



12TH Conference on Asphalt Pavements for southern Africa

13 -16 October 2019 | Sun City | South Africa

A Proposed National Protocol for Performing Frequency Sweeps on Bituminous Binder

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CSIR Smart Mobility

- Frequency Sweeps
 - Characterisation of binder for construction of Master Curves, Black Diagrams, etc
 - Protocol is for research purposes and NOT for SATS 3208
- Initial Conventional Practice at the CSIR
 - Determination of LVE limits at discrete temperatures using a DSR
 - Frequency sweeps are then performed on freshly cast samples at each temperature using the determined limits
- The initial conventional protocol:
 - Was more costly
 - Was more time consuming
 - Had increased sample loading (Increased chance of variability)

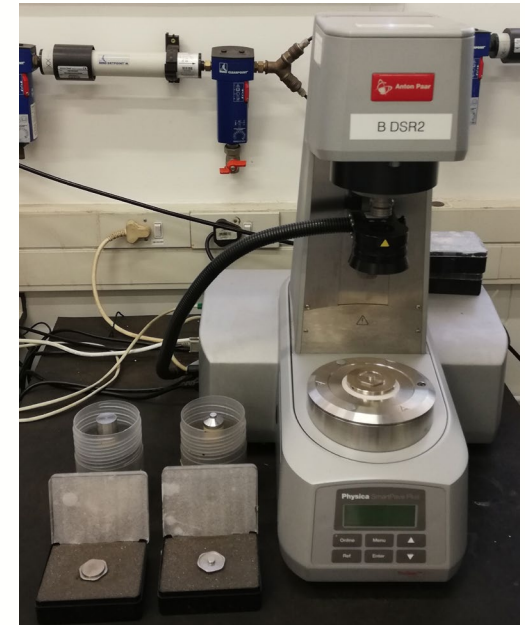
Initial Conventional Test Protocol:

- DSR frequency sweeps be done at temperatures and frequencies as depicted
- The frequency sweeps were done in duplicate
 - From low to high, and
 - High to low temperatures

Temperature (°C)	6, 14, 22, 28, 34, 46, 58, 64
Frequency (Log Radians / Second)	-0.6 to 1.4 (at intervals of 0.2)



- **Materials:**
 - SBS Modified Binder and
 - 50/70 Grade Bitumen
- **Frequency Sweep Testing Protocols:**
 - Three methods based on:
 - Sample loading
 - LVE Limit and Temperature
 - Strain Determination

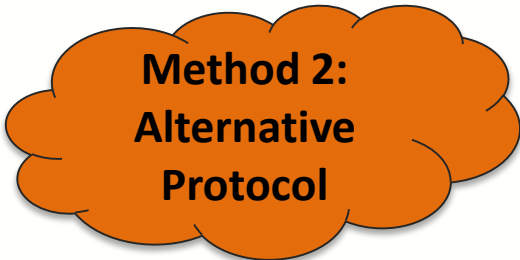


Frequency Sweep Testing Protocol

**Method 1: Initial
Conventional
CSIR Protocol**

Parameter	Description
Loading	New sample for each frequency sweep temperature
LVE / Temperature	<ul style="list-style-type: none">• Determine LVE limit for each temperature at the highest frequency• Test at that temperature using the determined LVE strain
Strain Determination	As determined by the equipment and using the equipment-recommended value

Frequency Sweep Testing Protocol



**Method 2:
Alternative
Protocol**

Parameter	Description
Loading	Same sample for all temperatures per spindle
LVE / Temperature	<ul style="list-style-type: none">Determine LVE limit at the lowest temperature and highest frequency for each spindleUse only that strain for each spindle at all temperatures
Strain Determination	As determined by the equipment and using the equipment-recommended value

Frequency Sweep Testing Protocol

**Method 3:
Alternative
Protocol**

Parameter	Description
Loading	Same sample for all temperatures per spindle
LVE / Temperature	No LVE limit determined
Strain Determination	Use fixed recommended values (as Per SATS 3208) of <ul style="list-style-type: none">• 1% for the 8mm spindle and• 2% for 25mm spindle

