Relating the Rheology of Recovered Binders from Asphalt Surfacing in the Field to their Fatigue Performance

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$G^*.Sin\delta$ and ΔT_C are two of many rheological parameters that have been proposed as potential specification properties for control of fatigue performance for hot mix asphalt. This paper assesses the extent of correlation between the values of these parameters and the presence of cracking in the hot mix asphalt surfacing from 11 sites carefully selected to represent a wide range of fatigue performance over periods ranging from 5 to 20 years. The binders were recovered using a modified Abson recovery process that accurately represents the properties of the aged in-situ binder.

Results indicate that ΔT_C correlates better with the condition of the asphalt surfacing, compared with $G^*.Sin\delta$. The results also demonstrate that although binder fatigue parameters may be an indicator of fatigue performance, the actual fatigue performance is also determined by other factors such as binder film thickness of the mix, traffic loading, climate and rate of ageing.

Keywords—Cracking, Fatigue Performance, $G^*.Sin\delta$, ΔT_C.

1. INTRODUCTION

A. G.Sinδ – the "Fatigue Parameter"*

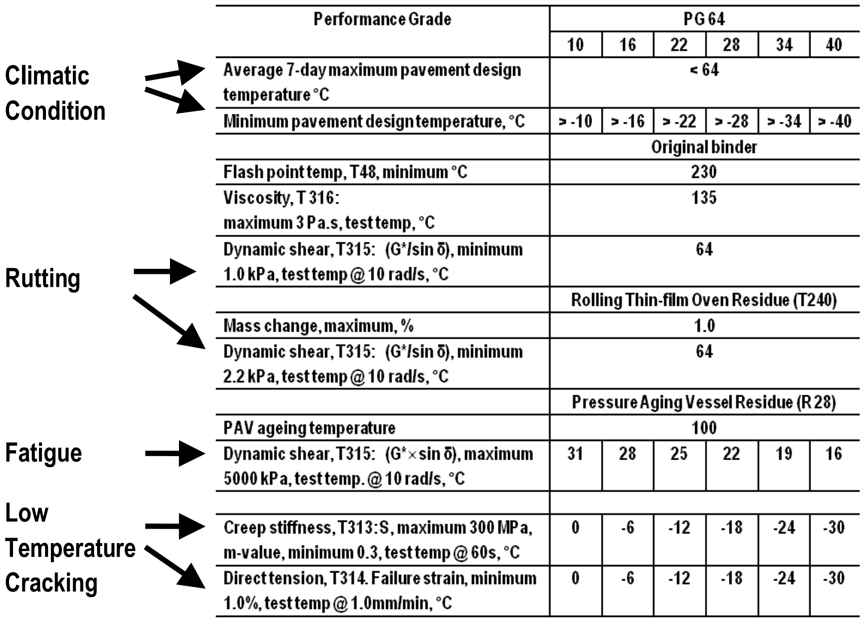
The first successful effort to establish a performance related asphalt binder specification led to the AASHTO SUPERPAVE® specification [1] in 1992 in the USA, also known as the Performance Graded (PG) Asphalt Binder Specification. The properties used for the specification were primarily:

- G*, the complex modulus, as determined by the dynamic shear rheometer (DSR), and
- S, the flexural creep stiffness, and m-value as obtained from the bending beam rheometer (BBR).

The grading system is classified by two numbers, e.g. " PG64-28". The first of these numbers is an indication of the bitumen's high temperature (HT) performance and the second relates to its low temperature (LT) performance, which is prescribed by the high and low temperature of the road where the asphalt binder is to be applied. The system was intended to be applicable to both unmodified and polymer-modified bitumens.

A portion of the PG bitumen specification is shown in Fig. 1. The specifications have been designed to address the three main failure mechanisms for asphalt mixtures:

- Permanent deformation (rutting) at high service temperatures (HT),
- Fatigue cracking at intermediate service temperatures (IT),
- Low temperature cracking at low service temperatures (LT).



