Investigating the \textit{in situ} Properties of Crumb Rubber Modified (CRM) Bitumen

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\textbf{ABSTRACT.} The heterogeneous nature of crumb rubber modified (CRM) bitumen makes it impossible to extract from asphalt as a single component. It is recovered as two separate entities, namely the rubber crumbs and the solvent soluble fraction containing the base binder. Additionally, the solvent recovery process destroys the chemical equilibrium of the CRM bitumen blend; this makes it impossible to re-blend the separated components to reproduce a CRM bitumen of the same properties as the in situ binder. Hence no means exist of extracting and testing the recovered CRM binder in order to determine the properties of the in situ binder.

The increased use of CRM bitumen in South African road pavement surfacings in the last few years has coincided with major highway distresses throughout the country. This has brought about a need to investigate the binder as a possible contributory cause of the observed distresses. This has led to indirect means of investigating the state of the in situ binder. This paper aims to show how tested properties of the original CRM bitumen with ageing can be correlated to the in situ binder in order to determine the performance of the binder in road pavements.

\textbf{KEYWORDS:} Crumb Rubber Modified Binder, Dynamic Shear Rheometer, Binder Performance.
1. Introduction

In South Africa, the main distresses contributing to asphalt pavement failures are fatigue cracking, permanent deformation and thermal cracking. Such distresses are affected by the rheological properties of the binder in the asphalt pavement. Bituminous binder behaves as a visco-elastic material when subjected to loading. The linear visco-elastic behaviour of the binder is influenced by loading time and temperature; and changes with ageing. Fatigue and thermal cracking is associated with lower temperatures and aged binder of high viscosity, while permanent deformation is associated with higher temperatures where its rheology approaches Newtonian behaviour.

An ideal binder should, therefore, display adequate elastic behaviour at higher pavement temperatures to resist permanent deformation with a reduced rate of ageing and lower viscosity at lower temperatures to prevent fatigue and thermal cracking. In order to attain such ideal rheological behaviour, thermoplastic polymers have been used extensively internationally, to improve the properties of unmodified bitumen.

In South Africa, rubber crumbs are a commonly used modifier due to their proven field performance in CRM bitumen (Potgieter et al., 1998). Until recently, empirical characterisation remained the only means of predicting performance of these binders, short of constructing pavement test sections. An improved characterization is provided in rheological characterisation using a dynamic shear rheometer (DSR). However, the binary morphology of CRM bitumen makes it a challenge to test using current methods and equipment. Furthermore, the heterogeneous state of the recovered binder makes it impossible to monitor the rheological properties of the binder in an asphalt mix with time.

The increased use of CRM bitumen in South African road pavement surfacings in the last few years has coincided with major highway distresses throughout the country. This has brought about a need to investigate the binder so that it may be excluded as a possible contributory cause of the observed distresses. This has led to the establishment of an indirect means of investigating the state of the in situ binder. An appropriate DSR method is presented in this paper for the rheological testing and characterisation of CRM bitumen with ageing and this characterisation is related to asphalt mix performance. This paper aims to show how the tested properties of the original CRM bitumen with ageing can be correlated to the in situ binder in order to determine the performance of the binder in road pavements.
Empirical characterisation of CRM bitumen

In South Africa, CRM bitumen is manufactured through blending penetration grade bitumen (72 – 82%), rubber crumbs (18 – 24%) and extender oil (0 – 4%) (TG1, 2007) at elevated temperatures of between 190 - 210°C. The blending is done by a high speed stirring device for 1 to 4 hours until the bitumen is considered modified.

The typical base bitumen used in South Africa is 80/100pen grade bitumen according to South African National Standard 307 (SANS 307, 2005) requirements. Table 1 shows the results of the 80/100pen grade bitumen used in this investigation. The extender oil is produced as per COLTO (Committee of Land Transport Officials) specification requirements (COLTO, 1998). Rubber crumbs are obtained through the ambient process of shredding vulcanized tyres. The crumb rubber particles used essentially passed the 1.18mm sieve and the majority retained on the 0.6mm sieve. The resultant CRM bitumen was blended by Much Asphalt (Pty) Ltd. The test results in Table 2 indicate that the CRM bitumen blend conformed to South African Technical Guideline 1 (TG1, 2007) asphalt requirements (A-R1 grade) for all tests except resilience, which was slightly above specification.

