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FINAL
REPORT

Project Title:	P31 Transfer of Crumb Rubber Modified Asphalt and Sealing Technology to Queensland (Phase 2)
Project No:	010595 & 010596
Author/s:	Joe Grobler, Andrew Beecroft & Dr Young Choi
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arrb GROUP Queensland Government

SUMMARY

This project was aimed at facilitating the increased use of crumb rubber modified binders in Queensland, particularly in sprayed seals and asphalt.

The key research activities undertaken include:

- preparing amendments to the Queensland Department of Transport and Main Roads specifications (TMR) for sprayed seals (i.e. MRTS11 *Sprayed Bituminous Surfacing (Excluding Emulsion)*) and polymer modified binders (i.e. MRTS18 *Polymer Modified Binder*)
- developing a new supplementary specification PSTS112 *Crumb Rubber Modified Open Graded Asphalt Surfacing*
- undertaking comparative binder testing in the laboratory to assess the properties of locally manufactured crumb rubber modified binders
- constructing and monitoring of a project that included a section of crumb rubber modified open graded asphalt (CRM OGA) as well as a control section of conventional polymer modified open graded asphalt (PMB OGA), and
- monitoring the emissions during construction of CRM OGA and PMB OGA surfacings.

The amendments to TMR sprayed sealing specification (MRTS11) that have been proposed as part of this project are substantial and will change the way TMR could specify sprayed seals in future. A ‘permissive’ approach to binder selection has been proposed, whereby the contractor has a choice between different binder classes for a specific sprayed sealing treatment type.

The proposed amendments to MRTS18 would align the Department with current Austroads practice for the specification of polymer modified binders (including crumb rubber), particularly with regards to nomenclature and binder properties.

A new supplementary specification for crumb rubber modified open graded asphalt was also developed as part of this project. The specification requirements were largely based on current practices in Arizona and California where crumb rubber modified asphalt is widely used.

The Australian Road Research Board tested locally manufactured crumb rubber modified binders as part of a comparative binder testing program. The testing demonstrated that local suppliers can manufacture a crumb rubber modified binder to meet the requirements specified in PSTS112.

Industry’s ability to manufacture and construct open graded asphalt with crumb rubber modified binder in accordance with PSTS112 was also demonstrated through a construction trial on Emu Mountain Road, North Coast district, in February 2017.

The emissions monitoring undertaken as part of the demonstration project found that crumb rubber modified open graded asphalt produced emissions that are comparable to those from polymer modified asphalt mixes, and that temperature was a dominant factor in determining the relative risk of personnel with regards to asphalt emissions. The study did however find evidence of elevated levels of Benzene in the CRM OGA mixes compared to PMB OGA, when measured through the emissions chamber. Considering that this type of assessment represented the absolute worst-case scenario (i.e. extracted from a confined space with limited dilution), it is unlikely to be representative of the actual exposure of construction workers to harmful emissions on site. Notwithstanding this, the Queensland Alliance for Environmental Health Sciences (QAEHS) recommended (in their report prepared as part of this project) that construction workers should use protective gear to minimise their risk of exposure.

Producing CRM OGA at lower temperatures (which was possible by the addition of a warm mix asphalt additive) was also found to be a feasible option to reduce the amount of potentially harmful emissions during asphalt operations compared to CRM OGA produced at conventional hot mix asphalt manufacturing temperatures. This may however depend on the type of warm mix technology used.

The project also identified several issues for further consideration, including:

- the variability of crumb rubber modified binder test results between different laboratories
- the current TMR and Australian Standard test methods for determining the binder content of asphalt are not necessarily suitable for testing crumb rubber modified binders and new methods (or modifications to existing methods) need to be developed
- assess the variability in CRM properties determined by different laboratories
- investigate the correlation between resilience recovery and torsional recovery of CRM binders
- undertake further monitoring of emissions (including benzene levels) during the manufacture and placement of crumb rubber modified asphalt, and further assess any health risks to workers
- the need for knowledge dissemination of learnings and outcomes from this project.

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1 INTRODUCTION

1.1 Background

Millions of tyres reach their end-of-life every year in Australia and this poses a significant risk to the environment if these tyres end up in landfill. In Queensland alone, 11 million equivalent passenger units (EPUs) were scrapped in 2009–2010, which equates to more than two EPUs per Queenslander per year (Denneman et al. 2015).

A previous project funded by the Queensland Department of Environment and Heritage Protection (DEHP) and the Queensland Department of Transport and Main Roads (TMR) identified the use of rubber from recycled tyres to modify bitumen as a potential high value destination for these materials in road construction. Crumb rubber modified (CRM) binders are manufactured by adding processed tyres to a conventional bitumen at high temperatures to produce a modified bitumen with enhanced elastic and durability properties compared to a non-modified bitumen. The outcomes of this earlier project were reported by Denneman et al. (2015).

Following the original work done by Denneman et al. (2015), Tyre Stewardship Australia (TSA), together with the Queensland Department of Environment and Heritage Protection (DEHP) and the Queensland Department of Transport and Main Roads (TMR) initiated this project to facilitate the increased use of recycled tyre rubber in asphalt and sprayed seals throughout Queensland.

1.2 Aim of the Project

The primary aim was to facilitate the increased use of CRM binders on the Queensland road network and the project comprised the following tasks:

- prepare amendments to TMR specifications MRTS11 *Sprayed Bituminous Surfacing (Excluding Emulsion)* (TMR 2017) and MRTS18 *Polymer Modified Binder* (TMR 2011) to facilitate the increased use of CRM binders in sprayed seals
- develop a draft supplementary specification PSTS112 (*Crumb Rubber Modified Open Graded Asphalt Surfacing–2016a*) for trial purposes
- undertake comparative binder testing to evaluate whether CRM binders can be manufactured locally in accordance with PSTS112
- arrange the construction of a demonstration project using CRM OGA and undertake emissions monitoring during its construction.

This report presents the results the findings of Phase 2 of the project, including recommendations for further work.

2 AMENDMENTS TO MRTS11 AND MRTS18

2.1 Amendments to MRTS11

The amendments to MRTS11 developed as part of this project are substantial and will change the way that TMR specifies sprayed seals on their network. The current 'mandatory' approach to specifying sprayed seals requires the principal (i.e. TMR) to nominate the seal type and binder class for a particular treatment. Where the contractor wishes to use an equivalent alternative binder class, they must submit an alternative tender that proposes a change to the binder class specified by the principal. This alternative tendering process can be cumbersome at times.

A more 'permissive' approach to binder selection will allow the contractor to choose an alternative binder class (that will provide equivalent performance) to the binder class specified without the need for the principal or contract administrator's approval. This approach will allow contractors to select their preferred binder class based on financial and operational considerations. It is believed that this approach will facilitate the increased use of alternative binder classes, such as crumb rubber modified binders.

A copy of the updated version of MRTS11 is included in Appendix A of this report.

2.2 Amendments to MRTS18

MRTS18 has been updated to align more closely with current national practice, as per AGPT/T190 *Specification Framework for Polymer Modified Binders* (Austroads 2014). Alignment of MRTS18 with current Austroads requirements should also promote efficiencies within industry. The changes to TMR's polymer modified binder (PMB) classification system are presented in Table 2.1.

Table 2.1: Proposed changes to PMB classification system

New PMB class (Updated MRTS18; AGPT/T190)	Old PMB class (MRTS18 – November 2011)
Sprayed sealing applications	
S10E	S0.25S
S15E	S0.7S
S20E	–
S25E	S4.5S
S35E	S0.3B
S45R	S1.8R
S15RF	S15RF
S18RF	S18RF
Asphalt applications	
A10E	A10S
A15E	A5S
A20E	A0.6S
A25E	A0.6B
A35P	A2V

A copy of the updated version of MRTS18 is included in Appendix B of this report.

3 CRM OGA SPECIFICATION

A draft TMR supplementary specification PSTS112-2016a *Crumb Rubber Modified Open Graded Asphalt Surfacing* was developed, in association with industry experts, as part of this project. It is generally aligned with CRM asphalt practices in California and Arizona, particularly with regards to the CRM binder properties. The current version of PSTS112 is intended for trial purposes, after which the specification would be finalised for use in projects.

PSTS112 differs from the requirements for conventional polymer modified open-graded asphalt (PMB OGA) in MRTS30-2016b *Asphalt Pavements* in so far that crumbed rubber-modified open-graded asphalt (CRM OGA) does not have to comply with the volumetric properties, binder drain-off requirements and asphalt particle loss requirements currently specified in MRTS30. Instead, the nominated binder content for the mix design must be selected by TMR based on an assessment of the following test properties for mix prepared at a range of binder contents:

- laboratory air void content
- binder film index
- asphalt particle loss
- asphalt binder drain-off.

Once more experience is gained with CRM OGA, it is likely that TMR will specify minimum requirements for these properties.

PSTS112 includes two CRM binder classes, i.e. CR1 or CR2. CR1 binders would typically have a higher level of modification and are better suited for the hotter climates in northern Queensland, whereas CR2 would be suited to use in south east Queensland. The properties for both these binder classes are summarised in Table 3.1 and Table 3.2.

A copy of draft supplementary specification PSTS112 is included in Appendix C of this report.

Table 3.1: CR1 binder properties

Property	Unit	Test method	Reaction time						
			60 mins	90 mins	120 mins	240 mins	360 mins	11 mins	TBN(1)
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm, (minimum)	–	AS 2341.12	10	–	–	10	–	10	10
Resilience @ 25 °C, (minimum)	%	ASTM D5329-15	25	–	–	25	–	25	25
Torsional recovery @ 25 °C 30 s	%	AGPT/T122: 2006	TBR(2)	–	–	TBR(2)	–	TBR(2)	TBR(2)
Softening point (minimum)	°C	AGPT/T131: 2006	57	–	–	57	–	57	57
Viscosity @ 175 °C	Pa.s	ASTM D2196-15 ASTM D7741/D7741M	TBR(2) 1.5–4.0						
Flash point (minimum)	°C	AGPT/T112: 2006	250						

Property	Unit	Test method	Reaction time						
			60 mins	90 mins	120 mins	240 mins	360 mins	11 mins	TBN(1)
Loss on heating (maximum)	%	AGPT/T103: 2006	0.6						

1 To be nominated by the contractor.

2 To be reported.

Table 3.2: CR2 binder properties

Property	Unit	Test method	Reaction time						
			60 mins	90 mins	120 mins	240 mins	360 mins	11 mins	TBN(1)
Penetration @ 4 °C, 200 g, 60 sec, 0.10 mm, (minimum)	–	AS 2341.12	15	–	–	15	–	15	15
Resilience @ 25 °C, (minimum)	%	ASTM D5329-15	20	–	–	20	–	20	20
Torsional recovery @ 25 °C 30 s	%	AGPT/T122: 2006	TBR(2)	–	–	TBR(2)	–	TBR(2)	TBR(2)
Softening point (minimum)	°C	AGPT/T131: 2006	55	–	–	55	–	55	55
Viscosity @ 175 °C	Pa.s	ASTM D2196-15 ASTM D7741/D7741M	TBR(2) 1.5–4.0						
Flash point (minimum)	°C	AGPT/T112: 2006	250						
Loss on heating (maximum)	%	AGPT/T103: 2006	0.6						

1 To be nominated by the contractor.

2 To be reported.

4 COMPARATIVE BINDER TESTING

A comparative binder testing program was conducted with a primary objective to assess locally-manufactured CRM binder properties against the CRM binder specification requirements included in PSTS112 (TMR 2016a). A CRM binder manufactured and used in California was also tested for comparison purposes.

The scope of the testing program was:

- testing of two terminal-blended no-agitation CRM binders manufactured locally and internationally
- testing of two laboratory-blended high-viscosity CRM binders made from locally-sourced materials.

4.1 Terminal-blended No-agitation CRM Binders

Two types of terminal-blended no-agitation CRM binders were tested as part of this project. Binder 4381 was manufactured in Australia and binder 4290 was manufactured in California. Each manufacturer prepared a binder sample and sent it to the ARRB laboratory for testing. Information on the component materials of each binder (e.g. class of base bitumen, test properties, etc.) was not provided.

Some of the PMB test methods included in Austroads specification AGPT/T190 *Specification Framework for Polymer Modified Binders* were used to characterise these binders (Austroads 2014). The test methods and results of the testing undertaken are discussed below.

4.1.1 Test Results of Binder 4381 and Analysis

The PMB tests conducted on binder 4381 are listed in Table 4.1. To evaluate polymer segregation susceptibility, the European storage stability test (EN 13399: 2010) was used to estimate the result of the Austroads segregation test (AGPT/T108: 2006) (refer to Note 3 in Table 4.1). Tests were mostly conducted in duplicate; however, the viscosity testing at 165 °C was conducted in triplicate, as required in the respective test methods. The average values are presented in Table 4.1.

The supplier reported that binder 4381 was manufactured to the A40R asphalt binder class. This binder class is no longer used in Australia; it used to be available for CRM binders for asphalt applications. Property requirements for the A40R binder grade were obtained from an earlier version of Roads and Maritime Services (RMS) QA Specification 3252 (RMS 2014). These requirements are presented in Table 4.1, where applicable. They show that binder 4381 conformed to A40R, except that the consistency at 60 °C was slightly lower than the required minimum value of 4500 Pa.s. It is uncertain whether this binder would meet the other requirements (e.g. flash point) not tested for this study.

The property requirements for the S45R, S15RF and S18RF sprayed sealing class binders are also presented in Table 4.1 for comparison purposes. A40R is an obsolete CRM binder class. However, comparing the binder tested with the sprayed sealing CRM binder classes currently in use was considered worthwhile, so that the properties of this obsolete binder can be understood comparatively. It is noted that these are all sprayed sealing binder classes and thus the property requirements are not directly applicable to binders used for asphalt. The Austroads PMB specification (AGPT/T190: 2014) includes a CRM binder class for asphalt applications known as A27RF. However, there were no property requirements to compare with (other than nominal rubber content).