	Performance Grade	PG 64					
		10	16	22	28	34	40
Climatic Condition	Average 7-day maximum pavement design temperature °C	< 64					
	Minimum pavement design temperature, °C	> -10	> -16	> -22	> -28	> -34	> -40
		Original binder					
	Flash point temp, T48, minimum °C	230					
	Viscosity, T 316: maximum 3 Pa.s, test temp, °C	135					
Rutting	Dynamic shear, T315: ($G^*/\sin\delta$), minimum 1.0 kPa, test temp @ 10 rad/s, °C	64					
		Rolling Thin-film Oven Residue (T240)					
	Mass change, maximum, %	1.0					
	Dynamic shear, T315: ($G^*/\sin\delta$), minimum 2.2 kPa, test temp @ 10 rad/s, °C	64					
		Pressure Aging Vessel Residue (R 28)					
	PAV ageing temperature	100					
Fatigue	Dynamic shear, T315: ($G^*\times\sin\delta$), maximum 5000 kPa, test temp. @ 10 rad/s, °C	31	28	25	22	19	16
Low Temperature Cracking							
	Creep stiffness, T313: S, maximum 300 MPa, m-value, minimum 0.3, test temp @ 60s, °C	0	-6	-12	-18	-24	-30
	Direct tension, T314. Failure strain, minimum 1.0%, test temp @ 1.0mm/min, °C	0	-6	-12	-18	-24	-30

Fig. 1. Extract from AASHTO M 320-05, Standard Specification for Performance Graded Bitumen.

Asphalt mixes become fatigued during their in-service life due to repeated traffic loading or environmental expansion and contraction in response to road temperature fluctuations. In order to limit fatigue failure in the asphalt mix, G*.Sinδ (also referred to as the 'fatigue parameter') was specified at intermediate pavement temperature (IT) to not exceed 5000 kPa. Intermediate service temperature is defined as:

$$IT = \frac{\mathrm{HT+LT}}{2} + 4 \qquad (1)$$

The fatigue life of viscoelastic asphalt mixtures can be described in terms of dissipated energy criteria where energy is dissipated during loading and unloading periods [2, 3]. This concept was used to derive the G*.Sinδ parameter and the limit of 5000 kPa was determined using field correlation.

Over time, it has been reported that in some instances the parameter G*.Sinδ exhibits poor correlation with cracking [4 – 6]. It has been proposed that the majority of asphalt binders tested during the Strategic Highway Research Program (SHRP) were unmodified bitumens [7] and G*.Sinδ does not reflect the fatigue performance of polymer-modified binders correctly.

B. ΔT_C – the "top-down Fatigue Parameter"

ΔT_C was proposed as a parameter to control fatigue in asphalt mixes in 2001 [8], but it gained popularity in 2011 when Anderson et al [9] demonstrated good correlation with non-load-related cracking in airport pavements. A number of roads agencies in North America have specified ΔT_C to control fatigue failure, especially when it is as a result of non-load-related top-down cracking [10].

ΔT_C is defined as

$$\Delta T_C = T_C.S - T_C.m \qquad (2)$$

where $T_C.S$ is the critical temperature at which S (at 60 s) = 300 MPa, and

$T_C.m$ is the critical temperature at which the m-value (at 60 s) = 0,3 MPa/s

The South African PG specification has adopted ΔT_C, and has a requirement for $\Delta T_C \geq -5$ °C [11]

C. Study Objective

This paper assesses the extent of correlation between *G*.Sinδ and* ΔT_C of recovered binders and the presence of cracking in the hot mix asphalt surfacing from 11 sites, which represent a wide range of fatigue performance over 5 to 20 years.

The binders were recovered using a modified Abson recovery process [12] to promote an accurate representation of the aged in-situ binder.

The outcomes of the study will help evaluate the efficacy of the ΔT_C specification in SATS 3208 [11] , while using the correlation of G*.Sinδ with cracking as a reference.

2. METHODOLOGY

A. Investigative Approach

The 11 sites selected for this study are listed in Table 1 in the chronological order in which they were investigated, but separated by the condition of the surface, with regards to the presence of cracking or not. The asphalt surfacing from these sites consists of continuously graded mixes used as a surfacing layer. The asphalt binder used in the asphalt mixes are not identified, because the performance parameters under investigation should be 'binder blind', i.e. their potential ability to predict binder performance should be independent of the grade and type of binder used, and whether the binder is modified or not.

Table 1: Field sites selected for evaluation of fatigue performance

Site	***Location***	***Condition of Surfacing***
1	N3, Germiston	No cracking is visible
2	Golden Highway, Soweto	
3	R104 , Pretoria	
4	R25, Modderfontein	
5	R 21, Kempton Park	Cracking - Base related*
6	R50, Pretoria, Mix 1	Cracking is visible
7	Zambezi Road, Pretoria	
8	N4, Pretoria	
9	Duiker Road, Pretoria	
10	George Storrar Road, Pretoria	
11	R50, Pretoria, Mix 2	

* Cracking – Base related designates that the cracking appears not to be related the binder condition but may be related to the condition of the base of the road.

