Development of RAP binder characterisation tests for use within viscosity grade binder specification framework

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ABSTRACT

Reclaimed asphalt pavement (RAP) is increasingly being re-used in new asphalt products. The properties of the binder in RAP will affect the behaviour of the asphalt material, especially for products containing a considerable proportion of RAP. This paper presents the results of a study aimed at developing an improved methodology of characterising RAP binder blends within a viscosity grade binder specification framework. The methodology comprises measurement of a complex viscosity parameter for the RAP binder using the dynamic shear rheometer (DSR). The parameter was selected to be comparable to the capillary tube viscosity, a test typically used in viscosity grade specifications for bitumen in Australia. The parameter can be used in the design of blends of RAP binder and virgin binder and/or rejuvenator to a specified viscosity value. The study included two experimental phases: the first phase was aimed at developing the DSR-based methodology for characterisation of the RAP binder; and in the second phase, performance-related tests on laboratory prepared asphalt mixes containing different percentages of RAP were performed to validate the binder characterisation methodology. The experimental work showed that the DSR can be used for viscosity measurement as an alternative to both the sliding plate micro-viscometer and the capillary viscosity test. The experiments on asphalt mixes containing various percentages of RAP showed the influence of RAP content on flexural modulus, fatigue and rut resistance of the material. The performance-related testing of asphalt mixes further confirmed that the RAP binder characterisation methodology developed as part of this study can be used to design binder blends containing RAP, virgin binder and rejuvenator, in such a way that the overall performance of a high RAP content mix is similar to that of a mix containing only virgin materials.

Keywords: Performance testing, Reclaimed asphalt pavement (RAP) Recycling, Rejuvenators, Viscosity

1. INTRODUCTION

The re-use of reclaimed asphalt pavement (RAP) in the production of asphalt mix has become standard practice. In many countries, RAP is by far the most recycled construction material product. Maximisation of the re-use of RAP in its highest value application, i.e. as new asphalt product, has significant economic and environmental sustainability benefits. The inclusion of RAP in asphalt mixes does however require due consideration during the mix design process to ensure satisfactory performance of the final product.

When designing asphalt mixes containing RAP, both the US Superpave asphalt mix design framework and the European EN 13108 asphalt specification framework assume, for the purpose of binder blend design, that full blending between the binder from the RAP and any added virgin binder or rejuvenator occurs during asphalt production. In the USA, McDaniel and Anderson (2001) proposed a procedure to develop blending charts for RAP and virgin binder to determine the performance grade for the combined binder. According to European specification EN 13108-1:2008, the binder class of the virgin binder may be used unaltered if the mix design includes less than 10% RAP for surfacing layers, and less than 20% RAP for base layers and binder courses. If higher proportions of RAP are used, the penetration and softening point values of the binder blend are to be determined using the equations in EN 13108-1:2008, Annex A. These properties are used in the design of binder blends to meet the specifications for virgin binder. Both these design frameworks require characterisation of the binder blend.

The current Australian practice differs between states, but generally either limits the percentage of RAP allowed, or compensates for the effects of RAP by using a softer grade of binder. The viscosity of the blended binder is usually not predicted or verified during the mix design or asphalt production.

The objective of this study was to develop a reliable and practical approach to the design of binder blends for use with viscosity grade binder specification frameworks, such as the Australian standard AS 2008-2013. To promote the increased use of RAP, the approach had to be both reliable and cost-effective, and practical so that it can be used in appropriate RAP stockpile management, which is critical for the performance of RAP mixes.

The work as presented in this paper consisted of two phases. In Phase 1, the binder blend characterisation methodology was developed. In Phase 2, performance-related tests on laboratory prepared asphalt mixes containing different percentages of RAP were performed to validate the binder characterisation methodology.

2. PHASE 1: Development of viscosity characterisation test

Before the introduction of the methodology described in this paper, typical criteria for the design of binder blends containing RAP and rejuvenator for use in Australia were provided in AP-T66-06 Asphalt Recycling (Austroads 2006). Characterisation tests included the capillary viscosity test at 60 ºC in accordance with AS/NZS 2341.3-1993, and the sliding plate 'Shell' micro-viscometer test at 45 ºC in accordance with AS/NZS 2341.5-1997 (R2013). The capillary viscosity test requires a significant amount of recovered RAP binder to perform the test (approximately 80 grams). This is one of the reasons why the sliding plate micro-viscometer has been commonly used in Australia for the characterisation of RAP binder. However, the equipment for this test is no longer produced.