Table 4.1: Test results of binder 4381 and property requirements for A40R and Austroads rubber-binder sealing grades

Property	Test method	Test result	Property requirements			
			A40R	S45R	S15RF	S18RF
Viscosity @ 165 °C (Pa.s)	AGPT/T111	0.87	1.5 max. (conform)	4.5 max. (conform)	–	–
Consistency @ 60 °C (Pa.s)	AGPT/T121	4391	4500 min. (below min. limit)	1000 min. (conform)	–	–
Consistency 6% @ 60 °C (Pa.s)	AGPT/T121	1809	–	TBR(1)	–	–
Softening point (°C)	AGPT/T131	73.5	68 min. (conform)	55–65 (above max. limit)	55 min. (conform)	62 min. (conform)
Torsional recovery @ 25 °C (%)	AGPT/T122	69	35 min. (conform)	25–55 (above max. limit)	25 min. (conform)	30 min. (conform)
Stiffness @ 25 °C (kPa)	AGPT/T121	56	–	–	–	–
Stiffness @ 15 °C (kPa)	AGPT/T121	Not tested Estimated to be > 187(2)		180 max. (above max. limit)		
Segregation (%)	AGPT/T108	Not tested Estimated to be ≅ 0(3)		8 (conform)		
Storage stability (°C)	EN 13399	–7.9	–	–	–	–
▪ Storage stability top (°C)		71.6				
▪ Storage stability bottom (°C)		79.5				

1 To be reported.

2 An analysis of the results obtained for the 23 bitumen and PMB samples which were subjected to stiffness testing at 15 °C and 25 °C (Austroads 2015) indicated that, if the binder stiffness at 25 °C was higher than 30 kPa, then the stiffness at 15 °C would be above the maximum limit which can be measured with the elastometer (187 kPa).

3 A comparison of the European storage stability tests and Australian segregation tests (Austroads 2013) results indicated that binders which had storage stability results up to the order of 35 °C would be expected to have a segregation value of close to 0%.

Source: Austroads (2014).

It can be seen from Table 4.1 that binder 4381 would meet the requirements for S15RF and S18RF binder classes, as the softening point and torsional recovery results were higher than the given minimum values. The binder was, however, expected to be more elastic than a S45R class binder, as the torsional recovery result was higher than the upper limit of the property requirement. The softening point was also higher than the upper limit. Binder 4381 is expected to be stiffer than binder S45R at lower temperatures, as the stiffness at 15 °C was estimated to be higher than the maximum limit (refer to Note 2 in Table 4.1).

The properties of binder 4381 were also compared to a number of elastomeric-class asphalt binders as shown in Table 4.2. The addition of crumb rubber to the bitumen produces an elastomeric PMB (Austroads 2008); as a result, comparing binder 4381 with other elastomeric binder classes included in the same specification was considered worthwhile. It should nonetheless be noted that these binder types are manufactured using very different types of polymers and thus the property requirements are not necessarily directly applicable.

Table 4.2: Test results of binder 4381 and property requirements for Austroads elastomer-class asphalt binder grades

Property	Test method	Test result	Property requirements			
			A25E	A20E	A15E	A10E
Viscosity @ 165 °C (Pa.s)	AGPT/T111	0.87	0.6 max. (above max. limit)	0.6 max. (above max. limit)	0.9 max. (conform)	1.1 max. (conform)
Consistency @ 60 °C (Pa.s)	AGPT/T121	4391	600 min. (conform)	600 min. (conform)	5000 min. (below min. limit)	6000 min. (below min. limit)
Consistency 6% @ 60 °C (Pa.s)	AGPT/T121	1809	TBR(1)	TBR	TBR	TBR
Softening point (°C)	AGPT/T131	73.5	52–62 (above max. limit)	65–95 (conform)	82–105 (below min. limit)	88–110 (below min. limit)
Torsional recovery @ 25 °C (%)	AGPT/T122	69	17–30 (above max. limit)	38–70 (conform)	55–80 (conform)	60–86 (conform)
Stiffness @ 25 °C (kPa)	AGPT/T121	56	45 max. (above max. limit)	35 max. (above max. limit)	30 max. (above max. limit)	30 max. (above max. limit)
Segregation (%)	AGPT/T108	Not tested Estimated to be ≅ 0(2)	8 (conform)	8 (conform)	8 (conform)	8 (conform)
Storage stability (°C)	EN 13399	–7.9	–	–	–	–
▪ Storage stability top (°C)		71.6				
▪ Storage stability bottom (°C)		79.5				

1 To be reported.

2 A comparison of the European storage stability tests and Australian segregation tests (Austroads 2013) results indicated that binders which had storage stability results up to the order of 35 °C would be expected to have a segregation value of close to 0%.

Source: Austroads (2014).

The results in Table 4.2 show that binder 4381 did not conform to all the requirements of the four asphalt grade PMBs. The most noticeable property was the stiffness at 25 °C, for which binder 4381 was found to be stiffer than the maximum limits in all cases.

Binder 4381 appears to be closest to an A20E class binder as the consistency at 60 °C, softening point and torsional recovery test results meet the specification requirements. The viscosity at 165 °C result was, however, slightly higher than the required maximum value of 0.6 Pa.s. The result conformed to the next higher level of polymer modification (i.e. A15E), indicating that binder 4381 may be handled in a similar manner to A15E class binders during manufacturing and construction.

Austroads (2008) states that A20E class binders are appropriate for applications where a moderate improvement in rutting and/or fatigue performance is required, or for more demanding OGA applications.

4.1.2 Test Results of Binder 4290 and Analysis

The test results obtained for binder 4290 are presented in Table 4.3. This binder was manufactured for asphalt applications in California. The property requirements for the A40R, S45R, S15RF and S18RF binder classes are presented in the table so that the properties of this binder could be compared with known Australian CRM binders.

Table 4.3 shows that binder 4290 conformed to the requirements for an A40R class binder, except that the viscosity at 165 °C was higher than the required maximum value of 1.5 Pa.s. The viscosity result obtained for binder 4290 (2.9 Pa.s) did, however, conform to the requirements for a S45R class binder as this binder class has a higher maximum limit of 4.5 Pa.s, suggesting that binder 4290 may be handled in a similar manner as S45R class binders. The estimated stiffness at 15 °C (refer to Note 2 in Table 4.3) was higher than the upper limit of the S45R binder class requirements, indicating that binder 4290 would be stiffer than a S45R binder at lower temperatures. The softening point result was also higher than the upper limit for S45R binder.

Binder 4290 would meet the requirements for S15RF and S18RF class binders, as the softening point and torsional recovery results were higher than the required minimum values.

Table 4.3: Test results of binder 4290 and property requirements for Austroads rubber-binder sealing grades

Property	Test method	Test result	Property requirements			
			A40R	S45R	S15RF	S18RF
Viscosity @ 165 °C (Pa.s)	AGPT/T111	2.90	1.5 max. (above max. limit)	4.5 max. (conform)	–	–
Consistency @ 60 °C (Pa.s)	AGPT/T121	4629	4500 min. (conform)	1000 min. (conform)	–	–
Consistency 6% @ 60 °C (Pa.s)	AGPT/T121	2090	–	TBR(1)	–	–
Softening point (°C)	AGPT/T131	72.0	68 min. (conform)	55–65 (above max. limit)	55 min. (conform)	62 min. (conform)
Torsional recovery @ 25 °C (%)	AGPT/T122	40	35 min. (conform)	25–55 (conform)	25 min. (conform)	30 min. (conform)
Stiffness @ 25 °C (kPa)	AGPT/T121	48	–	–	–	–
Stiffness @ 15 °C (kPa)	AGPT/T121	Not tested Estimated to be > 187(2)		180 max. (above max. limit)		
Segregation (%)	AGPT/T108	Not tested Estimated to be ≅ 0(3)		8 (conform)		
Storage stability (°C)	EN 13399	–18.7	–	–	–	–
▪ Storage stability top (°C)		50.7				
▪ Storage stability bottom (°C)		69.4				

1 To be reported.

2 An analysis of the results obtained for the 23 bitumen and PMB samples which were subjected to stiffness at 15 °C and stiffness at 25 °C tests (Austroads 2015) indicated that, if a binder showed a stiffness at 25 °C result greater than 30 kPa, then the stiffness at 15 °C result obtained for the material would be above the maximum limit which can be measured with the elastometer (187 kPa).

3 A comparison of the European storage stability tests and Australian segregation tests (Austroads 2013) results indicated that binders which had storage stability results up to the order of 35 °C would be expected to have a segregation value of close to 0%.

Source: Austroads (2014).

The properties of binder 4290 were also compared to the elastomeric-class asphalt PMB in Table 4.4. Binder 4290 would not meet any of the four asphalt binder classes if all the requirements shown in the table are considered. The viscosity at 165 °C and the stiffness at 25 °C were higher than the respective maximum limits in all cases.

As with binder 4381, binder 4290 appears to be closest to an A20E binder as the consistency at 60 °C, softening point and torsional recovery test results all conformed to the specification requirements.

Table 4.4: Test results of binder 4290 and property requirements for Austroads elastomer-class asphalt binder grades

Property	Test method	Test result	Property requirements			
			A25E	A20E	A15E	A10E
Viscosity @ 165 °C (Pa.s)	AGPT/T111	2.90	0.6 max. (above max. limit)	0.6 max. (above max. limit)	0.9 max. (above max. limit)	1.1 max. (above max. limit)
Consistency @ 60 °C (Pa.s)	AGPT/T121	4629	600 min. (conform)	600 min. (conform)	5000 min. (below min. limit)	6000 min. (below min. limit)
Consistency 6% @ 60 °C (Pa.s)	AGPT/T121	2090	TBR(1)	TBR	TBR	TBR
Softening point (°C)	AGPT/T131	72.0	52–62 (above max. limit)	65–95 (conform)	82–105 (below min. limit)	88–110 (below min. limit)
Torsional recovery @ 25 °C (%)	AGPT/T122	40	17–30 (above max. limit)	38–70 (conform)	55–80 (below min. limit)	60–86 (below min. limit)
Stiffness @ 25 °C (kPa)	AGPT/T121	48	45 max. (above max. limit)	35 max. (above max. limit)	30 max. (above max. limit)	30 max. (above max. limit)
Segregation (%)	AGPT/T108	Not tested Estimated to be ≅ 0(2)	8 (conform)	8 (conform)	8 (conform)	8 (conform)
Storage stability (°C)	EN 13399	−18.7				
▪ Storage stability top (°C)		50.7				
▪ Storage stability bottom (°C)		69.4				

1 To be reported.

2 A comparison of the European storage stability tests and Australian segregation tests (Austroads 2013) results indicated that binders which had storage stability results up to the order of 35 °C would be expected to have a segregation value of close to 0%.

Source: Austroads (2014).

4.2 Laboratory-blended High-viscosity CRM Binders

4.2.1 Materials and Blending Procedure

Two types of laboratory-blended high-viscosity CRM binders were tested. Binders A and B were blended at ARRB's Vermont South laboratory using component materials and blending recipes provided by two Australian suppliers. Binder A was blended with 22% rubber and 78% of bitumen (by weight), whilst binder B was blended with 20% rubber and 80% of bitumen (by weight). No additives were used for either blend. Information on the component materials (e.g. rubber and bitumen properties) was not provided.

The blending procedures used for the two binders included the following steps. The main differences in the blending procedure are summarised in Table 4.5:

1. A defined amount of bitumen was placed in a 4 L tin (e.g. approximately 3 L was used so that the binder did not overflow the tin after adding a volume of rubber).
2. The tin was placed in an oven to heat up the bitumen to the target temperature (Table 4.5). Once the bitumen was heated sufficiently, a low-shear mixer was introduced to stir the bitumen (Figure 4.1) in preparation for adding the rubber.
3. Once the bitumen reached the target temperature, a defined amount of rubber was added to the bitumen.

4. The low shear stirring of the rubber-binder blend was maintained (Table 4.5) at the target temperature for the defined duration.
5. During blending, small volumes of samples were taken at different times for subsequent testing (Table 4.5).

Figure 4.1: Laboratory blending of rubber-binder using oven and stirring equipment

Source: ARRB.

Table 4.5: Blending conditions used for binders A and B

Binder	**A**		**B**	
Target blending temperature (°C)	185–190		175 ± 10	
Blending duration (hours)	Initial blending	Extended blending	Initial blending	Extended blending
	1(1)	up to 96	1(2)	up to 24
Sampling periods (hours)	1, 4, 11, 96		1, 4, 11, 24	
Stirring conditions during blending	▪ Low shear mixer was used only up to 4 hours of blending at the target temperature. ▪ For the remaining period, the blend was kept at 180 °C without stirring (except for the brief remixing required for subsampling at 11 and 96 hours).		▪ Low shear mixer was used throughout 24 hours of blending at the target temperature.	

1 Prior to this 1-hour initial blending step for binder A, an additional 1 hour was allowed to add rubber (for about 30 minutes) and then to bring back the blend to the target temperature (for another 30 minutes). The designated sampling periods of binder A did not include this pre-blending step.

2 This 1-hour initial blending step for binder B included time to add rubber (about 5 minutes) and bring back the blend temperature (about 15 minutes). The timing for sampling of binder B therefore started when the rubber was added.

It should be noted that, for small-scale laboratory blending of rubber-binders (and also PMBs) as was the case in this experiment, the ARRB laboratory normally uses carbon dioxide to saturate the atmosphere inside the oven/heating block (fed at a constant rate from a pressurised gas container) to minimise oxidation of the binder during the heating and blending process. However, the Department requested that this practice not be followed in this experiment.