Repeatability Testing

- SBS modified binder
 - Four (4) repetitions
 - Each repeat carried out on a new sample
 - Testing was done after 40 hours of PAV ageing
 - 8mm Spindle (Temperatures 6 to 34 °C)
 - 25mm Spindle (Temperatures 46 to 70 °C)

Repeatability Testing (COV of Complex Modulus with Temperature)

Spindle	8 mm					25 mm			
Temperature (°C)	6	14	22	28	34	46	58	64	70
Average COV (Over all frequencies)	2.6	3.0	3.6	4.4	4.9	4.7	4.5	4.8	4.8

Method 1 vs Method 2

Temp. (°C)	Average Complex Modulus (Pa) @ 25.1 rad/s [1.4 log r/s]				Difference between averages (%)	COV
	Method 1 (Fresh sample)	Strain (%)	Method 2 (Same sample)	Strain (%)		
6	$6.17 * 10^7$	0.5	$6.19 * 10^7$	0.5	0.3	2.6
14	$2.06 * 10^7$	0.5	$2.00 * 10^7$	0.5	2.7	3.0
22	$5.28 * 10^6$	0.5	$5.57 * 10^6$	0.5	5.4	3.6
28	$1.78 * 10^6$	1.0	$1.88 * 10^6$	0.5	5.8	4.4
34	$5.50 * 10^5$	1.0	$5.68 * 10^5$	0.5	3.2	4.9
46	$7.90 * 10^4$	1.0	$8.31 * 10^4$	1.0	2.1	4.7
58	$1.35 * 10^4$	5.0	$1.36 * 10^4$	1.0	0.4	4.4
64	$6.07 * 10^3$	7.2	$6.02 * 10^3$	1.0	0.8	4.8
70	$2.81 * 10^3$	8.9	$2.80 * 10^3$	1.0	0.5	4.8

Method 1 vs Method 2

- 50/70 grade bitumen
- Evaluated after RTFOT for differences in results
- Difference between averages of Complex Modulus @ 25.1 radians / second [1.4 log radians / sec]
- The difference between the two sets of results compare well in relation to the COV established for the repeatability of the test

Method 1 vs Method 2: Fresh vs same sample for each temperature (Difference between averages of Complex Modulus @ 25.1 radians / second)

Temperature (°C)	6	14	22	28	34	46	58	64	70
Difference between averages (%)	0.3	2.7	5.4	5.8	3.2	2.1	0.4	0.8	0.5
Average COV (Over all frequencies)	2.6	3.0	3.6	4.4	4.9	4.7	4.5	4.8	4.8

Method 2: The effect of different strains using the same sample per spindle

- 50/70 grade bitumen
- Evaluated after 40 Hours PAV Aging
- Determine the difference between averages of Complex Modulus with the same sample per spindle, but using different strains for the analysis
- The results depicted are for a frequency sweep at 70 °C
- The difference between the two sets of results compare well.

Method 2: The effect of different strains using the same sample per spindle

Angular Frequency (log rad/s)	-0.6	-0.4	-0.2	0.0	0.2	0.4	0.6	0.8	1.0	1.2	1.4
Difference (%)	0.5	0.5	0.5	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.4
COV per frequency (70°C)	6.1	5.8	5.6	5.3	4.8	4.6	4.4	4.4	4.2	4.1	3.8