In contrast to the capillary viscosity or penetration tests, dynamic shear rheometer (DSR) testing only requires a small amount of recovered binder (approximately 1 gram). The DSR is a versatile piece of equipment which is increasingly used in the characterisation of bituminous binder properties. The complex viscosity (η^*) determined with the DSR can be used to approximate the results of other, more conventional, viscosity tests. The η^* parameter however provides more information on the visco elastic properties of the binder than conventional viscosity tests, especially when measured over a range of temperatures and load frequencies.

A laboratory test matrix was developed to investigate the relationship between the DSR and the conventional capillary viscosity test used in Australia. The binder laboratory test matrix per RAP binder source is shown in Table 1. The testing in the table was completed for two RAP materials sourced from Victoria and Western Australia. These two states have different climates, but the influence of climate on RAP condition did not form part of the scope of this study. The sources are referred to as RAP1 and RAP2, respectively, in this paper.

2.1 Laboratory procedures

The laboratory procedures in terms of binder extraction methodology, preparation of binder blends for the various viscosity tests, and viscosity test methods are explained in this section. The procedures used to extract the binders are as described in Austroads test method AGPT/T191-2015, which was developed as part of this research. Under the method, RAP binder is extracted from the aggregate using Toluene as a solvent and recovered using centrifugation. The objective of the method is to provide a sample of the binder representative of its in-service condition, primarily in terms of measured viscosity. Blends of various base binders with different percentages of recovered RAP1 and RAP2 binders were produced. The base binders included a Class 170, a Class 320, and a rejuvenating oil product. The blending proportions are provided in Table 3. Capillary viscosity tests at 60 ºC were performed on all virgin binders, in accordance with the procedures of AS/NZS 2341.3-1993. Due to the high viscosity of RAP at 60 ºC, capillary viscosity testing on extracted RAP binder often not possible.

The equipment and test configuration as described in AASHTO T315 were used as the basis for the DSR testing. The procedure to characterise the binder viscosity using DSR developed as part of this study provided the basis for the Austroads test method AGPT/T192-2015. A 25 mm diameter spindle with 1 mm gap DSR test configuration was used for all samples. Testing on the RAP binder was performed using a Temperature and frequency sweep tests were performed on the virgin binders, the binders recovered from the RAP sources, and each of the blends as shown in Table 3. The test results were used to develop complex viscosity (η*) master curves for the blend binders. Duplicate DSR temperature frequency sweep tests were carried out under oscillation frequencies (f) of 0.1–62.8 rad/s at 5 °C temperature intervals between 25 °C and 65 °C.

Table 1. Test matrix of binder per RAP source (two sources tested)

Test	**Extracted RAP binder content [%]**							**Total**
Blends	**0**	**10**	**15**	**20**	**30**	**60**	**90**	
Recovered RAP binder								
DSR sweep test (AASHTO T315)	2							2
Class 320								
DSR sweep (AASHTO T315)	2	2	2	2				8
Dynamic viscosity 60 °C (AS2341.3)	2							2
Class 170								
DSR sweep (AASHTO T315)	2	2		2	2			8
Dynamic viscosity 60 °C (AS2341.3)	2							2
Low viscosity oil								
DSR sweep (AASHTO T315)	2				2	2	2	8
Dynamic viscosity 60 °C (AS2341.3)	2							2
Design blend								
DSR sweep (AASHTO T315)						2		

2.2 Results

The mean results for the capillary viscosity tests at 60 °C for the individual binders tested as part of this project are shown in Table 2. The results indicate that the capillary viscosity at 60 °C for the Class 170 and Class 320 bitumen falls within the respective Australian specification limits set out in AS 2008-2013. Capillary viscosity tests were not performed on the extracted RAP binders because of the large amount of binder required for this test.

Table 2. Viscosity test results

Binder	**Capillary viscosity 60 °C (Pa.s)**	**DSR complex viscosity (*η**) at 60 °C 1 rad/s (Pa.s)**
C170	178	188
C320	305	295
Low viscosity oil	No result	0.67
RAP1	Not tested	5 708
RAP2	Not tested	33 620

Figure 1 shows an example of the η* master curves for C320 virgin binder and different proportions of a RAP source (in this case RAP1). For this study, a full set of master curves was developed for the DSR testing on C170, C320 and rejuvenating oil blended with different percentages of RAP1 and RAP2. The master curves were constructed by shifting the results for the temperature and frequency sweep test to a reference temperature of 45 ºC. The shift was performed by fitting the test data to a sigmoidal model using regression analysis in MS Excel. The master curves shown in Figure 1 are based on the average of the η* results for duplicate tests. The graphs show an increase in complex viscosity with the increase in RAP content.