4.2.2 Information on the Resilience Test Method

One of the main binder characterisation tests used in this study was the resilience test at 25 °C (ASTM D5329-15). This test is used in the USA to mainly characterise sealants for cracks and joints in pavements. The main purpose is to measure the elastic recovery properties of the material at ambient temperatures.

As the elastic recovery potential of CRM binders is an important property (e.g. could indicate the amount of rubber added to bitumen), this test method is also being adopted to test CRM binders in a number of state specifications (e.g. California, Arizona). As mentioned previously, the Department's specification PSTS112 (TMR 2016a) was developed largely based on these specifications; hence, resilience requirements were included for the same reason.

It was noted using this method that the test procedure appeared to be incorrect or ambiguous in the standard document. Item 10.5 of the ASTM procedure requires the operator to return the dial to zero before commencing the recovery phase of the testing. To obtain the correct percentage recovery values using the specified calculation method, the resetting of the dial should not be conducted.

Another issue noted during the analysis of the test results was the specified test variations. ASTM D5329 provides a set of variation limits as shown in Table 4.6. It is uncertain at present whether these variation limits should be used to validate individual test results (i.e. to discard significantly variable results) as the given limits appeared to be too rigorous for the two binders tested. As an example, the differences between the duplicate results for binder A (i.e. in-sample average of Sample 1 and Sample 2 in Table 4.7) were larger than the specified limit of 3% in all four cases. The resilience test results obtained for binder B (Table 4.10) also exceeded the variation limits in Table 4.6 in some cases.

Table 4.6: Resilience test variation limits

Test variation limit (ASTM D5329)	
Within sample tin	Maximum difference between triplicate tests on the same sample (i.e. one sample tin) should not differ by more than 4 resilience units (%)
Within laboratory	Results of duplicate tests on the same material (i.e. two sample tins) by the same operator should not differ by more than 3 resilience units (%)
Inter-laboratory	Results of two properly conducted tests in different laboratories should not differ by more than 33 resilience units (%)

It is also noted in Table 4.6 that the inter-laboratory variation limit was very high (i.e. 33%), which raises questions regarding the repeatability of the test results to meet these requirements. These variation limits were therefore not used to validate individual test results in this study.

4.2.3 Properties of Binder A

ARRB test results: binder A

Samples of binder A taken at different blending durations were subjected to the resilience test (ASTM D5329; procedure corrected as described in Section 4.2.2) and the softening point test (AGPT/T131). The results are presented in Table 4.7 and Table 4.8, respectively. For the resilience test, individual results are presented along with the averages so that typical test variations are shown in the table for information purposes.

The tables also include the respective property limits, as specified in PSTS112 (for a CR1 class binder), for a conformance check. Binder A conformed to the specified criteria in all cases.

Table 4.7: Results of resilience testing: binder A at different blending times

Resilience test (ASTM D5329)		**Blending duration (hours)**							
		1		**4**		**11**		**96**	
		Sample 1	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**
Recovery (%)	Triplicate tests on same sample	57.9	55.3	68.5	64.6	53.2	54.6	23.6	28.8
		59.1	55.4	68.0	66.0	50.6	56.2	25.2	27.9
		61.0	56.4	69.9	63.9	52.6	55.8	24.6	27.7
	In-sample average	59.3	55.7	68.8	64.8	52.1	55.5	24.5	28.1
	Average	**57.5**		**66.8**		**53.8**		**26.3**	
TMR PSTS112 criteria (CR1)		25 min.		25 min.		25 min.		25 min.	

Table 4.8: Results of softening point testing: binder A at different blending times

	Blending duration (hours)			
	1	**4**	**11**	**96**
Softening point (°C) (AGPT/T131)	83.5	85.0	86.0	64.5
TMR PSTS112 criteria (CR1)	57 min.	57 min.	57 min.	57 min.

Supplier test results: binder AS

The supplier blended a CRM binder in their laboratory using nominally identical component materials and recipe to those used by ARRB to manufacture binder A. This binder was designated as ‘AS’ for this report.

It is understood that the supplier’s blending procedure was broadly the same as the ARRB procedure (e.g. the same target temperature of 185 °C was used for blending). Sampling periods were also identical. However, there are other specific conditions (e.g. the size of blending tin, etc.) which may influence the end-properties and these were not known.

The results for binder AS as provided by the supplier are presented in Table 4.9. It can be seen that binder AS met the specified criteria in all cases after 1 hour of blending. These properties understandably changed as blending continued, but they mostly conformed to the requirements up to the maximum period of 96 hours. Only the resilience at 25 °C results obtained after 4, 11 and 96 hours of blending were lower than the required minimum of 25% (highlighted in bold in Table 4.9).

Table 4.9: Supplier-provided test results of binder AS at different blending periods

Property	**Test method**	**Blending duration (hours)**				**Property requirement (TMR PSTS112: CR1 class)**
		1	**4**	**11**	**96**	
Viscosity @ 175 °C (Pa.s)	ASTM D7741/D7741M	3.49	2.87	2.68	2.27	1.50–4.00
Penetration @ 4 °C (0.1 mm)	AS 2341.12	17	22	26	25	10 min.
Softening point (°C)	AGPT/T131	76.0	70.5	65.0	60.0	57 min.
Torsional recovery @ 25 °C (%)	AGPT/T122	55	47	46	39	TBR
Resilience recovery @ 25 °C (%)	ASTM D5329	26	**13**	**14**	**13**	25 min.

Comparison of binders A and AS

The resilience and softening point results obtained for binders A and AS are compared in Figure 4.2 and Figure 4.3, respectively.

Figure 4.2: Comparison of resilience test results: binders A and AS

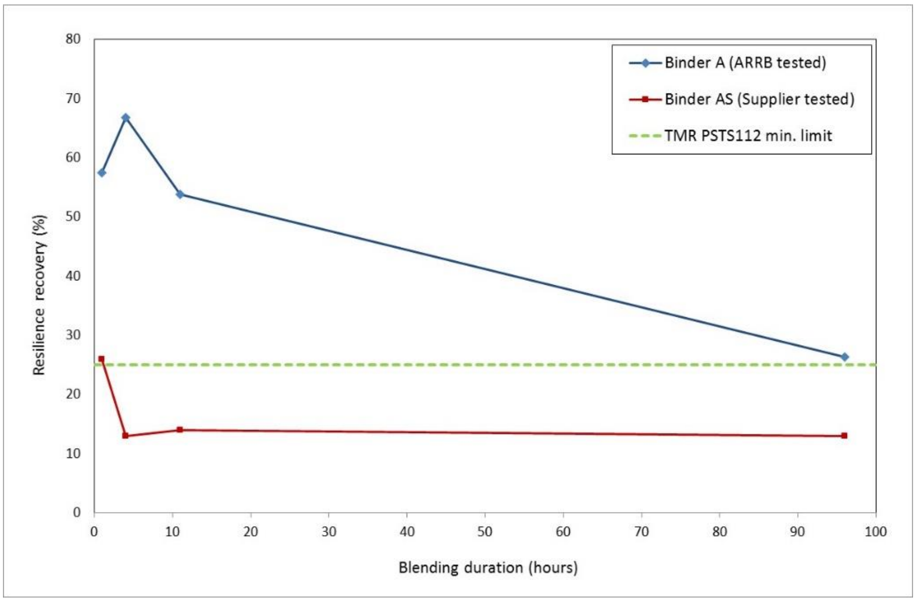
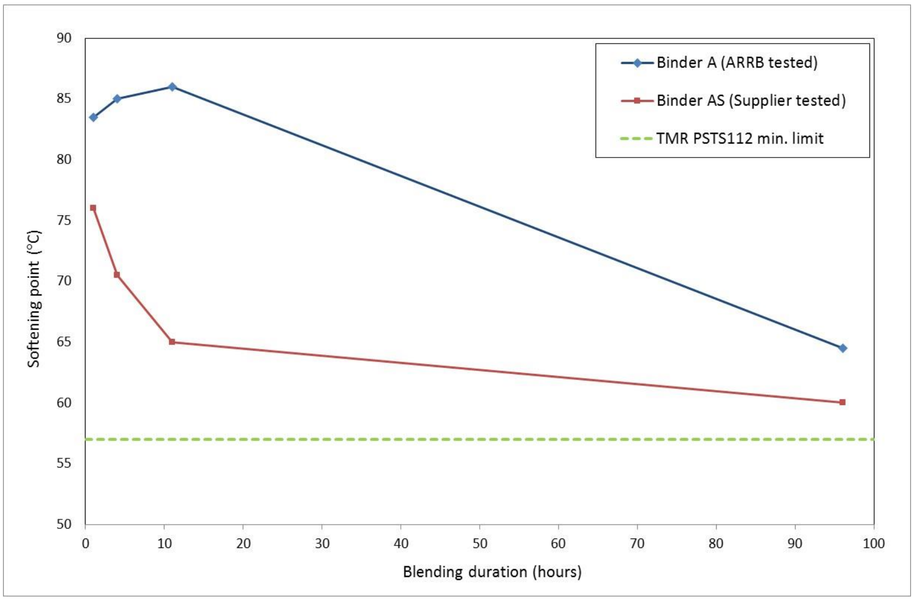


Figure 4.3: Comparison of softening point test results: binders A and AS



The resilience data in Figure 4.2 shows that samples were quite elastic up to 11 hours of blending. The value then declined close to the minimum limit after 96 hours. Binder AS, on the other hand, marginally conformed at 1 hour, but failed for the remaining periods.

The softening point data (Figure 4.3) also show noticeably different trends for the two materials. Binder A had an increasing value up to 11 hours, which then rapidly declined towards 96 hours. Binder AS had a lower softening point than binder A at 1 hour and this value further reduced as blending continued. Both binders conformed up to the maximum blending duration nonetheless.

A noteworthy observation from the two sets of data was that binder AS had lower resilience and softening point values than those obtained for binder A in all cases. Lower values could indicate that less rubber was added to the bitumen (due to the reduced elastic properties). Further discussion on these nominally identical binders and their different behaviour is provided in Section 4.2.6.

4.2.4 Properties of Binder B

ARRB test results: binder B

Samples of binder B taken at different blending durations were subjected to the resilience test (ASTM D5329; procedure corrected as described in Section 4.2.2) and the softening point test (AGPT/T131). The results are presented in Table 4.10 and

Table 4.11, respectively. Individual resilience testing results are presented along with the averages so that typical test variations are shown in the table for information purposes.

The tables also include the respective property limits, as specified in PSTS112 (for a CR1 class binder), for a conformance check. Binder B conformed to the specified criteria in all cases.

Table 4.10: Resilience of binder B at different blending times

Resilience test (ASTM D5329)		**Blending duration (hours)**							
		1		**4**		**11**		**24**	
		Sample 1	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**	**Sample 1**	**Sample 2**
Recovery (%)	Triplicate tests on same sample	38.5	43.3	59.0	61.6	38.2	40.0	35.3	34.7
		36.5	42.8	60.2	63.5	41.1	43.0	37.0	33.7
		35.8	44.2	60.3	63.4	44.5	35.5	36.7	35.8
	In-sample average	36.9	43.4	59.8	62.8	41.3	39.5	36.3	34.7
	Average	**40.2**		**61.3**		**40.0**		**35.5**	
TMR PSTS112 criteria (CR1)		25 min.		25 min.		25 min.		25 min.	

Table 4.11: Softening point of binder B at different blending times

	Blending duration (hours)			
	1	**4**	**11**	**24**
Softening point (°C) (AGPT/T131)	69.5	80.5	74.0	65.0
TMR PSTS112 criteria (CR1)	57 min.	57 min.	57 min.	57 min.

Supplier test results: binder BS

As already discussed, the supplier blended a CRM binder in their laboratory using nominally identical component materials and recipe to those used by ARRB to manufacture binder B. This binder was designated as ‘BS’ for this report.

It is understood that the supplier’s blending procedure was broadly the same as the ARRB procedure (e.g. the same target temperature of 175 °C was used for blending); however, other specific conditions (e.g. size of blending tin, etc.), which may influence the end-properties, were not known. During blending, samples were taken by the supplier at 1, 4, 11 and 96 hours for subsequent testing. The test results for binder BS, as provided by the supplier, are presented in Table 4.12.

Table 4.12: Supplier-provided test results at different blending durations: binder BS

Property	Test method	Blending duration (hours)				Property requirement (TMR PSTS112: CR1 class)
		1	4	11	96	
Viscosity @ 175 °C (Pa.s)	ASTM D7741/D7741M	3.50	3.80	4.00	**4.50**	1.50–4.00
Penetration @ 4 °C (0.1 mm)	AS 2341.12	27	30	32	35	10 min.
Softening point (°C)	AGPT/T131	64	65	65	70	57 min.
Torsional recovery @ 25 °C (%)	AGPT/T122	33	50	50	50	TBR
Resilience recovery @ 25 °C (%)	ASTM D5329	45	45	44	44	25 min.

It can be seen from Table 4.12 that binder BS met the specified criteria in all cases up to 11 hours and mostly up to the maximum period of 96 hours, with only the viscosity at 175 °C (4.50 Pa.s) obtained after 96 hours being slightly higher than the required maximum of 4.00 Pa.s. This was the only non-conformance as highlighted in bold in Table 4.12.

Comparison of binders B and BS

The resilience and softening point results for binders B and BS are compared in Figure 4.4 and Figure 4.5, respectively.

