NACOE
NATIONAL ASSET CENTRE OF EXCELLENCE

FINAL REPORT

P75: Transferring Crumb Rubber Modified Gap-graded Asphalt Technology to Queensland (2020–21)

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Summary

Rubber obtained from end-of-life vehicle tyres is considered a valuable resource that has a proven history of improving the performance of bituminous binders used in sprayed seals and asphalt. The use of crumb rubber as a modifier in bitumen can therefore provide a sustainable solution (amongst other solutions) to deal with the millions of scrap tyres that are produced annually in Australia.

The National Asset Centre of Excellence has previously developed a new technical specification for the use of crumb rubber modified (CRM) binders in asphalt. The new specification allows for the use of either a Brookfield or a hand-held rotational viscometer (such as the Rion viscometer) to determine the viscosity of the modified binder at 175 °C. However, subsequent testing by others found that the 2 viscometers did not necessarily provide similar results for a particular binder and further research was therefore required.

The study documented in this report undertook additional comparative testing of 4 crumb rubber modified binders using both a Brookfield and Rion viscometer. The test results confirmed that the 2 viscometers resulted in different viscosity results for the binders tested. The study also found that the differences in the results obtained between the Rion and Brookfield viscometers were dependent on the viscosity of the binder.

Even though a strong correlation was observed between the Brookfield and Rion viscometer results, a generic offset that would be suitable for quality assurance purposes could not be established. However, the study showed that a project-specific offset could potentially be established for a particular CRM binder that can be used for quality assurance purposes during construction. Based on the findings of the study, the following recommendations are made for TMR's consideration:

- Change the viscometer calibration verification requirement in the draft test method to a measured tolerance of ±10% to better align with the accuracy of the device. The requirement for checking the equipment against 3 reference oils could also be reconsidered (2 reference oils may be adequate).
- Standardise the units for viscosity to Pa.s in the draft test method so that they align with the units used in the Australian pavements industry.
- Include a reference in PSTS112 for the use of 4-litre tins for viscosity testing when using a hand-held rotational viscometer.
- Review the appropriateness of using the current Brookfield test method (considering the variable shear rate) to determine the viscosity of CRM binder.
- Review the viscosity requirements in PSTS112 if a Brookfield viscometer will be used for the binder design and quality assurance purposes.
- Consider the use of binder-specific correlations between the hand-held and Brookfield viscometers in future updates to the specification.

Acknowledgements

The project team would like to acknowldge the contribution made by the staff of the Queensland Department of Transport and Main Roads testing laboratory.

Contents

Tables

Figures

1. Introduction

1.1 Background

Millions of vehicle tyres reach the end of their life in Australia annually. Rubber obtained from these end-of-life tyres is considered a valuable resource that has a proven history of improving the performance of bituminous binders used in sprayed seals and asphalt (Denneman et al. 2015).

In 2015, the Queensland Department of Transport and Main Roads (TMR) and the Australian Road Research Board (ARRB) commenced a multi-year National Centre of Excellence (NACOE) research project to facilitate the use of crumb rubber modified (CRM) binders in asphalt. The first phases of the project developed a new technical specification for the manufacture and placement of CRM open-graded asphalt (OGA) and gap-graded asphalt (GGA) that was trialled on several construction projects (Grobler et al. 2017; Grobler 2020). The CRM binder properties adopted in the new specification were primarily based on the requirements specified by the Arizona Department of Transportation (ADoT), but with some modifications to reflect local materials and construction practices.

The second phase of the project benchmarked the performance of locally manufactured CRM binders in a standard GGA mix against the performance of 2 binders sourced from California (Grobler 2021). It was found that the locally manufactured binders provided similar laboratory performance compared to the binders sourced internationally.

A portable hand-held rotational viscometer (e.g. Rion viscometer) is commonly used internationally (including in Arizona) to determine the viscosity of CRM binders. However, in Australia, the Brookfield viscometer is used to determine the viscosity of modified binders, and hand-held rotational viscometers were not widely available in Queensland at the time of developing project-specific technical specification PSTS112 *Crumb Rubber Modified Asphalt*. PSTS112 therefore allows for the viscosity of CRM binders to be determined using either the Brookfield viscometer or a hand-held rotational viscometer.

Subsequent testing by the Western Australian Road Research and Innovation Program (WARRIP) found that the 2 viscometers did not necessarily provide similar viscosity values (van Aswegen 2019). There was therefore a need to further investigate the differences in viscosity values measured with the Brookfield and Rion viscometers.

1.2 Project Scope and Objectives

The third year (2020–2021) of this multi-year NACOE project investigated the differences in viscosity of 4 CRM binders determined using a Brookfield and a Rion viscometer. The project objectives included the following:

- establishing an appropriate sample-handling protocol prior to undertaking the comparative laboratory testing
- determining the viscosity of 4 different CRM binders in the laboratory using both a Brookfield and Rion viscometer
- analysing the test results and establishing a relationship between the viscosity results determined with the 2 viscometers
- identifying proposed amendments to the draft hand-held viscometer test method and PSTS112
- documenting the findings and recommendations in a project report (this report).

1.3 Report Structure

Section 2 provides a summary of the comparative laboratory testing undertaken, including an analysis of the test results. Proposed amendments to the draft hand-held viscometer test method and PSTS112 are provided in Section 3. This is followed by the study conclusions and recommendations in Section 4.

2. Laboratory Investigation

2.1 CRM Binders

The viscosity of 4 different commercially manufactured CRM binders was tested at various temperatures to evaluate the relationship between the Brookfield and hand-held Rion viscometer results. The CRM binders used in the study were the same binders that were tested by Grobler (2021) and comprised the following:

- Binder A with 12% w/w crumb rubber (Binder A – 12% CR)
- Binder B with 17% w/w crumb rubber (Binder B – 17% CR)
- Binder C with 20% w/w crumb rubber (Binder C – 20% CR)
- Binder D with 21% w/w crumb rubber (Binder D – 21% CR).

The crumb rubber content in the binders tested varied between 12% and 21% by weight of the total binder when tested in accordance with Transport for New South Wales test method T737 *Rubber Content of a Scrap Rubber Mix* (2012), and therefore represented a wide range of different levels of modification.

2.2 Testing Plan and Methodology

A draft TMR test method to determine the viscosity of CRM binders using a hand-held rotational viscometer was developed in NACOE project P111 *Improved Crumb Rubber Modified Binder Sprayed Sealing Practices (2019–2020)*. This draft method was used to conduct the hand-held viscosity tests in the study.

The draft test method is primarily based on the procedures included in ASTM D7741/D7741M – 18, *Standard Test Method for Measurement of Apparent Viscosity of Asphalt-rubber or Other Asphalt Binders by Using a Rotational Handheld Viscometer* (2018). A Rion viscometer with a number 1 spindle was used for the comparative viscosity testing undertaken as part of the study.