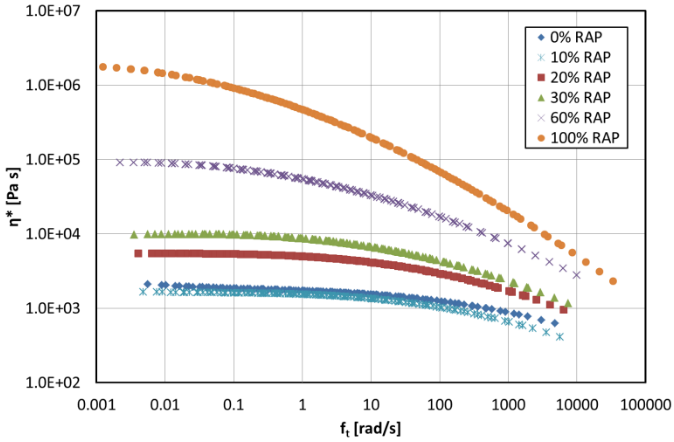

Figure 1: η* master curves at 45 °C reference temperature for C320 and RAP1

The master curve can be used to determine η* for any combination of temperature and frequency. Therefore, it was possible to determine the value of η* under loading conditions similar to those of the capillary viscosity test. Figure 2 shows the results for the viscosity at 60 °C as measured using the capillary viscometer and the DSR at an angular frequency of 1 rad/s. The figure also highlights the specification limits for C170 and C320 binders according to AS 2008-2013. The results are also included in Table 2. The DSR setting of 1 rad/s was chosen arbitrarily to some extent, but mainly for the following reasons. The shear rate in the capillary viscometer is not constant and can only be identified after conducting the test; it differs per bitumen source, between binder classes, and capillary tube types selected for testing. It would also differ per RAP source and binder blend. Therefore, even if the capillary viscometer shear rate for a virgin binder could be replicated in the DSR, it would have to change as more RAP is added to the blend. The 1 rad/s setting in the DSR yields a viscosity result similar to that of the capillary viscometer. For characterisation of the influence of RAP content on viscosity of the binder, it is unnecessary for the result to be exactly equivalent to the capillary viscosity result. The juxtaposition of capillary viscometer at 60 °C and DSR η* results is only of interest for comparison to the binder requirements in the Australian viscosity binder grading system.

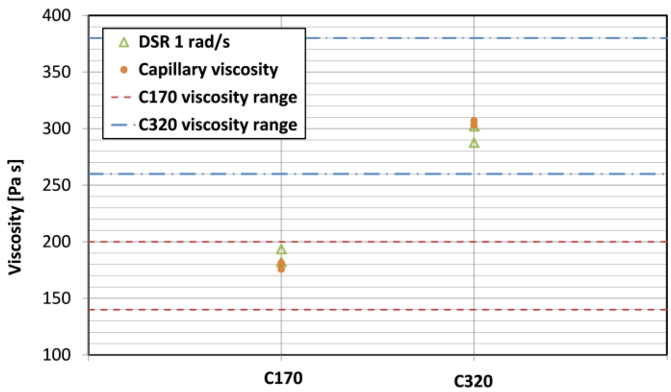

Figure 2: Comparison of viscosity readings from the DSR and capillary viscometer

Figure 3 shows η* at 1 rad/s and 60 °C measured for the blends containing different percentages of RAP. The figure also shows the trend in viscosity increases with increasing RAP percentage, as predicted using a blending equation. The so-called Chevron equation (Centeno et al. 2011), shown here as Equation 1, was used to predict the viscosity at various RAP contents in order to plot the trend line.

$$VBI_i = \frac{\log \vartheta_i}{3 + log\vartheta_i}$$

$$VBI_\beta = \sum_{i=1}^{n} x_i VBI_i$$

(1)

$$\mu = 10^{\left(\frac{3\,VBI_{\beta}}{1-VBI_{\beta}}\right)}$$

Where

ϑ_i	=	viscosity of i^{th} component (cP)
VBI_i	=	viscosity blending index of i^{th} component
VBI_{β}	=	viscosity blending index of the blend
x_i	=	volume fraction of i^{th} component
μ	=	viscosity of the blend (cP).

