AAPA STUDY TOUR
QUESTIONS LIST &
STATE OF BINDERS RESEARCH IN SA

7th September 2011

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CSIR

Current South African Bitumen Spec

Are penetration or viscosity graded binders used?

Are there different specifications for asphalt and sprayed sealing grades of road grade and modified binders?

1	2	3	4	5	6
Property	Penetration grade				Test method
	40/50	60/70	80/100	150/200	
	Requirements				
Penetration at 25 °C/100 g/5 s, 1/10 mm	40-50	60-70	80-100	150-200	ASTM D5-IP49
Softening point (ring and ball), °C	49-59	46-56	42-51	36-43	ASTM D36*
Viscosity at 60 °C, Pa.s	220-400	140-250	75-150	30-60	ASTM D4402˚
Viscosity at 135 °C, Pa.s	0,27-0,65	0,22-0,45	0,15-0,40	0,12-0,30	ASTM D4402˚
Performance when subjected to the rolling thin film oven test:					ASTM D2872
a) mass change, % (by mass fraction), max.	0,3	0,3	0,3	0,3	ASTM D2872
b) viscosity at 60 °C, % of original, max.	300	300	300	300	ASTM D4402˚
c) softening point (ring and ball), °C, min.	52	48	44	37	ASTM D36*
d) increase in softening point, °C, max.	7	7	7	7	ASTM D36*
e) retained penetration, % of original, min.	60	55	50	50	ASTM D5-IP49
Spot test#, % xylene, max.	30	30	30	30	AASHTO T102

˚ Recommended apparatus is the RV viscometer, using SC 4 spindles with thermosel system.

\# Actual values to be reported in five-unit intervals.

* Using shouldered ring

Amdt 1; amdt 2; amdt 3; amdt 4; amdt 5; amdt 6; amdt 7

HMA Performance Parameter

Project undertaken to improve the mechanistic-empirical design method in South Africa (under auspices of SANRAL

- a number of different hot mix asphalts were evaluated in terms of the "Guide for Mechanistic-Empirical Design" (NCHRP, 2004)
- Guide recommends the use dynamic modulus as performance parameter for hot mix asphalt
- Guide recommends the use of the Witczak equation in order to predict dynamic modulus.
- Hirsch was evaluated in addition to Witczak

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Hierarchical Design Inputs – Where does Witczak fit in?

Level of engineering effort exerted in 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 - low accuracy (low traffic / cost)

A mixture of level can occur

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Witczak

$$\log\left|E^*\right| = 3.750063 + 0.029232P_{200} - 0.001767(P_{200})^2 - 0.002841P_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{(V_{beff}+V_a)} + \frac{\left[3.871977 - 0.0021P_4 + 0.003958P_{38} - 0.000017(P_{38})^2 + 0.00547P_{34}\right]}{1 + e^{(-0.603313 - 0.313351\log f - 0.393532\log\eta)}}$$

where:

E^* = dynamic modulus, psi.

η = bitumen viscosity, 10^6 Poise.

f = loading frequency, Hz.

V_a = air void content, %.

V_{beff} = effective bitumen content, % by volume.

P_{34} = cumulative % retained on the ¾ in (19.0mm) sieve.

P_{38} = cumulative % retained on the 3/8 in (9.5 mm) sieve.

P_4 = cumulative % retained on the No. 4 (4.75mm) sieve.

P_{200} = % passing the No. 200 (75 micron) sieve.

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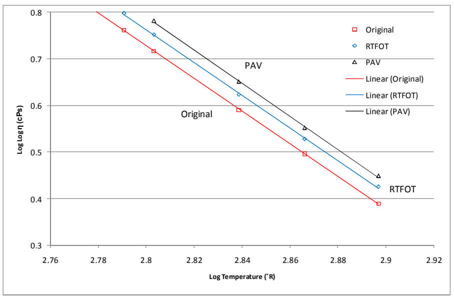
Representation of Viscosity



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

A = regression intercept;

VTS = regression slope of viscosity temperature susceptibility

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Determination of Viscosity

Multiple Methods allowed but conversion to Poise required

Has any attempt made to link empirical properties to performance?