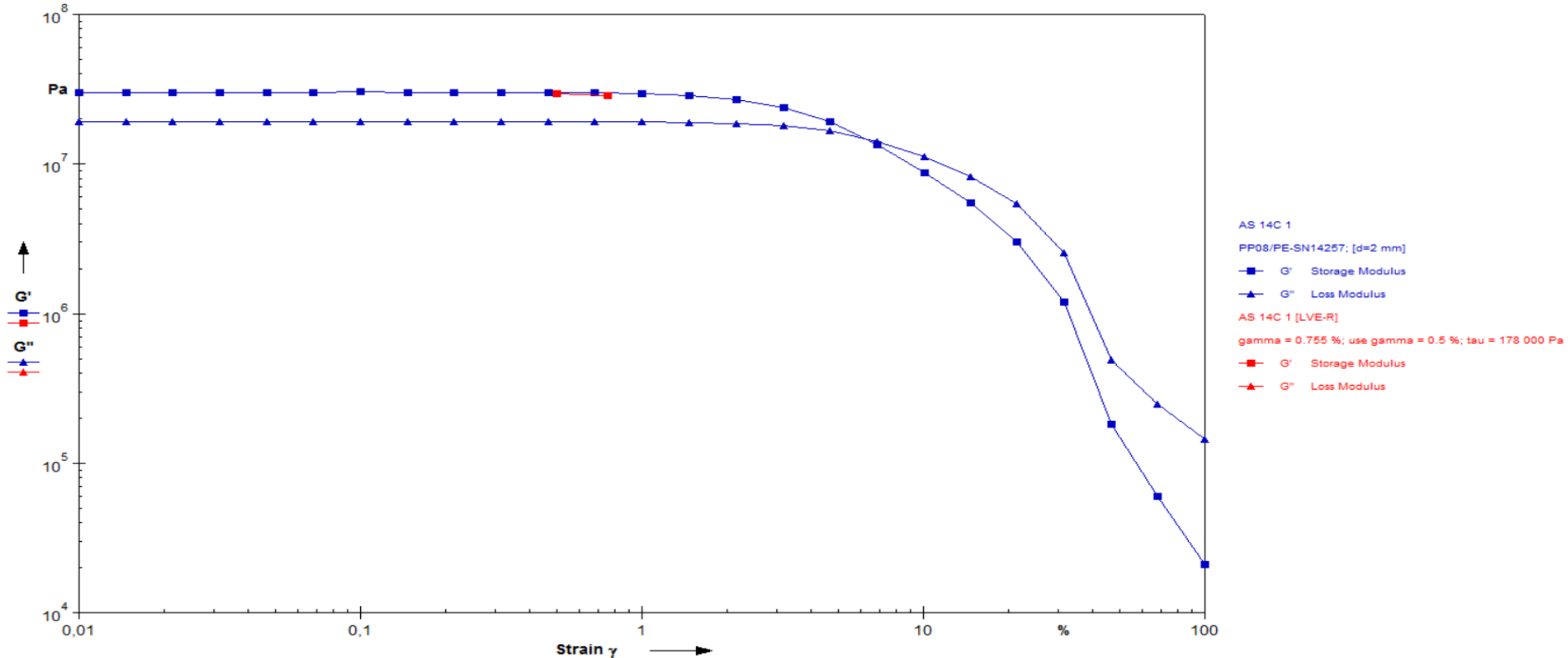
Method 3: No LVE determined, use fixed recommended values

Method 3 was abandoned, as the 1% strain values were beyond the strain limit (between 14°C to 28°C).



RESULTS

Amplitude sweep at 14 °C of 50/70 grade bitumen



Repeatability testing using 4 sets of result

- The average coefficient of variation ranged from 2.6 to 4.9% for temperatures between 6 and 70 °C.
- The average coefficient of variation increased with increasing temperature

Two sets of results comparing Method 1 (Initial) and Method 2

- The differences between the two methods compare well in relation to the COV established for the repeatability

CONCLUSION

The results have demonstrated that the protocol to determine LVE limits can be **significantly shortened** by:

- using the same sample for each spindle, and
- using only one strain value for each spindle (which is determined at the lowest temperature and highest frequency for that spindle)



Based on the results the following Research protocol is recommended for National implementation:

- Determine the LVE for each spindle at the **lowest temperature** and **highest frequency** for that spindle
- Use the **same sample for each spindle** when performing frequency sweeps
- For the 8 mm spindle, the frequency sweeps were done from **highest to lowest** temperature
- For the 25 mm spindle, the frequency sweeps were done from **lowest to highest** temperature

- Ensure that there is at least **one temperature overlap** for the 8 mm and 25 mm spindles.
- Recommended **testing temperatures** (as per variations in complex modulus testing):
 - 6 °C, 14 °C, 22 °C, 28 °C, 34 °C, 46 °C, 58 °C, 64 °C and 70 °C
- Proposed **testing frequencies** are 11 frequencies between:
 - – 0.6 to 1.4 (log basis) at 0.2 intervals

- I would like to thank
 - Co-Authors Mr Johan O'Connell and Ms Nomashaka Hawes
 - Mr Geoff Rowe for advice received in writing the paper
 - SANRAL and Much Asphalt for funding of the project

Thank You

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