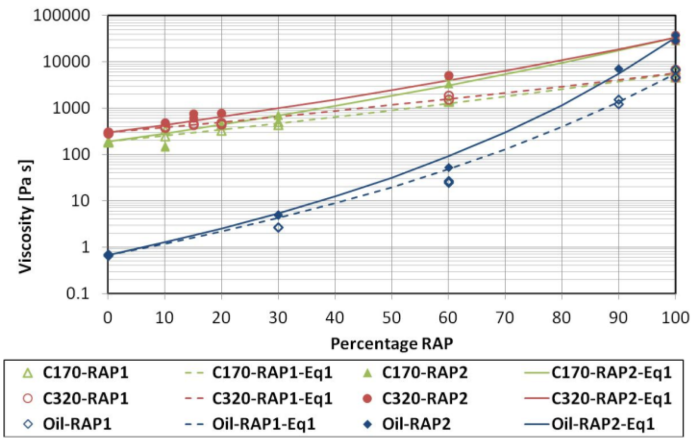

Figure 3: Complex viscosity as measured in the DSR at 1 rad/s and 60 ºC

The prediction requires the viscosity values of the virgin binder and the RAP binder as inputs to predict the viscosity of a blend with various proportions of either component. As stated in the introduction, complete blending of the different binder components is assumed for the purpose of binder blend design. Whether full blending occurs during asphalt production is a topic of debate amongst practitioners. The relationship was found to provide acceptable accuracy for the results in this study. It was chosen over more conventional log-linear viscosity blending charts, such as described in ASTMD4887M-11, because these were previously reported to be less precise for blends containing rejuvenator oil (Chaffin et al. 1995). This issue can also be observed in Figure 3, where the trend in the results for the rejuvenator oil would not be well approximated by a log-linear relationship. The Chevron equation was found to provide acceptable accuracy in an extensive study comparing the predictive performance of different blending rules by Centeno et al. (2011). No attempt was made to develop a viscosity prediction equation based on the results of this study, because only a limited number of RAP sources and virgin binders were included.

It is proposed that the η* at 1 rad/s and 60 °C parameter (refer Section 2.2) should be used in combination with the blending rule in Equation 1, to design binder blends containing RAP to a desired viscosity. The binder blend can be designed targeting specified capillary viscosity values. In the Australian context, the midpoint of 140 Pa.s to 200 Pa.s would be targeted to create an equivalent C170 bitumen, and the midpoint of 260 Pa.s to 380 Pa.s for a binder equivalent to C320. The procedure would comprise the following steps:

- Collect a representative sample of the RAP in accordance with AS 1141.3.1.
- Extract a representative sample of the RAP binder in accordance with AGPT/T191-2015.
- Determine the complex viscosity of the extracted RAP binder, the virgin binder and the rejuvenator oil using the DSR at 60 °C and 1 rad/s, in accordance with AGPT/T192-2015.
- Predict the viscosity of the binder blend using Equation 1.
- If the viscosity is outside the desired range for the design, adjust the proportion of the binder blend components with the help of Equation 1.

• Check the viscosity of the final design blend directly using the DSR.This blend design procedure has recently been converted into an Austroads test method (AGPT/T193-2015). The methodology for sample preparation is also provided in the test method.

2.3 Verification of binder blend design procedure

To verify the accuracy of the viscosity prediction procedure, it was applied to design binder blends containing a high percentage of RAP to meet a target viscosity. Three different blends were designed to meet the viscosity requirements for Class 320 bitumen. The blend components are shown in Table 3. The first blend contained 50% RAP1 by mass, 40% C170, and 10% rejuvenator oil. The viscosity predicted using Equation 1 approaches the average viscosity measured in the DSR at 60 °C and 1 rad/s. The second blend contained 50% of RAP2, and it was determined that the blend required about 33% C170 and 17% rejuvenator oil for the viscosity to fall within the C320 specification range. The accuracy of the prediction compared to the measured value for blend 2 is not as good as the case of blend 1, but nonetheless acceptable.

The results for blend 1 and 2 showed that it is possible to design a binder blend to a desired viscosity range (to meet a binder viscosity specification) using the procedure presented in this paper. The next step was to verify whether it is possible to use this procedure to design an asphalt mix containing RAP that has similar performance to an asphalt mix containing virgin binder only.

Blend 3 in Table 3 is the design blend for an asphalt mix containing 60% RAP by mass of mix. Since the binder content of the RAP is low (4%), it only provides 40.5% of the total required mix design binder content of 5.6%. Using Equation 1, it was determined that if the RAP binder is blended with 52.5% C170 binder and 7% rejuvenating oil, it would meet the viscosity range for C320 binder. The measured result in Table 3 indicates that, from a viscosity blending perspective, the procedure was successful. The next section investigates whether equivalent viscosity values of the binder blend procedure leads to equivalent performance of the actual asphalt mix.

Table 3. Blend design results

	Component 1	Component 2	Component 3	Measured η^* [Pa.s]	Predicted η^* [Pa.s]
Blend 1	RAP1 (50%)	C170 (40%)	Oil (10%)	365	368
Blend 2	RAP2 (50%)	C170 (33%)	Oil (17%)	330	380
Blend 3	RAP1 (40.5%)	C170 (52.5%)	Oil (7%)	356	338

3. PHASE 2: Validation through performance-based testing of RAP mixes

To validate the RAP binder characterisation methodology, a series of performance-related laboratory tests on asphalt mixes were undertaken as part of this study. The objective was to demonstrate the influence of RAP content on the performance properties of asphalt mixes. A further objective was to assess the capability of the binder blend design methodology presented in the previous section, to correct the mix properties for the influence of the hard RAP binder.

