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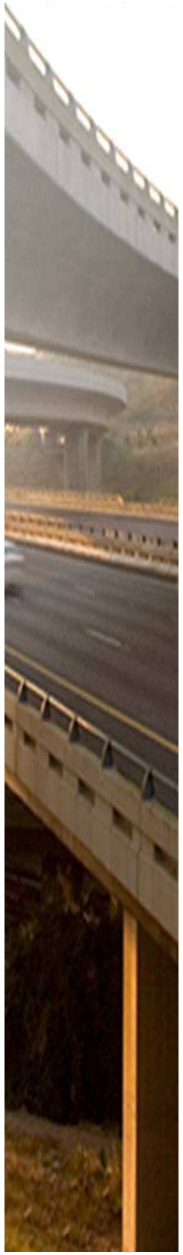

Resilient response models for bituminous materials

ROADS PAVEMENTS FORUM

November 2010

Johan O’Connell

CSIR
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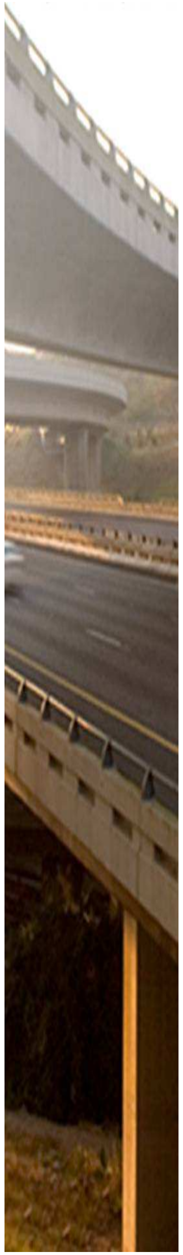
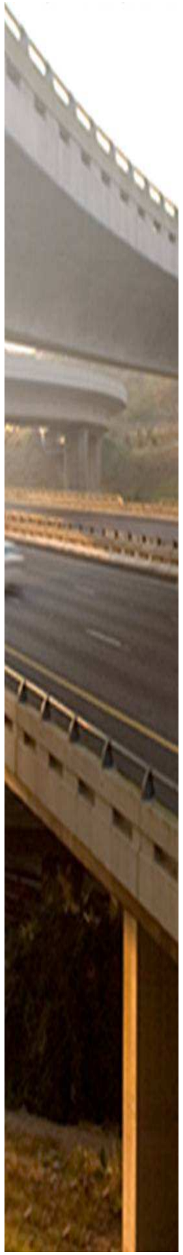


Background to the Presentation

In 2004 NCHRP in the USA released its "Guide for Mechanistic-Empirical Design"

In turn this led to a SANRAL project: Revision of South African Pavement Design Method.



Hierarchical Design Inputs

Level of engineering effort exerted in the pavement design process should be consistent with relative importance, size and cost of the project

3 Levels of input

- Level 1 – high accuracy (heavy traffic / cost)
- Level 2 - intermediate accuracy (intermediate)
- Level 3 - lowest accuracy (low traffic / cost)

A mixture of level can occur

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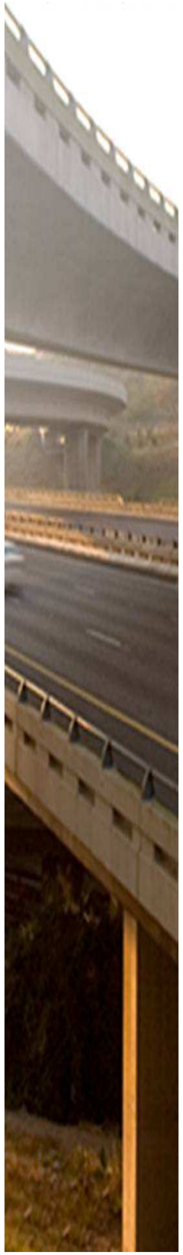
Fundamentals of the Design Method



Resilient Response (eg Dynamic modulus) is a key determinant of the pavement’s response to traffic loading in terms of stresses / strains – inputs into Damage Models.

Key to predicting pavement life and rehabilitation requirements

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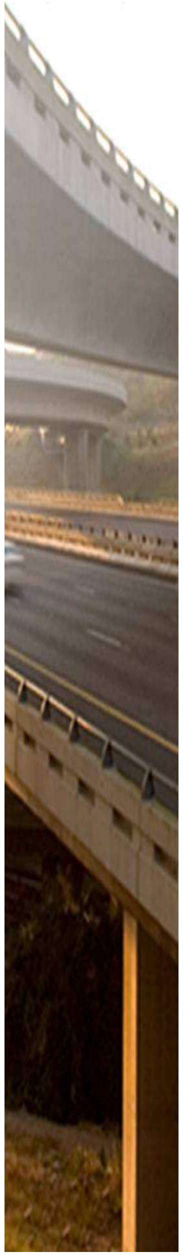
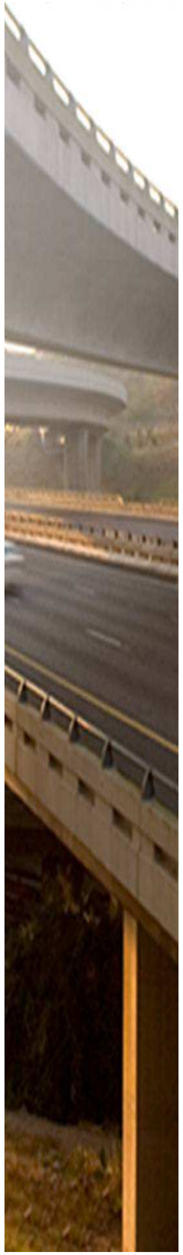


Hierarchical Levels for HMA Stiffness

- Level 1 – Full asphalt modulus and binder testing required. Development of master curves from experimental data
- Level 2 - No asphalt modulus required. Binder testing provides the input data for a predictive equation to provide estimated moduli
- Level 3 – No binder testing – typical values for viscosity representing a binder type are employed

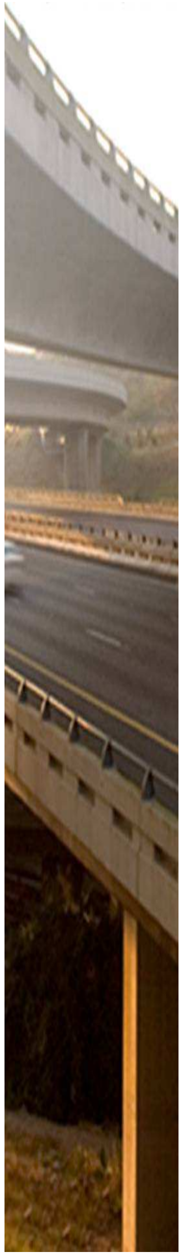


Predictive Equations

Equations providing resilient response models include:

- Witczak (NCHRP)
- Hirsch

Witczak



$$\log\left|E^*\right| = 3.750063 + 0.029232P_{200} - 0.001767\left(P_{200}\right)^2 + 0.002841P_4 - 0.058097V_a - 0.82208\frac{V_{beff}}{\left(V_{beff} + V_a\right)} + \frac{\left[3.871977 + 0.0021P_4 + 0.003958P_{38} - 0.000017\left(P_{38}\right)^2 + 0.00547P_{34}\right]}{1 + e^{\left(-0.603313 - 0.313351\log f - 0.393532\log \eta\right)}} \tag{15}$$

where:

|E*| = asphalt mix complex modulus, in psi (145 psi = 1 MPa);

η = binder viscosity, in 10^6 poise (10 Poise = 1 pa.s);

f = load frequency, in Hz;

Va = % air voids in the mix, by volume;

Vbeff = % effective bitumen content, by volume;

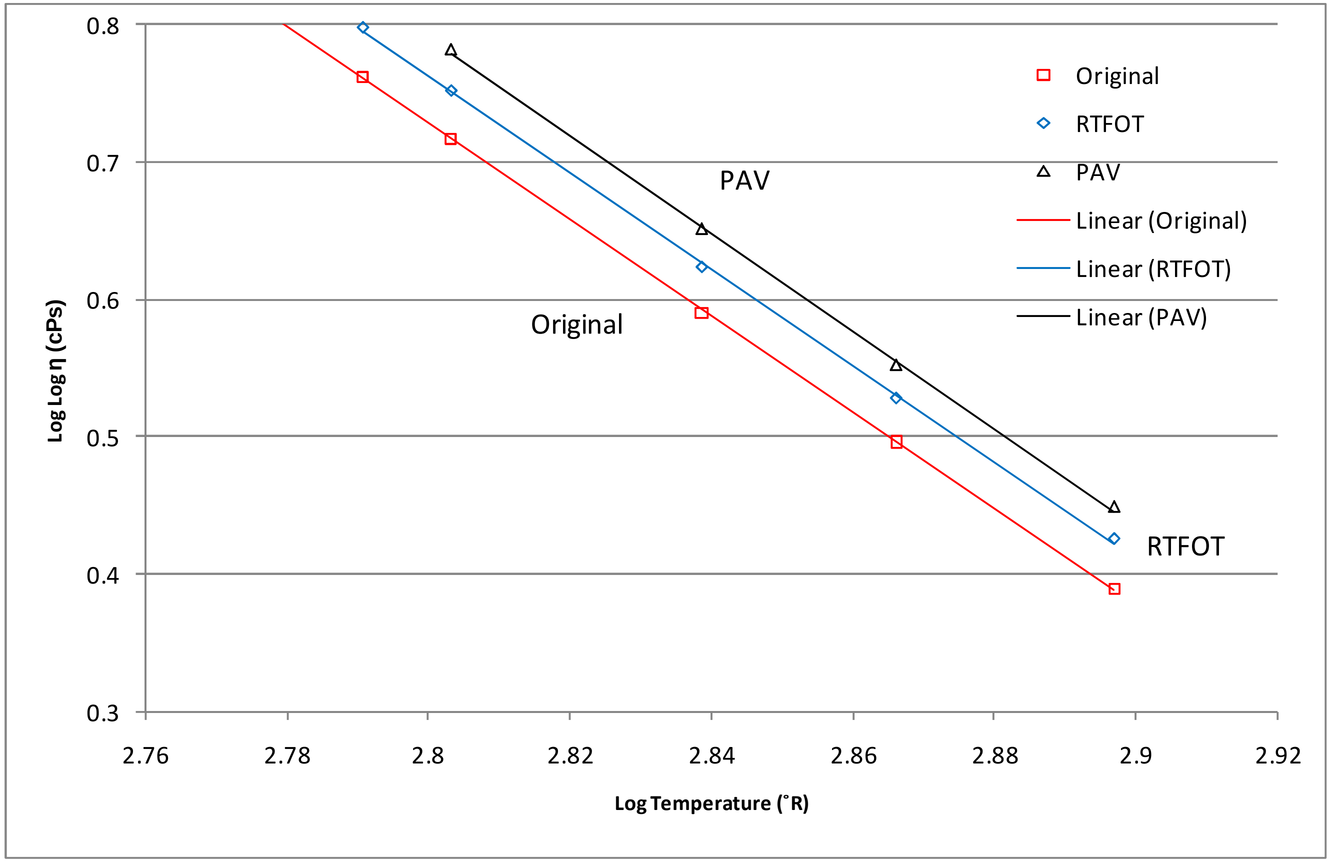
$P_{3/4}$ = % retained on ¾-in. [19.0-mm] sieve, by total aggregate weight (cumulative);

$P_{3/8}$ = % retained on 3/8-in. [9.5-mm] sieve, by total aggregate weight (cumulative);

P_4 = % retained on No. 4 [4.75-mm] sieve, by total aggregate weight (cumulative);

P_{200} = % passing No. 200 [0.075-mm] sieve, by total aggregate weight.