Table 1. Bitumen grade requirements for an 80/100pen grade binder

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>Requirements</th>
<th>Results</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration (1/10 mm)</td>
<td>80-100</td>
<td>81</td>
<td>ASTM D5</td>
</tr>
<tr>
<td>Softening Point (°C)</td>
<td>42-51</td>
<td>45.2</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Viscosity @ 60°C (Pa.s)</td>
<td>75-150</td>
<td>97</td>
<td>ASTM D4402</td>
</tr>
<tr>
<td>Viscosity @ 135°C (Pa.s)</td>
<td>0.15-0.40</td>
<td>0.30</td>
<td>ASTM D4402</td>
</tr>
<tr>
<td>After Rolling Thin Film Oven Treatment (RTFOT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass Change (%)</td>
<td>0.3 Max</td>
<td>0.05</td>
<td>ASTM D2872</td>
</tr>
<tr>
<td>Viscosity @ 60°C (% of original)</td>
<td>300 Max</td>
<td>229</td>
<td>ASTM D4402</td>
</tr>
<tr>
<td>Softening Point (°C)</td>
<td>44 Min</td>
<td>50.4</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Increase in Softening Point (°C)</td>
<td>7 Max</td>
<td>5.2</td>
<td>ASTM D36</td>
</tr>
<tr>
<td>Retained Penetration (% of original)</td>
<td>50 Min</td>
<td>64</td>
<td>ASTM D5</td>
</tr>
</tbody>
</table>
Table 2. **CRM bitumen properties for asphalt (A-R1) and seals (S-R1)**

<table>
<thead>
<tr>
<th>PROPERTY</th>
<th>Unit</th>
<th>Results</th>
<th>Test Method</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softening Point</td>
<td>°C</td>
<td>62.8</td>
<td>MB-17</td>
<td>55-62</td>
</tr>
<tr>
<td>Dynamic Viscosity @ 190°C</td>
<td>dPa.s</td>
<td>35</td>
<td>MB-13</td>
<td>20-40</td>
</tr>
<tr>
<td>Compression</td>
<td>5 mins</td>
<td>86.6</td>
<td>MB-11</td>
<td>&gt;70</td>
</tr>
<tr>
<td>Recovery</td>
<td>1 hour</td>
<td>%</td>
<td>&gt;70</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4 days</td>
<td>N/A</td>
<td>&gt;25</td>
<td></td>
</tr>
<tr>
<td>Resilience @ 25°C</td>
<td>%</td>
<td>42</td>
<td>MB-10</td>
<td>13-35</td>
</tr>
<tr>
<td>Flow</td>
<td>mm</td>
<td>14</td>
<td>MB-12</td>
<td>15-70</td>
</tr>
</tbody>
</table>

1.2. **Digestion viscosity curve of CRM bitumen**

CRM bitumen properties change with temperature, digestion time and energy consumed during the digestion process.

The various stages of CRM bitumen blends can be defined in terms of viscosity as depicted in Figure 1. Stage 1 is characterised by an increase in viscosity initially upon blending. In this phase, the rubber particle dimensions increase as the oil and/or lighter components of the bitumen diffuse into the three dimensional rubber networks of poly-isoprene and poly-butadiene linked by sulphur-sulphur bridges. The diffusion process varies according to the amount of cross-links in the rubber, the molecular compatibility between the rubber and the diffusing particles as well as the molecular weight of the latter (Treolar, 1975; Airey et al., 2002). Thereafter, an additional viscosity increase occurs from a further incorporation of the diffusing matter into the rubber particles as the sulphur-sulphur bonds thermally dissociate.

The thermal dissociation process continues until a maximum viscosity point is reached referred to as Stage 2. The viscosity then decreases with digestion time in Stage 3 as the network disintegrates due to the loss of the sulphur linkages. Once the decrease in viscosity reaches a point of constant viscosity, the CRM bitumen blend is referred to as terminal. This has been depicted as Stage 4 in the digestion viscosity curve.