Asphalt samples were prepared in the laboratory at a range of RAP contents, some including a softer class binder of C170. The mixing procedure (including selection of mixing and compaction temperature) as prescribed in AS 2891.2.1 was adhered to. Rejuvenator oil was pre-blended with the virgin bitumen. To simulate oxidative aging of binder that takes place during production of asphalt and transport to site, samples were conditioned in accordance with the short term aging procedure in AASHTO protocol R30. All results are compared to that of an existing registered reference mix with a nominal maximum aggregate size of 10 mm containing 5.6% of Class 320 binder by weight of total mix. The binders and RAP1 material characterised as part of the Phase 1 study were used in the production of the asphalt samples. The experimental matrix with various RAP percentages by weight is shown in Table 4. The aggregate particle distributions for the mixes containing different percentages of RAP were optimised so that they closely resemble that of the reference mix. The resulting aggregate grading and mix proportions are shown in Table 5.

The following three key performance requirements for asphalt were compared:

- flexural modulus (four-point bending) in accordance with EN 12697-26
- fatigue (four-point bending) in accordance with AGPT/T233-2006
- wheel tracking deformation (rut resistance) in accordance with AGPT/T231-2006.

Asphalt mixes and test specimens were prepared in the laboratory in accordance with AGPT/T230. The results of these asphalt tests are presented in the following sections.

3.1 Mix stiffness – master curves

The results of flexural modulus temperature and frequency sweep testing were used to develop modulus master curves for the different asphalt mixes. Four beams were tested per mix type. Figure 4a shows the master curves for asphalt mixes with C170 and RAP contents of 15, 30 and 60%. At 15% and 30% RAP content, the master curves are similar. As the RAP content increases to 60%, there is a significant increase in the flexural modulus of the asphalt mix.

Selected master curves are presented in Figure 4b. Important information in this figure is that the flexural modulus master curve for the asphalt mix with the designed binder blend and 60% RAP (Blend 3 from Table 3) matches that of the C320 reference mix. This confirms that an asphalt mix with very high RAP content can be designed to match the stiffness of a mix without RAP. This however does require characterisation of the RAP binder. The test results validate that the viscosity prediction methodology can be applied successfully to correct for the effect of the harder RAP binder on the modulus of asphalt.

Table 4. Test matrix of performance testing on asphalt mix (RAP Source 1)

Test	RAP content [%]				Total tests
	0	15	30	60	
Mix with class 320 binder					
Modulus (EN 12697-26)	6	6	5		17
Wheel tracking (AGPT/T231)	2	2	2		6
Fatigue (AGPT/T233)	9	9	9		27
Mix with class 170 binder					
Modulus (EN 12697-26)		5	5	5	15
Wheel tracking (AGPT/T231)		2	2	2	6
Fatigue (AGPT/T233)		9	9	9	27
Mix with designed binder blend					
Modulus (EN 12697-26)				6	6
Wheel tracking (AGPT/T231)				2	2
Fatigue (AGPT/T233)				9	9

Table 5. Aggregate grading at different percentages of RAP (Source 1)

% RAP added	**0 (reference)**	**15**		**30**		**60**	
Binder class	**C320**	**C170**	**C320**	**C170**	**C320**	**C170**	**Designed blend**
% RAP bitumen	0.0	0.6	0.6	1.1	1.1	2.3	2.3
% virgin C320 added	5.6		5.0		4.5		
% virgin C170 added		5.0		4.5		3.3	2.9
% virgin low viscosity oil added							0.4
% total bitumen in mix	5.6						
	Aggregate grading						
26.5 mm	100	100	100	100	100	100	100
19.0 mm	100	100	100	100	100	100	100
13.2 mm	100	100	100	100	100	100	100
9.5 mm	98	98	98	98	98	98	98
6.7 mm	85	85	85	85	85	86	86
4.75 mm	68	68	68	67	67	67	67
2.36 mm	46	46	46	45	45	45	45
1.18 mm	33	33	33	33	33	33	33
0.600 mm	23	24	24	24	24	25	25
0.300 mm	16	16	16	17	17	18	18
0.150 mm	10.0	10.0	10.0	10.0	10.0	11.0	11.0
0.075 mm	6.5	6.5	6.5	6.5	6.5	7.0	7.0

3.2 Fatigue characterisation

The measured strain controlled fatigue life (to 50% reduction of the modulus) and the fatigue regression line for C170 and C320 asphalt mixes are presented in Figures 5a and 5b respectively. Nine samples were tested per mix type, divided over three different strain levels. Figure 5a shows that for the asphalt mixes with C170 binder, there is a clear correlation between the strains controlled fatigue life and RAP content. As shown in the figure, the fatigue life reduces when the percentages of RAP content increased from 15 to 30% and 60%.