Representation of Viscosity

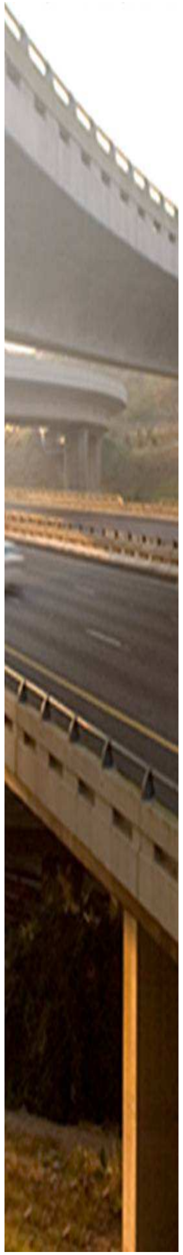


$$\log \log \eta = A + VTS \log T_R$$

A = regression intercept;

VTS = regression slope of viscosity temperature susceptibility

Determination of Viscosity



Multiple Methods allowed but conversion to Poise required

- Penetration
- Softening Point
- Kinematic Viscosity
- *Absolute Viscosity*
- *Brookfield Viscosity*
- DSR

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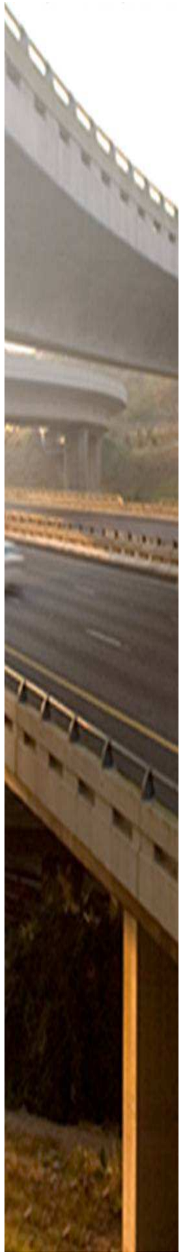
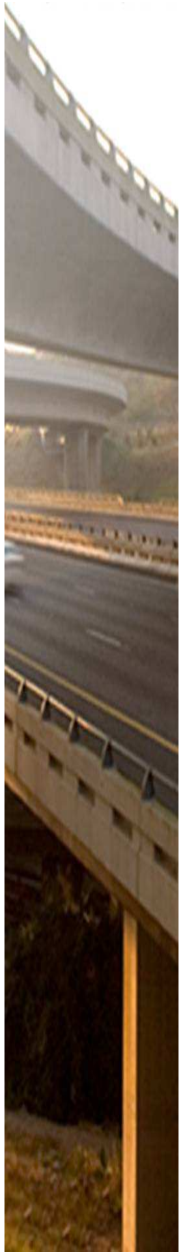
Conversion of Softening Point



13 000 Ps @ Softening Point Temperature



Conversion of Penetration

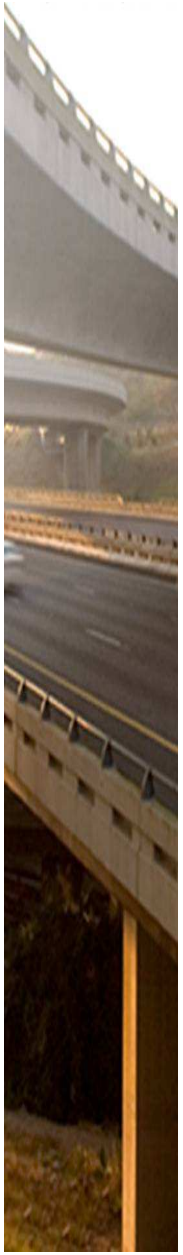
$$\text{Log } \eta = 10.5012 - 2.2601 \log (\text{pen}) + 0.00389 \log (\text{pen})2$$

where:

η = viscosity, in Poise

Pen = penetration for 100 g, 5 sec loading, 0.1mm

Only pen at two different temperatures can be used (15,25)



Conversion of DSR

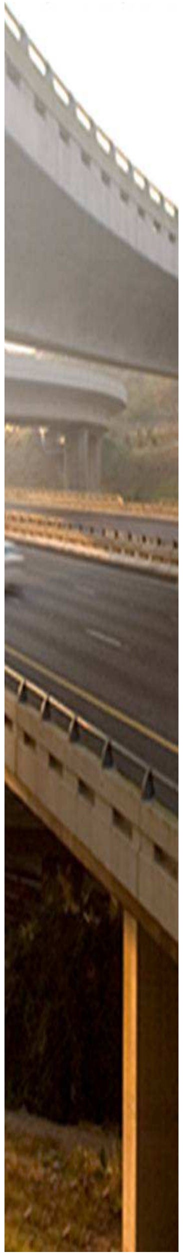
$$\eta = \frac{G^*}{10}\left(\frac{1}{\sin\delta}\right)^{4.8628}$$

where;

G^* = complex shear modulus of the binder

δ = phase angle

η = viscosity (Pa.s)



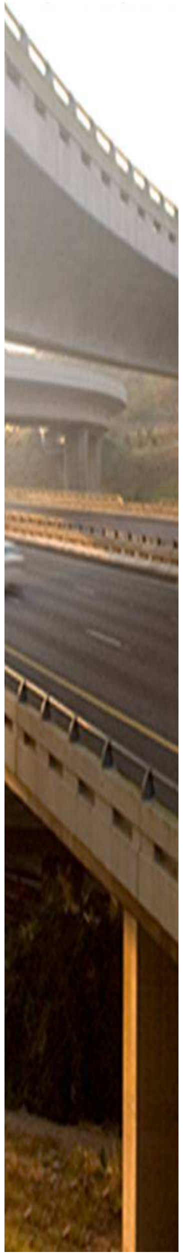
Determination of Viscosity

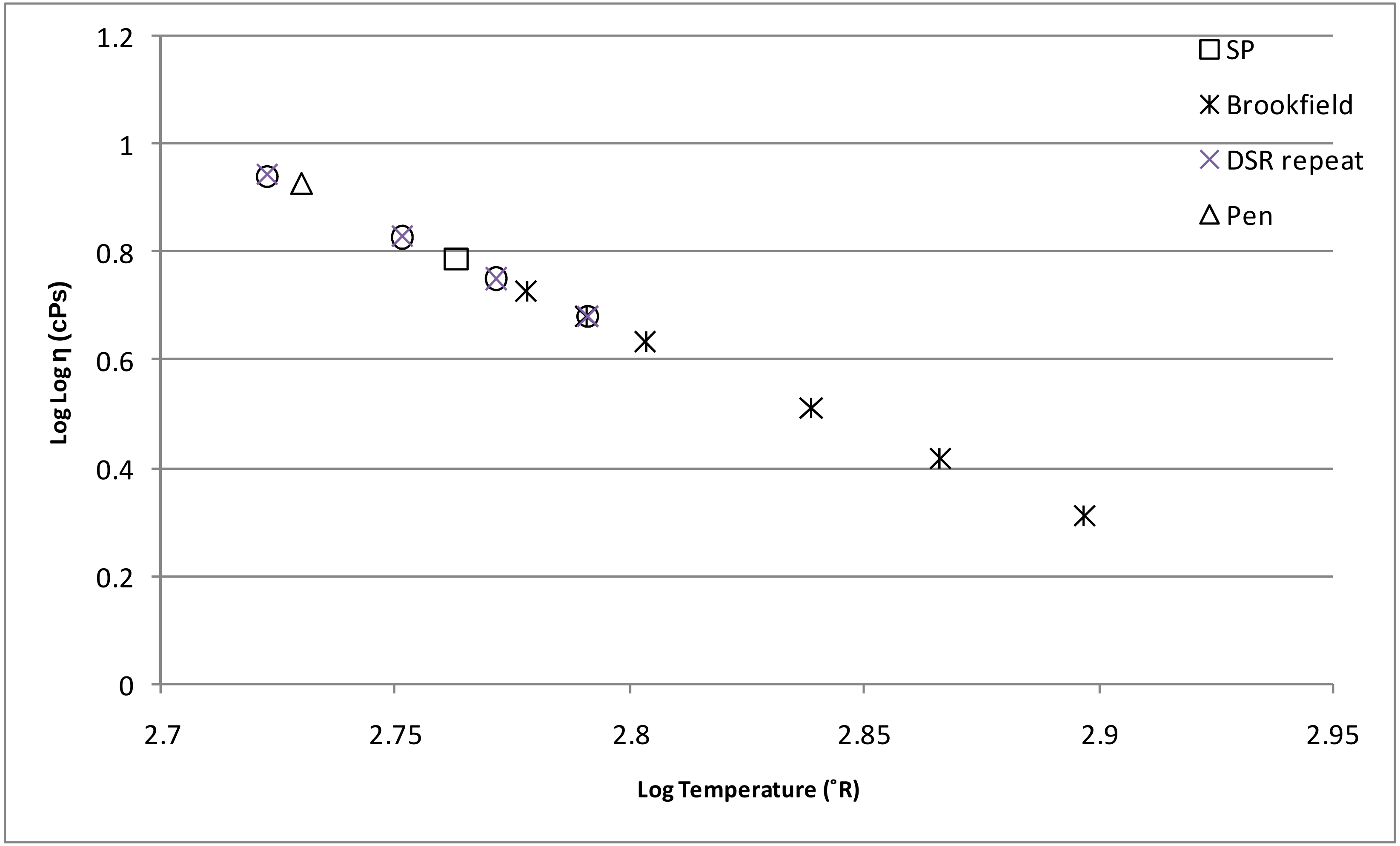
- Which method to use?
- Are they truly interchangeable as related by the NCHRP documents?

For verification purposes 3 binders are presented:

- 60/70
- 20/30
- SBS

60/70 original





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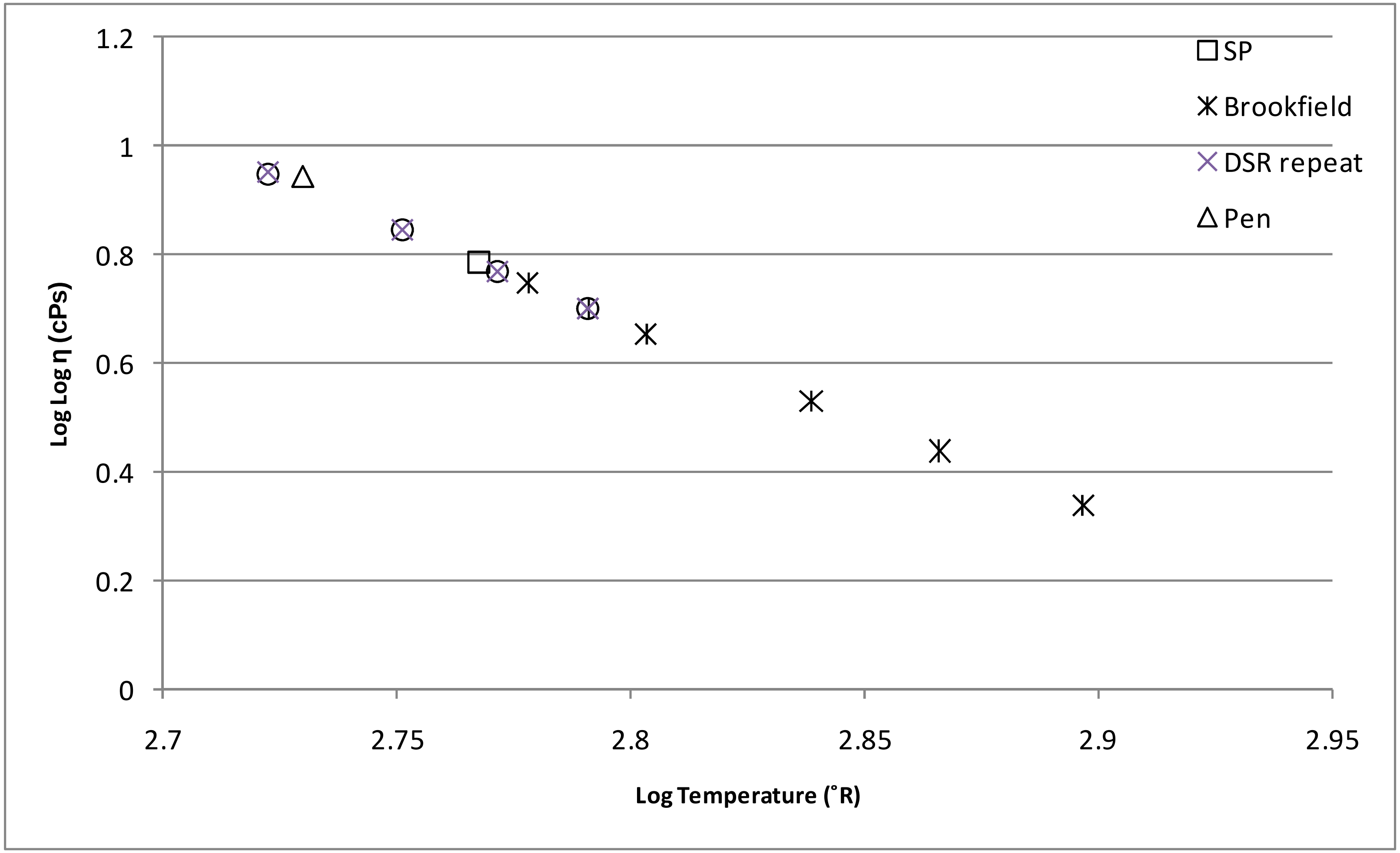
60/70 RTFOT