Brookfield viscometer testing was performed using an SC4-29 spindle in accordance with AGPT/T111 *Handling Viscosity of Polymer Modified Binders (Brookfield Thermosel)*.

The viscosities of the CRM binders were determined using the 2 different viscometers at 10 °C temperature intervals between 135 °C and 175 °C. Photographs of the viscometers used are shown in Figure 2.1 and Figure 2.2.

Figure 2.1 Brookfield viscometer

Figure 2.2 Rion viscometer

2.2.1 Calibration

The draft TMR test method developed for hand-held rotational viscometers requires that the accuracy of the device be verified prior to use with 3 different standard reference oils (with known viscosities in the range between 1.0 and 5.0 Pa.s). The test method indicates that the viscometer is accurate if the viscosity values obtained for the reference oils are within 0.3 Pa.s of the known viscosity values.

The laboratory was able to source 2 reference oils with viscosities of 1.0 and 5.1 Pa.s at 23 °C, respectively. The results of the verification testing undertaken are summarised in Table 2.1.

Table 2.1: Rion viscometer verification testing

Reference oil	Spindle size	Reference value (Pa.s)	Rion measurement (Pa.s)	Difference in results (Pa.s)	Percentage difference in results (%)
RT1000	#3	1.0	1.0	0	0
RT5000	#1	5.1	4.6	0.5	9.8

The Rion viscometer used in the study yielded a viscosity result within 0.3 Pa.s for the RT1000 reference oil, but exceeded the allowable difference for the RT5000 reference oil. It should be noted that the viscometer does not have any user settings and it therefore cannot be calibrated by the laboratory based on the verification testing. The manufacturer states that the viscometer has an accuracy of ±10%, which suggests that the verification results obtained are within the accuracy of the instrument.

There is therefore a need to review the accuracy verification requirements in the draft test method, given that the allowable difference between the known and measured viscosity of the reference oils is 6% at 5.0 Pa.s, which is lower than the accuracy of the viscometer. It is recommended that a ±10% difference in the known and measured viscosities be allowed in the calibration process.

2.2.2 Sample Handling Protocol

The draft TMR hand-held viscometer test method specifies that a 4-litre sample tin be filled with 3 litres of binder for the viscosity testing. It was found that it took approximately 6.5 hours to heat this amount of binder from ambient to a target test temperature of 185 ºC in an oven. Smaller samples used for the Brookfield testing were able to be heated in a significantly shorter time. It is well documented that the properties of CRM binders are influenced by the time the binder is stored at elevated temperatures due to ongoing digestion/degradation of the rubber particles (Sabita 2019).

Furthermore, Brookfield viscosity testing can be conducted at different temperatures either by conducting sequential tests on a single sample by incrementally increasing temperatures or conducting tests on different samples at each required test temperature. Testing a single binder sample at multiple temperatures would increase the time a sample was heated which could potentially have an impact on the viscosity due to the ongoing digestion/degradation of the rubber particles.

The differences in the sample handing procedures noted above could potentially affect the viscosity results and were therefore further investigated prior to commencing the comparative testing.

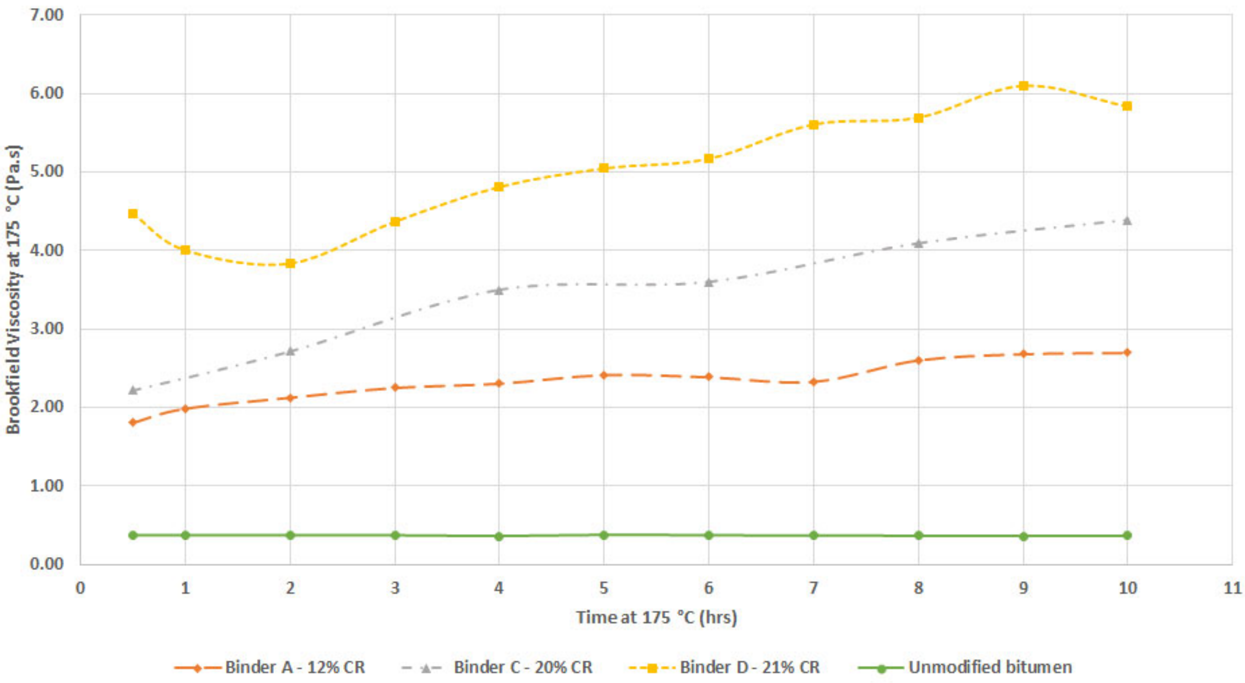
The effect of heating time

As mentioned above, concerns were raised that the extended heating time required to achieve the target test temperatures for the Rion viscometer could potentially affect the viscosity results.

To assess the sensitivity of the CRM binders to the heating time and temperature, 3 CRM binders and 1 unmodified bitumen sample were heated in a 4-litre tin to 175 °C in an oven. The lid on the 4-litre tin had a hole punched in the middle to allow the probe to be inserted close to the centre of the sample whilst reducing the risk of binder oxidation occurring. The 175 °C temperature was maintained for a 10-hour period and the viscosity of the binders was determined at regular intervals using a Brookfield viscometer. An unmodified bitumen was included in the testing given that the viscosity of this binder was not expected to be affected by the rubber digestion process.

Figure 2.3 shows the viscosity results at 175 °C obtained with the Brookfield device over a 10-hour period. The viscosity of the CRM binders increased between 30% and 98% over time, whereas the viscosity of the unmodified bitumen remained constant. Figure 2.3 also indicates that binders with higher crumb rubber contents experienced a greater change in viscosity over time.