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

Conversion to Viscosity Units

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

Where:
G^* = complex modulus of the binder (Pa)
δ = phase angle
η = viscosity (Pa.s

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

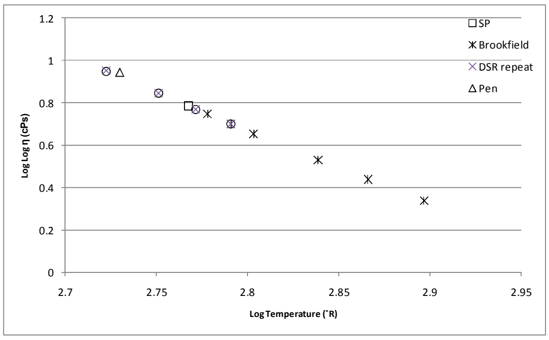
Where:
η = viscosity, in Poise
Pen = penetration 100 g, 5 sec loading, 0.1mm

η = 13 000 Poise at the softening point temperature

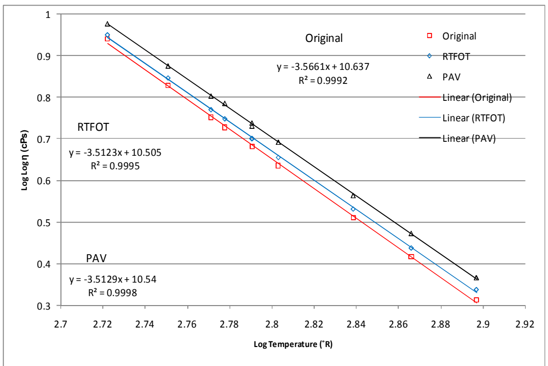
Determination of Viscosity

- Which method to use?
- Are they truly interchangeable in the Witczak Equation as related by the NCHRP documents? If empirical values are good predictors of performance – they should be interchangeable
- Interchangeability should be reflected by all values lying in a straight line on the A-VTS graph

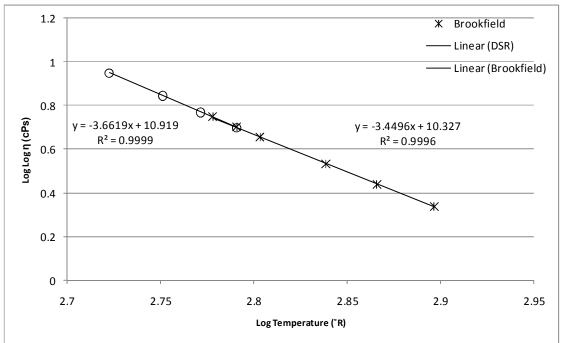
60/70 RTFOT



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

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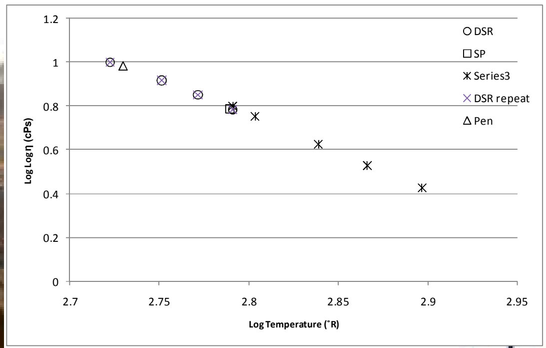
20/30 RTFOT



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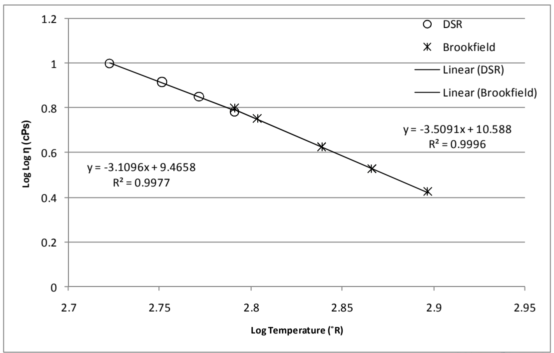
20/30 Separate A-VTS Parameters



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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