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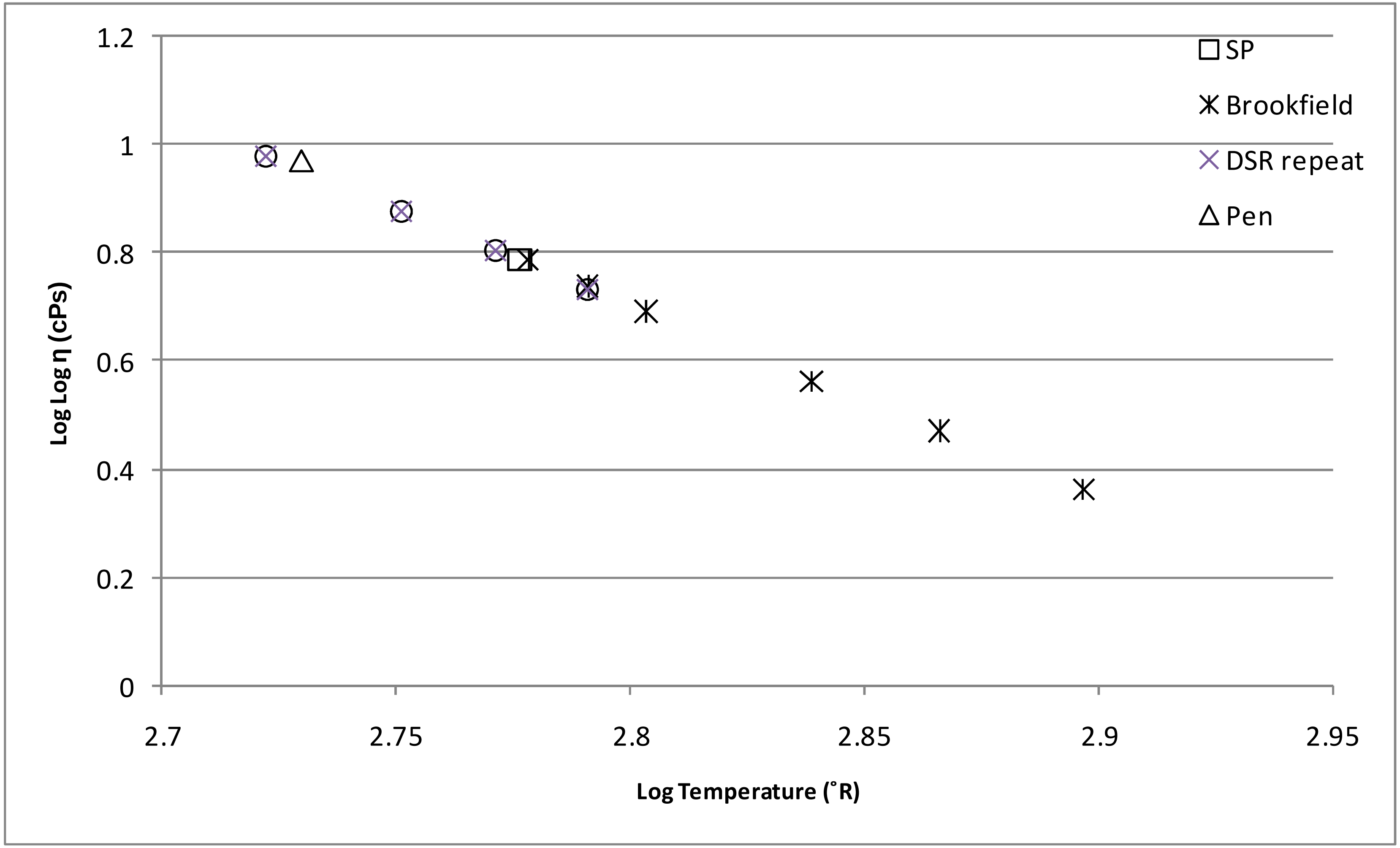
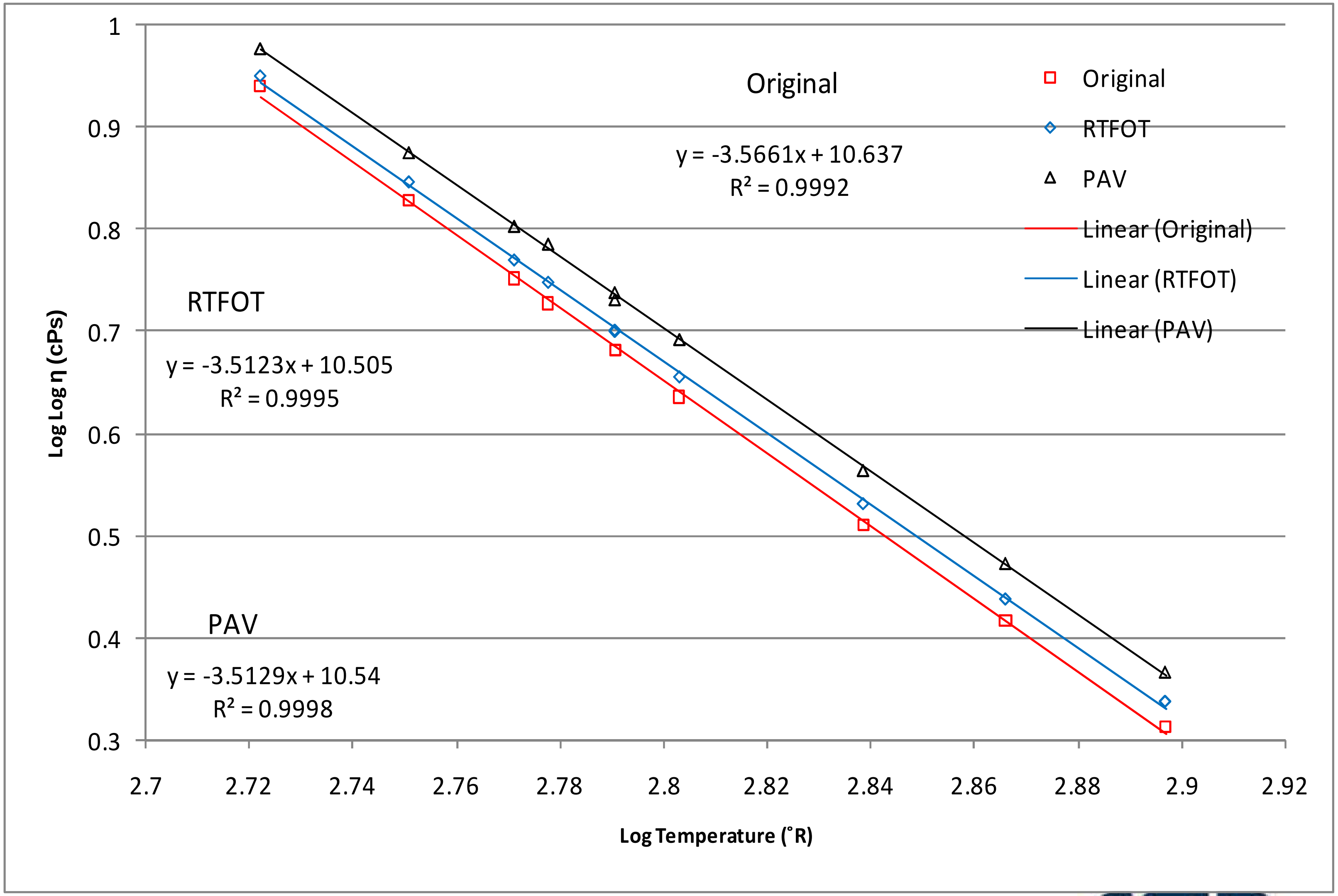
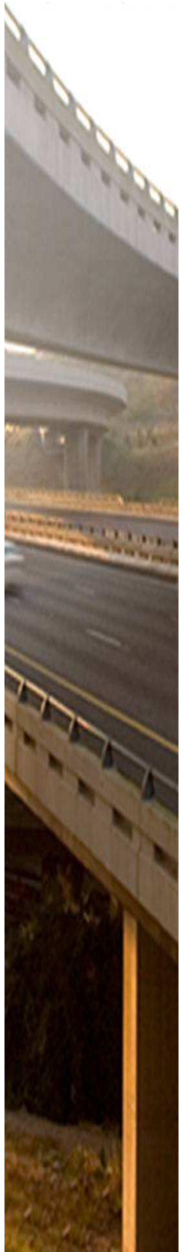
60/70 PAV



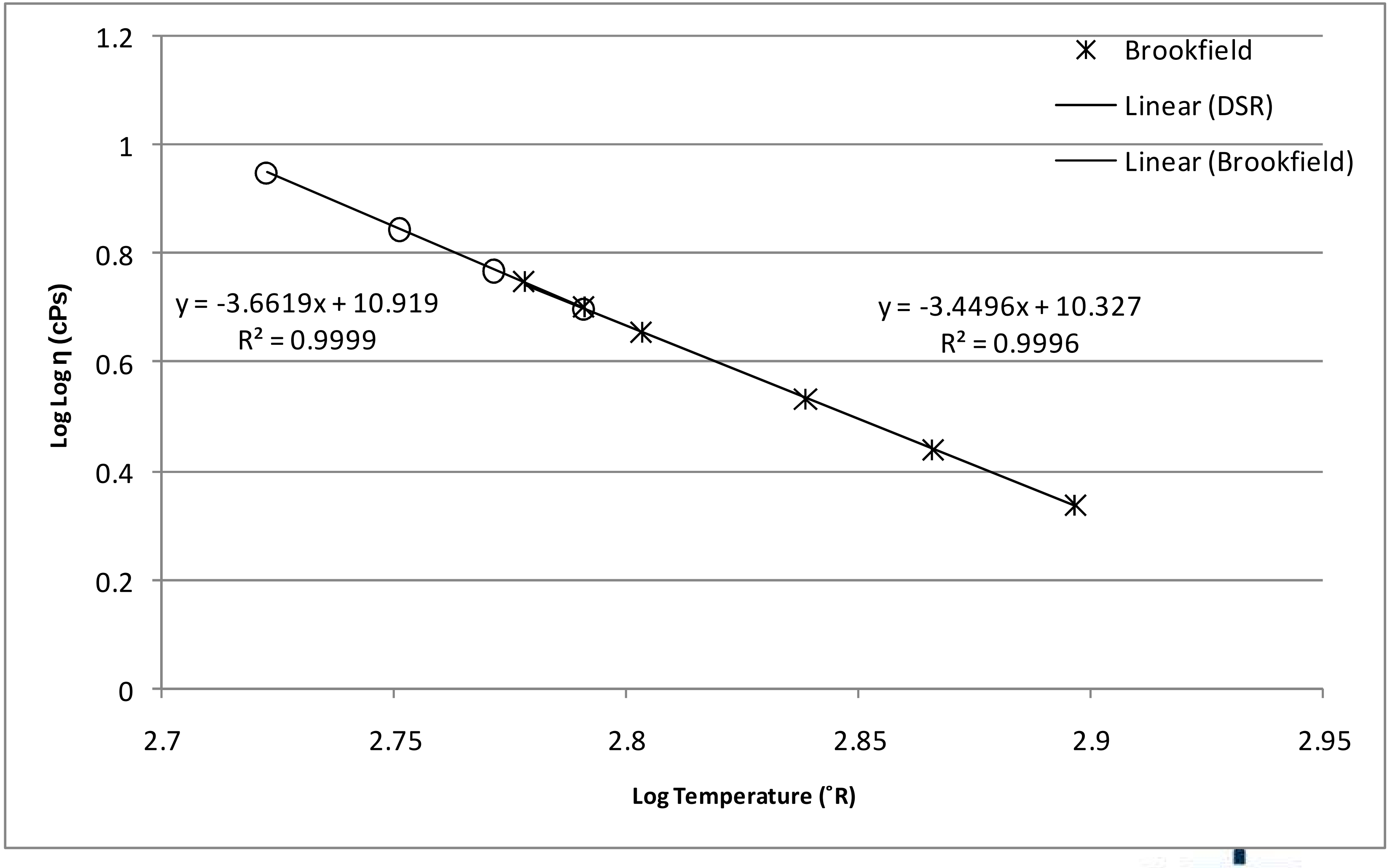
1.2
1
0.8
0.6
0.4
0.2
0
Log Log η (cPs)
2.7
2.75
2.8
2.85
2.9
2.95
Log Temperature (˚R)
☐ SP
✳ Brookfield
× DSR repeat
△ Pen