Figure 2.3: Change in viscosity at 175 °C over time



The increase in viscosity of the CRM binders observed over time was surprising given that it is a commonly held view that the viscosity of these binders generally decreases over time when stored at elevated temperatures, which is opposite to the observations in this study. Nonetheless, the test results suggest that the viscosity of the CRM binders is sensitive to the heating time, and that similar sample heating times should therefore be adopted for any comparative Brookfield and Rion viscosity testing.

A revised binder heating protocol was developed, whereby subsamples for Brookfield testing were taken from the 4-litre tin once the binder reached 185 °C in the oven. This ensured that the different samples used for the comparative viscosity testing experienced similar heating times (as far as practical).

The Brookfield samples were then cooled down to 120 °C and heated back up to the required test temperatures in the Brookfield thermosel prior to testing.

Samples tested using the Rion viscometer were initially tested in the 4-litre tin at the highest temperature and the samples were then allowed to cool in air so that viscosity results at lower temperatures could be obtained.

Single versus multiple samples using the Brookfield viscometer

The effect of undertaking multiple viscosity tests at different temperatures on a single sample in the Brookfield device versus testing separate individual samples at each temperature was also assessed. Multiple subsamples were taken from the 4-litre tin and tested individually at each temperature (i.e. multiple sample testing). Another subsample was also taken from the 4-litre tin and the same subsample was tested repeatedly at each of the different test temperatures (i.e. single sample testing). An illustration of the sampling undertaken is shown in Figure 2.4.

Figure 2.4: Sampling methodology

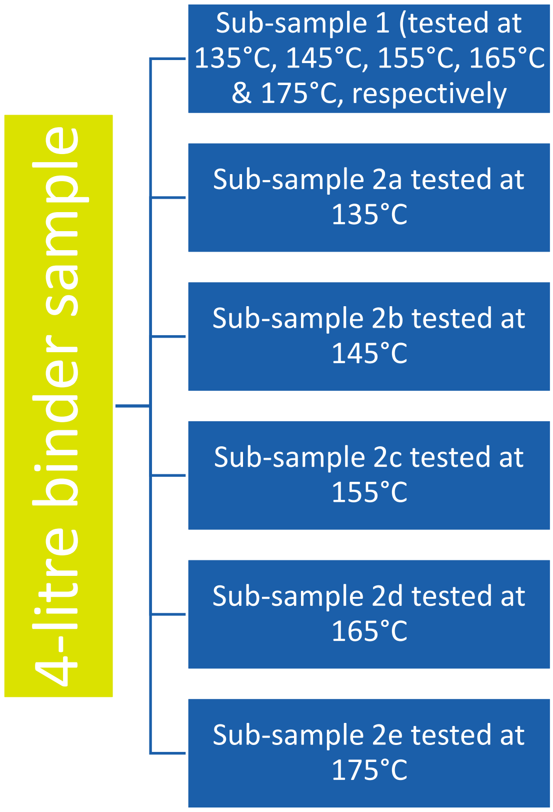
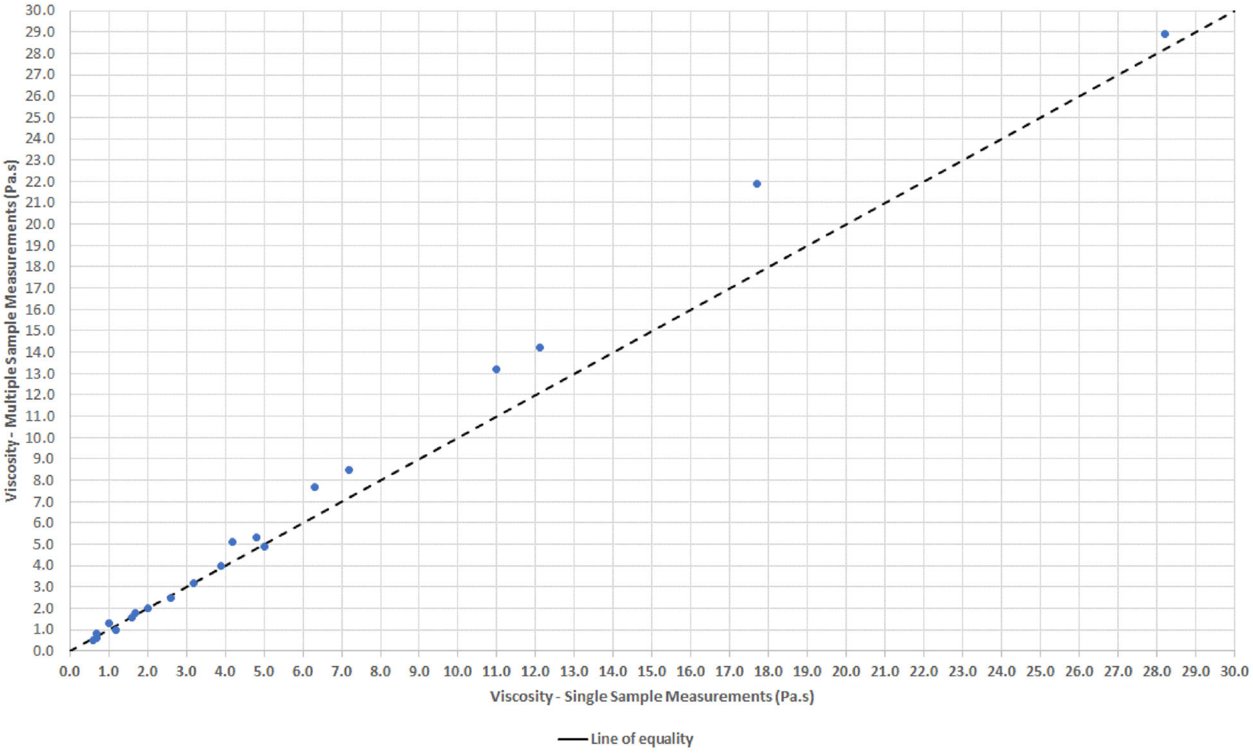


Figure 2.5 shows the viscosity results obtained from the single and multiple samples for each of the 4 CRM binders tested. The differences in viscosity between the 2 methods appear to be negligible for a viscosity range of between 0.6 and 5.3 Pa.s but become more significant at higher viscosities. It is worth noting that the viscosity range specified for the CRM binders in PSTS112 is between 1.5 and 4.5 Pa.s and testing binders in this viscosity range using either method is therefore unlikely to have a significant effect on the test results.

Figure 2.5: Single vs multiple sample testing with the Brookfield viscometer



Effect of sample tin size

The draft TMR hand-held viscometer test method specifies certain test conditions that may affect the viscosity measurement when using the Rion viscometer, including the size of the sample tin in which the binder is tested. The distance between the spindle surface and the walls of the tin may influence the shear rate applied to the binder and therefore the viscosity results. In Queensland, it is common practice to sample binders in 1-litre tins during construction, whereas the draft test method requires the binder to be tested in a larger 4-litre tin.