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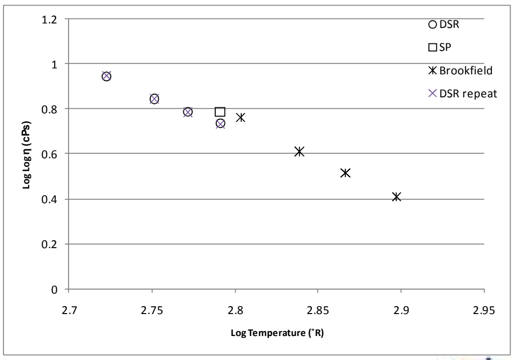
SBS RTFOT



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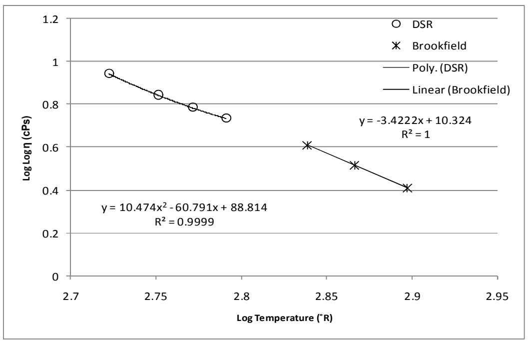
SBS Separate A-VTS Parameters



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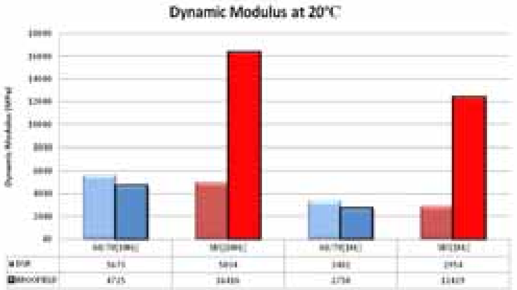
SBS vs 60/70 Separate A-VTS Parameters



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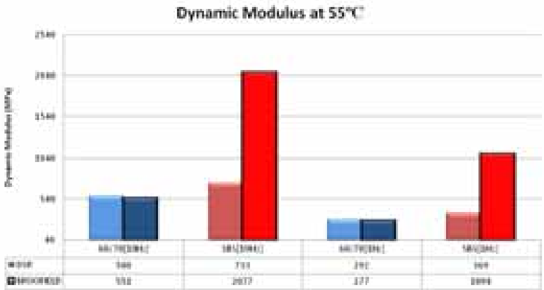
SBS vs 60/70 Separate A-VTS Parameters



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Which is correct? DSR vs Viscosity

- DSR Measures at the pavement operating temperatures, Viscometer you have to extrapolate
- DSR data is generated in the same temperature range within which the dynamic modulus data is generated
- Relationship between DSR predicted values and actual Dynamic Modulus is more in line with that obtained from unmodified binders
- Fundamentally Viscosity extrapolation is incorrect as it does not correlate with reality See illustration
- Rheologically, as binders become harder (eg 20/30 or polymer-modified,) they become increasingly shear-thinning ie the viscosity becomes increasingly shear rate dependent. Viscosities for such binders are not interchangeable/comparable because the Brookfield and DSR have generated these viscosities at different shear rates.

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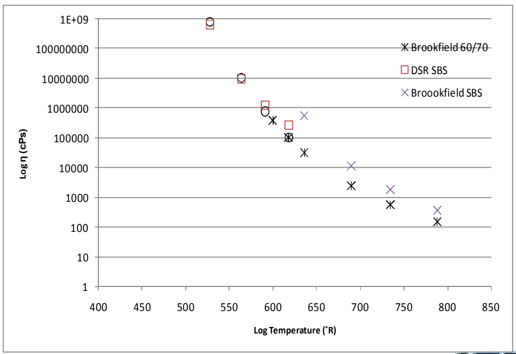
Nature of Modifier -60/70 vs SBS



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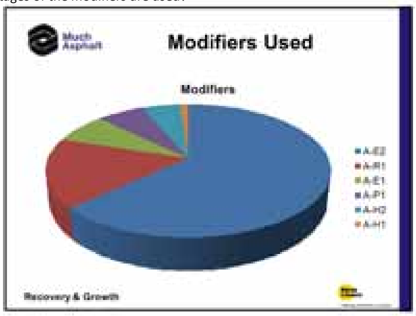
Modified Binders used in asphalt

What modified binders are commonly used in asphalt manufacture? Is the selection based on performance? Have long term performance trials been undertaken to assess the advantages?