60/70 Combined A-VTS Parameters

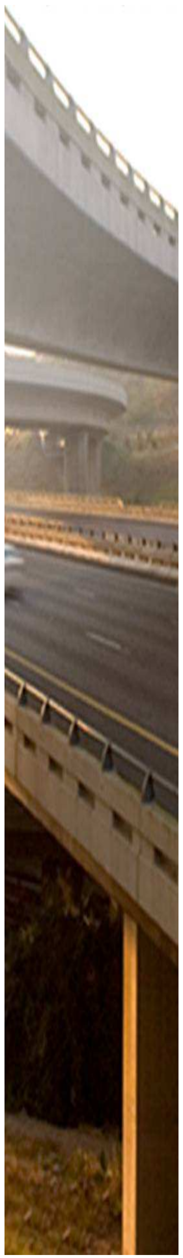




60/70 Separate A-VTS Parameters



60/70 60/70 Separate A-VTS Parameters

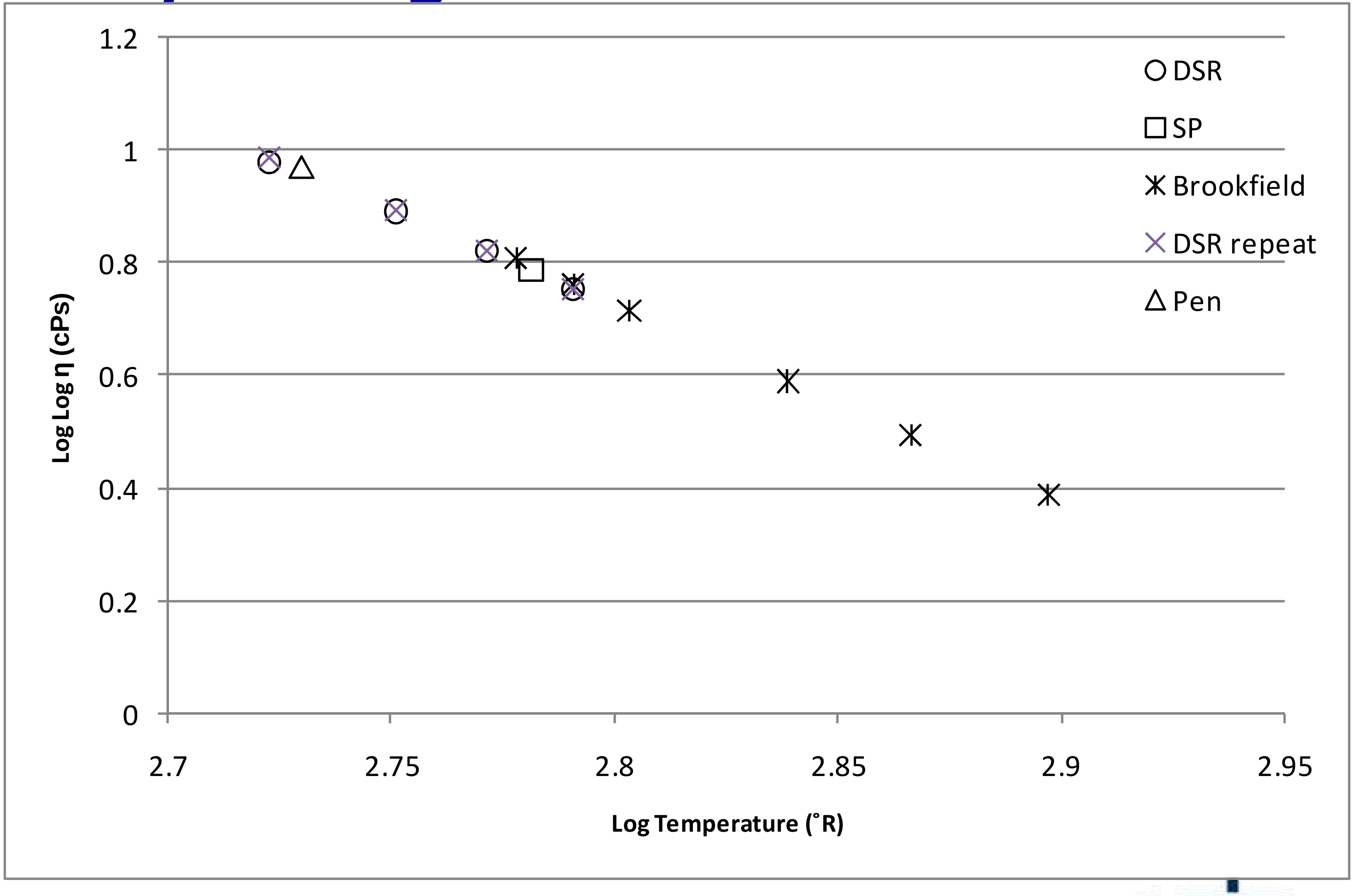


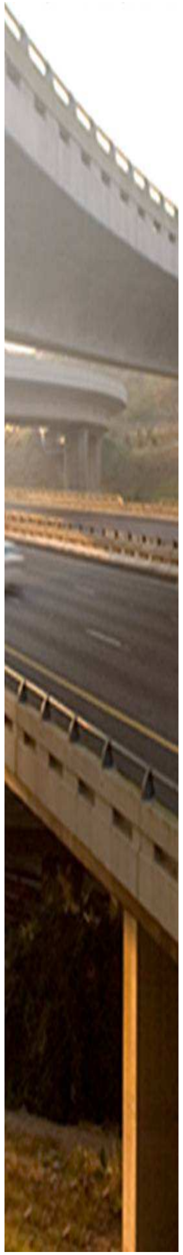
Binder	Ageing	Regression parameters and coefficients		
		A	VTS	R 2
60/70	DSR	10.919	-3.662	0.9999
	Brook	10.327	-3.450	0.9996

Method	E* (MPa) @ 20 C 0.5 HZ	E* (MPa) @ 55 C O.5 Hz	E* (MPa) @ 20 C 10 HZ	E* (MPa) @ 55 C 10 Hz
DSR	2 853	236	5 637	576
Brook	2 287	225	4 695	547