B. *Test Methods*

The test methods used in this investigation are listed in Table 2 .

Table 2:Test methods used in the investigation.

Property / Procedure	***Test Method***
G*.Sinδ	AASHTO T315 [13]
Flexural Creep Stiffness and m-Value	AASHTO T313 [14]
Binder recovery from the field	BE-TM-BINDER-1-2006 [12]

3. RESULTS

A. *Repeatability of Results*

One site was selected to produce duplicate results, including duplication of the recovery process. This was done to illustrate how well a single result can be duplicated and does not have any statistical significance. The results are given in Table 3.

Table 3: Duplication of the results of Site 2.

Property	First Binder Recovery	Second Binder Recovery
G.Sinδ (kPa)*	12 700	14 400
ΔT_C (°C)	- 5.5	- 6.9

The relatively large difference in ΔT_C can be attributed to the lower repeatability of the m=value as illustrated Fig. 2, where $T_C.S$ differs by 0.1 °C and $T_C.m$ differs by 1.5°C for the duplicate recoveries.

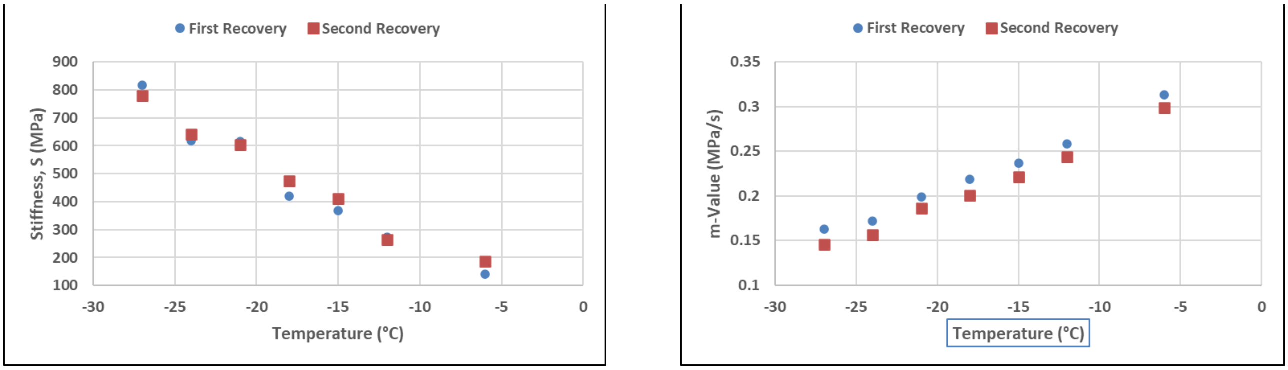


Fig. 2. Duplication of results for S and the m-value with temperature.

B. *G*.Sinδ and ΔT_C Values for the Recovered Binders*

The results of *G*.Sinδ and* ΔT_C for the recovered binders are given in Table 4.

Table 4:Softening Point as an AIP for the Original and Recovered Binders.

Site	***Location***	***Condition of Surfacing***	***Binder Film Thickness (µm)***	***ΔT_C (°C)***	***G*.Sinδ (kPa) at 22°C***
1	N3, Germiston	No cracking is visible	6.1	- 5.4	9 700
2	Golden Highway, Soweto		6.0	- 5.5	12 700
3	R104, Pretoria		6.1	- 1.4	8 400
4	R25, Modderfontein		7.2	- 9.5	10 300
5	R21, Kempton Park	Cracking - Base related	7.7	- 1.0	6 700
6	R50, Pretoria, Mix 1	Cracking is visible	6.8	-10.5	20 900
7	Zambezi Road, Pretoria		5.9	-14.6	14 800
8	N4, Pretoria		6.8	- 10.3	16 900
9	Duiker Road, Pretoria		6.0	- 8.4	14 000
10	George Storrar Road		5.7	- 9.3	13 600
11	R50, Pretoria, Mix 2		6.5	-14.6	-

The results are graphically depicted in Fig. 3 and Fig. 4. The specification limits presented in Fig. 3 and Fig. 4 have been included for reference purposes only, as the specification limits do not apply to recovered binders