Figure 2 shows the CRM bitumen blend exhibiting a gradual viscosity increase. This indicates that the blend was in Stage 1 of the digestion circle at the time of testing. Figure 3 shows both Stage 3 and 4 viscosity behaviour of the blend with over digestion.
Figure 1. Typical digestion viscosity curve of CRM bitumen

Figure 2. Viscosity vs. Time of the CRM bitumen blend at 190°C
Figure 3. Viscosity vs. Time of the CRM bitumen blend at 210°C (after initial digestion as shown in Figure 2)

2. Rheological Testing of CRM Bitumen

The development of the Performance Graded (PG) specification system for binders in the United States by the Strategic Highway Research Program (SHRP) program, focused on selecting the proper binder grade for the climate in which the binder is to be utilized. The PG system uses parameters measured with a DSR to predict rutting and fatigue resistance at various temperatures. This system was a major improvement over empirical testing and the intent was to develop binder specifications that could be applied universally to all binders.

The determination of binder rheological properties using a DSR is specified in AASHTO (American Association of State Highway and Transportation Officials) Test Method T 315 (2005). According to the test method, the limits of the test temperature and frequency ranges are a function of the binder stiffness (which is affected by binder grade, type of modification, etc.) and the capacity of the DSR. The following guidelines (SHRP-A-370, 1994) are used in approximation for selecting plate diameters and sample thickness (gap):

- 8-mm parallel plates with a 2-mm gap are recommended when the absolute value of G* ranges from 0.1 to 30 MPa.
- 25-mm parallel plates with a 1-mm gap are recommended when G* ranges from 1.0 to 100 kPa.
- 50-mm parallel plates (less common) are recommended when G* < 1 kPa.
2.1. Limitations of the PG specification system

The majority of the SHRP research was conducted using straight penetration grade binders. The resultant test methods and binder specifications were not verified for modified binders. Consequently, the PG specification system does not fully characterize polymer modified binders (such as CRM bitumen) with proven field performance.

Furthermore, AASHTO T315 (2005) is also incapable of correctly characterizing CRM bitumen rheologically due to the requirements of its testing system. The plate gap thickness would require adjustment to avoid interference from the crumb rubber particle size (Airey et al., 2002; McGennis, 1995; Shen et al., 2005).

2.2. DSR Analysis of CRM bitumen

Mturi et al. (2010) have previously demonstrated the need for a gap adjustment when analysing CRM binders. This was demonstrated by plotting complex moduli (G*) and phase angle (δ) values at various frequencies and gap settings for a 60/70pen grade bitumen and CRM bitumen. A 60/70pen grade bitumen of similar stiffness to CRM bitumen was used as a control sample. Frequency sweeps of the two binders were measured at 55°C for various gap settings. All measurements were done within the linear visco-elastic (LVE) range using a 25-mm diameter parallel plate configuration. Table 3 contains the coefficients of variation at different frequencies and gap thickness for the binder samples. The frequency sweep results for the 60/70pen grade bitumen showed good reproducibility in terms of G* (coefficient of variation: 1.0–2.3%) and δ (coefficient of variation: 0.0–1.0%) at all gap thicknesses between 1-2mm. On the other hand, the results for the CRM bitumen blend showed poor reproducibility of both G* (coefficient of variation: 1.1–8.1%) and δ (coefficient of variation: 2.0–14%) values at the 1-mm gap setting and more especially towards lower frequencies. As the gap thickness was increased the reproducibility improved until a gap range was reached where the frequency sweeps became reproducible (at a 2-mm gap, coefficient of variation: 0.0–2.0% for G*; and 0.2–0.9 for δ).

Mturi et al. (2010) showed that a minimum DSR gap is required for any CRM bitumen, probably dependent on the maximum particle size of the rubber crumbs in the blend. The maximum rubber particle size would depend on the initial size of the crumb rubber prior to blending, the diffusion process as well as the stage of the blend in the digestion viscosity curve at the time of testing. Fortunately, the type, amount and size of rubber crumbs in South African blends are fairly consistent. It was therefore recommended that repeated DSR testing of local CRM bitumen blends be done at a 2-mm gap thickness. The calculated standard deviation for G* and δ measurements should establish whether a gap adjustment is required.
3. Rheological Profile of CRM Bitumen with Ageing

On doing a frequency sweep at various temperatures, a black diagram of the bitumen can be plotted. This characterises the bitumen in terms of rheology, at various temperatures and frequencies for various conditions of ageing.

The effect of ageing on CRM binders differs to unmodified bitumen. Figure 4 shows the complicated nature of the binary system. The unaged CRM binder exhibits increased complex moduli with decreased phase angle at higher temperatures compared to unmodified bitumen. Upon ageing, it partially loses its proportional elastic contribution at higher temperatures but such elastic contribution remains much higher than that for unmodified binders. At lower temperatures, ageing results in decreased phase angle. But the oxidative ageing of CRM bitumen is juxtaposed against S-S bond scission, leading to unpredictable changes in $G^*$. However, the complex moduli and phase angles at lower temperatures remain lower than that of unmodified bitumen, resulting in enhanced resistance to low temperature cracking, as would be expected for modified binders.