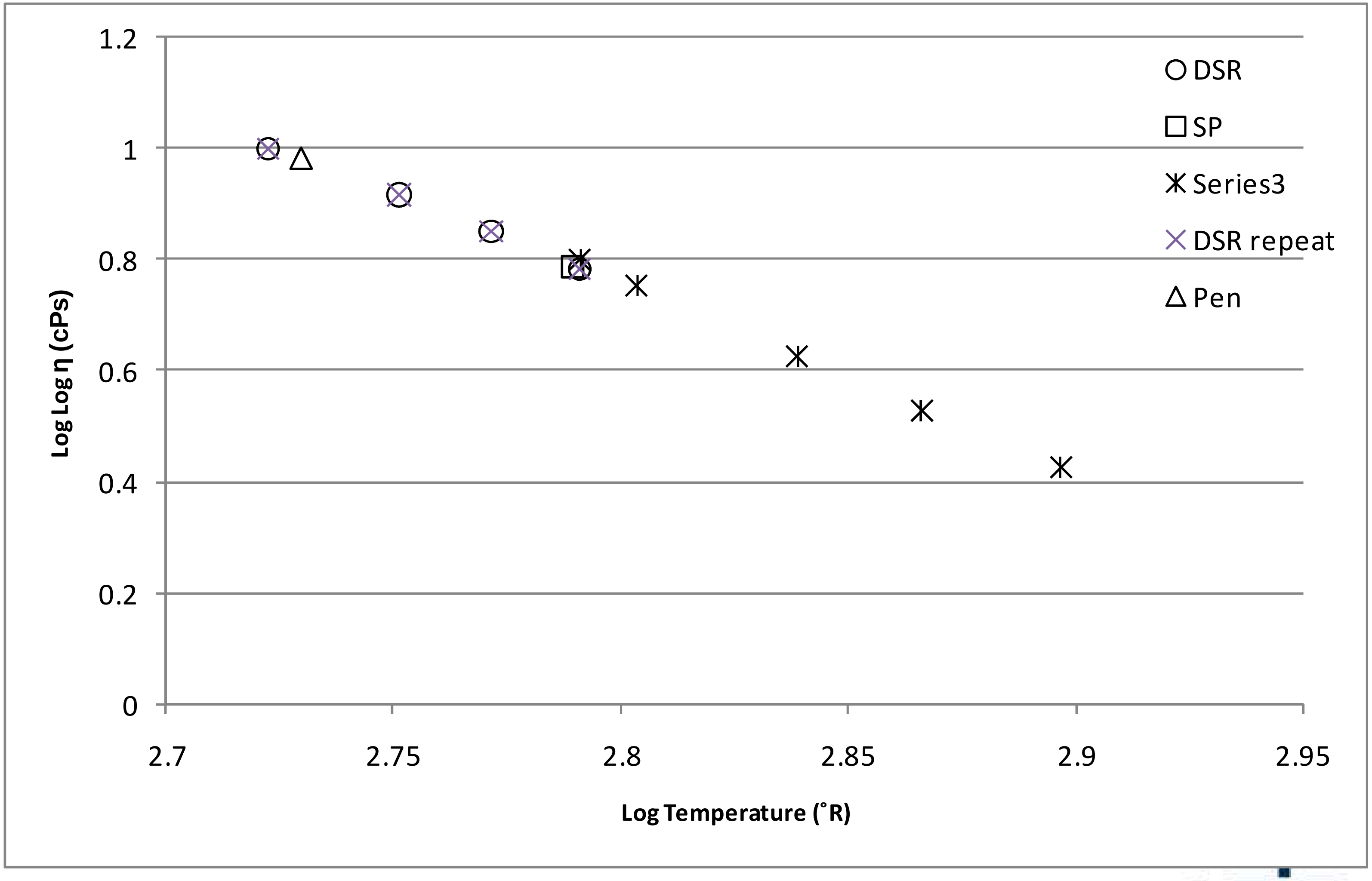
25 %
higher

20/30 original

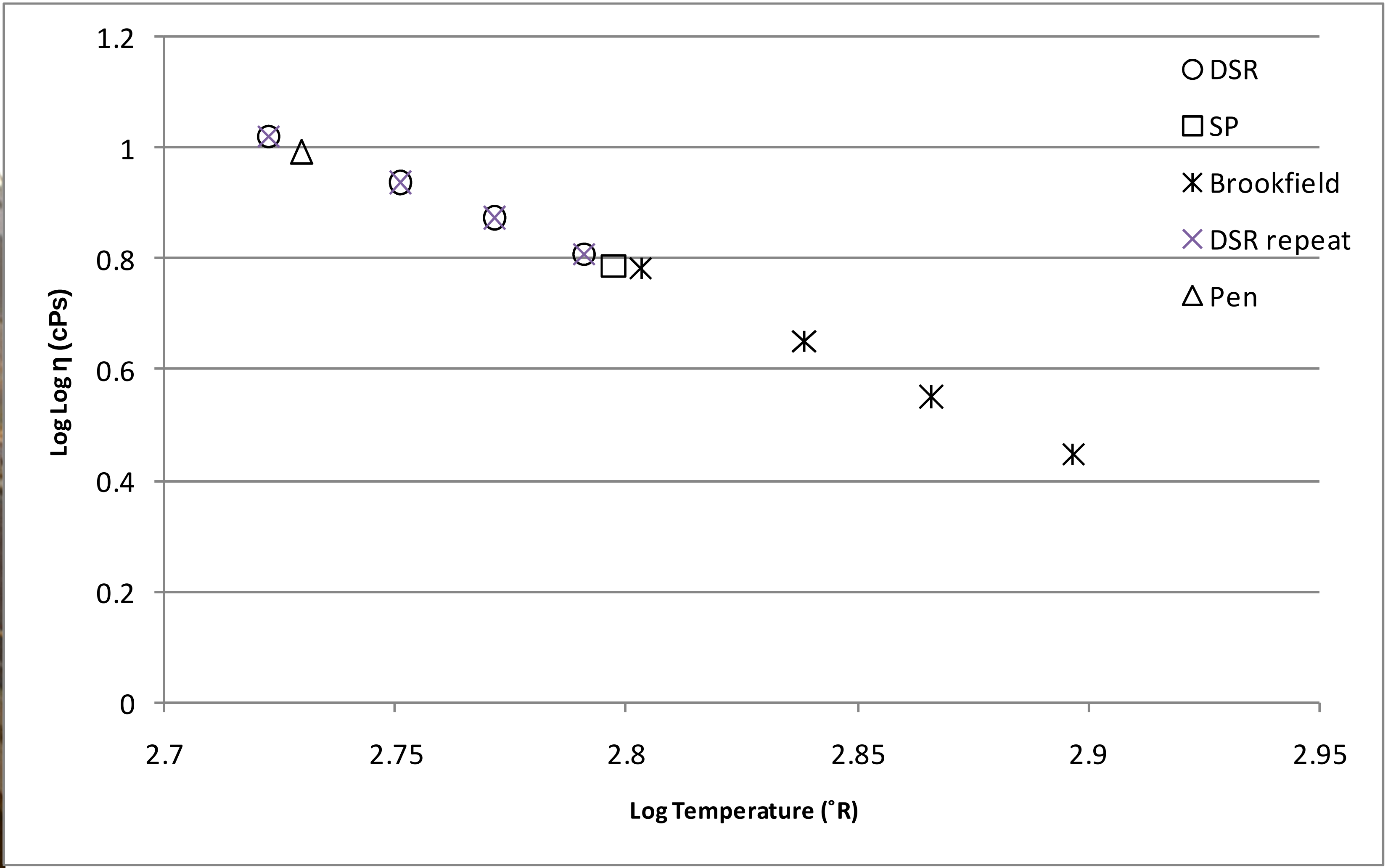




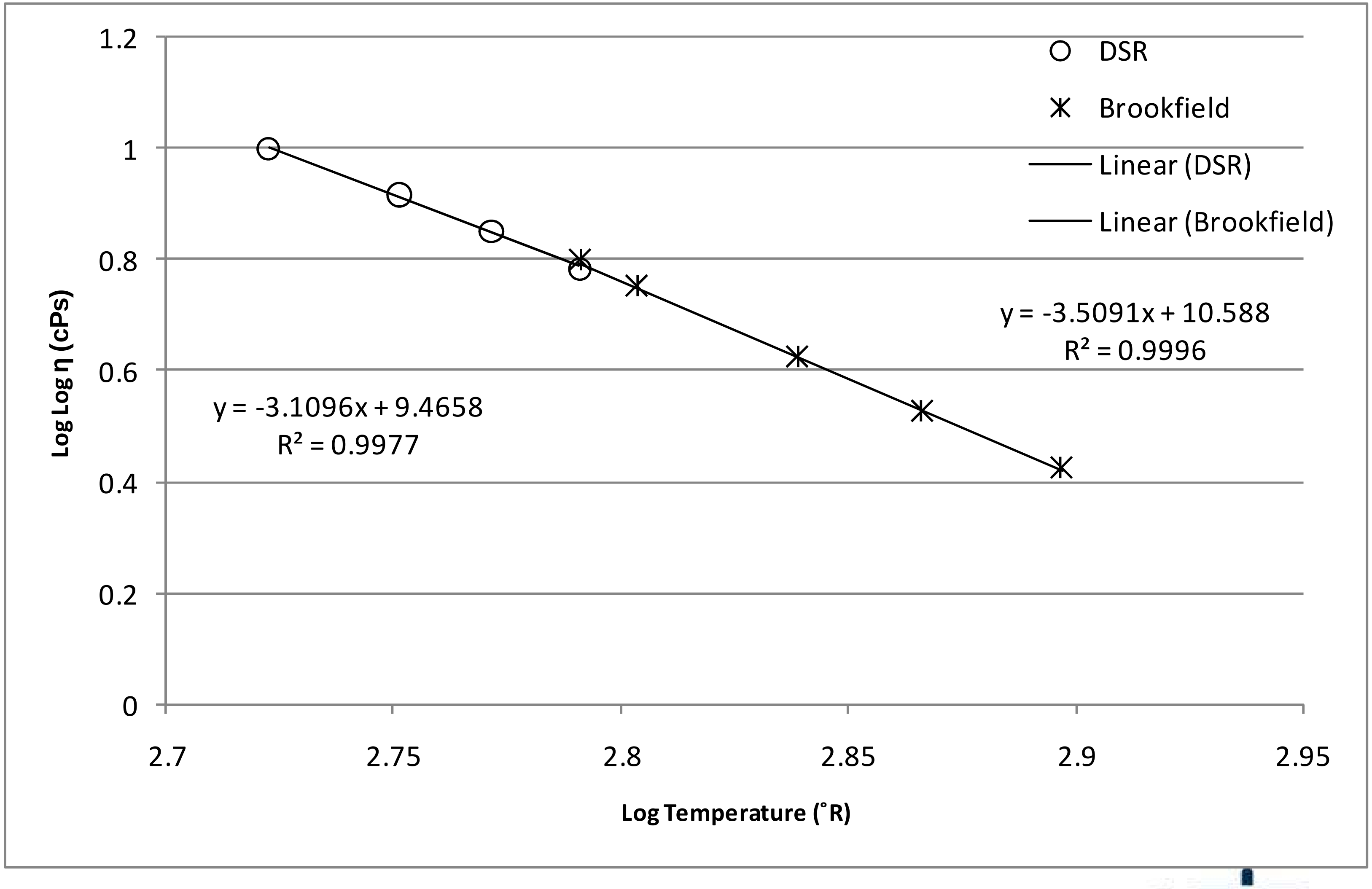
20/30 RTFOT


1.2
1
0.8
0.6
0.4
0.2
0
Log Log η (cPs)
2.7
2.75
2.8
2.85
2.9
2.95
Log Temperature (˚R)
○ DSR
□ SP
⋇ Series3
× DSR repeat
△ Pen

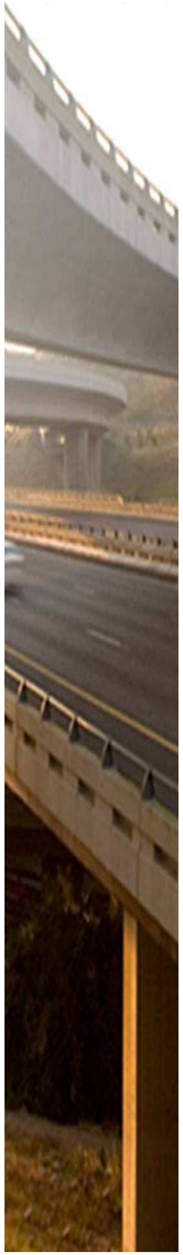
20/30 PAV


1.2
1
0.8
0.6
0.4
0.2
0
Log Log η (cPs)
2.7
2.75
2.8
2.85
2.9
2.95
Log Temperature (˚R)
○ DSR
□ SP
⁎ Brookfield
× DSR repeat
△ Pen

20/30 Separate A-VTS Parameters



20/30 Separate A-VTS Parameters

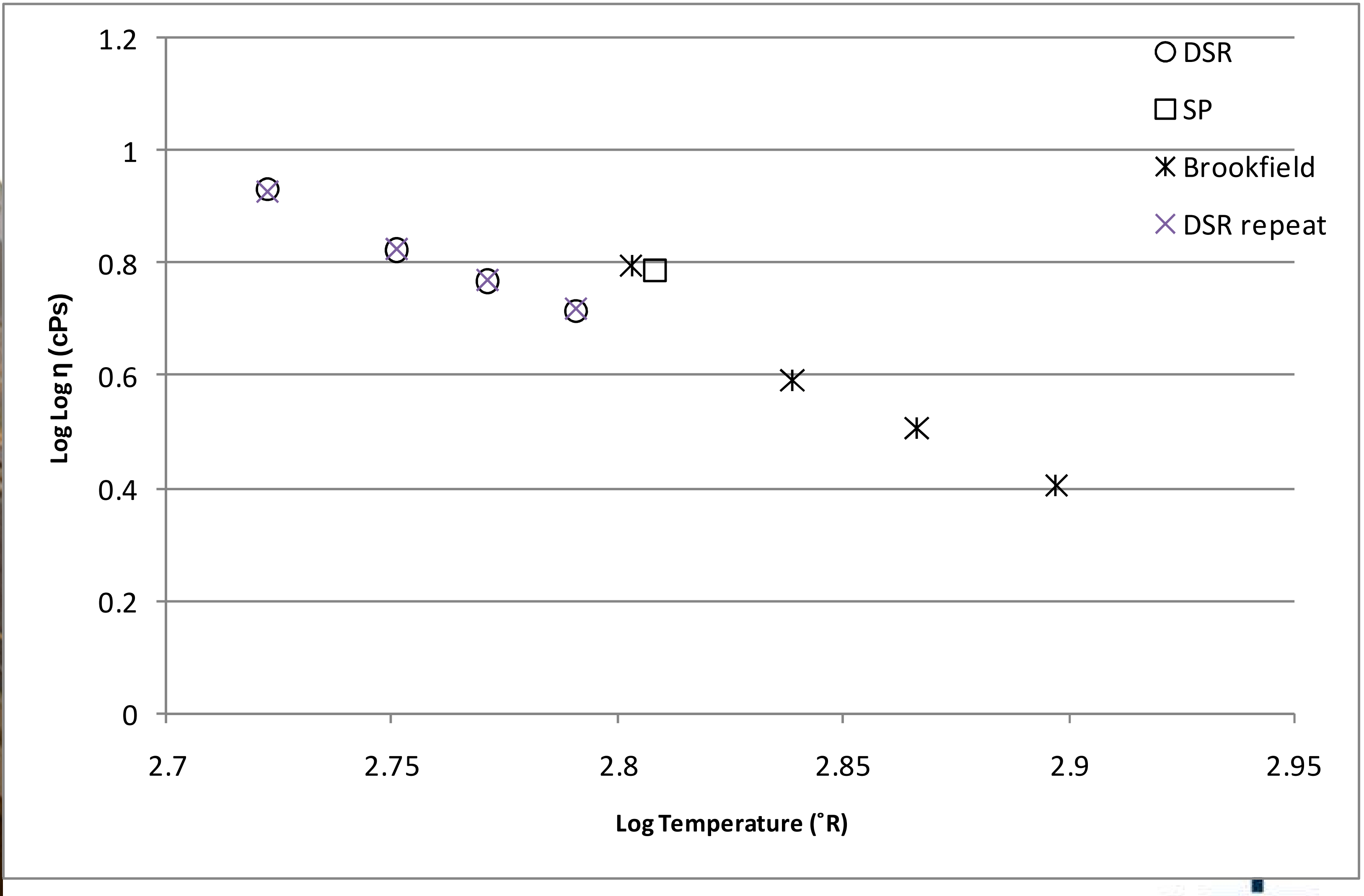


Binder	Ageing	coefficients		
		A	VTS	R 2
20/30	DSR	9.466	-3.110	0.9977
	Brook	10.588	-3.509	0.9996

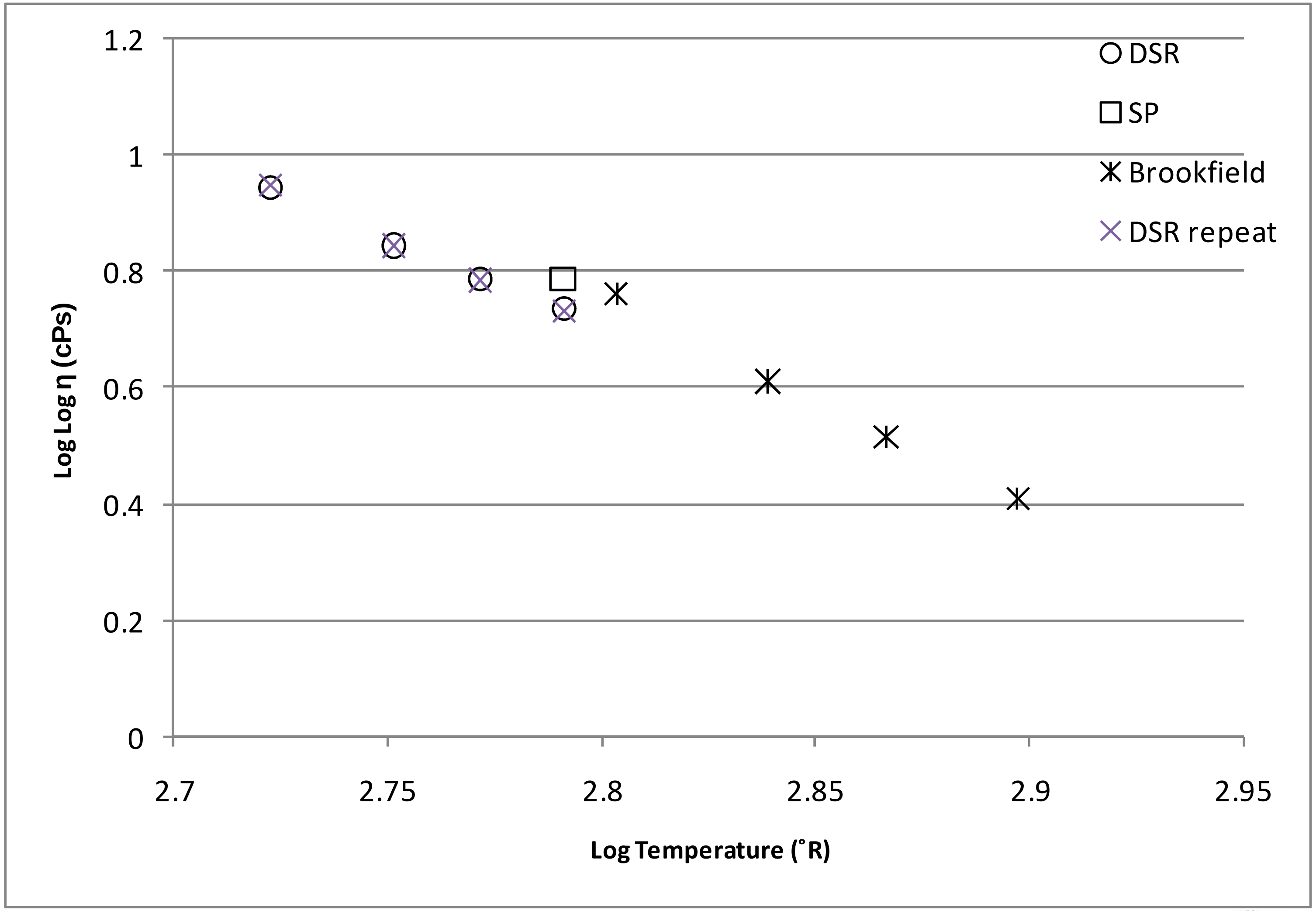
Method	E* (MPa) @ 20 C 0.5 HZ	E* (MPa) @ 55 C O.5 Hz	E* (MPa) @ 20 C 10 HZ	E* (MPa) @ 55 C 10 Hz
DSR	4 918	538	8 401	1 280
Brook	7 200	621	11 227	1 463