The boundary effects due to different sized sample tins were evaluated by heating Binder A – 12% CR and Binder D – 21% CR in 1-litre (10.4 cm internal diameter), 2-litre (13.7 cm internal diameter) and 4-litre (17.2 cm internal diameter) tins. The spindle used in the Rion viscometer had a radius of 1.2 cm.

The viscosity of the different binders was then determined in each of the tins at 3 different temperatures. Figure 2.6 and Figure 2.7 show that there are differences in the Rion viscosity results when different sized sample tins are used for testing. The difference in viscosity appeared to be more pronounced with an increase in binder viscosity (i.e. when testing the binder at lower temperatures).

Strangely, the viscosity values of the binder in the 4- litre tin were lower than the viscosities of the binder in the 1-litre tin but higher than the viscosities of the binder in the 2-litre tin. The reason for this possible anomaly is unknown and was not investigated further as part of the study.

The testing undertaken indicates that the boundary conditions of the test (and more specifically the sample tin size) can affect the viscosity results determined with the Rion viscometer.

Considering the above, it is important that a standardised sample tin size be adopted when determining the viscosity of CRM binders using a hand-held rotational viscometer. It is therefore recommended that the 4-litre tin size in the draft test method be retained at this stage. It is also recommended that PSTS112 be updated to reflect the requirement for taking 4-litre binder samples when undertaking hand-held viscometer testing.

Figure 2.6: Effect of sample tin size on viscosity (Binder A – 12% CR)

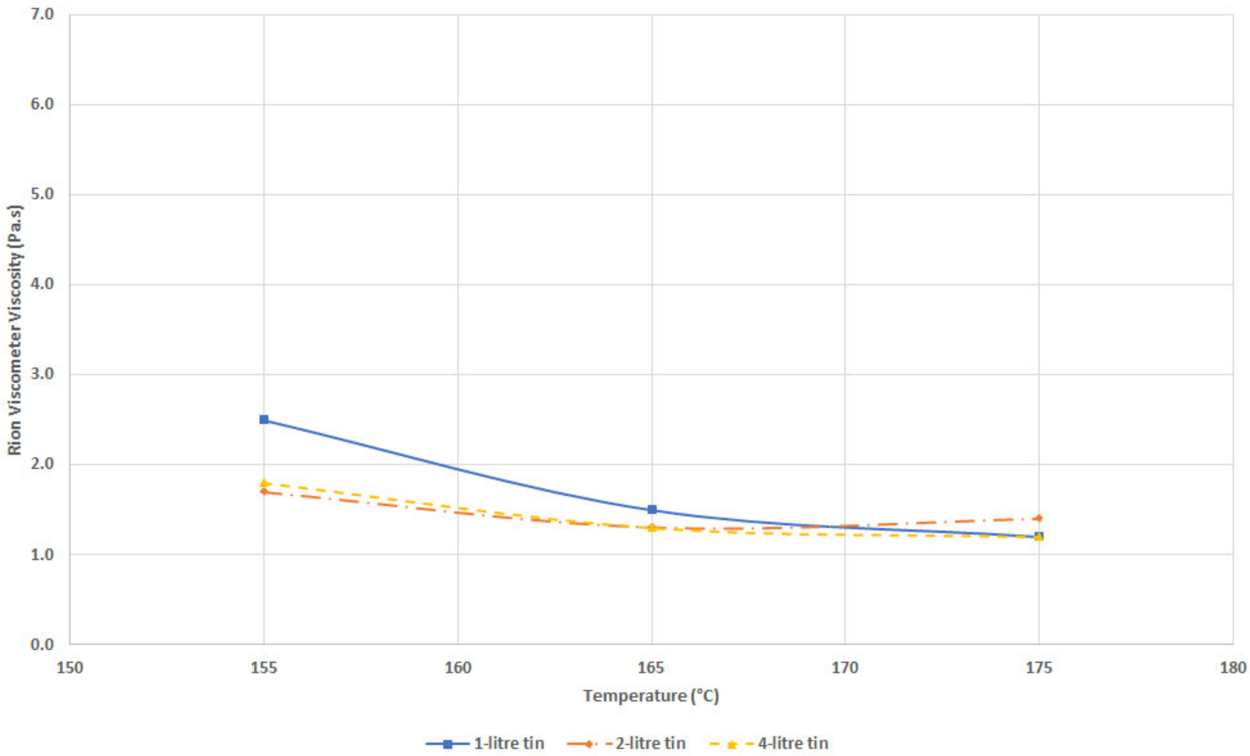
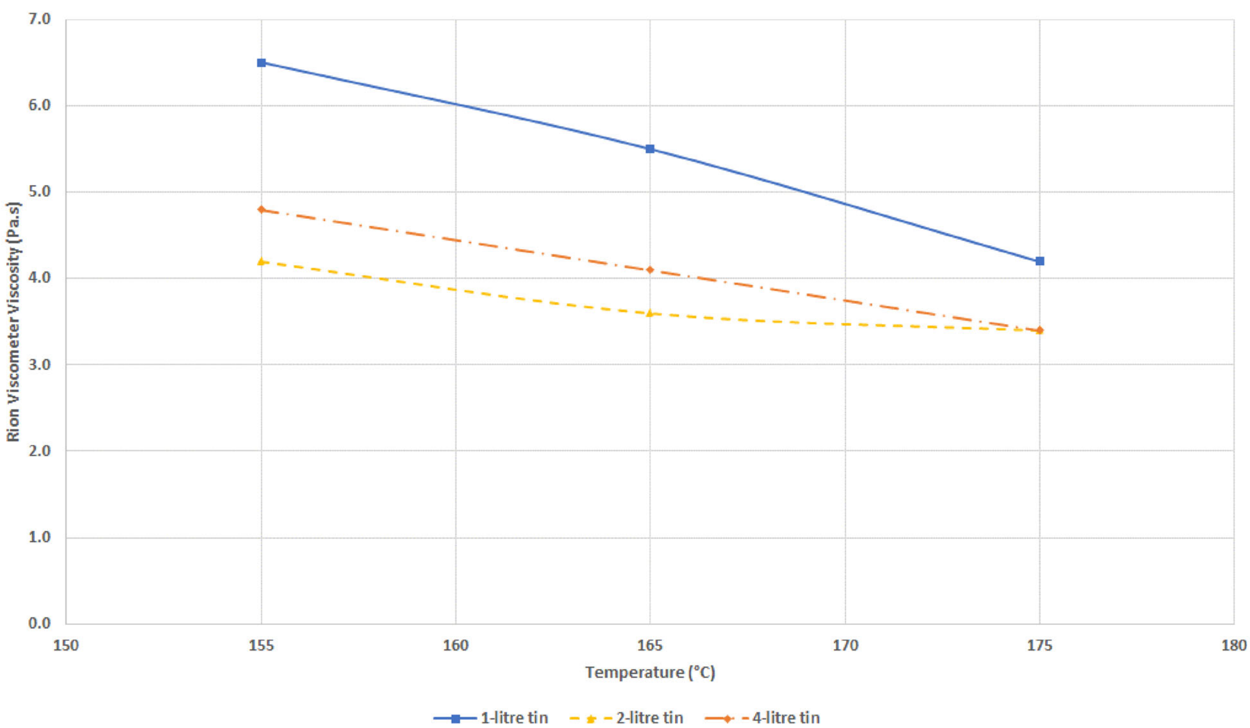