Figure 4.4: Comparison of resilience test results: binders B and BS

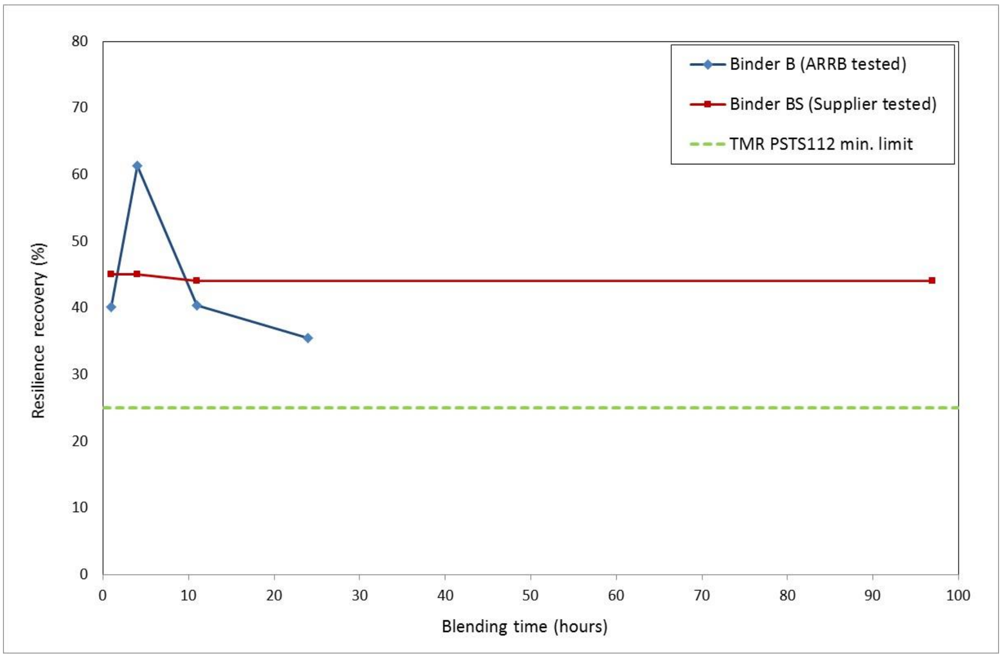
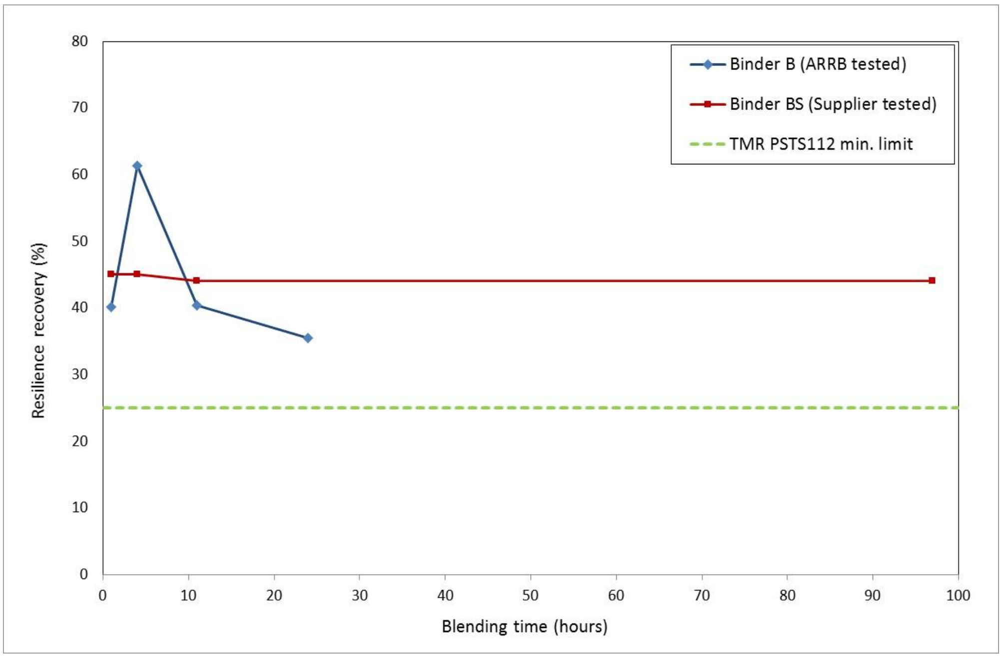


Figure 4.5: Comparison of softening point test results: binders B and BS



It can be seen from Figure 4.4 that the resilience of binder B peaked after 4 hours and then rapidly declined when blended up to 24 hours. The resilience of binder BS, on the other hand, did not change noticeably up to 96 hours of blending.

The softening point data in Figure 4.5 also show markedly different trends for the two binders. Similar to the case for the resilience test, the softening point of binder B peaked after 4 hours and then rapidly declined when blended up to 24 hours. The softening point of binder BS was lower than binder B after 1 hour, but then gradually increased as the blending time increased. As a result, binder BS had a higher softening point at 96 hours than binder B after 24 hours.

Further discussion on these nominally identical binders and their different behaviour is provided in Section 4.2.6.

4.2.5 Comparison of Binders A and B

The resilience and softening point test results obtained for binders A and B are compared in Figure 4.6 and Figure 4.7, respectively.

Figure 4.6: Comparison of resilience test results: binders B and BS

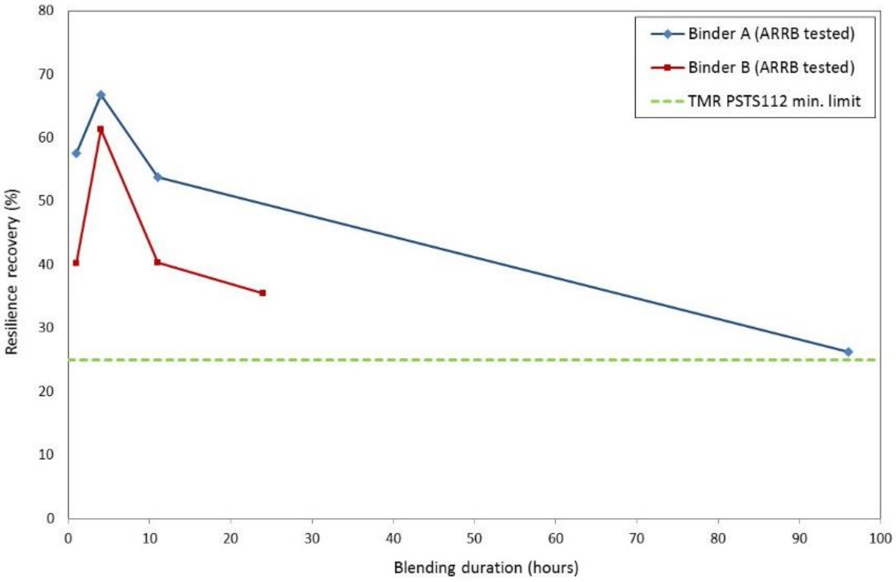
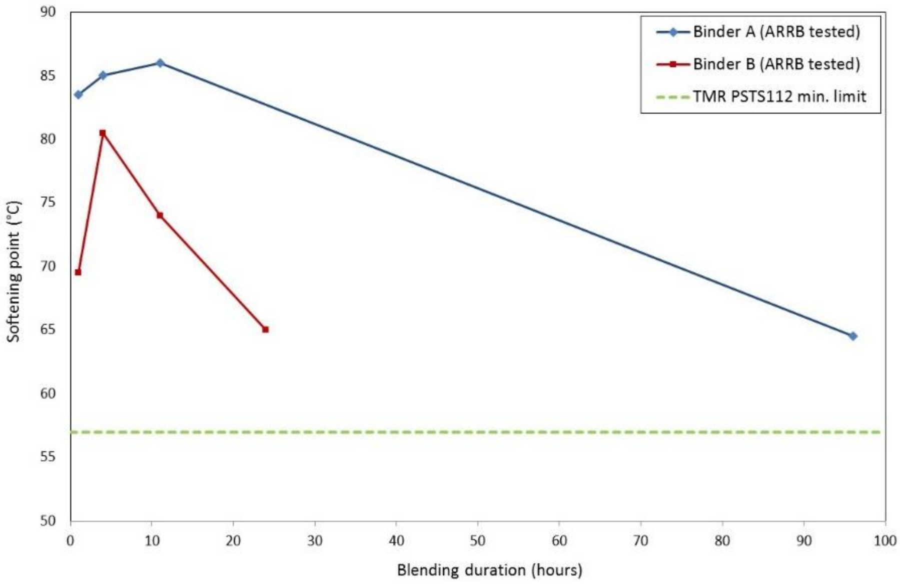


Figure 4.7: Comparison of softening point test results: binders A and B



The resilience data in Figure 4.6 show that the resilience of both binders peaked after 4 hours and then rapidly declined as blending continued. The softening point data in Figure 4.7 also show a similar trend for both binders. It was also noted that the softening points of the two binders after their respective full blending (24 and 96 hours) were very similar.

A noteworthy observation from the two sets of data was that binder A had higher resilience and softening point values than those obtained for binder B in all cases. It is well known that CRM binders with a higher rubber content tend to have enhanced elastic properties (resulting in higher values in these test properties). The test results agreed with the fact that binder A contained more rubber (i.e. 22%) than binder B (i.e. 20%) (refer to Section 4.2.1). It is also noted that the properties of both binders rapidly reduced as blending continued, indicating that the rubber may have deteriorated as a result of prolonged blending.

Appearance of binders A and B during blending

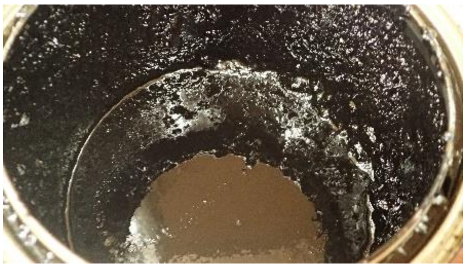
A series of photos are presented in Figure 4.8 which compare the changes in visual appearance of binders A and B during blending. A number of noteworthy observations (also in relation to the test results) were:

- Binder A appeared to be slightly thicker and lumpier than binder B; this agreed with the higher rubber content in binder A.
- Samples of binder A after 4 and 11 hours of blending appeared to be thicker/lumpier than the other samples; this agreed with the higher softening point values observed at these times as shown in Figure 4.7.
- For binder B, the 4-hour sample appeared to be thickest/lumpiest; this agreed with the peak resilience and softening point values shown in Figure 4.6 and Figure 4.7.
- After their respective full blending, the amount of visible rubber granules in both binders was markedly reduced. This agreed with the distinctively lower values of resilience and softening point after 96 and 24 hours respectively as shown in Figure 4.6 and Figure 4.7. This indicated that the rubber may have deteriorated during prolonged blending.

In conclusion, the test results obtained by ARRB were considered reasonable based on the following observations:

- The test results for binders A and B were generally consistent with the changes in appearance of the corresponding samples (e.g. thicker/lumpier samples were expected to be more elastic and result in higher test results accordingly).
- The changes in properties of binders A and B during blending were as expected. It is known that CRM binders become more elastic with blending (as the rubber is better dispersed and digested) but only up to a certain point. Prolonged blending/storage at high temperatures can lead to excessive deterioration of the rubber, resulting in lower resilience and softening point values as was demonstrated in this study.

Figure 4.8: Change in appearance of binders A and B during blending

Binder A	Binder B
 1 hour	 1 hour
 4 hours	 4 hours
 11 hours	 11 hours
 96 hours	 24 hours

4.2.6 Discussion

The test results obtained for both the ARRB and supplier blended binders, which were nominally identical, were very different. The observed variations were generally considered to be much larger than the inter-laboratory variation that may be expected for this type of experiment.

One potential reason may be that the resilience tests conducted by the two laboratories were different, possibly due to the error in the standard procedure as discussed in Section 4.2.2. As this is a new test method in Australia, it is possible that each laboratory interpreted the testing procedure differently. However, it should be noted that the softening point test also produced very different results for both binders (Figure 4.3 and Figure 4.5). As softening point is an established quality control test method in Australia, the testing procedure would be unlikely to be misinterpreted.

If the tests were conducted properly, the ARRB and supplier blended binders could be somewhat different. Possible causes may include:

- difference in the blending conditions (e.g. sizes of blending tin, types of stirrer)
- variation in the rubber content (actual rubber content may be slightly different to the target content, particularly for large-scale blending)
- difference in the number of times the sample was heated. It was reported that samples of binder B were heated twice, whereas the BS samples were heated once prior to testing. Samples of binders A and AS were all heated once prior to testing.
- different storage durations (at ambient temperatures) prior to testing. It was reported that samples of binder A were tested within 24 hours from sampling, whereas samples of binder AS were stored for a longer duration prior to testing due to logistic reasons.

4.3 Summary of Findings

The results of the testing of the two types of terminal-blended no-agitation CRM binders appeared to be closest to an A20E class binder commonly used in asphalt applications.