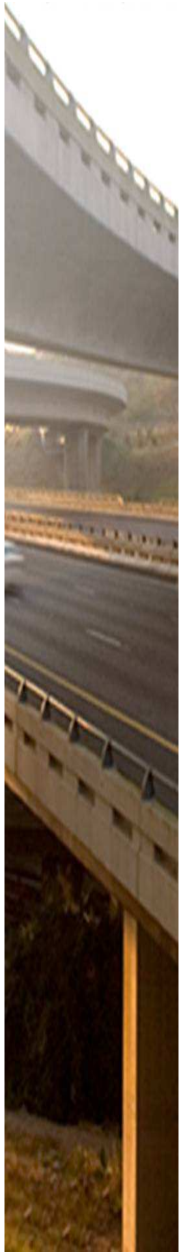
46 % higher

SBS original

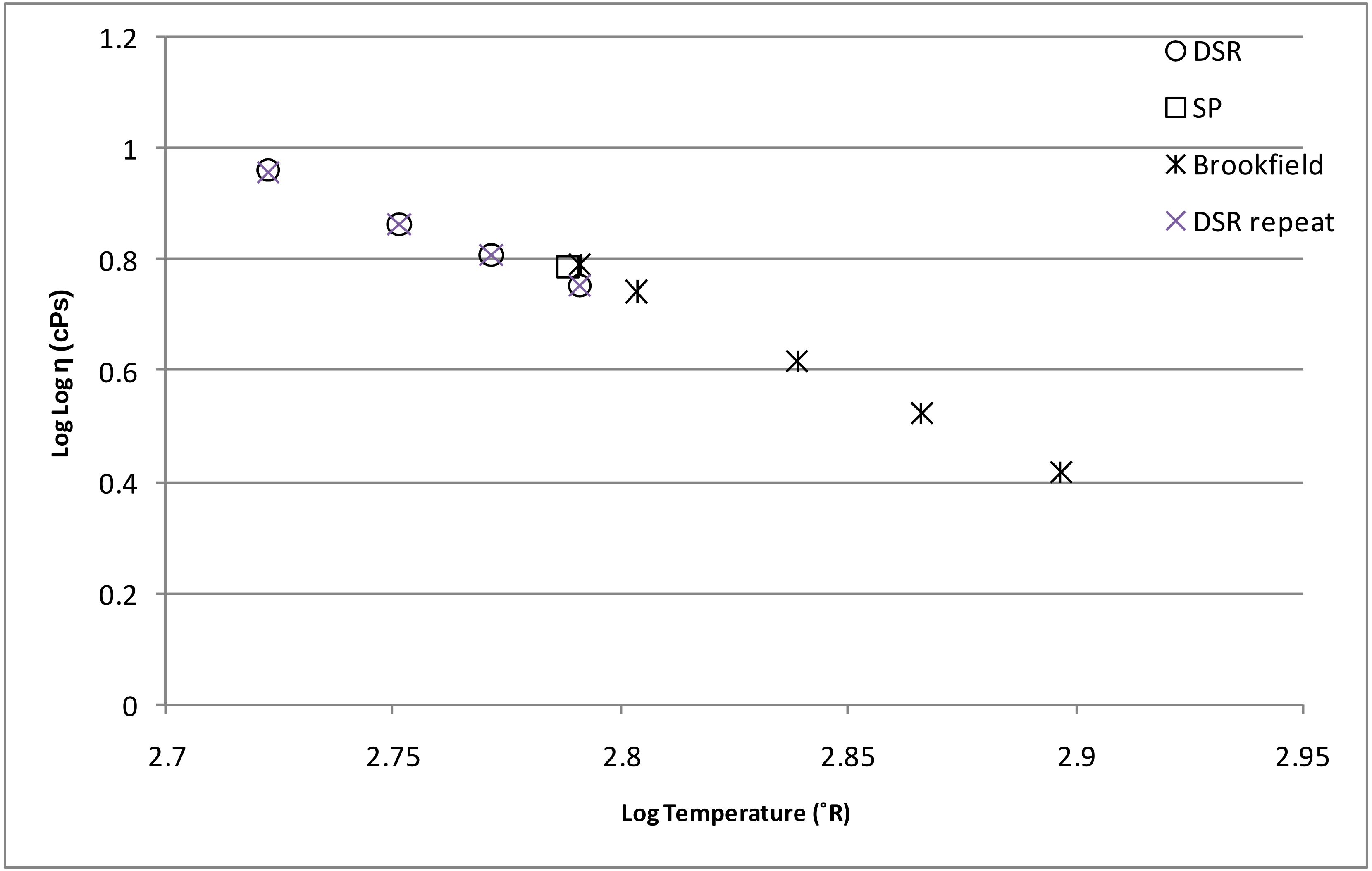


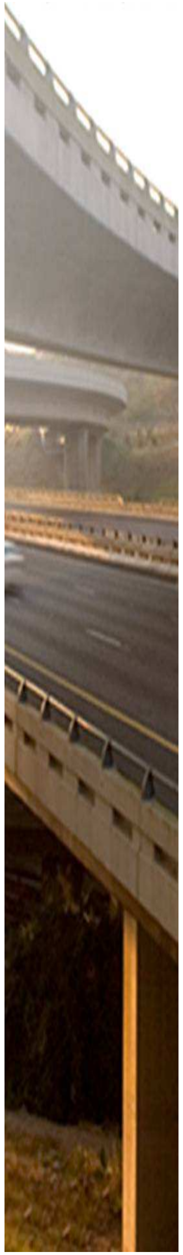
SBS RTFOT


1.2
1
0.8
0.6
0.4
0.2
0
2.7
2.75
2.8
2.85
2.9
2.95
Log Log η (cPs)
Log Temperature (˚R)
○ DSR
□ SP
⚹ Brookfield
× DSR repeat



SBS PAV





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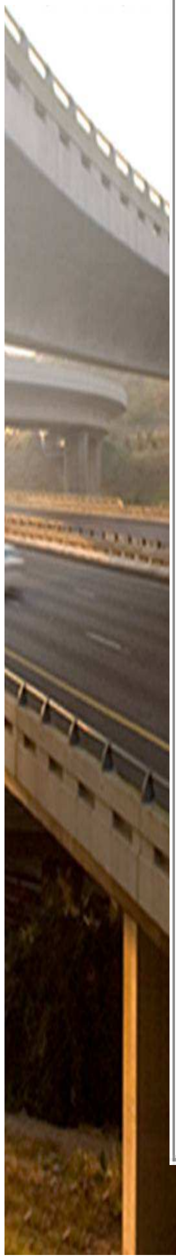
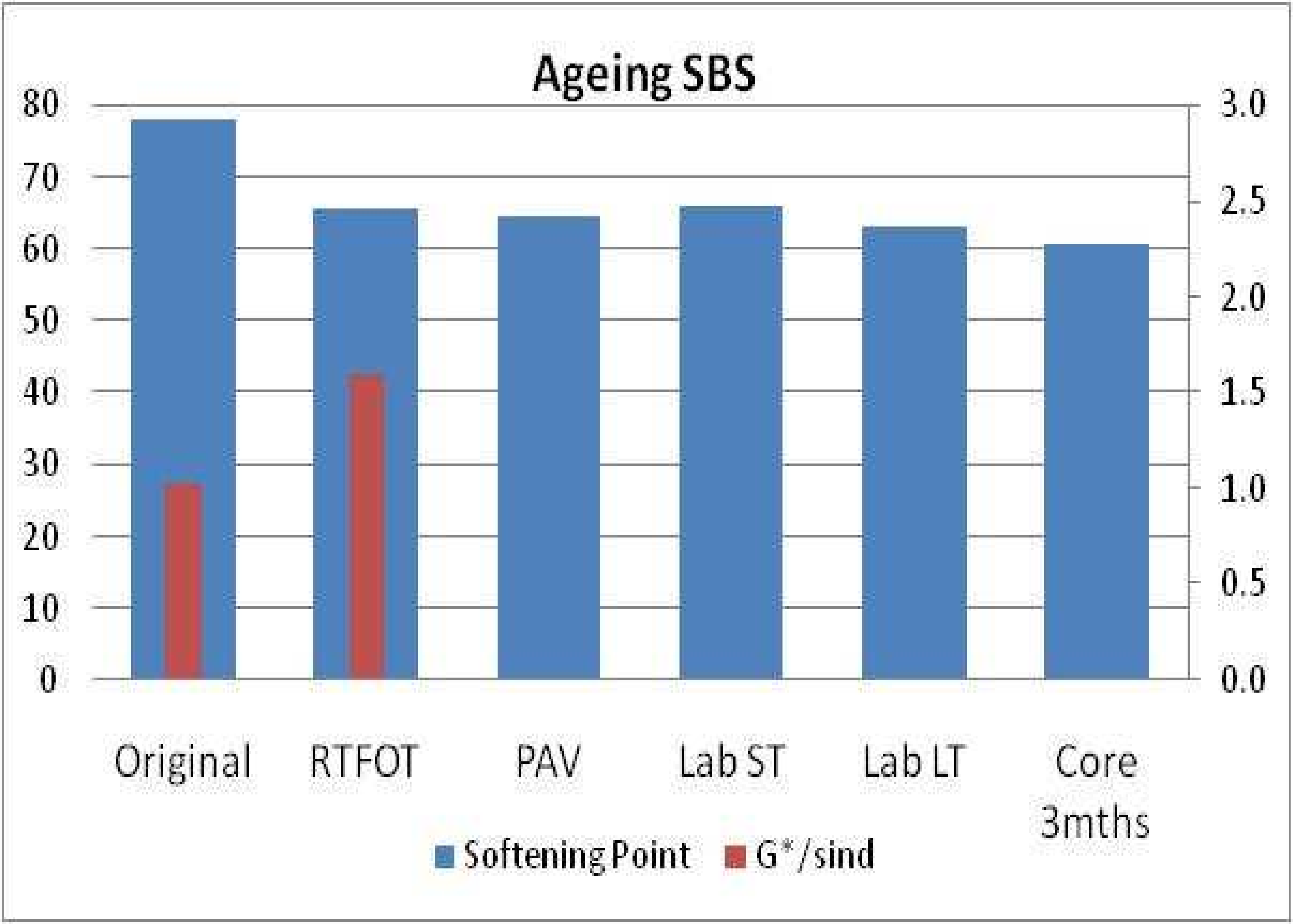
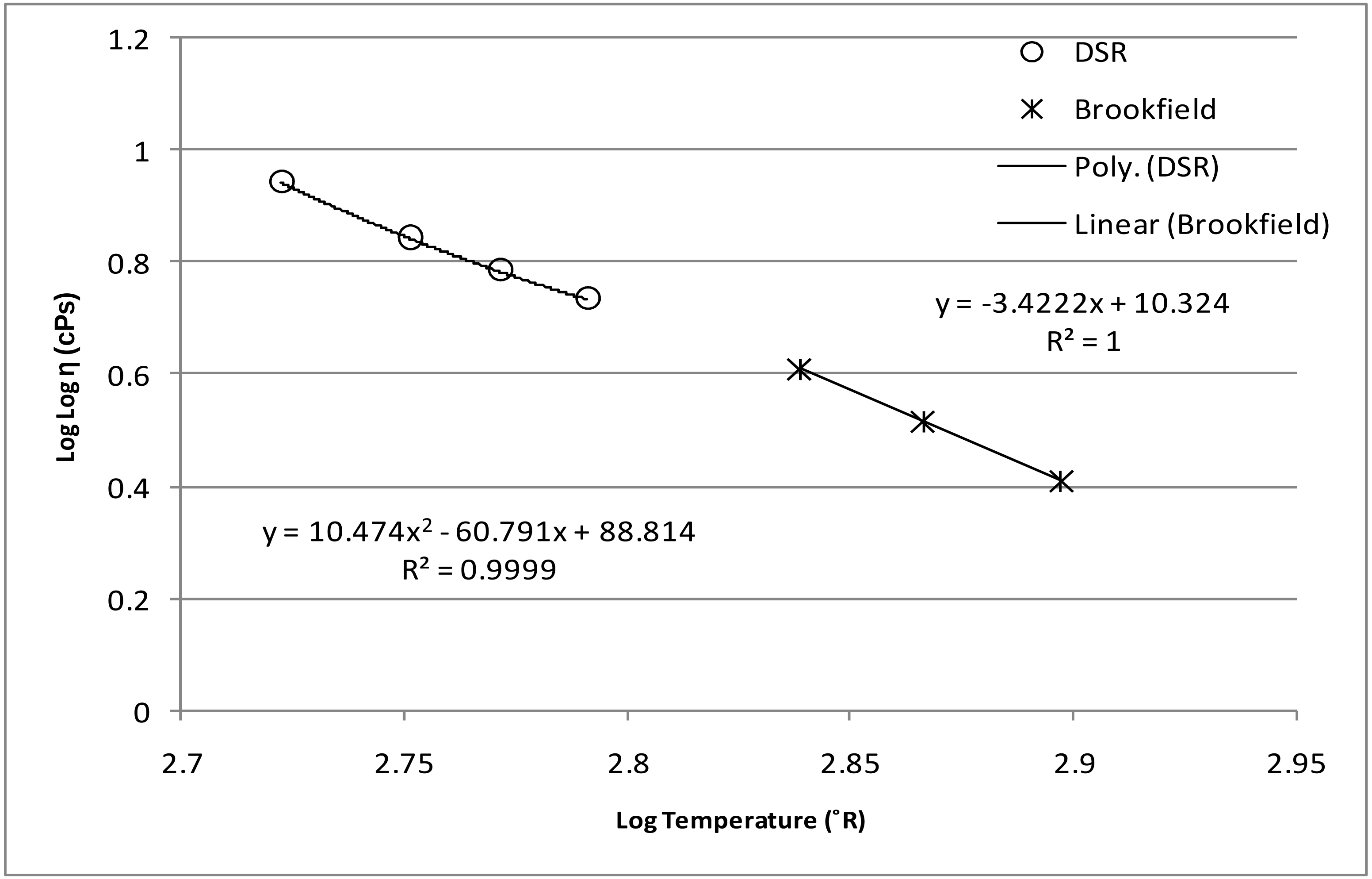
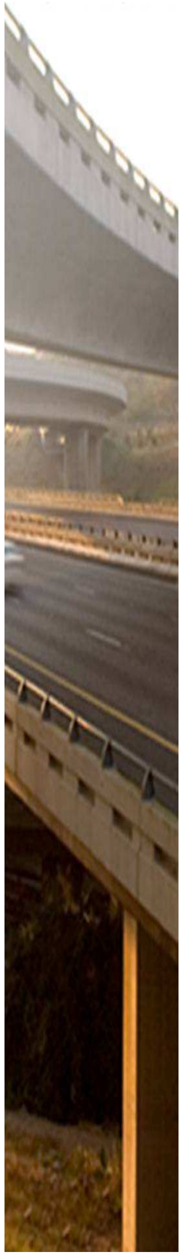