Figure 2.7 Effect of sample tin size on viscosity (Binder D – 21% CR)



Sample handling protocol adopted for the comparative testing

Considering the findings above, the following sample handling protocol was adopted to reduce possible variability during the comparative viscosity testing:

- Approximately 3.2 kg of the CRM binder samples were oven-heated in a 4-litre tin to a target temperature of approximately 185 °C.
- A single subsample (approximately 125–150 g) was taken for each of the binders from the 4-litre tin. The subsample was allowed to cool down to a nominal temperature of approximately 120 °C under ambient conditions and then reheated to 135 °C, 145 °C, 155 °C, 165 °C and 175 °C in the Brookfield's thermosel for viscosity testing using the Brookfield viscometer.
- The 4-litre tin with the remaining binder was removed from the oven and placed on a hotplate to maintain the binder's temperature at 175 °C for the first test using the Rion viscometer. The binder was then allowed to cool down to 165 °C, 155 °C, 145 °C and 135 °C under ambient conditions for subsequent viscosity testing using the Rion viscometer.

2.3 Differences between the Brookfield and Rion Viscometers

Comparative laboratory testing was carried out to determine the differences (if any) between the viscosity results obtained for 4 CRM binders when using the Brookfield and Rion viscometers for testing. A comparison of the viscosity results is provided in Table 2.2.

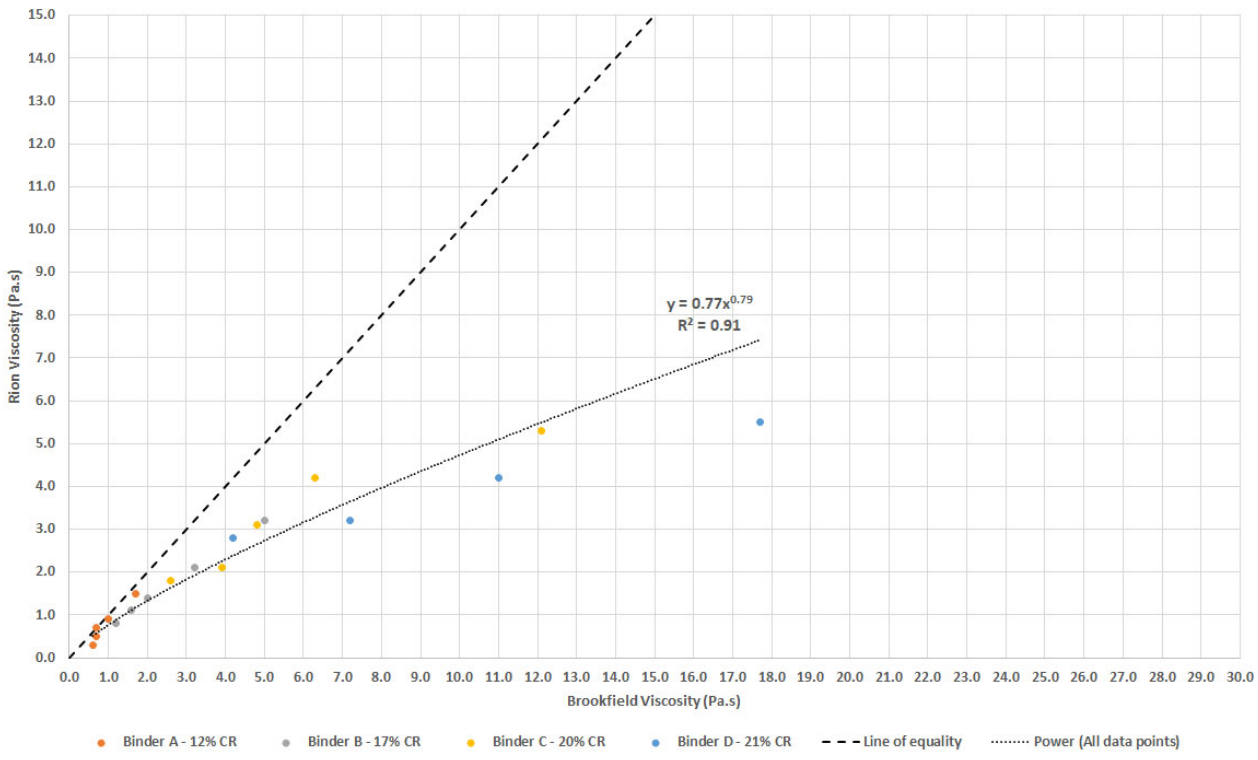
Table 2.2: Viscosity results

Binder	Temperature (°C)	Viscosity – Rion viscometer (Pa.s)	Viscosity – Brookfield viscometer (Pa.s)	Difference (Pa.s)	Percentage difference
Binder A – 12% CR	135	1.5	1.7	0.2	13
Binder A – 12% CR	145	0.9	1.0	0.1	11
Binder A – 12% CR	155	0.7	0.7	0.0	4
Binder A – 12% CR	165	0.5	0.6	0.1	18
Binder A – 12% CR	175	0.3	0.6	0.3	67
Binder B – 17% CR	135	3.2	5.0	1.8	44
Binder B – 17% CR	145	2.1	3.2	1.1	42
Binder B – 17% CR	155	1.4	2.0	0.6	35
Binder B – 17% CR	165	1.1	1.6	0.5	37
Binder B – 17% CR	175	0.8	1.2	0.4	40
Binder C – 20% CR	135	5.3	12.1	6.8	78
Binder C – 20% CR	145	4.2	6.3	2.1	40
Binder C – 20% CR	155	3.1	4.8	1.7	43
Binder C – 20% CR	165	2.1	3.9	1.8	60
Binder C – 20% CR	175	1.8	2.6	0.8	36
Binder D – 21% CR	135	11.0(1)	28.2	17.2	88
Binder D – 21% CR	145	5.5	17.7	12.2	105
Binder D – 21% CR	155	4.2	11.0	6.8	89
Binder D – 21% CR	165	3.2	7.2	4.0	77
Binder D – 21% CR	175	2.8	4.2	1.4	40

Note: This test result was removed from the subsequent analysis given that it falls well outside the range of the calibration check undertaken.