The rheological monitoring of binder ageing in asphalt mixes is very complicated for CRM bitumen. The binder cannot be recovered as a single entity and the recovered elements cannot be re-combined to produce the same binder as it existed before in the asphalt. In the recovery process, the binder is dissolved in benzene then separated from the aggregates before it is recovered back again through distillation. Crumb rubber particles do not dissolve in benzene hence they are separated out with the aggregate. The solvent recovery process destroys the CRM bitumen network and the chemical equilibrium of the blend; this makes it impossible to re-blend the separated components to reproduce the binder as it occurred previously in the asphalt. As a result only the base binder, the extender oil together with the benzene soluble polymer fractions from the crumb rubber can be recovered and tested. Figure 5 shows black diagrams of the recovered base binder mixture from the CRM bitumen blend. The ageing observed is a combination of

<table>
<thead>
<tr>
<th>BINDER</th>
<th>1 mm Gap Setting</th>
<th>&gt;1 mm Gap Setting</th>
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<tbody>
<tr>
<td></td>
<td>$G^*$</td>
<td>$\delta$</td>
</tr>
<tr>
<td>60/70pen grade binder (control)</td>
<td>1.0-2.3 %</td>
<td>0.0-1.0 %</td>
</tr>
<tr>
<td>CRM bitumen</td>
<td>1.1-8.1 %</td>
<td>2.0-14 %</td>
</tr>
</tbody>
</table>

| (1-2 mm Gap Setting)         | (2 mm Gap Setting) |

Table 3. Coefficients of variation for $G^*$ and $\delta$ between 0.0126-50.2Hz
oxidative hardening of the base bitumen together with the increased incorporation of de-linked polymers into the recovered bitumen.

In essence, the ageing observed for the recovered base binder cannot be related to that of the CRM bitumen blend, but remains the only practical way of monitoring ageing of these binders. A method for linking the properties of the recovered base binder with the in situ CRM bitumen blend is discussed further on in the paper.

Figure 4 illustrates that the black diagram of CRM bitumen curves twice towards lower phase angles in a “3” like profile. The authors postulate that one curve represents the elastic portion from the binder-soluble polymer emanating from S-S bond scission (typical of most modified binders), whereas the second curve represents elastic support from the insoluble 3-D vulcanised polymer network. This postulation is supported by the disappearance of the second curve when the binder is extracted as illustrated in Figure 5.

![Figure 4. Black diagram of CRM bitumen with ageing [RTFOT = Rolling Thin-Film Oven Test; PAV = Pressure Ageing Vessel]]
4. Using CRM Bitumen Rheology to Predict Asphalt Mix Performance

For mechanistic-empirical design purposes, the dynamic modulus of a mix is an important input parameter for damage models pertinent to the design model. It is not always practical to determine the dynamic modulus of a mix, and so use is made of predictive equations which relate the viscosity of a bituminous binder after RTFOT to the dynamic modulus value.

The importance of this section lies in the facts that:

- Predictive equations cannot be utilised correctly without a good idea of the in situ properties of CRM bitumen in the mix.
- Predictive equations cannot be utilized correctly without an effective DSR method of analysis of CRM bitumen.

\[
\log[E^*] = 3.750063 + 0.029232 P_{38} - 0.001767 (P_{38})^2 - 0.002841 P_{4} - 0.058097 V_a - 0.802208 \left(\frac{V_{\text{beff}}}{V_{\text{beff}} + V_a}\right) + \left[3.871977 - 0.0021 P_{34} + 0.003958 P_{4} - 0.000017 (P_{4})^2 + 0.00547 P_{4}\right] \frac{1}{1 + e^{0.005353 - 0.515937 \log(1 - 0.505353 \log(17))}} \]

where:

- \(E^*\) = dynamic modulus, psi.
- \(\eta\) = bitumen viscosity, 106 Poise.
- \(f\) = loading frequency, Hz.
- \(V_a\) = air void content, %.
- \(V_{\text{beff}}\) = effective bitumen content, % by volume.
- \(P_{34}\) = cumulative % retained on the \(\frac{3}{4}\) in (19.0mm) sieve.
- \(P_{38}\) = cumulative % retained on the \(\frac{3}{8}\) 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.