Ageing SBS
80
70
60
50
40
30
20
10
0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Original
RTFOT
PAV
Lab ST
Lab LT
Core 3mths
Softening Point
G*/sind

SBS Separate A-VTS Parameters



SBS Separate A-VTS Parameters



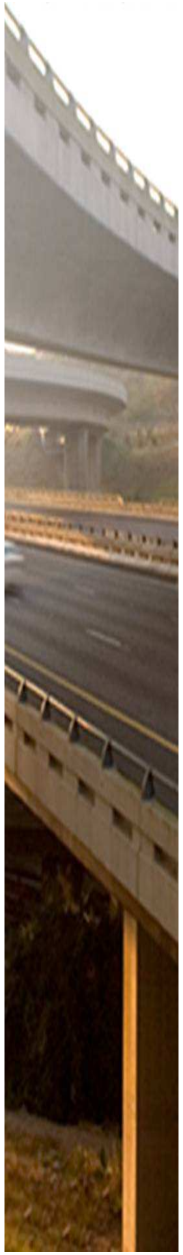
Binder	Ageing	coefficients		
		A	VTS	R 2
SBS	DSR	9.267	-3.059	0.9949
	Brook	10.324	-3.422	0.9996

Binder	Ageing	Regression parameters and coefficients			
		A	VTS - 1	VTS - 2	R 2
SBS curve	DSR	88.814	10.474	-60.791	0.9999
	Brook	10.324	-3.422	n/a	0.9996

Method	E* (MPa) @ 20 C 0.5 HZ	E* (MPa) @ 55 C O.5 Hz	E* (MPa) @ 20 C 10 HZ	E* (MPa) @ 55 C 10 Hz
DSR	2 431	294	4 937	719
Brook	6 460	571	10 763	1 369
DSR curve	2 622	280	5 257	683

266 % higher

Which Parameter Should Be Used?

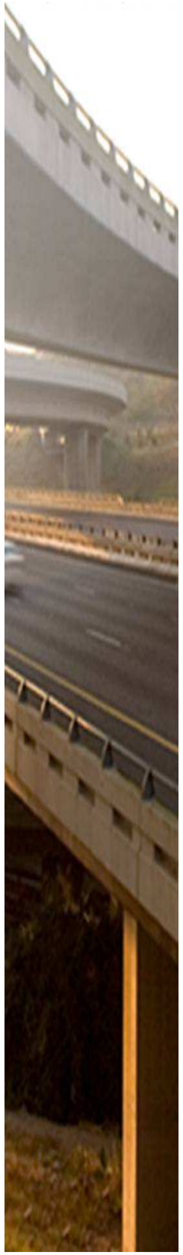


It was hoped to use Brookefield viscosity for obvious reasons.

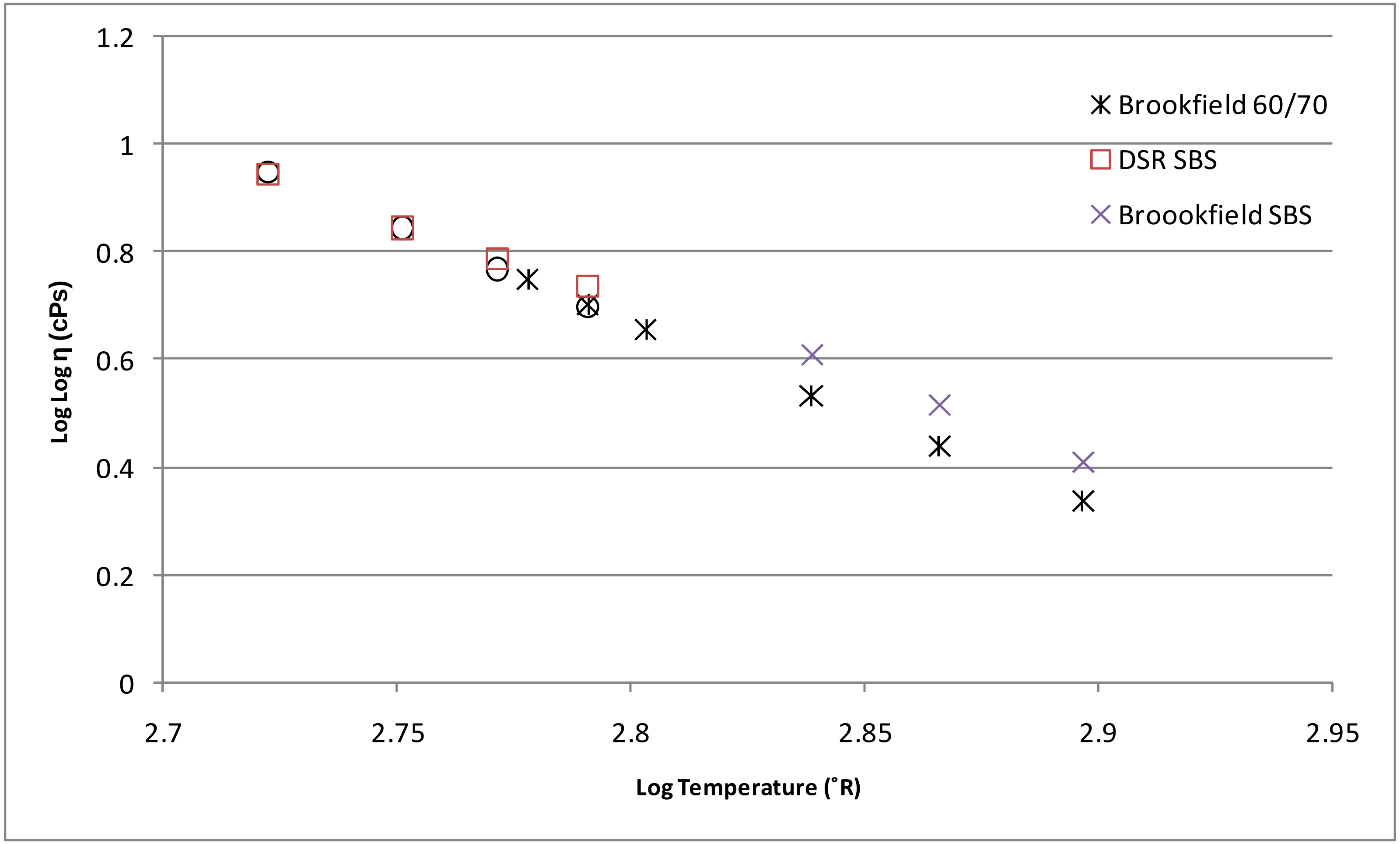
The best method is determined by two main factors, namely:

- Which test method determines viscosity at temperatures representing in-service pavement conditions?

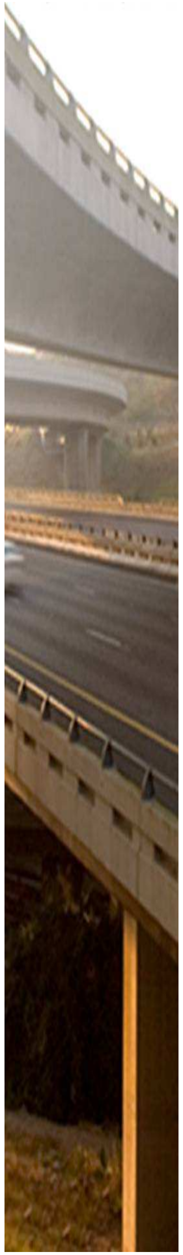
- Which test method gives “logical” results?



Viscosity - 60/70 vs SBS



Hirsch E* (Dynamic Modulus)



$$|E^*|_{mix} = P_c\left[4{,}200{,}000\left(1-\frac{VMA}{100}\right)+3\,|G^*|_{binder}\left(\frac{VFA\;x VMA}{10{,}000}\right)\right]+\frac{1-P_c}{\left[\frac{\left(1-\frac{VMA}{100}\right)}{4{,}200{,}000}+\frac{VMA}{3VFA\,|G^*|_{binder}}\right]} \qquad (16)$$

$$P_c = \frac{\left(20+\frac{VFAx3\,|G^*|_{binder}}{VMA}\right)^{0.58}}{650+\left(\frac{VFAx3\,|G^*|_{binder}}{VMA}\right)^{0.58}}$$

where:

$|E^*|$ = dynamic modulus (psi);

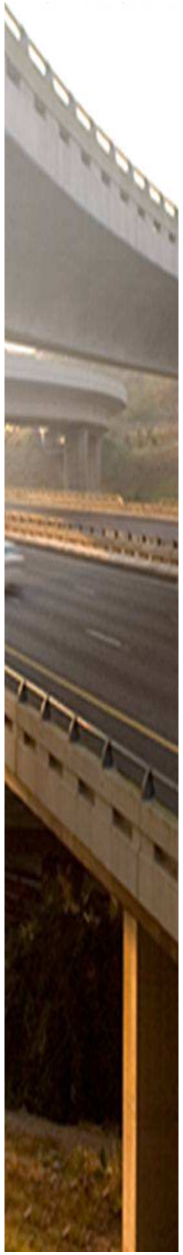
$|G^*|_{binder}$ = shear complex modulus of binder (psi);

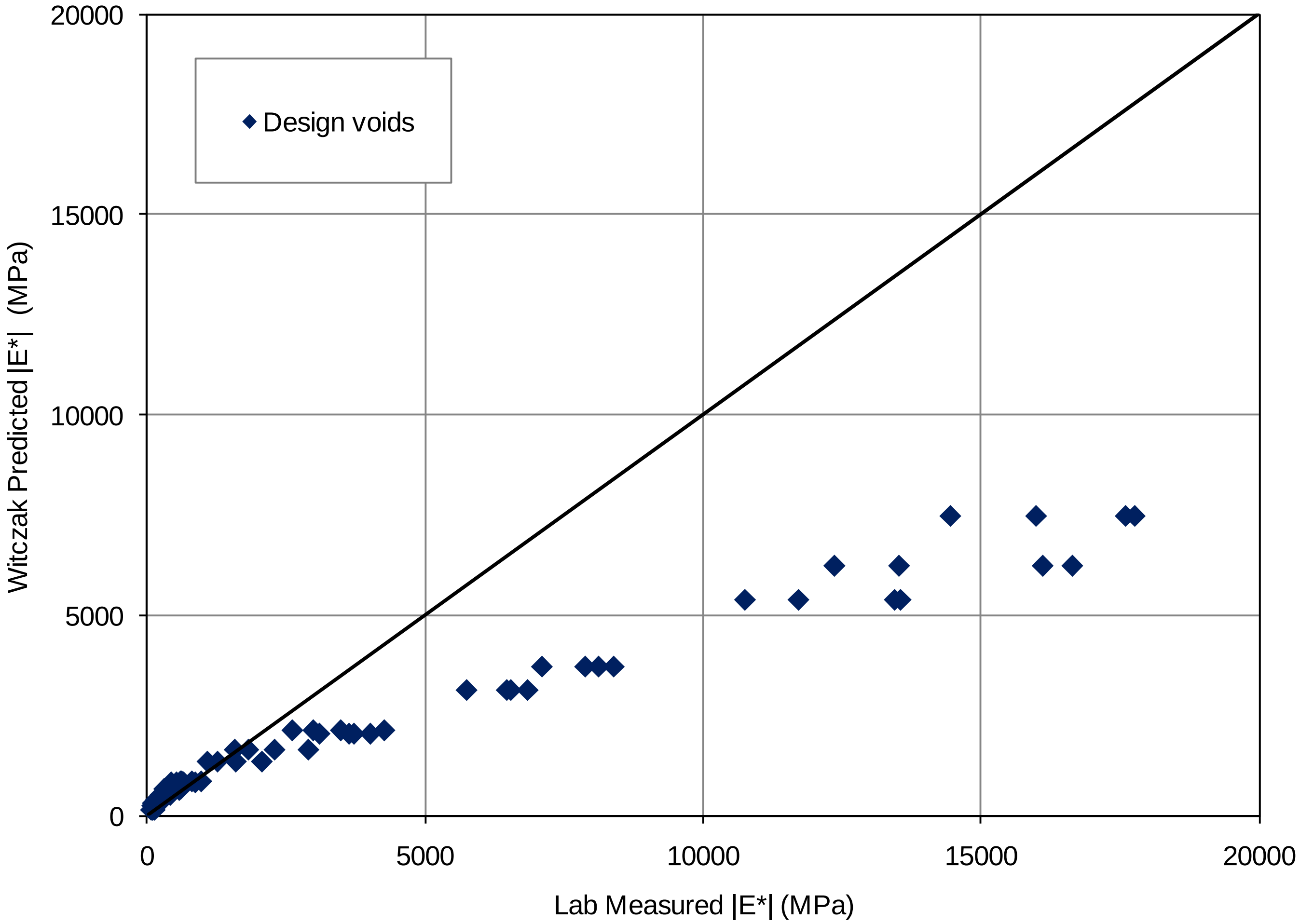
VMA = percent voids in mineral aggregates