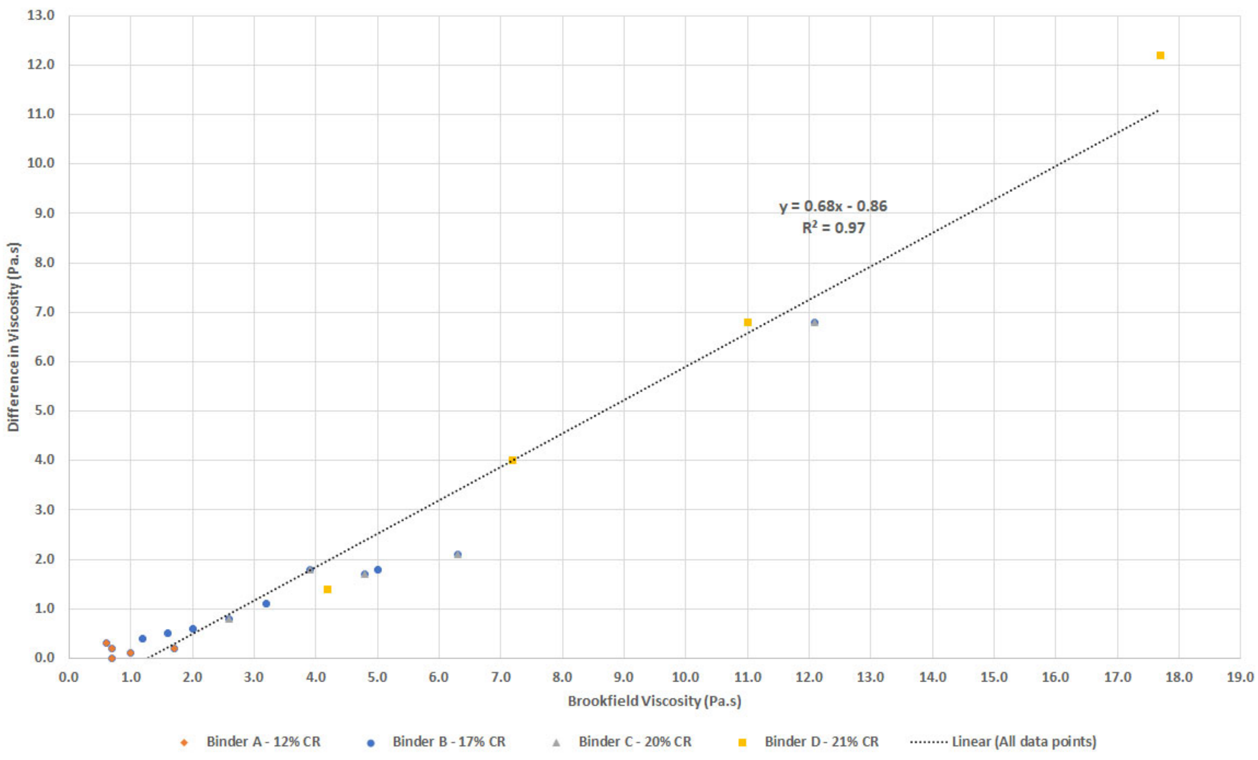
Figure 2.8 also shows a comparison between the viscosities determined at different temperatures with the 2 viscometers.

Figure 2.8: Relationship between the Rion and Brookfield viscometer results



The viscosities measured with the Brookfield viscometer were consistently higher than the viscosities measured with the Rion viscometer. There was however a strong correlation between the 2 test devices (i.e. the R-squared value obtained from a power fit to the data was found to be 0.95). It was also found that the differences in viscosities determined with the 2 viscometers increased with an increase in binder viscosity (i.e. with a decrease in test temperature) (Figure 2.9).

Figure 2.9: Differences between Rion and Brookfield viscometer results



The reasons for the differences in viscosity results obtained with the 2 viscometers were not investigated in detail as part of the study but could be due to the different shear rates applied by the 2 devices. AGPT/T111 does not specify a fixed shear rate when testing the viscosity of binders with the Brookfield device and the shear rate applied was therefore not necessarily the same in the different tests.

For instance, the estimated fixed shear rate at the surface of the spindle in a Rion viscosity test was approximately 13 s^{-1} for the 4-litre tin size, whereas the shear rate estimated for the Brookfield device varied between approximately 0.4 s^{-1} and 15 s^{-1} for the different binders tested at different temperatures. Lower viscosity binders are tested using higher shear rates when the Brookfield device is used.

This variable shear rate when using the Brookfield viscometer could reduce the ability to precisely measure the viscosity of CRM binders. It is however worth noting that the Brookfield device provides better temperature control compared to hand-held viscometers.

Based on the relationship shown in Figure 2.8, the following equation was used to estimate the Rion viscosity based on the more commonly available Brookfield results for the binders tested in the study.

$$v_R = 0.77 \times v_B{}^{0.79} \qquad (1)$$

where

v_R = Rion viscosity in Pa.s

v_B = Brookfield viscosity in Pa.s

Consequently, the viscosity range (1.5–4.5 Pa.s at 175 °C) specified in PSTS122 and originally developed using a hand-held rotational viscometer is equivalent to an estimated viscosity range of 2.3–9.3 Pa.s when using the Brookfield viscometer (based on the binders tested in the study).