The influence of RAP content on the performance of the asphalt mixes with C320 in Figure 5b is less well-defined. The strain controlled fatigue life for the 0, 15 and 30% RAP samples are very similar. In fact, the regression line for the 15% RAP mix shows slightly higher strain controlled fatigue life than the mix with 0% RAP. This can be partially explained by the limited number of fatigue beams used in the experimental test program, as well as the inherent variability in fatigue beam test results.

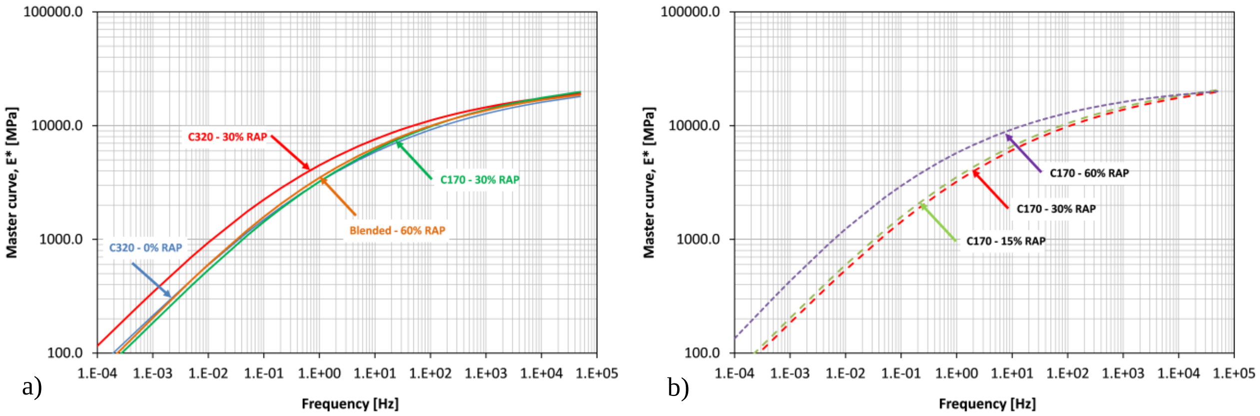

Figure 4: Flexural modulus master curves

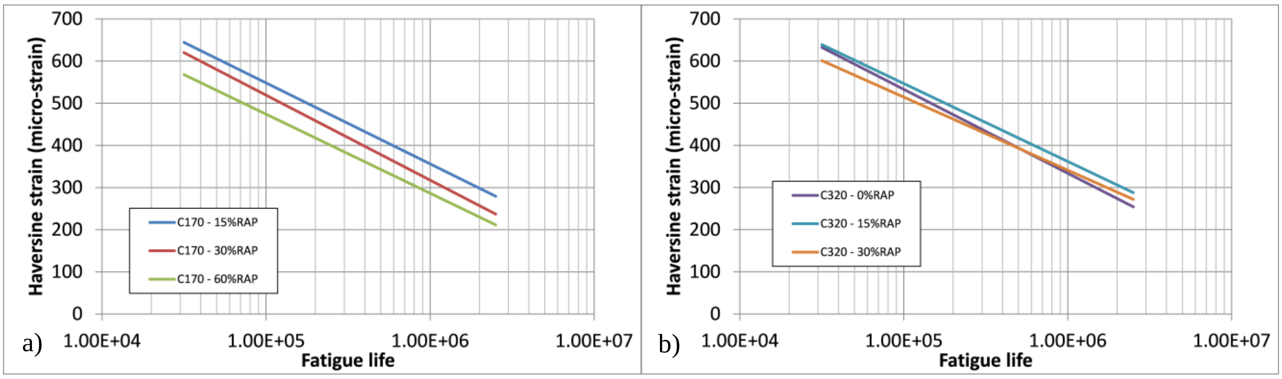

Figure 5: Median fatigue curves

For the purpose of this paper, only a summary of the stiffness and fatigue data is provided in Figure 4 and Figure 5. The full dataset, including individual data points are published in Austroads report AP-T286-15 (Austroads 2014).

3.3 Wheel tracking rut depth measurement

To measure the rutting performance of different asphalt mixes, wheel tracking tests were performed in duplicate. Figure 6 presents both the central rut depth after 10 000 passes as well as the steady-state tracking rate. The wheel tracking rate was determined in accordance with the procedures in AGPT/T231. The rut depth and steady-state track rate generally decrease (i.e. rut resistance improves) with increasing percentage of RAP in the asphalt mix. The rut resistance of the "Blended" 60% RAP mix with rejuvenator appears to be slightly reduced compared to the C320 reference mix.