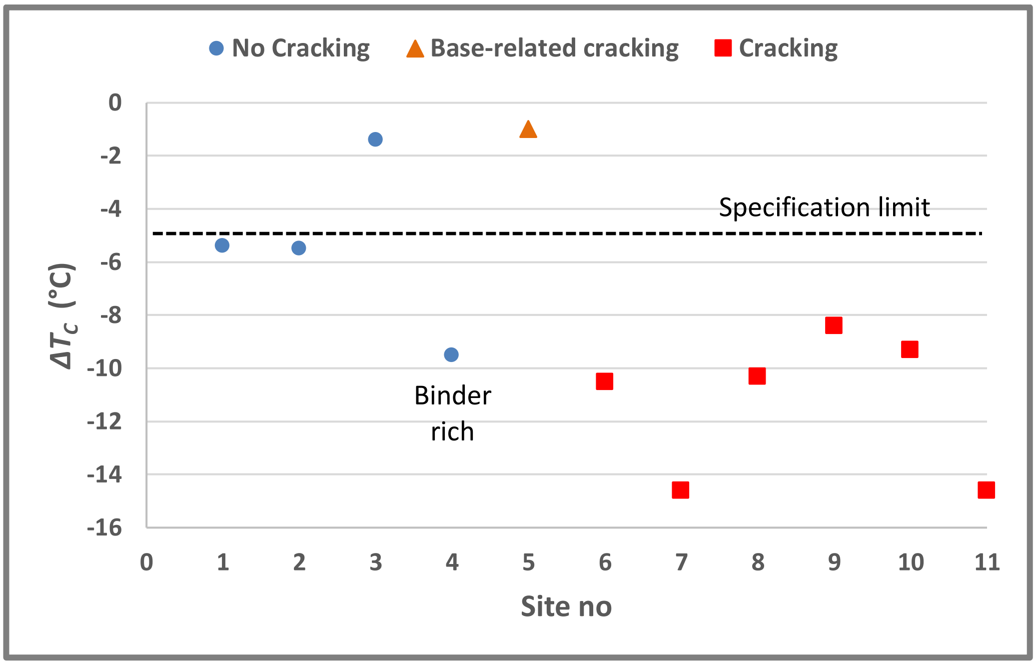


Fig. 3. Visual correlation of ΔT_C with cracking.

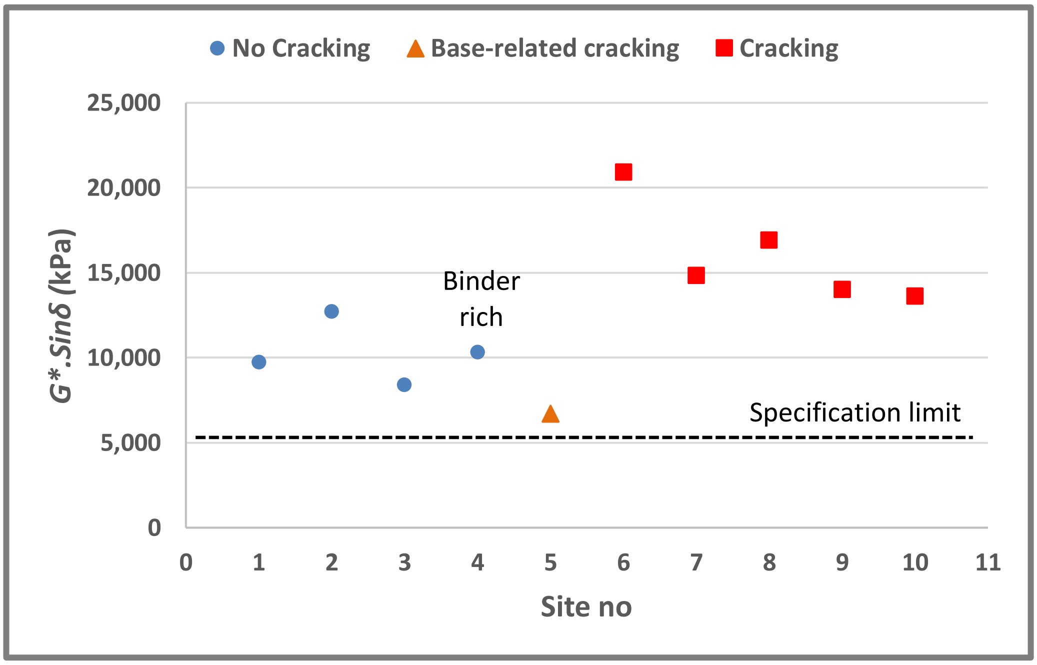


Fig. 4. Visual correlation of G*.Sinδ with cracking.

C. Correlation between G*.Sinδ and ΔT_C

The correlation between G*.Sinδ and ΔT_C is presented in Fig. 5.