What elastomeric and plastomeric modifiers are available? Does the specification identify them by type?

What relative percentages of the modifiers are used?



Hirsch E* (Dynamic Modulus)

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

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

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

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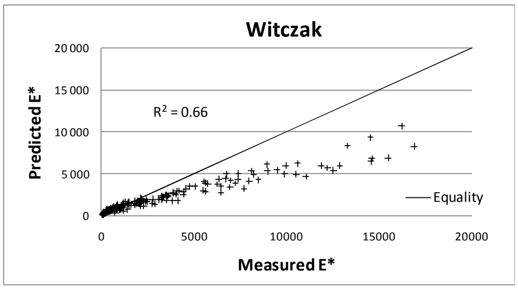
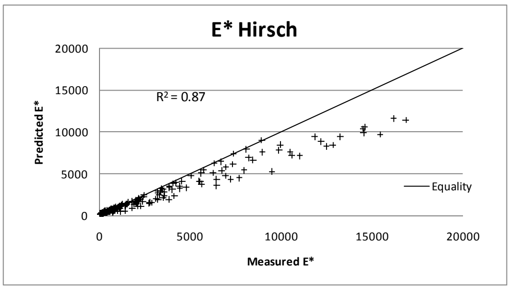
Witczak Model Prediction



Witczak Model Prediction



Under- Prediction: WHY???

*Variation within Witzak, Hirsch itself – especially at higher binder stiffness values

*Incorrect Binder ageing Protocol

- The RTFOT procedure cannot simulate ageing for 'non-standard' mixes that vary from those around which the procedure was developed. Mixes that have significantly higher mixing and compaction temperatures (eg SBS, 20/30, CRM) will have binders that will be significantly stiffer after laying than that predicted by the RTFOT procedure > ie resulting in lower prediction for dynamic modulus. (Opposite will be true for warm mixes)
- The RTFOT procedure cannot simulate ageing for 'non-standard' mixes where the film thickness varies significantly from the norm.
- The RTFOT procedure makes no provision for the distance of the site from the HMA plant. A greater distance between the HMA plant usually necessitates a higher mixing temperature, which aggravates the longer ageing time that passes before the mixture is paved.

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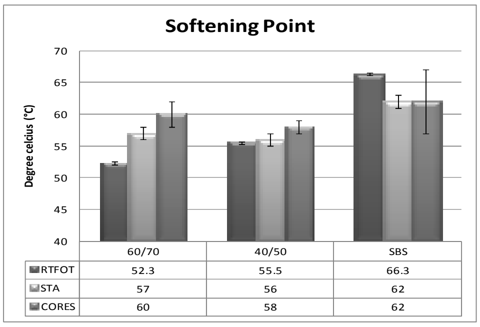
Extended RTFOT using Softening Point



	60/70	40/50	SBS
RTFOT	52.3	55.5	66.3
STA	57	56	62
CORES	60	58	62

RTFOT needs to change for Performance Prediction

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

Extended RTFOT - Goals

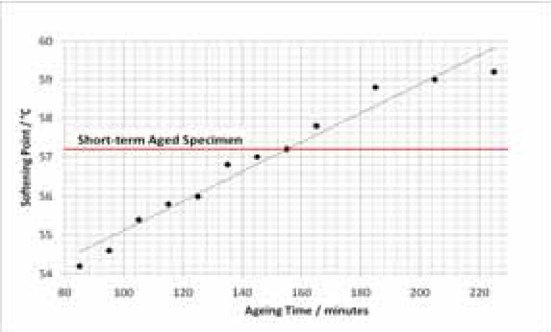
- Establishment of a modified protocol for a binder type/class.