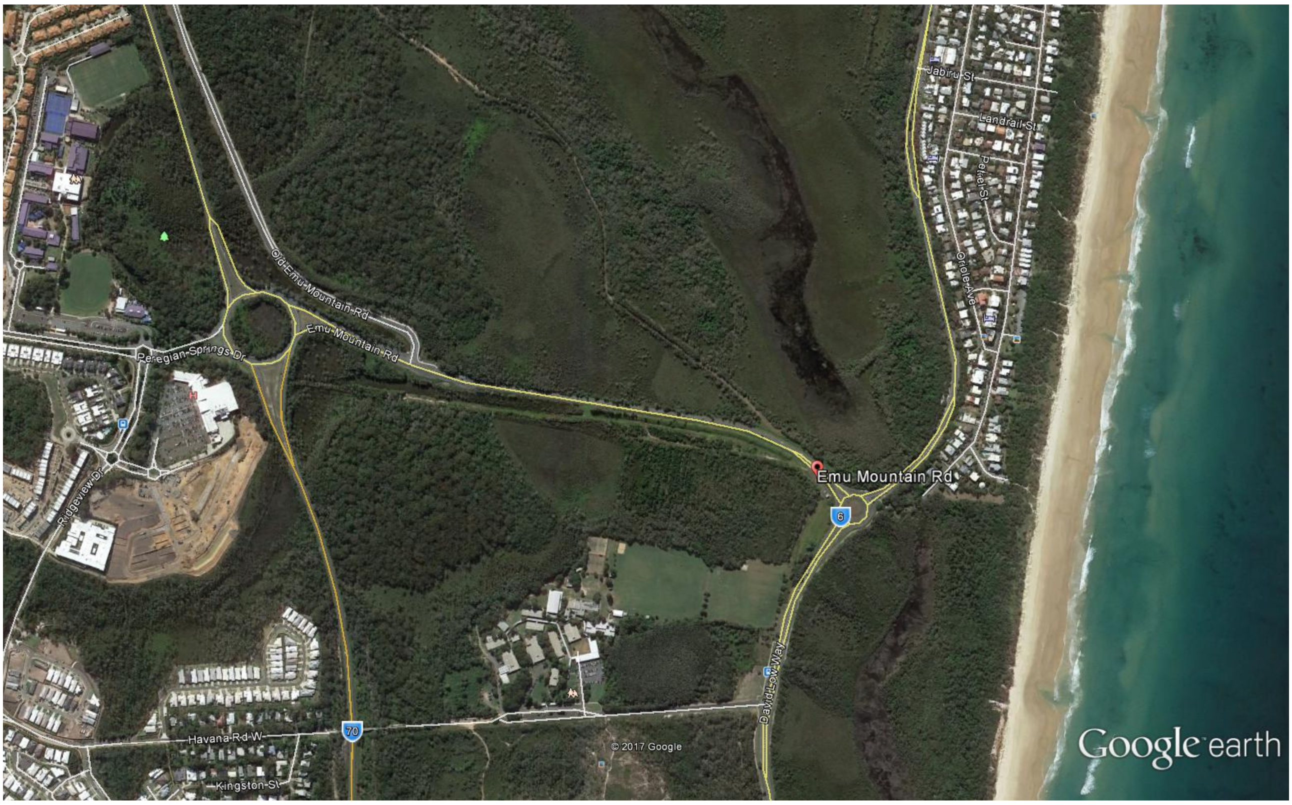
Two locally-manufactured, high-viscosity CRM binders were also tested as part of this study. The primary objective of this laboratory investigation was to assess whether the locally-manufactured binders would be able to conform to the property requirements specified in PSTS112. Whilst the binders blended by ARRB mostly conformed to the criteria for the tested properties, the binders blended and tested by the suppliers had non-conformances in some cases. The two binders were respectively blended by ARRB and the suppliers using reportedly the same component materials and recipe, but the test results between the laboratories were significantly different for both binders. The reason for the difference in test results between the laboratories remains unclear at this stage.

It is therefore recommended that further work be undertaken in subsequent phases of this project to assess the variability in CRM binder testing observed. Furthermore, it is recommended that a correlation between the resilience test and the Australian torsional recovery test be investigated. In Australia, the torsional recovery test at 25 °C (AGPT/T122) was purposely developed to evaluate the elastic recovery of PMBs, including CRM binder, i.e. the same reason the resilience test was adopted for CRM binders in the USA. The torsional recovery test should therefore be able to replace the resilience test if these test methods are found to be interchangeable.

5 CRM OGA DEMONSTRATION PROJECT

A demonstration project using CRM OGA was constructed on 23 February 2017 by TMR and Downer Group (Downer). The demonstration project was undertaken on a section of Emu Mountain Road between chainages 0.150 km and 0.550 km in the North Coast district (Figure 5.1).

Figure 5.1: Location of demonstration project



Source: Google earth 2017, 'Emu Mountain Road, Peregian Beach', image, Google, California, USA.

The aim of the demonstration project was to evaluate the constructability, performance and health and safety aspects of CRM OGA in Queensland. Three asphalt mixes were tested. Emissions monitoring was also undertaken. The findings of the emissions monitoring are presented in Section 6 of this report.

5.1 Details of Construction

5.1.1 Site Details

TMR identified a section of Emu Mountain Road for resurfacing as part of the Road Asset Maintenance Contract (RAMC) in the North Coast district. This section of Emu Mountain Road comprises an asphalt surface over an unbound granular pavement and carried approximately 15 300 vehicles per day in 2016 (of which 4.3% were classified as heavy vehicles). The pavement was showing signs of pavement distress, including crocodile cracking and pavement deformation. The maintenance works undertaken prior to the demonstration project included deep lift asphalt patches (nominal 215 mm thick) of the distressed areas. The road was also resurfaced with a polymer modified 50 mm thick AC14M asphalt layer prior to overlaying the road with a new waterproofing seal and 30 mm of 10 mm OGA. The project comprised of the following three sections:

- Section 1: CRM OGA (hot mix) – chainages 0.150 km to 0.270 km
- Section 2: PMB OGA (hot mix) – chainages 0.270 km to 0.425 km (control section)

- Section 3: CRM OGA (warm mix) – chainages 0.425 km to 0.550 km.

The chainage locations are shown in Appendix D of this report.

5.1.2 Asphalt Mix Design

The control section comprised a conventional nominal 10 mm OGA with an A5S polymer modified binder. The asphalt mix was designed to meet the requirements of MRTS30 and registered (mix registration no: D:OG10/16/4017).

The CRM OGA was designed to meet the binder and asphalt requirements in PSTS112 and the CRM binder was manufactured to achieve the properties specified for a CR2 binder in PSTS112. The CRM OGA warm mix was also designed in accordance with PSTS112, but included 0.5% CecaBase® as a warm mix additive.

Bituminous Products Pty Ltd supplied the CRM binder and the asphalt was manufactured by Downer at their asphalt plant at Bli Bli.

The production temperatures nominated for each of the mix types were:

CRM OGA (hot mix):	165 °C
PMB OGA (hot mix):	165 °C
CRM OGA (warm mix):	145 °C

5.2 Construction Monitoring

Representatives from ARRB, TMR and the Australian Asphalt Pavement Association (AAPA) attended the construction. The site observations are discussed in more detail in the following sections.

5.2.1 Temperature Distribution during Paving Operations

PMB OGA

Figure 5.2 and Figure 5.3 show a thermal image of the PMB OGA during paving, with temperatures generally between 135 °C and 150 °C behind the paver. The temperatures across the asphalt mat were evenly distributed with no apparent cold spots (other than a single small localised cold spot as shown in Figure 5.2).

Figure 5.2: Polymer-modified OGA paving_1

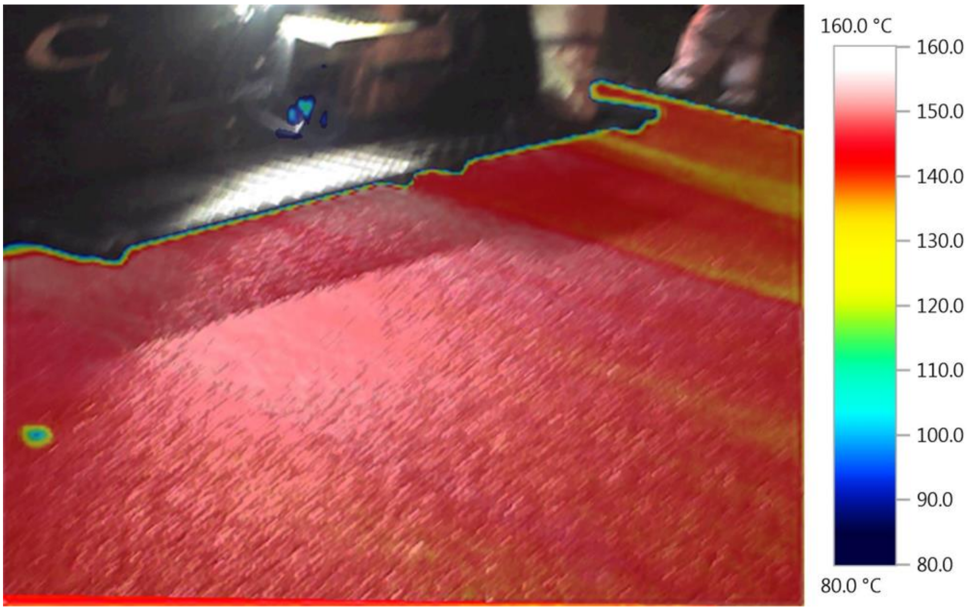
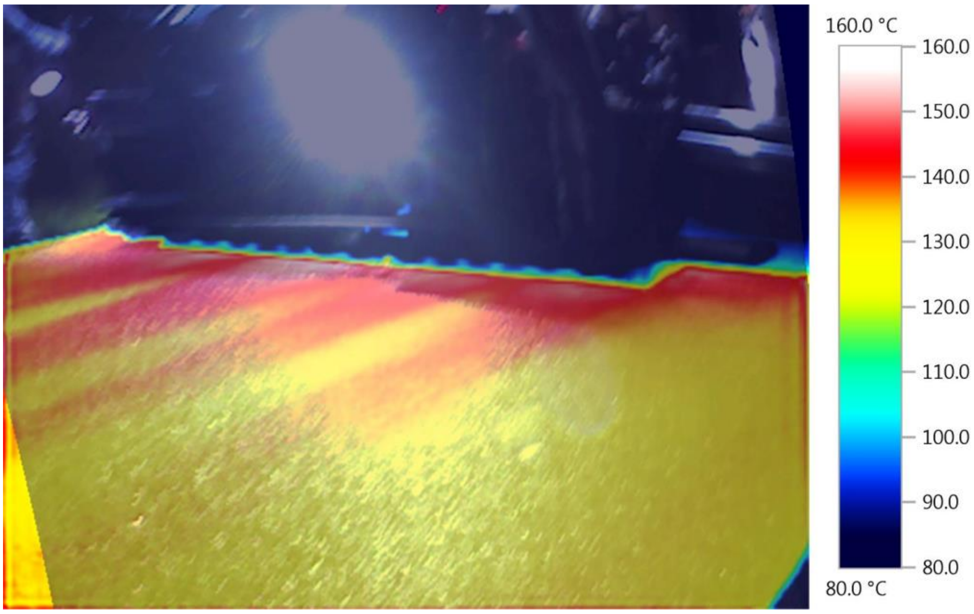


Figure 5.3: Polymer-modified OGA paving_2



CRM OGA

Figure 5.4 and Figure 5.5 show the temperature distribution of the CRM OGA hot mix behind the paver. It can be seen that the temperature behind the paver varied between 130 °C to 145 °C and was slightly lower than PMB OGA. Again, the temperatures across the asphalt mat were evenly distributed.

For the warm mix CRM OGA, the temperature at the back of the paver varied between 125 °C and 140 °C, which was approximately 10 °C lower than the PMB OGA (Figure 5.6). This is consistent with the lower production temperatures used for this section.