Viscosity can be determined from the complex shear modulus generated by the DSR by using the conversion equation [2]:

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

where:

- \(G^*\) = complex modulus of the binder, Pa.
- \(\delta\) = phase angle.
- \(\eta\) = viscosity, Pa.s.

The Hirsch predictive equation [3] (Christensen et al., 2003) is also widely used.
where:

$|E^*| = \text{dynamic modulus, psi.}$

$|G^*_{\text{binder}}| = \text{shear complex modulus of binder, psi.}$

$\text{VMA} = \text{voids in mineral aggregates, \%}.$

$\text{VFA} = \text{voids filled with binder, \%}.$

$P_c = \text{aggregate contact factor.}$

Both these equations were evaluated using a BRASO asphalt mix (CRM bitumen with a semi-open aggregate grading) manufactured in the CSIR Built Environment pavement materials laboratory. The binder rheology was determined using a DSR. The dynamic modulus ($E^*$) test was conducted on samples compacted to design and field voids using a CSIR protocol for asphalt mixtures in South Africa (Anochie-Boateng, 2009) and a commercially available Universal Testing Machine (UTM-25) testing device. Predicted dynamic modulus values are compared with measured values in Figures 6 and 7 ($E^*$ unit of measurement is MPa).

The results indicate that the Hirsch equation provided a better prediction of the measured dynamic modulus than the Witczak equation did for this particular mix and protocol under consideration.

Generally, alternative rheological indicators such as apparent viscosity (as determined by the Brookfield viscometer) may also be used in the Witczak prediction equation. However, Brookfield viscosity cannot be determined accurately for a two-phase CRM bitumen. This emphasizes the importance of the rheological characterisation of CRM bitumen with the aid of a DSR, considering that no alternative rheological tests would provide usable viscosity values.
Figure 6. Predicting Dynamic Modulus using the Witczak Equation [Unit: MPa]

Figure 7. Predicting Dynamic Modulus using the Hirsch Equation [Unit: MPa]
5. Using CRM Bitumen Rheology to Predict Asphalt Mix Performance

Two case histories are discussed whereby rheological analyses were used to investigate whether the CRM binder was a possible contributory factor in the cause of cracking (Section 5.1) or bleeding (Section 5.2) of hot mix asphalt pavements on major South African highways.

5.1. Cracking of Asphalt

Slabs were received from sections of a national road showing cracking of the asphalt layer a few months after construction. The slabs were observed having excessively high uncoated fines present within the surfacing layer (see Figure 8). No definitive conclusions could be made with regards to the source of the fines since the authors were not on site when sampling was done. However, a visual examination of the fines with regards to colour and positioning along the asphalt layer, does allow for the possibility that the fines originated from the base, having been ‘pumped’ to the surface by sub-surface moisture.

![Figure 8. Photograph of asphalt slab once split up](image)

It was not possible to recover the in situ CRM binder intact, as the binder recovery process results in two separate fractions. The authors needed to devise a method to determine a relationship between the properties of the in situ CRM bitumen and the recovered benzene-soluble binder. This was accomplished by determining ratios between the properties of CRM bitumen and the soluble binder at various stages of ageing. It was determined that the properties of the recovered
benzene soluble binder changes more notably with ageing compared to the intact CRM bitumen, as depicted in Figure 9. This is because the properties of the intact CRM bitumen are a composite effect of the 'binder-soluble' polymer (which increases with ageing) and the vulcanised 'insoluble network' (which decreases with ageing), whereas the benzene soluble binder contains the 'binder soluble' polymer only, which increases with ageing, resulting in a greater change in properties with time.

![Figure 9. G*/sinδ values of CRM bitumen and the corresponding benzene soluble recovered binder.](image)

In order to establish a database of data, CRM bitumen blends had to be prepared, aged, tested and recovered then re-tested. Knowing the properties of the CRM bitumen and those of its corresponding recovered binder with ageing, it was possible to estimate the properties of the in situ binder from the soluble binder of the asphalt slabs.