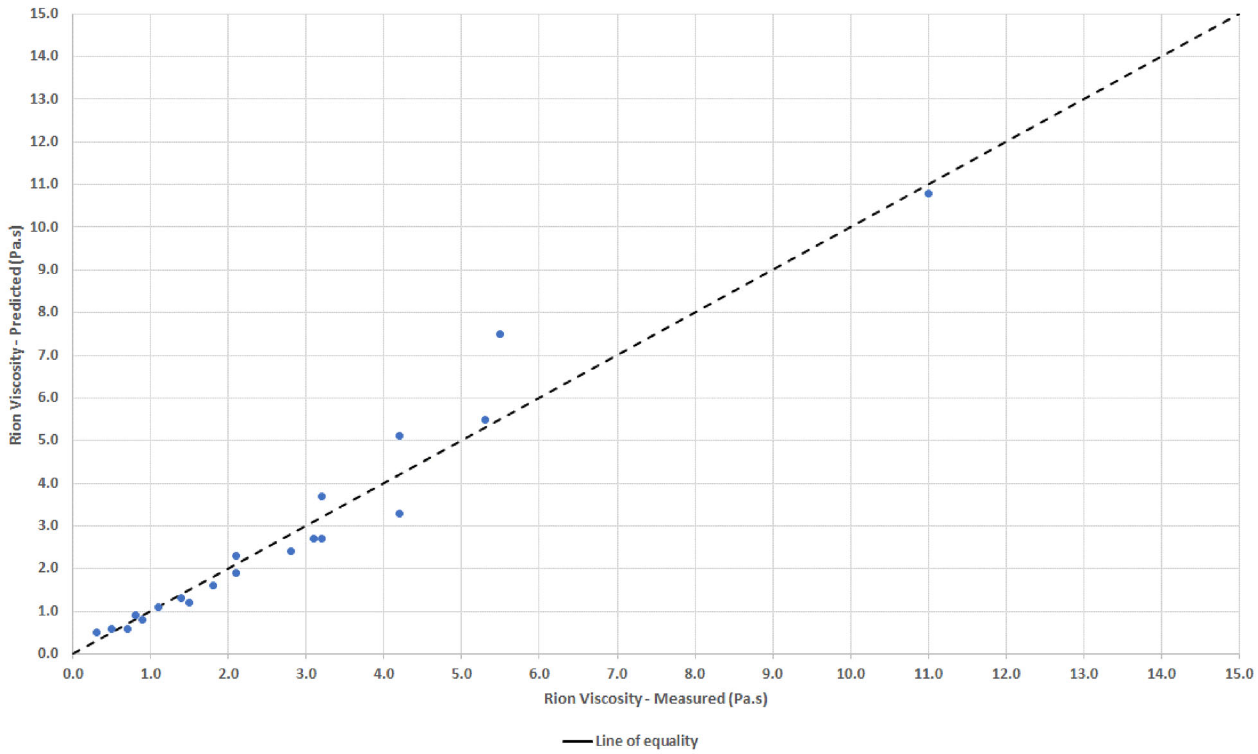
The generic relationship for the 4 binders tested (Equation 1) was further investigated to assess its suitability to determine an offset between the Rion and Brookfield viscometer for use in quality assurance testing during construction. The error values (absolute difference) in the predicted versus measured viscosities are summarised in Table 2.3. A comparison between the measured and predicted viscosities is also shown in Figure 2.10.

Table 2.3: Measured versus predicted Rion viscosity results (generic model)

Measured Brookfield viscosity (Pa.s)	Measured Rion viscosity – (Pa.s)	Predicted Rion viscosity – (Pa.s)	Error (Pa.s)	Percentage error
1.7	1.5	1.2	0.3	22
1.0	0.9	0.8	0.1	12
0.7	0.7	0.6	0.1	15
0.7	0.5	0.6	0.1	18
0.6	0.3	0.5	0.2	50
5.0	3.2	2.7	0.5	17
3.2	2.1	1.9	0.2	10
2.0	1.4	1.3	0.1	7
1.6	1.1	1.1	0.0	0
1.2	0.8	0.9	0.1	12
12.1	5.3	5.5	0.2	4
6.3	4.2	3.3	0.9	24
4.8	3.1	2.7	0.4	14
3.9	2.1	2.3	0.2	9
2.6	1.8	1.6	0.2	12
17.7	5.5	7.5	2.0	31

Measured Brookfield viscosity (Pa.s)	Measured Rion viscosity – (Pa.s)	Predicted Rion viscosity – (Pa.s)	Error (Pa.s)	Percentage error
11.0	4.2	5.1	0.9	19
7.2	3.2	3.7	0.5	14
4.2	2.8	2.4	0.4	15

Figure 2.10 Comparison between the measured and predicted viscosities (generic model)



The absolute differences (error) between the measured and predicted Rion viscosity values ranged between 0.0 and 2.0 Pa.s which may be acceptable for quality control (as an indication only) but not necessarily for quality assurance purposes.

However, the error between the measured and predicted viscosity results reduced significantly when the individual binder-specific relationships were used (Table 2.4). The binder-specific relationships resulted in an error value of between 0.0 and 0.6 Pa.s, and project-specific offset values between a specific Rion and Brookfield viscometer could therefore potentially be developed for quality assurance purposes.

Table 2.4: Measured versus predicted Rion viscosity results (binder-specific models)

Binder	Measured Brookfield viscosity (Pa.s)	Measured Rion viscosity – (Pa.s)	Predicted Rion viscosity – (Pa.s)	Error (Pa.s)	Percentage error
Binder A – 12% CR	1.7	1.5	1.5	0.0	0
Binder A – 12% CR	1.0	0.9	0.9	0.0	0
Binder A – 12% CR	0.7	0.7	0.5	0.2	33
Binder A – 12% CR	0.7	0.5	0.5	0.0	0
Binder A – 12% CR	0.6	0.3	0.4	0.1	29
Binder B – 17% CR	5.0	3.2	3.1	0.1	3
Binder B – 17% CR	3.2	2.1	2.1	0.0	0
Binder B – 17% CR	2.0	1.4	1.3	0.1	7
Binder B – 17% CR	1.6	1.1	1.1	0.0	0
Binder B – 17% CR	1.2	0.8	0.8	0.0	0

Binder	Measured Brookfield viscosity (Pa.s)	Measured Rion viscosity – (Pa.s)	Predicted Rion viscosity – (Pa.s)	Error (Pa.s)	Percentage error
Binder C – 20% CR	12.1	5.3	5.9	0.6	11
Binder C – 20% CR	6.3	4.2	4.1	0.1	2
Binder C – 20% CR	4.8	3.1	3.2	0.1	3
Binder C – 20% CR	3.9	2.1	2.6	0.5	21
Binder C – 20% CR	2.6	1.8	1.6	0.2	12
Binder D – 21% CR	28.2	11.0	9.7	1.3	13
Binder D – 21% CR	17.7	5.5	5.3	0.2	4
Binder D – 21% CR	11.0	4.2	3.7	0.5	13
Binder D – 21% CR	7.2	3.2	3.1	0.1	3
Binder D – 21% CR	4.2	2.8	2.9	0.1	4

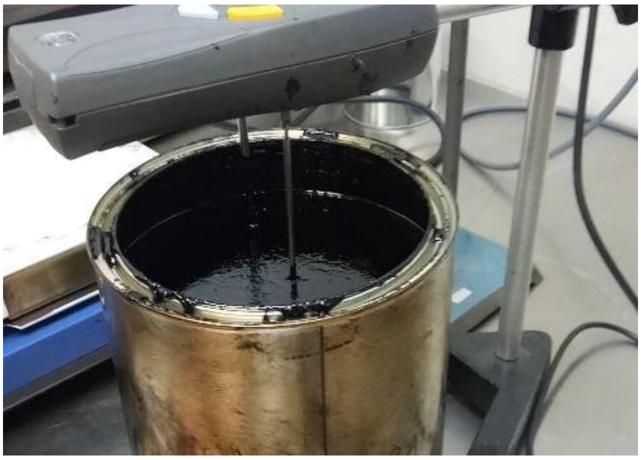
2.4 Rion Viscometer Testing Observations

Several important observations were made during the Rion viscometer testing carried out at the TMR laboratory:

- Using the stand for the Rion viscometer was slow and cumbersome which led to difficulties when trying to test at a specific temperature as the binder cooled down due to the additional time required to adjust the stand prior to testing.
- 'Drilling' (i.e. the displacement of rubber particles away from the spindle), which is sometimes observed when testing the viscosity of CRM binders with the Rion viscometer, was not observed during the study. In fact, the rubber particles appeared to interact and flow with the binder as shown by the difference between the binder surfaces in Figure 2.11 and Figure 2.12.
- The use of the 4-litre tin for testing resulted in extended heating times in the oven due to the large amount of binder required (e.g. 3 litres).
- There was some difficulty in achieving stable binder temperature readings when measuring the temperature of the binder using a thermocouple type thermometer. It was found that using a thermos-resistor type thermometer resulted in more stable (although not instantaneous) results.
- It took between 3 to 4 minutes for the temperature of the 4-litre sample of binder to start dropping more than a degree below the temperature at which the sample was removed from the hot plate. This would suggest that adequate time is available to undertake the necessary testing at the required test temperature.