Figure 5.4: Hot mix CRM OGA paving_1

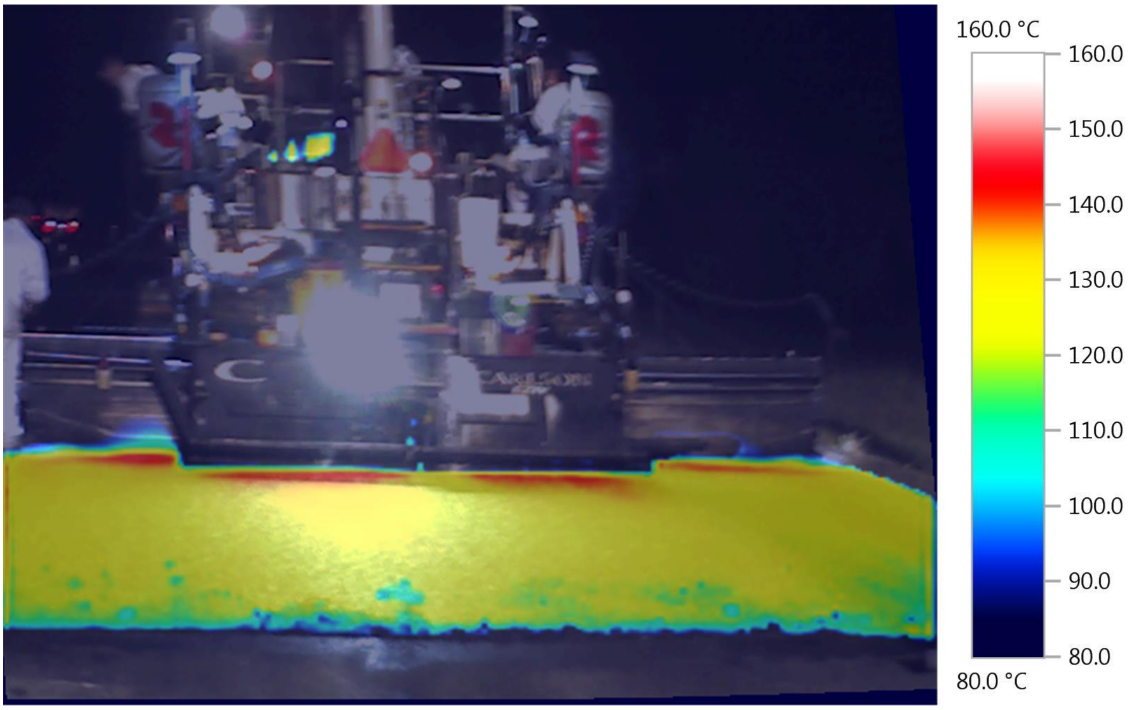


Figure 5.5: Hot mix CRM OGA paving_2

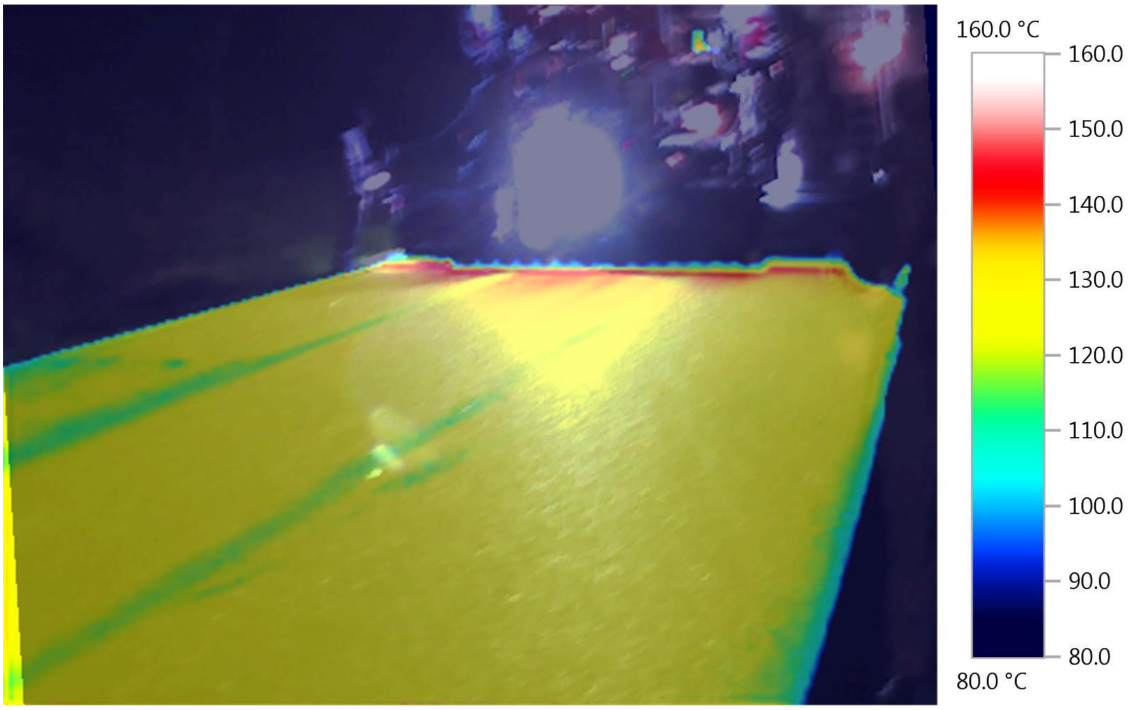
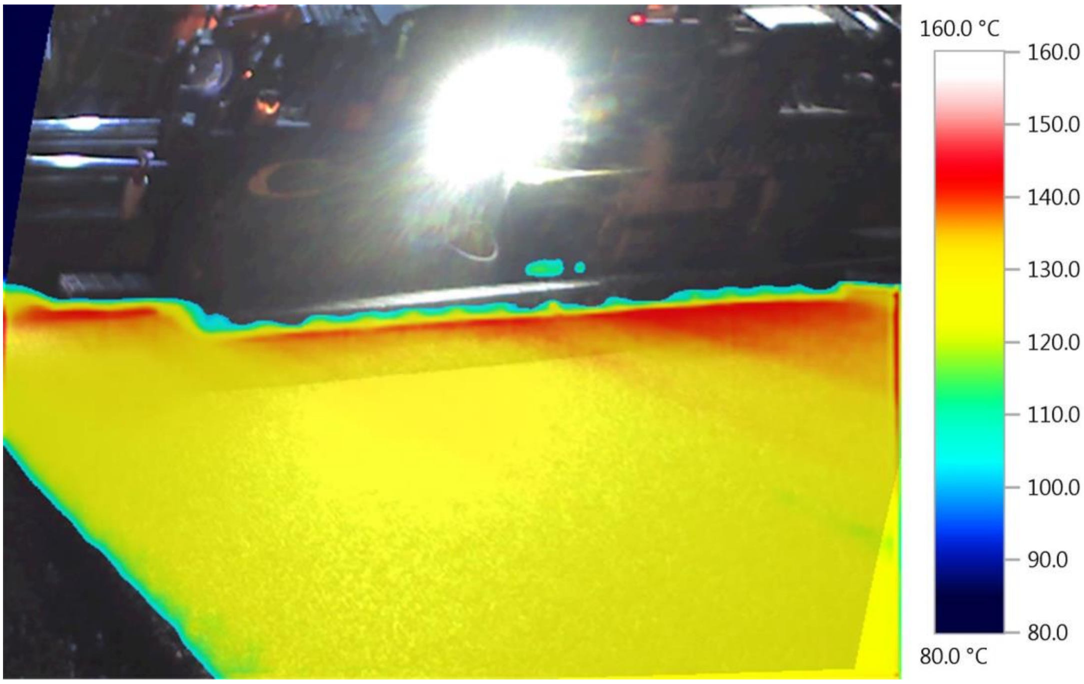


Figure 5.6: Warm mix CRM OGA paving_1



5.2.2 Paving Practices

The contractor did not vary the paving practices for the three different mix types placed during the demonstration project. Asphalt compaction commenced immediately after paving with a steel-wheel vibratory roller. A minimum of five passes were applied to the completed OGA layer. There were no issues with compaction during the construction process. This confirmed that CRM OGA could be placed and compacted using conventional construction equipment and techniques.

5.2.3 Production Testing

The contractor undertook the following production testing as part of their Asphalt Quality Management Plan:

- aggregate grading
- binder content
- compacted density (50 Marshall blows)
- maximum density
- air void content.

All of the production test results indicated that the mix was manufactured in accordance with the specification, with the exception of binder content. The binder content of the CRM OGA mixes determined in accordance with test method AS/NZS 2891.3.1: 2013 were lower than the specification limits. The reason for this lower binder content is discussed in Section 5.4.

5.3 Long-term Performance Monitoring

The long-term performance of the demonstration project will be monitored as part of TMRs ongoing long-term pavement performance monitoring program (LTPP). The following key performance measures will be monitored:

- any signs of visual distress, including ravelling, cracking and potholing

- permanent deformation (i.e. rutting)
- riding quality (i.e. roughness)
- texture depth.

A baseline survey was undertaken on 3 April 2017 (approximately five weeks after construction) using ARRB's network survey vehicle (NSV). The average condition values for each section are summarised in Table 5.1.

Table 5.1: Pavement condition survey results

Mix Type	Chainage (km)	Direction	Roughness (NAASRA counts/km)	Rutting (mm)	Estimated texture depth (mm)(1)
CRM OGA (hot mix)	0.150–0.275	Westbound	16	2.3 (OWP)(2) 2.1 (IWP)(2)	1.1 (OWP) 1.1 (between WP)
		Eastbound	16	2.4 (OWP) 2.3 (IWP)	1.1 OWP) 1.2 (between WP)
PMB OGA (hot mix)	0.275–0.425	Westbound	15	1.5 (OWP) 2.3 (IWP)	1.2 (OWP) 1.3 (between WP)
		Eastbound	19	1.6 (OWP) 2.0 (IWP)	1.3 (OWP) 1.3 (between WP)
CRM OGA (warm mix)	0.425–0.550	Westbound	20	1.3 (OWP) 2.1 (IWP)	1.1 (OWP) 1.2 (between WP
		Eastbound	16	1.5 (OWP) 2.0 (IWP)	1.1 (OWP) 1.1 (between WP)

1 Estimated Texture Depth = 0.8 x mean profile depth + 0.2 (Austroads 2009).
2 OWP: outer wheelpath. IWP: inner wheelpath.

It can be seen from Table 5.1 that there was no significant difference in the pavement condition properties in the three sections; and that all the results were within the limits expected for a newly-placed wearing course. There were no visual signs of pavement distress.

5.4 Key Learnings

A number of key learnings were taken from the demonstration project that should be considered when implementing CRM OGA in Queensland.

Construction practices

The CRM OGA was placed using construction procedures typically used for the placement and compaction of conventional OGA. There is therefore no need to change current construction practices when implementing CRM OGA.

Testing of materials

The binder content of asphalt mixes manufactured in accordance with MRTS30 is determined by means of either the ignition oven or reflux method. The contractor raised a concern that they were not able to determine an accurate binder content during the mix design process.

When modifying bitumen with rubber, the rubber becomes partially digested by the bitumen. Using conventional test methods to determine the binder content of CRM asphalt mixes may not be accurate due to the undigested component not being accounted for during the extraction process. A correction factor to the binder content is therefore required when the reflux method is used. Alternatively, the ignition oven should be calibrated to the specific CRM binder blend being used (Southern African Bitumen Association 2016. It is therefore recommended that amendments be made to existing test methods to enable the accurate determination of the binder content of crumb rubber modified asphalt.

PSTS112 specifies that the viscosity of the CRM binder immediately prior to use should be between 1.5–4.0 Pa.s, when tested with a rotational viscometer in accordance with test method ASTM D7741/D7741M-11. Given that, for many projects, the binder will be manufactured off site, there would be a need for the contractor to have this testing capability at the asphalt plant. The rotational viscometer is, however, locally available in Australia and the cost is not considered to be prohibitive.

6 EMISSIONS MONITORING

6.1 Background

During the course of scoping the first Queensland crumbed rubber trial, which demonstrated the use of rubber in sprayed seals, concerns were raised that the introduction of rubber to the mix at high temperatures may lead to increased hazardous emissions. An increased production of harmful organic compounds during mix production and paving could potentially lead to adverse health effects for road workers and production staff at the asphalt plant.

As a part of the sprayed sealing trial, a thorough literature search was conducted, documenting previous studies into CRM asphalt and sealing emissions. This research was documented in Denneman, Lee and Foster (2014).

The literature review highlighted several notable considerations which are pertinent to any future CRM sealing or asphalt trials, including:

- the emission of common gases and pollutants during production does not appear to be significantly different for CRM binder than for conventional binders
- emissions are higher when the material is in a ‘loose’ condition (i.e. during production, transport and in pavers) compared to after paving and compaction
- a strong odour has been recognised as a broad worker and community concern, even in cases where emissions are not found to be hazardous.

The previous trial of CRM in sprayed seals included field measurements of the levels of air pollutants on the roadside during and after construction. The study included air sampling using vacuum canisters and active air sampling for particulate and organic pollutants. Samples were collected from the roadside in the downwind direction utilising two air samplers, with samples collected and stored until analysis could be completed off-site at a later time. Testing also included background sampling (conducted prior to sprayed sealing) to establish a ‘baseline’ level of pollutants. Samples were analysed for both volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) using standard protocols. This study was undertaken on both the CRM binder sprayed seal trial section and the PMB sprayed seal control section.

The results of this testing suggested that exposure to particulate matter was higher in CRM binder spray sealing works, with levels of total suspended particles in the first three hours after sprayed sealing exceeding the Queensland State Government air quality objective of 90 $\mu g/m^3$ (Queensland Government 2017). It should however be noted that this objective refers to the average exposure over a one-year period. The report therefore acknowledged that the average annual concentration will be lower than the concentration measured during spraying operations, thereby reducing the risk to the public. This is consistent with previous findings in other countries. The level of total suspended particles dropped after several hours, which indicates minimal risk to those outside the immediate vicinity of the sprayed sealing operation. Total suspended particles were not found to exceed the guidance figure in the conventional spray sealing treatment.

The levels of benzo(a)pyrene and PAHs did increase immediately after construction in both the CRM and control sections; however, at no time were these levels found to exceed the air quality objective of 300 pg BaP/m^3 set by the Queensland State Government. There was no increase in the levels of these pollutants in CRM sprayed seals compared to conventional PMB sprayed seals.

However, due to time constraints, it was not possible to include comprehensive monitoring of emission flux or exposure to workers in the direct vicinity of these materials. As a result, there were still some concerns surrounding the health and safety of those operating in the immediate vicinity of CRM binders, and it was important that these concerns were allayed before the department could commit to extensive works incorporating CRM binder in asphalt or sprayed seals in the future.

As a result, emissions monitoring of the CRM OGA at the demonstration project was undertaken to further assess the emissions from a CRM binder and 'conventional' PMB binder during asphalt works.

6.2 Emission Monitoring Plan

The emission monitoring plan was developed in conjunction with researchers from the Queensland Alliance for Environmental Health Sciences (QAEHS), a research centre within the University of Queensland. QAEHS had previously assisted with the emission monitoring during the CRM sprayed sealing trial in 2015.

Much of the sampling methodology detailed under this monitoring plan has been adapted from the method developed by the University of California Pavement Research Centre as part of the California Department of Transportation study into warm mix asphalt (Farshidi, Jones & Harvey 2013).

As with the initial trial in Queensland, the team at the University of California wanted to distinguish between emissions from the roadside and those directly attributable to the asphalt itself. Roadside monitoring was therefore not appropriate, and there was not a ready-made solution for direct monitoring of road surface emissions. This required the development of a purpose-built device and associated sampling methodology.

The emissions monitoring consisted of two key elements: measuring emissions from the loose asphalt mix at the plant and measuring the exposure to harmful emissions for workers in close proximity to paving operations.

A trial at the TMR laboratory at Bulwer Island was undertaken which involved sampling emissions from hot loose-mix asphalt using the new flux chambers. This assisted with determining the suitability of the chamber, the sampling apparatus and the various sorbent tubes.