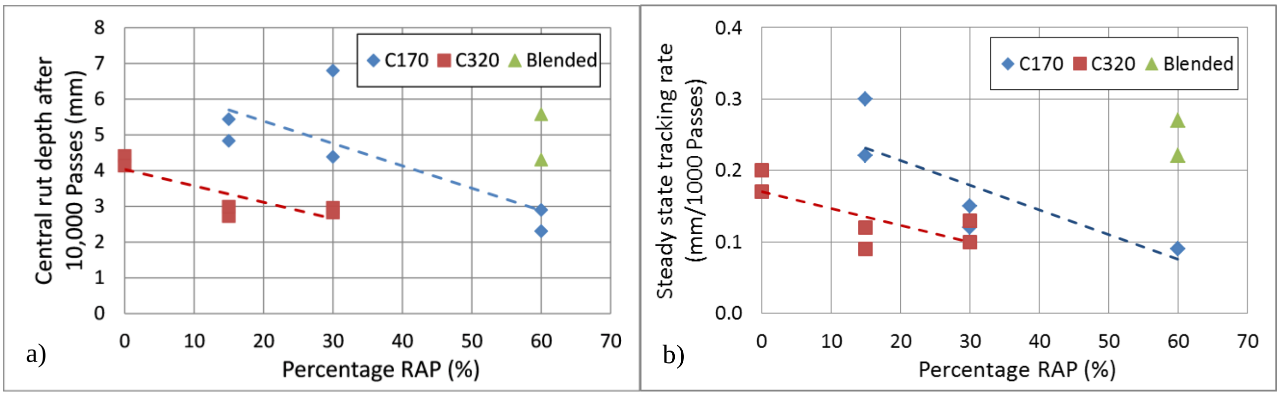

Figure 6: Wheel tracking results

3.4 Discussion on the effect of combined viscosity on asphalt mix performance

The results of this study confirmed the hardness of the RAP binder differs between sources and that this has an influence on the properties of the asphalt material the RAP is added to. Therefore, the RAP content by itself is an inadequate indicator for mix performance of asphalt mixes. The viscosity of the binder blend was found to be a more appropriate predictor of binder blend, and ultimately, the asphalt mix performance in the laboratory. These results will be verified for production mixes in a subsequent field performance study. Figure 7 summarises the results of the performance-related tests for asphalt mixes with different percentages of RAP, plotted against the measured viscosity of the binder blend. The performance test results show a strong correlation with the viscosity of the binder blend. Figure 7(a) shows the complex modulus value of different asphalt mixes and the results can be broadly divided into three groups. Asphalt mixes in Group 1 contain different percentages of RAP, yet they have very similar complex modulus values. In this particular case, this can be explained by the fact that the blended binder viscosity (i.e. virgin + RAP + rejuvenator) results in a lower predicted viscosity. As the blended viscosity increased in Group 2 and Group 3, the complex modulus increased in a generally linear trend. Similar trends could not be drawn if the asphalt mixes were categorised according to the percentage of RAP content.

The central rut depth (Figure 7(b)) measured in the different asphalt mixes also shows a similar linear trend. Group 1 (lower viscosity) generally has a greater rut depth than Group 3 (higher viscosity).

The fatigue life relationship (Figure 7(c)) also shows a similar trend, although it appears to be more scattered. In general, Group 3 (higher viscosity) has a lower average fatigue life than the asphalt mixes in Group 1 (lower viscosity). Strain controlled fatigue life is known to be strongly correlated with mix stiffness, and the mix containing higher viscosity binder would yield much higher stresses than the mix containing lower viscosity binder. Note that this does not necessarily mean that RAP mixes would have poorer fatigue performance in the field, as use of a stiffer RAP mix may result in smaller strains under traffic loading.

Based observations in this study, the combined binder viscosity (as predicted using the viscosity prediction rule) is considered a reliable indicator for mix performance and an important factor that needs to be accounted for during asphalt mix design.