  eg 40/50 x minutes

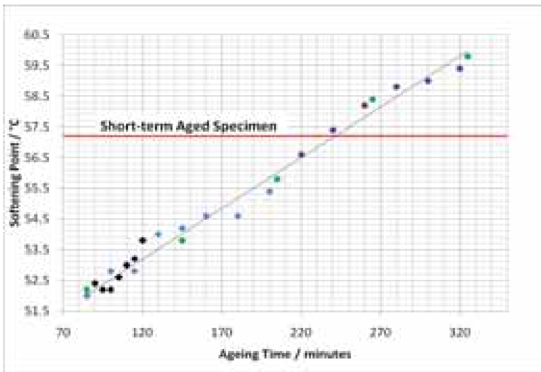
  60/70 y minutes

  - requires data from a number of sites for statistically valid value
- Refinement of the ageing model via adjustment factors for
  - binder film thickness eg ± 10 mins for every ± µm
  - travelling time between HMA plant and construction site. ± 10 mins for every 20 min deviation from the average

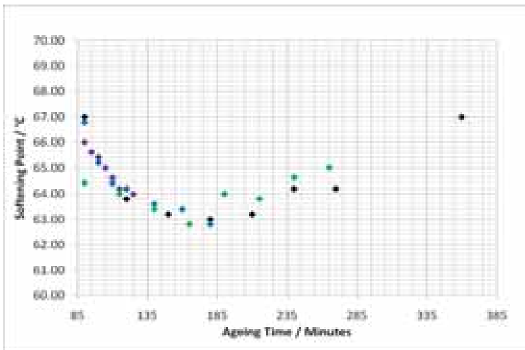
Extended RTFOT using Softening Point – 40/50



Extended RTFOT using Softening Point – 60/70



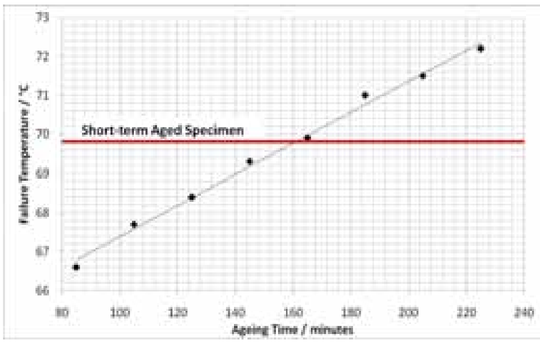
Extended RTFOT using Softening Point – SBS



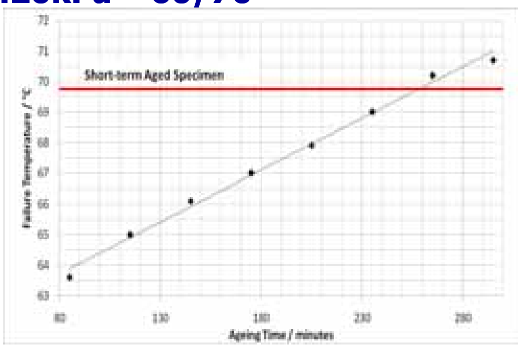
Extended RTFOT using Softening Point

- 155 ± 10 minutes for the 40/50 penetration-grade bitumen
- 242 ± 10 minutes for the 60/70 penetration-grade bitumen

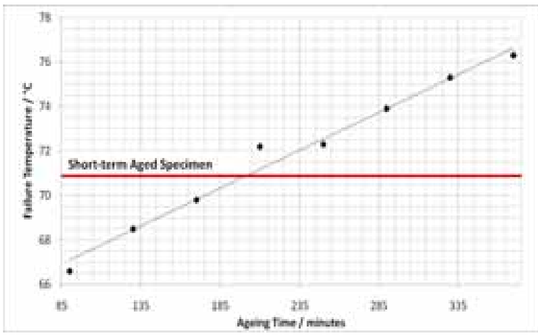
Extended RTFOT using Failure Temperature where |G*|/sin δ = 2.20kPa – 40/50



Extended RTFOT using Failure Temperature where |G*|/sin δ = 2.20kPa – 60/70



Extended RTFOT using Failure Temperature where |G*|/sin δ = 2.20kPa – SBS



Extended RTFOT using Failure Temperature where |G*|/sin δ = 2.20kPa – SBS

•160 ± 5 minutes for the 40/50 penetration-grade bitumen (155 for softening point)