VFA = percent voids filled with binder

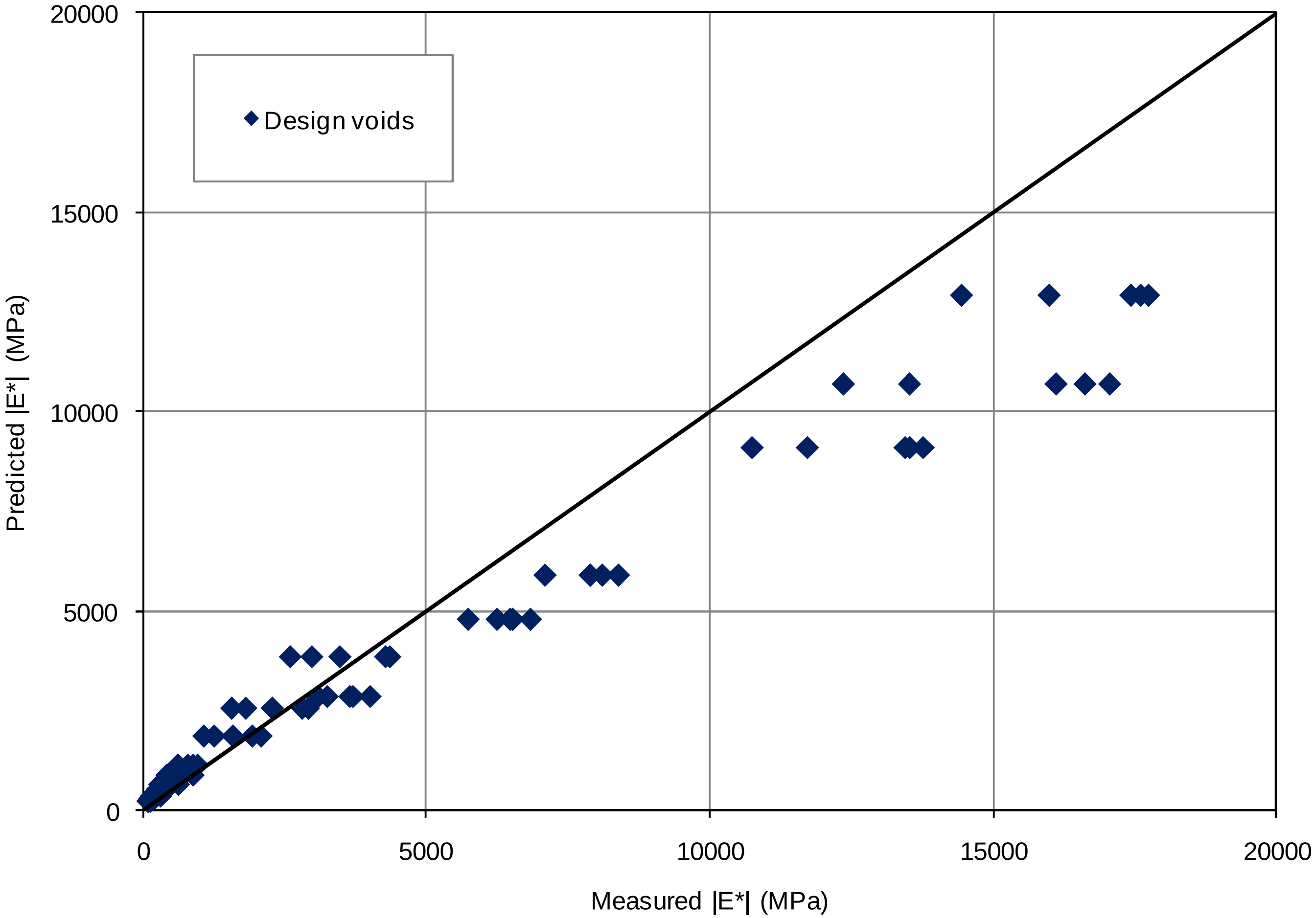
P_c = aggregate contact factor

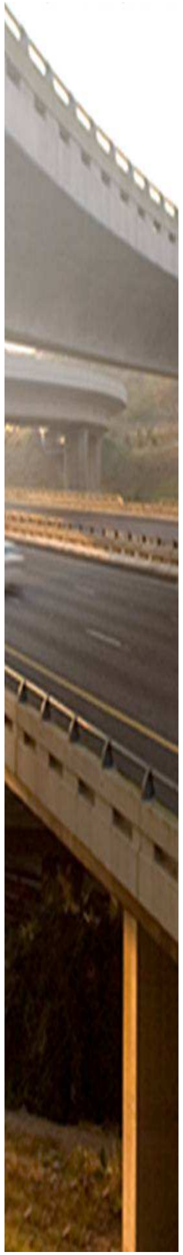
Witczak moduli vs Actual 40/50 BTB Dynamic Modulus

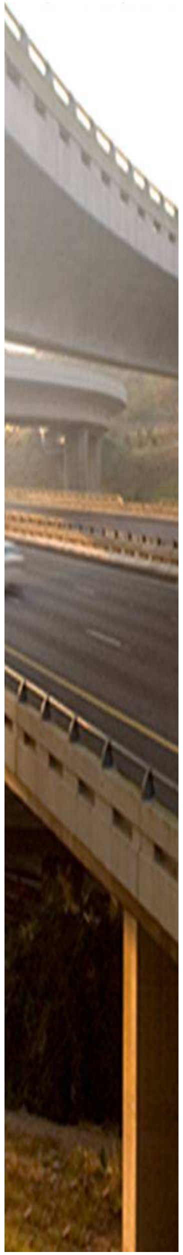




Hirsch moduli vs Actual 40/50 BTB Dynamic Modulus



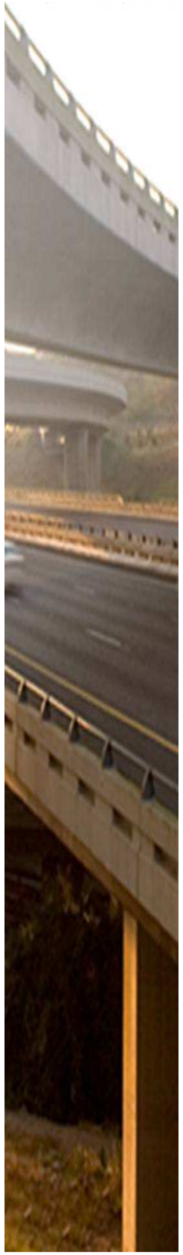




Importance of using the DSR?

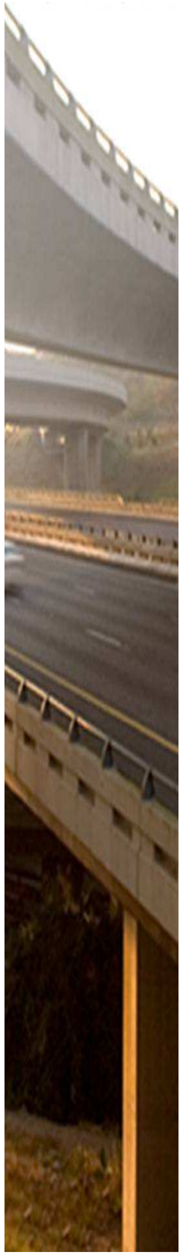
- For Witczak it is imperative to use DSR if we are to include modified binders in our resilient response predictions
- Hirsch only allows for DSR
- The international trend is towards DSR.

Reasons for large deviations from predicted values



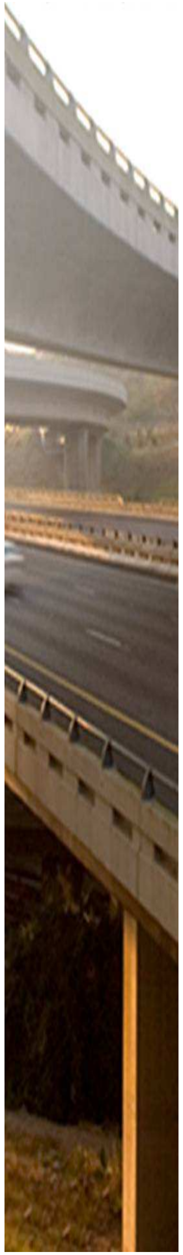
- * Variation within Witzak, Hirsch itself Requires recalibration at high binder stiffness
- * Incorrect Binder ageing Protocol

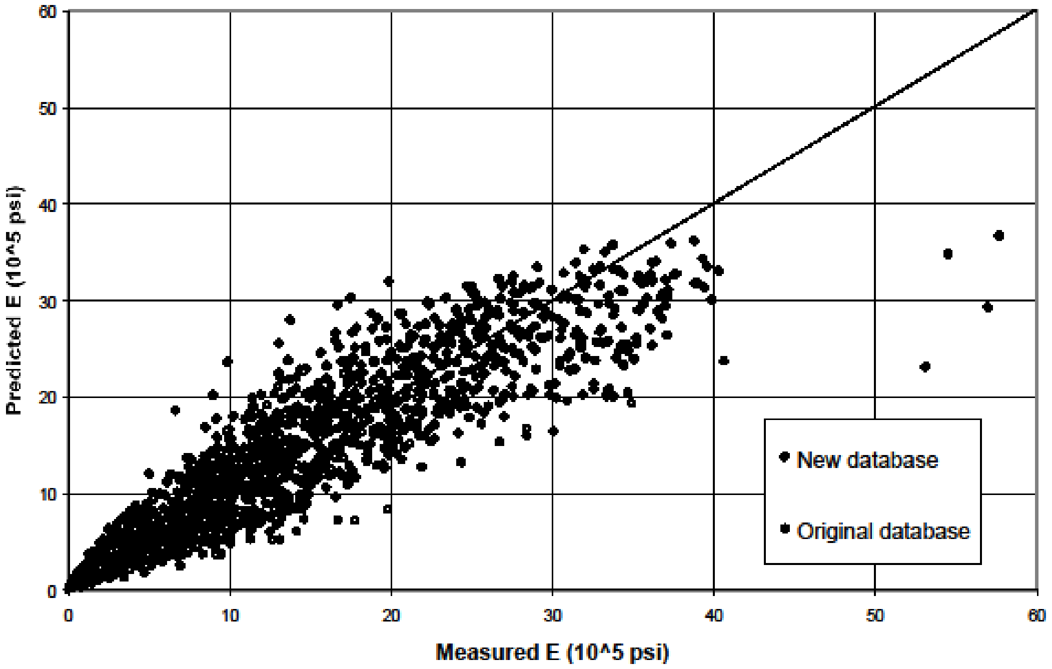
Witczak Model



- 205 mixes– 34 modified
- $R^2 = 0.886$
- For measured values of 14 000 MPa, predicted values range from 9 000 MPa to 20 000 MPa

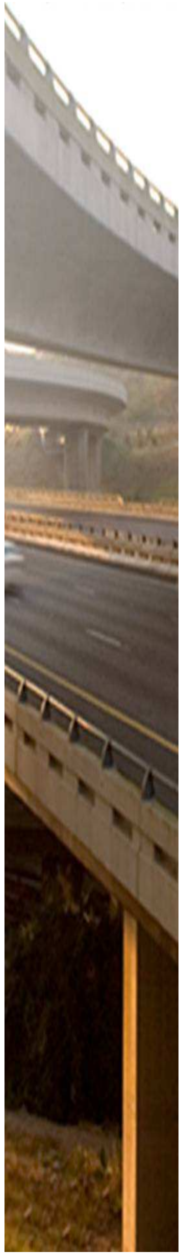
Witczak Model





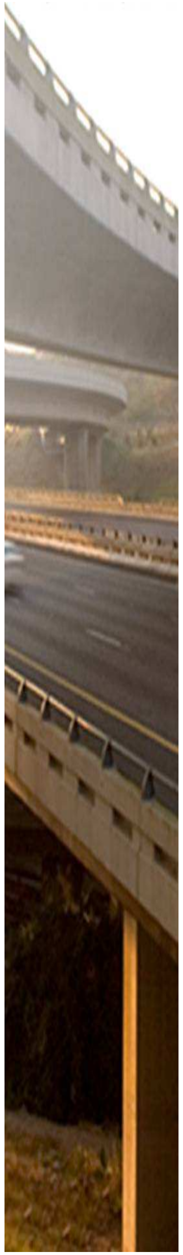
Issues Regarding the Ageing Protocol

- RTFOT currently 163°C, 75 minutes
- Proposed changes could include:
  - - extended time
  - - higher temperature



Differences between RTFOT and Recovered binder properties

Binder	Recovered Properties					
	RTFOT		Lab Aged		Field	
	R&B	Viscosity	R&B	Viscosity	R&B	Viscosity
60/70	52	220	56 - 58	950 - 1050		
40/50	55	607	55 - 58	700 - 1300	60 - 62	1 000 - 2300



The way forward

- Look at elongated RTFOT time to simulate increased initial binder stiffness in the field
- Put together a new calibrated model for South African mixes.