The CRM bitumen was prepared in the laboratory as per the client’s recommended simulation of the manufacturing conditions. The fatigue cracking resistance nature of the binder was analysed by the Superpave PG system, which requires the determination of G*.sinδ (PG fatigue property) of the binder after ageing. The PG system requires ageing to be done using a pressure aging vessel (PAV) to simulate long-term in-service aging because fatigue (shrinkage/expansion-contraction) cracking takes exposure to environmental factors over time before it occurs. However, for this particular investigation, the PG fatigue property of the lab
prepared binder was to be monitored with ageing and the PAV was found to be too inflexible and time-consuming. Consequently, ageing was done in two ways:

- Using a hot plate/paddle stirrer but extending the ageing time at the blend preparation temperature of between 190-200°C
- Using extended rolling thin-film oven test (RTFOT)

Figure 10 is a plot of the PG fatigue parameter with temperature of the retained CRM bitumen samples as well as lab prepared CRM bitumen blends. The tight distribution of results shows that the CRM bitumen blends were prepared to a consistency similar to that attained by the retained samples.

Figures 11-14 show the PG fatigue property with temperature of the CRM bitumen blends and their respective soluble binders at various stages of ageing. The ratio of the two sets of fatigue values have been plotted in Figure 15. The lines represent the fatigue property ratios at the various temperatures for the differently aged CRM bitumen blends. The ratio lines seem to shift with ageing but the slope remains fairly consistent. The maximum and minimum fatigue property ratios of the soluble binder to CRM bitumen were therefore determined at each tested temperature.

Figure 16 shows the PG fatigue property with temperature of the soluble binder recovered from the slab samples. The values are comparable to the soluble binder results recovered from the RTFOT sample after 24 hours of ageing. Based on the fatigue ratios determined in Figure 15, the maximum and minimum fatigue properties of the corresponding in situ CRM bitumen in the slabs were determined. The highest fatigue failure temperature for the in situ CRM bitumen was determined to be ~16°C (where $G^* \sin \delta > 5000 \text{kPa}$) which corresponds to an actual pavement temperature of below -28°C (conservatively assuming the binder corresponds to a PG 52) where the binder would have failed the PG fatigue criteria. It is unlikely that the pavement would have reached such temperatures in South Africa; it is therefore highly improbable that fatigue cracking due to the CRM bitumen binder would have resulted in the observed distress on the highway. Additionally, binder samples from the last proven instance of premature cracking caused by excessive binder stiffness in South Africa (Bahia et al., 2004) had fatigue failure temperatures of ≥30°C. This illustrates how far removed the CRM bitumen fatigue temperatures are from initiating cracking.

The resolution to the problem above may have been more complicated if the section had cracked several years after paving, instead of a number of months as had been the case. Long term ageing is simulated using PAV ageing which employs high temperatures (90 – 110°C). S-S bond scission (de-vulcanisation) occurs more rapidly at these elevated temperatures, whereas stabilizers present in the crumb rubber prevent this from occurring in the surfacing during ageing of the in situ CRM bitumen in the asphalt surfacing. Artificial long term ageing may result in a less correct ratios (CRM bitumen: soluble binder) being applied to the problem.
Figure 10. Graph of $G^* \sin \delta$ vs. temperature of retained and lab prepared CRM bitumen blends

Figure 11. Graph of $G^* \sin \delta$ vs. temperature (Hot plate 6hrs)
Figure 12. Graph of $G^*.\sin\delta$ vs. temperature (Hot plate 9hrs)

Figure 13. Graph of $G^*.\sin\delta$ vs. temperature (Hot plate 29hrs)
Figure 14. Graph of $G^*\sin\delta$ vs. temperature (RTFOT 24hrs)

Figure 15. Graph of the ratio of $G^*\sin\delta$ (CRM Bitumen: Soluble binder) vs. temperature
Figure 16. Graph of $G^* \sin \delta$ vs. temperature of the slab recovered soluble binders and the projected minimum and maximum $G^* \sin \delta$ of the in situ CRM bitumen

5.2. Bleeding of Seals

Bleeding was observed on various national highways with certain CRM bitumen seal applications. The distress was most severe when an 80/100pen grade base binder from refinery 1 was used to blend CRM bitumen compared to when the base binder originated from refinery 2. The clients claim to have experienced a much softer in situ CRM binder when using the refinery 1 base binder, with different performance properties to when the CRM bitumen of refinery 2 was applied.