•258 ± 5 minutes for the 60/70 penetration-grade bitumen (242 for softening point)

•200 ± 5 minutes for SBS-modified binder

Dynamic Modulus generated at 10 Hz for 60/70

Temperature	RTFOT	STA	Core
0°C	15 090	19 655	22 965
50°C	740	1 080	1 512

Recommended Ageing Model - NCHRP

The Global Ageing System (GAS), a system of four models, namely:

- Original to mix/lay-down model
- Surface aging model
- Air void adjustment
- Viscosity-depth model

Alternative Models – Tentative CSIR

$$\eta_{aged} = \eta_{\mathrm{mod}\,RTFOT} + \frac{t}{t_{PAV}} \times (\eta_{PAV} - \eta_{\mathrm{mod}\,RTFOT}) \qquad (2.16)$$

Where,

η_{aged} =viscosity after t months (cPs)

$\eta_{modRTFOT}$=viscosity after t months (cPs)

η_{PAV} =viscosity after t months (cPs)

t =time in months

t_{PAV} = x, y z months to PAV stiffness depending on climate zone, voids, film thickness

Ultimate Use for Ageing Viscosity

Thermal Cracking – Pothole Prevention

Proposed Future Binder Spec for South Africa

Performance graded binder spec using a DSR would have the following benefits:

- The industry would be in a better position to predict asphalt mix performance, thereby reducing or eliminating premature mix failures that can be attributed to the mix binder. This could result in significant savings in the long term.
- A DSR-based performance graded binder specification would be aligned with the needs of the new SAPDM.
- Long-term ageing of the binder is currently not in the South African specification. Consequently, long-term performance could now be evaluated and predicted.
- The current two specifications (one of which accommodates modified binders) will be reduced to one specification. The space and amount of laboratory equipment required for testing will be reduced
- Internationally, the trend is towards performance graded systems using a DSR. Eventually South Africa will need to adopt a similar system if we are to make use of international research data for national implementation.

Proposed Future Binder Spec for South Africa

Is any attempt made to compare to international grades of binders (Superpave Performance Grading)?

Binder Class	**58 S**	**64 S**	**64 H**	**64 V**
Original Binder				
Average 7 day maximum pavement design temperature (˚C)	< 58	< 64	< 64	< 64
DSR |G*|/sinδ _ min 1.0	@ 58˚C	@ 64 ˚C	@ 64 ˚C	@ 64 ˚C
Viscosity Pa.s (DSR) @ 135˚C	≤ 3	≤ 3	≤ 3	≤ 3
Flash Point (˚C)	< 230	< 230	< 230	< 230
Percent Recovery at σ = 3.2 kPa	N/A	N/A	> 15	>30
Storage Stability @ 160˚C Maximum difference between top and bottom	N/A	N/A	0.3 kPa @ 64˚C	0.3 kPa @ 64˚C
RTFOT Binder				
Mass Change (m/m%, max)	0.3			
J_{nr} (at σ = 3.2 kPa)	≤ 4.0 kPa^{-1}@ 58˚C	≤ 4.0 kPa^{-1}@ 64 ˚C	≤ 2.0 kPa^{-1}@ 64 ˚C	≤ 1.0 kPa^{-1}@ 64 ˚C
A, VTS viscosity parameters	report only	report only	report only	report only
Rolling Stones Test (% cover)	40	40	50	60
PAV Binder - @ 100˚C				
DSR |G*|sinδ	Max 5 000 kPa @ 22 ˚C	Max 5 000 kPa @ 22 ˚C	Max 6 000 kPa @ 22 ˚C	Max 6 000 kPa @ 22 ˚C

Additional Questions

- What efforts are being made to use alternatives to crude oil sourced bituminous binders? Are their binders commercially available?
- Much and no

- Are cut-back binders used, if yes what percentage of the overall binder usage? Are there best performance guides for blending cutback in the field?
- Yes (Pre-coat and Prime)
- Don't know (100% of pre-coat and prime)
- No (For Safety and Financial reasons)

MC30 and Emulsified Cutback