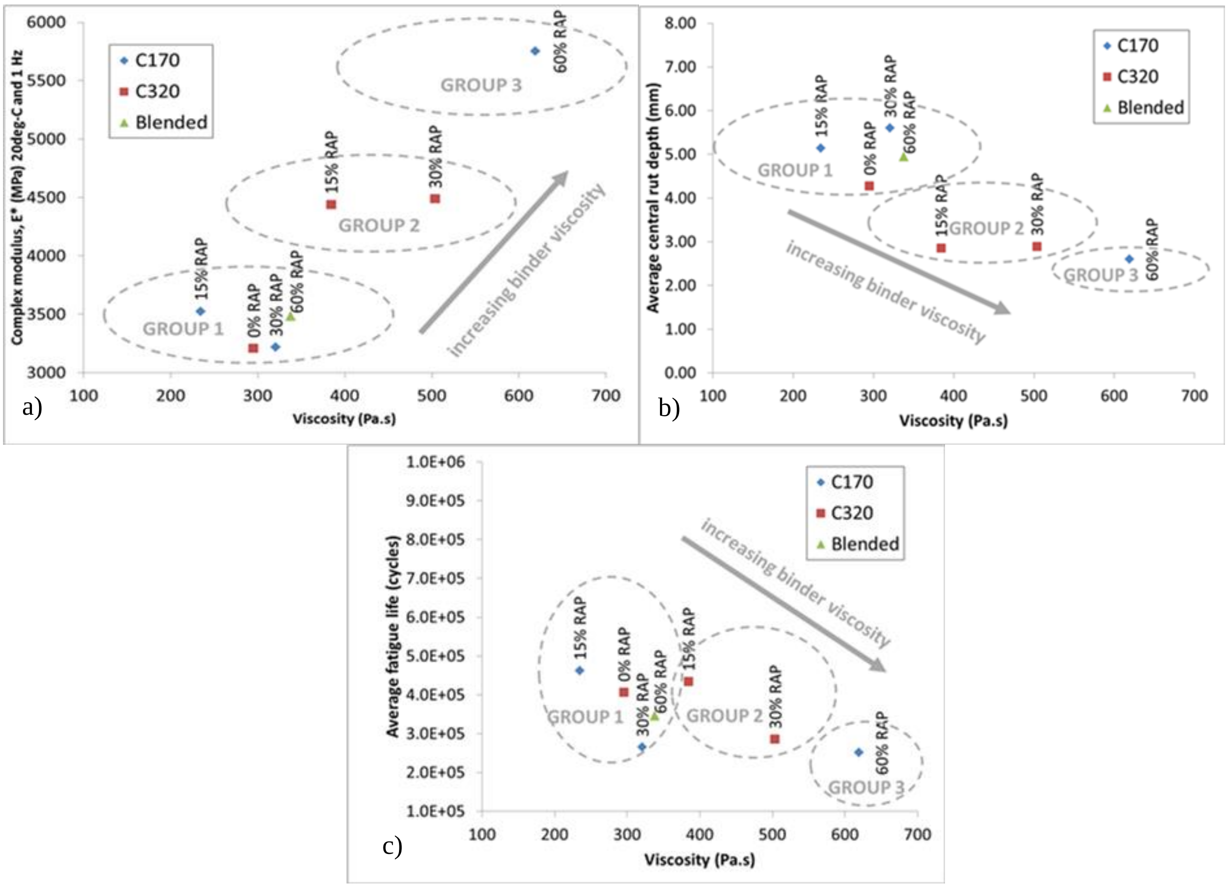

Figure 7: Influence of viscosity of performance indicators

Summary and Conclusions

The objective of this study was to develop a reliable and practical approach to the design of binder blends for use with viscosity grade binder specifications frameworks. The experimental work showed that the dynamic shear rheometer (DSR) can be used for viscosity measurement as an alternative to both the sliding plate micro-viscometer test and the capillary viscosity test. The DSR-based methodology developed in this study provides a practical, consistent and cost-

effective method to characterise RAP binder blends. As successfully demonstrated in this study, the viscosity results from the DSR tests can be used to design RAP binder blends to a desired viscosity. To validate the binder blend viscosity characterisation methodology, performance-related laboratory testing was conducted on asphalt mixes containing different percentages of RAP. It was found that the measured viscosity of the combined binder blend has a significant effect on performance-related parameters of asphalt mixes, including flexural modulus, permanent deformation resistance and fatigue life. More importantly, the results of this study have validated the RAP binder blend design methodology. Using the viscosity prediction equation, a blended binder was designed to have a viscosity similar to the C320 binder requirement. The performance of the 60% RAP mix containing this blended binder performed very similarly to the reference mix with a C320 binder with 0% RAP. The methodology can be used with confidence for plain binders to design mixes that will yield laboratory performances comparable to a mix containing virgin binder only. The results of this study required further validation through full scale field experiments. The blend design methodology has recently been applied to the design of field production mixes. Binder characterisation tests were performed on the different components (RAP, virgin, rejuvenator) as well as on the binder sampled at various stages of the production process and recovered from field cores. Laboratory tests on asphalt samples from the field containing different percentages of RAP were also performed. The results of the field verification trials are expected to be published in early 2016.
The binder blend design methodology presented in this paper was not validated in this study for polymer modified bitumen, multigrade and hard penetration grade binders.

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