It is the authors’ views that bleeding of CRM bitumen seals is more often the result of:

- insufficient aggregate to maintain an elongated orientation, and thus insufficient voids
- over-application of binder
- under-modification to maintain an elongated orientation, and thus insufficient voids
- incorrect aggregate shape and dimension
- punching of aggregate due to fatty substrates, soft substrates, binder contamination, etc.
It is important to point out that the above-mentioned and other construction factors were not investigated; the investigation was limited to analysing CRM binder properties as a possible contributory factor to the observed distress.

In order to investigate whether the binder may have contributed to bleeding, the CRM bitumen blends were prepared and aged to simulate changes in the properties of the in situ binder during, transport, storage and spraying, (as well as environmental ageing during the early part of the binder’s pavement life). The properties were monitored using viscosity and softening point measurements.

Figures 17 and 18 contain the viscosity-time and softening point-time curves, respectively for CRM bitumen blends made from the pure base binders of refinery 1, refinery 2 and blends of the two at 70:30 and 30:70 ratios respectively.

TG1 recommends (see Table 2) that CRM bitumen used for S-R1 class surfacing seals be within a viscosity range of 4000-2000 cP (40-20 dPa.s). The viscosity of the CRM bitumen blends conformed to the recommended viscosity range after 6-9 hours of mixing at 190-200°C (see Figure 17). The blends stayed in this viscosity range for a limited timeframe before falling below the minimum required viscosity value of 2000 cP (20 dPa.s), this occurred after approximately 3-4 hours.

TG1 also recommends (see Table 2) that CRM bitumen used for S-R1 class surfacing seals conform to a softening point range of 55-62°C. Figure 18 shows softening points plotted against time for the five CRM bitumen blends whilst being continuously mixed at 190-200°C. Except for the CRM bitumen of refinery 2, all other blends conformed to the recommended softening point range (or moved to an acceptable vicinity) after less than 5 hours of mixing. The CRM bitumen of refinery 1 dropped outside the minimum limit after merely 7-8 hours of mixing.

When the base binder from refinery 2 was used in combination with that from refinery 1, the softening points of the CRM bitumen increased. It also took longer for these binders to fall below the minimum recommended softening point limit. At 30% base binder from refinery 2, the CRM bitumen took 9-10 hours of blending to fall below the lower limit. At 70% base binder of refinery 2, the softening point of the blend lingered on the lower limit even after 30 hours of mixing.

The CRM bitumen purely based on the base binder from refinery 2 took about 9 hours of mixing to drop into the recommended softening point range. But the blend remained in the upper end of the range even after 30 hours of mixing.

It could not be proven that the low softening points measured for the CRM bitumen of refinery 1 were the result of incompatibility between the base binder and the rubber crumb particles. If this was the case, there would have been large differences in the storage stability results between the various blends, especially between those emanating from the two pure penetration grade binders. But this was not the case (Mturi et al., 2011b). Additionally, the rate of decrease in softening points shown in Figure 18 would be different between compatible and incompatible
blends. It can therefore be assumed that the observed differences between the CRM bitumen are primarily the result of rheological differences between the base binders from the two refineries.

In summary, CRM bitumen blends based on the base binder from refinery 1 needed to be sprayed within 7-8 hours of mixing otherwise the S-R1 binder would be below the TG1 recommended softening point range. The time of construction would further be restricted if the clients also waited for the blend viscosity to reach the recommended range. This would have given the clients less than a 2 hour window period when these blends met the recommended limits for both softening point and viscosity.

The use of the base binder from refinery 2, even in combination with that from refinery 1, increased this window period of application. It increased the softening points of the modified blend and kept them in the recommended range for a longer timeframe. This meant that the blend viscosity was the only deciding factor in determining application time frames.

Figure 17. Digestion Viscosity curves of the CRM bitumen blends from the 5 base binders at 190-200°C
Figure 18. Softening point curves with time of CRM bitumen blends produced from the 5 base binders at 190-200°C

6. Conclusion

A method for determining the rheology of CRM bitumen using a DSR has been demonstrated. The results were used successfully for the prediction of resilience response of a BRASO asphalt mix. Rheological analysis also showed that a rheological property of CRM bitumen can be correlated to that of its soluble binder in order to follow the ageing of the binder with time. This enabled the authors to simulate the in situ CRM binder within an asphalt mix, which was subsequently tested and found not to have contributed to the pavement distress. The second investigation showed the importance of characterising CRM bitumen properties with digestion time; it enables the determination of the best conditions of application for CRM bitumen products in order to maintain the optimal performance properties of the in situ CRM binder.

7. Bibliography

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