6.2.1 Measuring Emissions from the Loose Asphalt Mix

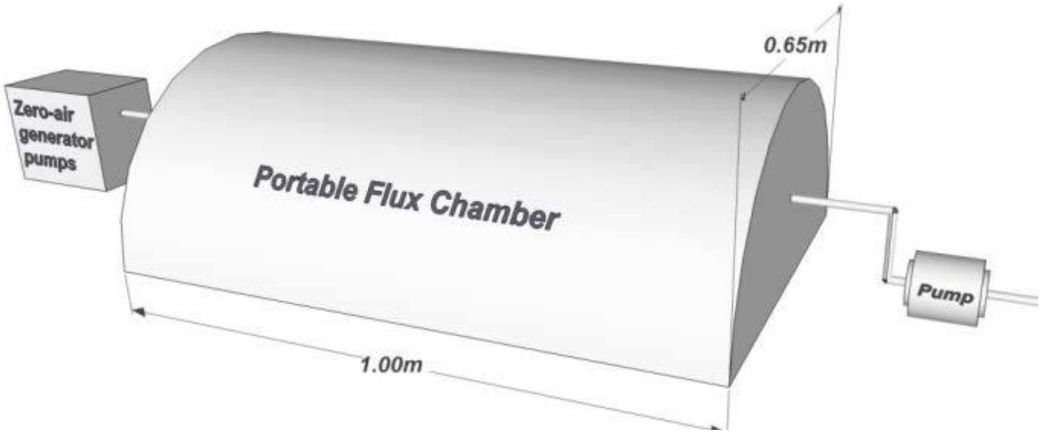
As discussed previously, a key driver behind this comprehensive study into emissions involves determining the composition of emissions from the material in a loose condition. This necessitates a tailored approach to measuring these emissions.

Equipment required

The flux chamber design and method adopted by Farshidi, Jones and Harvey (2013) was used for the emissions monitoring. The design was modified slightly to allow for connection to the sampling and air-purification systems in use in Australia.

The flux chamber consisted of a steel half-cylinder 1 metre long, 0.65 metres wide and 0.33 metres high (Figure 6.1 and Figure 6.2). To ensure reliable and repeatable results, all testing was duplicated with a second flux chamber. This also provided a degree of contingency in the event of a flux chamber failing during the trial. The two flux chambers were procured and manufactured in Brisbane (Figure 6.3).

Figure 6.1: Portable flux chamber as designed for the University of California emissions study



Source: Farshidi, Jones and Harvey (2013).

Figure 6.2: University of California portable flux chamber during field sampling

Source: Farshidi, Jones and Harvey (2013).

Figure 6.3: Flux chambers procured for the NACoE project

Source: ARRB (2016).

Sampling procedure

Previous studies of emissions had shown that the temperature of the mix is often the most critical factor for the production of harmful emissions. The stages where asphalt is likely to be at its highest temperature are when it is loaded into the truck for delivery to the site, and when it arrives at the site before the commencement of paving. The exact method of sampling at this stage of the process was decided based on safety, operational and logistical considerations with respect to the trial location and asphalt manufacturer.

The asphalt supplier and the emissions monitoring team agreed that locating the primary emissions chamber testing away from the site was preferable. The sampling method involved a front-end loader delivering a bucket of material from the plant to a location to the side of the facility. The material was dumped and shovelled into shape of roughly the dimensions of the emissions chamber. The temperature was monitored from this point to mirror the temperature that it was likely to be as it arrived on site; this meant that there was a small delay before the start of testing.

While it would be ideal to also test the pavement after compaction to determine any potential longer-lasting effects, due to operational, safety and time constraints, the critical emissions period was the primary focus of testing for this trial.

6.2.2 Worker Exposure Assessment

While it is important to sample emissions in a ‘worst case’ scenario, the practical implication of this study was to determine the likely health risks to road workers and neighbouring residents. In order to achieve this, sampling of emissions was undertaken at the higher-risk locations of road workers during paving operations. In consultation with the crew on site, it was decided that the paver operator, and the worker supervising the delivery of asphalt into the material transfer vehicle, would typically be exposed to the highest levels of emissions in the paving team.

Personal monitoring devices (i.e. DustMate by Turnkey Instruments Ltd) were chosen for this purpose; they are capable of recording the particulate matter in the air at regular intervals.

6.3 Laboratory Analysis

Testing of the samples was conducted at the QAEHS laboratory in Brisbane. The three key samples taken during the monitoring period included:

- *Polycyclic aromatic hydrocarbon (PAH) emissions:* sampling of a series of 13 PAH compounds (recommended by the US Environmental Protection Agency) was undertaken through active air sampling.
- *Volatile organic compound (VOC) emissions:* sampling for volatile organic compounds (VOCs) was undertaken through the air sampled from the flux chamber.
- *Total particulate matter:* the total particulate matter and particulate matter under 10 µm and under 2.5 µm are regularly measured in urban areas. They were monitored for this trial using both personal monitoring devices and the emissions chamber.

6.4 Emissions Monitoring Results and Analysis

Each of the three mixes used in the demonstration project was tested for their emissions. Emissions were measured with the emission chambers at the production plant, while two DustMate fume and dust detectors (Figure 6.4) were carried by selected paving crew members. These devices are capable of reading the total suspended particles in the air, as well as the total particulate matter under 10 µm and under 2.5 µm. The devices were placed in a backpack or satchel with the air intake exposed so that the workers did not have to physically hold the device, but in such a way that the particulate matter readings were still as representative as possible of those likely to be encountered by a worker on site. As just discussed, the devices were attached to the paver driver, who was located closest to the material as it was transferred into the paver from the material transfer vehicle, and the crew member who was supervising the transfer of asphalt from the delivery truck into the material transfer vehicle. However, one of the DustMate devices failed soon after the paving commenced and, as a result, the results of only the device attached to the asphalt delivery supervisor were included in the analysis.

A copy of the emissions monitoring report prepared by QAEHS is included in Appendix E of this report (QAEHS 2017).

Figure 6.4: DustMate device from Turnkey Instruments

Source: Turnkey Instruments (n.d.).

6.4.1 Particulate Matter

The total suspended particles (TSP), particulate matter smaller than 10 μm in diameter (PM_{10}) and particulate matter smaller than 2.5 μm in diameter ($PM_{2.5}$) were measured using the DustMate. The TSP was also measured by the emission chambers.

TSP are airborne particles of up to roughly 100 μm (Queensland Government 2017). They are assessed primarily against 'nuisance' based criteria. Within the TSP, PM_{10} and $PM_{2.5}$ are measured as particles 'capable of penetrating the lower airways of humans and can cause negative health effects for humans' (Queensland Government 2017). The Queensland Government maintains standards for particulate matter based on the National Environment Protection Measure for Ambient Air Quality (Air NEPM) (Table 6.1). Each of these values is intended to be averaged over 24 hours, and this needs to be taken into account when looking at figures for hourly intervals.

Table 6.1: Air NEPM standards in Australia

	Air NEPM standard	Averaging time
TSP (μg/m^3)	80	24 hours
PM_{10} (μg/m^3)	50	24 hours
$PM_{2.5}$ (μg/m^3)	25	24 hours

Source: Queensland Government (2017).

Putting these values in context, many heavily-industrialised cities such as Beijing regularly record 24-hour average $PM_{2.5}$ values of over 200 µg/m^3, which are considered very unhealthy (World Air Quality Index 2017).

Table 6.2 summarises the results of the particulate monitoring from the DustMate and Table 6.3 shows the results from the emissions chamber. Not surprisingly, the values in the emissions chamber are higher in general, as the sampling is focussed immediately at the surface of the fresh asphalt. The mean values for the DustMate are lower than the emissions chamber but there is a much greater variability. The DustMate recorded values for $PM_{2.5}$ of 600 µg/m^3 or more for several of the 1-minute sampling intervals, which were possibly during periods of asphalt being transferred from the truck to the paver. Graphs of the 1-minute emissions recorded over a one-hour period can be found in Appendix E of this report.

The particulate matter measured during Run 6 of the warm mix placement was lower than Run 5 for the same mix. The reason for this lower value is not clear at this stage, but the report prepared by QAEHS suggest that this could be due to the lower temperature of the mix on site during Run 6.

$PM_{2.5}$ levels of 300–600 µg/m^3 or more can be encountered for entire 24-hour periods on extreme days in heavily-polluted cities. While long-term exposure to such high levels is certainly a health hazard, it is not clear whether exposure at such levels for several minutes during a paving operation would pose significant health concerns. The mean values for $PM_{2.5}$ during each paving run were in the range of 41.64–133.7 µg/m^3, which are higher than the recommended 24-hour average standards of 25 µg/m^3 from Air NEPM (Queensland Government 2017).

Currently, there are no legal limits for occupational exposure to asphalt fumes in Australia. However, the proposed limits for asphalt fumes (expressed as TSP) that have been developed for the United States (refer QAEHS report Table 4 in Appendix E) were not exceeded in any of the paving runs as measured by the DustMate.

Finally, the study found that there was no significant difference in the concentration of TSP, PM_{10} and $PM_{2.5}$ measured between the different asphalt mixes during paving.

Table 6.2: Particulate matter from DustMate during trial

			Hot-mix CRM (µg/m^3)	Warm-mix CRM (µg/m^3)		Polymer mix (µg/m^3)	Background (on site) (µg/m^3)	
Source	**Name**		**Run 1**	**Run 5**	**Run 6**	**Run 4**	**Test #1**	**Test #2**
DustMate	Total suspended particulate matter	TSP	622.6	1017	167.6	665.6	228.2	144.9
	Particulate matter less than 10 µm	PM_{10}	547.9	961.3	125.9	630.9	138.1	88.54
	Particulate matter less than 2.5 µm	$PM_{2.5}$	125.6	133.7	41.64	117.5	24.41	14.31

Table 6.3: Particulate matter from emissions chamber during trial

			Hotmix CRM (µg/m^3)		Warm mix CRM (µg/m^3)		Polymer mix (µg/m^3)		Background (on site) (µg/m^3)
Source	**Name**		**0–1 hr**	**1–2 hr**	**0–1 hr**	**1–2 hr**	**0–1 hr**	**1–2 hr**	
Emissions chamber	Total suspended particulate matter	TSP	360	1100	1400	1400	1800	–	< LOR

LOR = Limit of report.

6.4.2 PAH Emissions

The Centers for Disease Control and Prevention (CDC) (2016a) notes that people are exposed to PAHs through breathing air ‘contaminated with motor vehicle exhaust, cigarette smoke, wood smoke, or fumes from asphalt roads’, or through ingesting foods such as grilled or charred meats. PAHs are processed in the body and passed out as urine and faeces. The overall health impact of low level exposure to PAHs is unknown, however high concentrations of some PAHs has been shown to cause irritation in the eyes and throat, blood and liver abnormalities, and some combinations are considered carcinogenic and cancer-causing.

As discussed in the QAEHS report (refer Appendix E), a subset of 13 PAHs were analysed in this study, with 12 of these 13 compounds identified as being among the priority PAHs listed by the US Environment Protection Agency (EPA) (i.e. there is some evidence to suggest that these 12 may have health effects on humans at high concentrations). Of these, benzo[a]pyrene (BaP) is known to be carcinogenic to humans, dibenzo[a,h]anthracene (DahA) is considered to probably be carcinogenic to humans, and other PAHs such as such as benzo[a]anthrancene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), indeno[1,2,3-c,d]pyrene (IcdP) are listed as being possibly carcinogenic to human (International Agency for Research on Cancer 2015).

The PAHs were measured during the CRM OGA demonstration project through the emissions chamber. The results for the PAHs with known, probable or possible carcinogenic effects are listed in Table 6.4.

Only BaP has a designated annual average exposure limit nominated by the NEPM, which is listed at 0.0003 µg/m^3. There are no exposure limits set in Australia for PAHs as a whole, nor are there limits established in the United States of America where CRM binders are used. There are potentially hundreds of varied PAHs that may be present in asphalt fumes, but it is not clear what the potential health effects of many of these compounds are.

Table 6.4: Emission concentrations of polycyclic aromatic hydrocarbons (PAHs) during trial

			Hot-mix CRM (µg/m^3)		Warm-mix CRM (µg/m^3)		Polymer mix (µg/m^3)	Background (on site) (µg/m^3)
	Name		**0–1 hr**	**1–2 hr**	**0–1 hr**	**1–2 hr**	**0–1 hr**	
Known carcinogens	Benzo[a]pyrene	BaP	0.0021	< LOR	< LOR	< LOR	0.0067	< LOR
Probably carcinogens	Dibenzo[a,h]anthracene	DahA	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR
Possible carcinogens	Benzo[a]anthrancene	BaA	0.50	0.16	0.10	0.068	0.23	< LOR
	Chrysene	Chr	0.32	0.10	0.059	0.041	0.14	< LOR
	Benzo[b]fluoranthene	BbF	0.0068	0.0027	0.0017	0.0010	0.014	< LOR
	Benzo[k]fluoranthene	BkF	0.0018	< LOR	< LOR	< LOR	0.0049	< LOR
	Indeno[1,2,3-c,d]pyrene	IcdP	< LOR	< LOR	< LOR	< LOR	0.0015	< LOR

LOR = Limit of report.

For the purposes of this study, it is not appropriate to directly compare annual average exposure limits to the readings taken in the emissions chamber, due to the sampling size and the sampling period. However, it can be seen that, of the three mixes, the PMB OGA (hot mix) produced the highest BaP emissions during the first hour of testing, with the CRM OGA (hot mix) the second highest and the warm mix CRM OGA the lowest. The CRM OGA (hot mix) dropped below the limit of reporting after the first hour.

Furthermore, the total concentration of the 13 PAHs measured was the highest for the CRM OGA (hot mix), whereas the CRM OGA (warm mix) produced the lowest total concentration of PAHs.