Figure 2.11 Static Rion test

Figure 2.12 Active Rion test



3. Proposed Test Method and Specification Amendments

Based on the findings of the study, the following amendments to the draft hand-held rotational viscometer test method and PSTS112 are recommended for consideration by TMR:

Draft test method

- The draft test method specifies that the accuracy of the viscometer must be verified against 3 standard reference oils. The viscometer is considered to be accurate if the values obtained are within 0.3 Pa.s of the known viscosity. However, as discussed in Section 2.2.1, the Rion viscometer has an accuracy of ±10% as stated by the manufacturer, which is less accurate than the ±0.3 Pa.s specified at 5 Pa.s. It is therefore recommended that the requirement in the test method be revised to specify a ±10% tolerance compared to the known values of the reference oils. Furthermore, given that only 2 reference oils were found to be readily available it is recommended that 2 instead of 3 reference oils be used for the calibration testing.
- The draft test method currently references Pa.s, dPa.s and centipoise as units for viscosity results. It is recommended that the unit is standardised for viscosity to Pa.s, similar to what is currently being used in the Australian pavements industry.

PSTS112 *Crumb Rubber Modified Asphalt*

- Include a reference to the use of 4-litre tins for viscosity testing when using a hand-held rotational viscometer.
- Additional clarity should be provided in the specification that the viscosity range specified is based on using a hand-held rotational viscometer. An alternative viscosity range may be applicable for CRM binders when tested using a Brookfield viscometer.
- The use of binder-specific correlations between the hand-held and Brookfield viscometers could be considered in future updates to the specification. Any binder-specific correlations developed in future would however have to consider an appropriate binder heating protocol, as discussed in Section 2.2.2.

4. Conclusions and Recommendations

4.1 Summary of Findings

NACOE previously developed a new technical specification for OGA and GGA manufactured with CRM binders. The viscosity specified at 175 °C is an important requirement for CRM binders used in asphalt and is commonly measured using a hand-held rotational viscometer (such as the Rion viscometer). However, the Rion viscometer was not widely available in Queensland at the time when the new technical specification was developed, and allowance was therefore made to also use the more commonly available Brookfield viscometer for both binder design and quality assurance purposes.

Subsequent preliminary testing by WARRIP did however indicate that the viscosity measured with the 2 different viscometers was not necessarily equal for a particular CRM binder. A new NACOE project (this project) was therefore commissioned to investigate the differences in viscosity measured with the Brookfield and Rion viscometers and establish an offset between the 2 devices (if possible).

Comparative laboratory testing of 4 commercially manufactured CRM binders with a crumb rubber content range between 12% and 21% by weight of the binder was undertaken using a Brookfield and a Rion viscometer. Testing was undertaken at a range of different temperatures between 135 °C and 175 °C. Similar to the previous WARRIP study, laboratory testing showed that there was a difference between the viscosity measured with each viscometer. Furthermore, it was found that the differences in the results obtained between the Rion and Brookfield viscometers were dependent on the viscosity of the binder.

Even though a strong correlation was observed between the Brookfield and Rion viscometer results, a generic offset that would be suitable for quality assurance purposes could not be established. However, the study showed that a project-specific offset could potentially be established for a particular CRM binder that could be used for quality assurance purposes during construction.

The study also found that the sample tin size used for the Rion viscosity testing influenced the test results, particularly more so for the smaller 1-litre tin size. The sample heating protocol adopted for testing CRM binders can also affect the viscosity results and it is therefore important to standardise the sample tin size and binder reheating protocol used for future testing.

4.2 Recommendations

Based on the findings of the study, the following recommendations are made for consideration by TMR:

- Change the viscometer calibration verification requirement in the draft test method to a measured tolerance of ±10% which is more aligned with the accuracy of the device. The requirement for checking the equipment against 3 reference oils could also be reconsidered (2 reference oils may be adequate).
- Standardise the unit for viscosity to Pa.s in the draft test method, similar to what is currently being used in the Australian pavements industry.
- Include a reference in PSTS112 for the use of 4-litre tins for viscosity testing when using a hand-held rotational viscometer.
- Review the appropriateness of using the current Brookfield test method (considering the variable shear rate) to determine the viscosity of CRM binder.
- Review the viscosity requirements in PSTS112 if a Brookfield viscometer will be used for the binder design and quality assurance purposes.
- Consider the use of binder-specific correlations between the hand-held and Brookfield viscometers in future updates to the specification.

References

Denneman, E, Lee, J, Raymond, C, Choi, Y, Khoo, KY & Dias, M 2015, *Optimising the use of crumb rubber modified bitumen in seals and asphalt*, National Asset Centre of Excellence (NACOE), Brisbane, Qld.

Grobler, JA, Beecroft, A, Choi, Y 2017, *P31 Transfer of crumb rubber modified asphalt and sealing technology to Queensland*, National Asset Centre of Excellence (NACOE), Brisbane, Qld.

Grobler, JA 2020, P75 *Transfer of crumb rubber modified gap-graded asphalt technology to Queensland and Western Australia*, National Asset Centre of Excellence (NACOE), Brisbane, Qld.

Grobler, JA 2021, P75 *Transferring crumb rubber modified gap-graded asphalt technology to Queensland*, National Asset Centre of Excellence (NACOE), Brisbane, Qld.

Sabita 2019, *Guidelines for the design, manufacture and construction of bitumen-rubber asphalt wearing courses, Manual 19*, South Africa.

van Aswegen, E 2019, *Transfer of appropriate crumb rubber modified bitumen technology to WA*, Western Australian Road Research and Innovation Program (WARRIP), Perth, WA.

ASTM International Standards

ASTM D7741/D7741M – 18, *Standard test method for measurement of apparent viscosity of asphalt-rubber or other asphalt binders by using a rotational handheld viscometer*.

Austroads Test Methods

AGPT/T111-2006 *Handling viscosity of polymer modified binders (Brookfield thermosel)*.

Transport for New South Wales Test Methods

T737-2012 *Rubber content of a scrap rubber mix.*