology measurements were compared to the deformation measurements of the ALF test site at different temperatures. A similar comparison was performed for rut depth measurements performed on the pavement section in the Nevada test site.
- The correlations suggest that the ZSV is a reasonable parameter for controlling the effect of the binder with respect to permanent deformation.

Summary 2 of 2

- Equivalent specification parameters for ZSV correspond to 100 Pa.s and 250 Pa.s for TANK and RTFOT conditions respectively.
- Since the ZSV is measured at conditions close to the current specification requirement for G*/sind the existing test equipment (DSR with 25mm plate and 1mm gap) can be used.
- A test procedure is proposed that involves the determination of G* and phase angle for 21 frequencies.
- At the values of ZSV to be obtained by the proposed test procedure the estimated error due to calculation methods is anticipated to be less than 1 C.
- The developed procedures for grade determination and acceptance involve the replacement of the G*/sinδ requirement in the existing specifications with a direct substitution of the ZSV requirement.
- Grade "bumping" due to traffic loading and speed effects is more fundamentally correct using a ZSV approach.
- The amount of grade bump required is directly related to traffic flow and speed compared to the agencies' definition of free-flow conditions.
- **Using ZSV, grade bumps could involve adjustments of 2 or 3 grades to obtain equivalent binders that are in routine use today with typical SHRP+ specifications.**