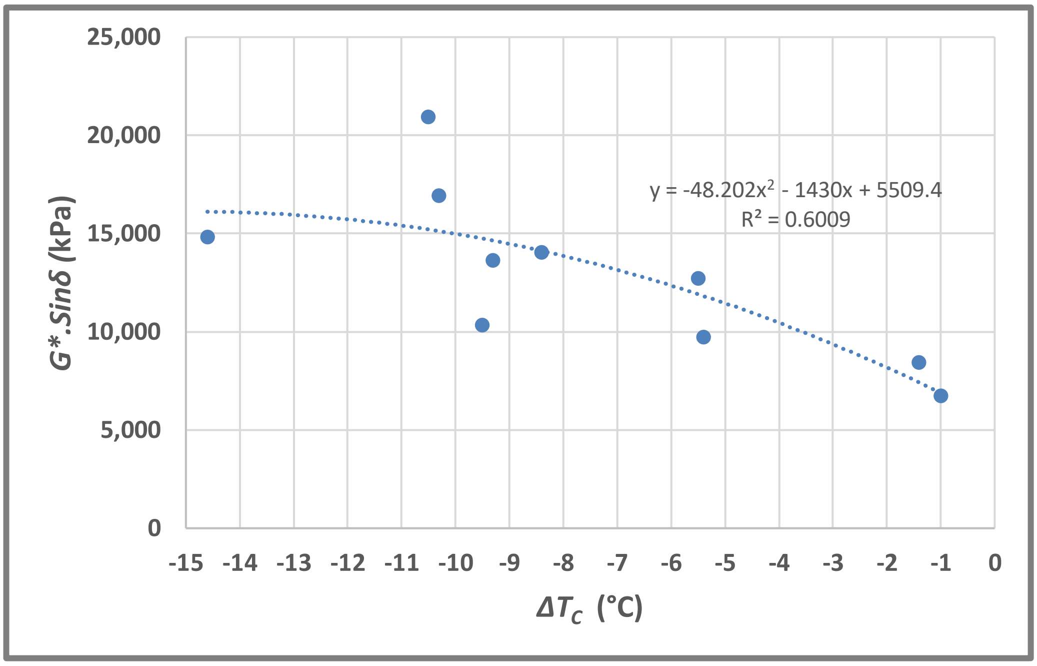


Fig. 5. Correlation of G*.Sinδ vs ΔT_C.

4. DISCUSSION AND CONCLUSION

The visual correlation in Fig. 3 shows there is a good relationship between ΔT_C and cracking. The recovered binder from Site 4 (no cracks) has a relatively low ΔT_C value of -9.5 °C, compared with the other binders (-5.5 to -1.4 °C) recovered from sites that are not cracking. This may relate to the age of the mix on site 4 (12 years old). A lack of cracking on Site 4 may be due to the higher binder film thickness at Site 4 (7.2 µm) compared to Sites 1 to 3 (6.0 to 6.1 µm). Site 4 is the only site to exhibit bleeding, implying that the mix contained excess binder. This demonstrates that although binder fatigue parameters may be an indicator of fatigue performance, the actual fatigue performance is also determined by other factors such as binder film thickness of the mix, traffic loading, climate and rate of ageing.

The ΔTC values for sites 1 – 3 breach the lower specification limit of -5°C [11], taking into considering that the limits are not applicable to recovered binders. However, it may be an indication that the current limits could be adjusted to a lower value by a degree or two, depending upon further validation studies.

It is confirmed in Fig. 3 that the recovered binder from Site 5 has a high ΔT_C value of -1.0°C, and it is highly unlikely that the cracking observed at Site 5 is related to binder fatigue.

The visual correlation in Fig. 4 shows that the relationship between G*.Sinδ and cracking is less apparent. The separation between the data points from the non-cracking and cracking sites is less pronounced that in Fig. 3. Once again, the recovered binder from Site 5 has the lowest value for G*.Sinδ, confirming that the cracking is not related to binder fatigue.

Fig.5 shows that there is no correlation between G*.Sinδ and ΔT_C, and this study confirms that G*.Sinδ would be poor choice for use as a fatigue specification parameter in South Africa.

Future work will include the evaluation of other parameters related to fatigue, including Glover-Rowe (G-R) parameter and the master curve R-value.

5. ACKNOWLEDGEMENT

The authors express their gratitude to South African National Roads Agency Limited (SANRAL), AECI Much Asphalt (Pty) Ltd and the Council for Scientific and Industrial Research (CSIR) for funding this research.”

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