Of the other six potentially hazardous PAHs, the highest readings were from the PMB OGA (hot mix) mix for BbF, BkF and IcdP, and from the CRM OGA (hot mix) for BaA and Chr. The DahA readings were below the limit of reporting for all samples.

From this, it can reasonably be concluded that CRM OGA (warm mix) is likely to produce lower PAH emissions than either CRM OGA (hot mix) or PMB OGA (hot mix).

6.4.3 VOC Emissions

The VOCs were measured by taking a rapid sample in the emissions chamber through a vacuum canister at the start of each hour of testing. These were tested at the laboratory, with the main focus on BTEX compounds. The tables in this section do not represent the total emissions of VOC during the trial, as they focus on the key compounds identified as being potentially hazardous in high concentrations. The full set of emissions results from all compounds can be found in the attached QAEHS report.

It was also found that the total concentration of VOCs measured for all of the asphalt mixes was below the permitted exposure limits listed by the National Institute for Occupational Safety and Health (NIOSH 2016). The CRM OGA mixes had a relatively high proportion of benzene and xylene emissions compared to the PMB OGA, while the PMB OGA produced relatively more toluene emissions. The report prepared by QAEHS did, however, note that the concentration of benzene emitted from both the CRM OGA mixes could exceed the exposure limits proposed in the USA in a worst-case scenario (such as measured by the emissions chamber).

Values for naphthalene for the CRM OGA (hot mix) are just below the NIOSH 8-hour time weighted average recommended exposure limit of 10 ppm, while they exceed this value for the PMB OGA (hot mix) (CDC 2016b). However, each of the three mixes was below the NIOSH short-term limit of 15 ppm and well below the NIOSH limit for immediate danger to life or health of 250 ppm. The total exposure for workers over a typical paving operation would have to be evaluated before making any conclusions about the overall health risks from naphthalene. Naphthalene is classified as ‘possibly carcinogenic to humans’ according to the International Agency for Research on Cancer (IARC) (World Health Organisation / IARC 2002).

BTEX compounds

BTEX refers to a group of four compounds that are commonly found in petroleum products, including asphalt and in oils used in the production of bituminous binders (Leusch & Bartkow 2010). BTEX comprises **B**enzene, **T**oluene, **E**thylbenzene and **X**ylenes; they are relatively abundant in the atmosphere and the environment due to their widespread use in many petroleum-based products. Cities often have background levels of several hundred parts per billion (ppb), while total BTEX levels of over 5000 ppb have been measured at petrol stations (IPCS 1993, ATSDR 2007a, NTP 2005 in Leusch & Bartkow 2010). Benzene is considered to be the most toxic of the four BTEX compound (Leusch & Bartkow 2010).

While it’s difficult to ascertain worker health effects based on a controlled emissions chamber test, BTEX levels measured in the chamber can be evaluated for the purposes of comparison between the three mix types. Bituminous binders are often made up of varying fractions of petroleum compounds; as a result, when comparing a mix manufactured with a rubberised binder and another with a PMB, it is not unexpected that there are large differences.

It can be seen from the emissions monitoring undertaken that the CRM OGA (warm mix) has lower emissions than the CRM OGA (hot mix) for all BTEX compounds, except for toluene which returned similar results for both mixes (Table 6.5). The two CRM asphalt mixes were identical in composition except for a small quantity of additive in the warm mix binder, so it appears as though temperature has a significant role in lowering BTEX emissions. This can also be seen through the large drop-off in emission concentration in the second hour of testing compared to the first hour.

Chlorinated alkanes

Chloromethane and methylene chloride (also known as dichloromethane) are considered toxic and potentially carcinogenic (NIOSH 2016). In the case of both chemicals, the levels (see Table 6.5) were below those considered hazardous for worker exposure (according to NIOSH). These chlorinated alkanes are sometimes present in cutter oils for lubrication, which may explain their presence in these asphalt mixes, albeit in very low concentrations.

Table 6.5: Emission concentrations of volatile organic compounds (VOCs) in emission chamber (in ppm as mass/vol.)

		Hot-mix CRM (ppm)		Warm-mix CRM (ppm)		Polymer mix (ppm)	Background (on site) (ppm)
Name		**0–1 hr**	**1–2 hr**	**0–1 hr**	**1–2 hr**	**0–1 hr**	
BTEX compounds	Benzene	2.17	0.11	1.04	0.16	0.08	0.04
	Toluene	0.46	0.10	0.48	0.13	6.24	0.41
	Ethylbenzene	0.92	0.14	0.38	0.19	0.41	< LOR
	Xylene (m, p)	12.67	5.13	7.65	5.67	2.60	0.22
	Xylene (o)	0.80	0.11	0.33	0.15	0.82	0.05
Chlorinated alkanes	Chloromethane	0.02	0.03	0.05	0.03	0.03	0.03
	Methylene Chloride	0.08	0.30	0.10	0.04	0.05	0.04

LOR = Limit of report.

6.5 Summary of Findings

The purpose of this study was to investigate both the emissions immediately at the surface of the pavement (i.e. worst-case scenario), as well as the exposure of road workers during paving operations. The two forms of monitoring both returned results that were consistent with those from previous studies undertaken internationally – i.e. that CRM asphalt mixes produce emissions that are comparable to those from PMB asphalt mixes, and that temperature was a dominant factor in determining the relative risk of personnel with regards to asphalt emissions. It was also found that producing asphalt at lower temperatures (which may require the use of warm mix asphalt additives) could reduce the emissions during asphalt manufacture and placement. It is worth noting that an earlier study in California found that the concentration of alkane emissions does depend on the type of warm mix technology; and recommended that any comments regarding a reduction in emissions should be limited to a specific warm mix technology (Farshidi, Jones and Harvey 2013).

The concentration of benzene measured in the emissions chamber was, however, higher for the CRM OGA mixes; however, the potential health impact on workers could not be fully evaluated due to the evaluation method representing the absolute worst-case scenario.

While the emissions chamber was not intended to replicate the typical emissions exposure for road construction personnel or the general public, it nonetheless showed that overall levels were generally below recommended limits. There was, however, evidence of elevated levels of potentially harmful emissions while the mixes were at a high temperature. This may present health risks should workers be exposed to high temperature asphalt in close proximity for a large proportion of a typical paving shift.

Considering this, the report prepared by QAEHS recommended that appropriate protective gear be used by workers to minimise their exposure risk to harmful emissions during construction.

It should be noted, however, that, due to the size and scope of this study, the emissions monitoring undertaken is not a definitive statement on the potential health and safety impacts of CRM binders in asphalt. Further investigation into benzene emissions in particular should be undertaken to better understand the results obtained as part of this project.

7 CONCLUSIONS AND RECOMMENDATIONS

The main focus of Phase 2 of this research project was facilitating the increased use of CRM binders in sprayed seals and OGA. This report presents the findings of the work undertaken to date, including:

- amendments to TMR specifications MRTS11 and MRTS18 to facilitate the increased use of CRM binders in sprayed seals
- the development of a new supplementary specification (PSTS112) for the supply and construction of CRM OGA
- comparative testing of locally-manufactured CRM binders to demonstrate their engineering properties and compliance with PSTS112
- a demonstration project that included the construction of a trial with three OGA mixes, including CRM OGA (hot mix), CRM OGA (warm mix) and PMB OGA. The demonstration project also included emissions monitoring of the different mix types.

The amendments to MRTS11 are substantial and will change the way TMR specifies sprayed seals on their road network. A ‘permissive’ approach to binder selection will allow the contractor to choose an alternative binder class (that will provide equivalent performance) to the binder class specified without the need for the principal or contract administrator’s approval. This approach will allow contractors to select their preferred binder class based on financial and operational considerations. It is believed that this approach will facilitate the increased use of alternative binder classes, such as crumb rubber modified binders.

MRTS18 has been updated to align the nomenclature and specification properties with current national practice, as per AGPT/T190 *Specification Framework for Polymer Modified Binders*. It is envisaged that this alignment with Austroads will promote efficiencies within the industry.

A new supplementary specification (PSTS112) was developed for CRM OGA. The specification, and, more specifically, the binder requirements, are primarily based on current practices in Arizona and California where CRM binders are widely used. A demonstration project undertaken in the North Coast region showed that CRM OGA can successfully be manufactured and placed locally in accordance with PSTS112.

A comparative binder testing program was undertaken to assess the properties of locally-manufactured CRM binder against specification requirements. The comparative testing found that local industry has the capability to manufacture CRM binders in accordance with PSTS112. However, it was also found that there were some potential issues associated with the variability of the test results between different laboratories, specifically with regards to the resilience recovery test. It is therefore recommended that this variability between different laboratories be further investigated. It is also recommended that the torsional recovery test, which is a test widely used in Australia, be considered as an alternative to the resilience recovery test.

The demonstration project also compared emissions from CRM OGA (hot mix), CRM OGA (warm mix) and PMB OGA mixes. The monitoring undertaken clearly showed the impact of mix temperature on the amount of emissions generated during the placement of the asphalt. The emissions monitoring also found, similar to other studies, that CRM asphalt mixes produce emissions that are comparable to other asphalt mixes. There was, however, evidence of elevated levels of Benzene in the CRM OGA mixes compared to PMB OGA, when measured through the emissions chamber. The assessment used represented a worst-case scenario (i.e. extracted from a confined space with limited dilution) and may not necessarily be representative of the actual exposure of construction workers to harmful emissions on site. Notwithstanding this, QAEHS (2017) recommended that construction workers should use protective gear to minimise their risk of exposure.

Producing CRM OGA at lower temperatures (by using a warm mix asphalt additive) was found to be a feasible option to reduce the amount of potentially harmful emissions during asphalt operations compared to CRM OGA (hot mix). This may however depend on the type of warm mix technology used.

The following key issues were identified for future work:

- Finalise supplementary specification PSTS112 for implementation based on the findings of the demonstration project. It is proposed that an implementation plan be developed for CRM OGA as part of TMR’s new Accelerated Innovation Implementation Program.
- Investigate the correlation between resilience recovery and torsional recovery of CRM binders. This would allow the widely-used torsional recovery test to be used in Australia instead of introducing a new test method.
- Further assess the variability in CRM properties determined by different laboratories.
- Develop guide notes or a new test method for determining the binder content of CRM asphalt mixes.
- Develop training material and provide technical workshops to disseminate the research findings to stakeholders.
- Undertake further monitoring of emissions (including benzene levels) during the manufacture and placement of crumb rubber modified asphalt, and further assess any potential health risks to workers.

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APPENDIX A UPDATED MRTS11 *SPRAYED BITUMINOUS SURFACING (EXCLUDING EMULSION)*

Technical Specification

Transport and Main Roads Specifications
MRTS11 Sprayed Bituminous Treatments (Excluding Emulsion)

October 2017

Queensland
Government

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Contents

1 Introduction

This Technical Specification applies to the application of sprayed bituminous treatments, but excludes the use of bituminous emulsions. It covers the treatment types listed in Table 1.

Table 1 – Treatment types

Treatment Type	Treatment Label
Initial Treatments	
Prime	P
Initial Single/Single Seal	I-S/S
Initial Double/Double Seal	I-D/D
Secondary Treatments and Retreatments	
Single/Single Seal	S/S
Double/Double Seal	D/D
High Stress Single/Single Seal for medium traffic loadings	HSS1-M
High Stress Single/Single Seal for heavy traffic loadings	HSS1-H
High Stress Double/Double Seal for medium traffic loadings	HSS2-M
High Stress Double/Double Seal for heavy traffic loadings	HSS2-H
Extreme Stress Double/Double Seal	XSS
Strain Alleviating Membrane for slow moving cracks	SAM-S
Strain Alleviating Membrane for rapid moving cracks	SAM-R
Strain Alleviating Membrane Interlayer	SAMI
Waterproofing Seal under asphalt[1]	WP-A
Geotextile Reinforced Seal with a Single/Single Seal	GRS-S/S
Geotextile Reinforced Seal with a Double/Double Seal	GRS-D/D
Surface Enrichment	SE
Scatter Coat	SC

[1] The WP-A treatment type is typically used to waterproof the underlying pavement when an open graded or stone mastic asphalt surfacing is used. It may also be used to waterproof pavements that contain a lightly bound base. For unbound pavements, a S/S treatment is typically used to waterproof the pavement prior to placement of an asphalt surfacing.

This Technical Specification shall be read in conjunction with MRTS01 *Introduction to Technical Specifications*, MRTS50 *Specific Quality System Requirements* and other Technical Specifications as appropriate. This Technical Specification forms part of the Transport and Main Roads Specifications Manual.

2 Definition of terms

The terms used in this Technical Specification shall be as defined in Clause 2 of MRTS01 *Introduction to Technical Specifications*. Further definitions are as defined in Table 2.

Table 2 – Definition of terms

Term	Definition
AAPA	Australian Asphalt Pavement Association
Actual Spray Rate	The spray rate of bituminous material actually achieved during the surfacing operation
Actual Spread Rate	The spread rate of cover aggregate or prime cover material actually achieved during the surfacing operation
Additive	Cutter oil, flux oil and/or adhesion agent
Adjusted Designed Spray Rate	The spray rate of bituminous binder as adjusted by the Seal Designer's Delegate in accordance with Clause 6
Adjusted Designed Spread Rate	The aggregate spread rate as adjusted by the Seal Designer's Delegate in accordance with Clause 6
Binder	Bitumen, cutback bitumen and/or polymer modified binder
Bituminous material	Bitumen, cutback bitumen, bitumen with cutter oil and/or flux oil and/or adhesion agent, and polymer modified binder (which includes crumb rubber modified binder)
Cover aggregate	Aggregate complying with the requirements of MRTS22 *Supply of Cover Aggregate*, and which forms a permanent wearing surface on a pavement
Cutting back bitumen	The temporary reduction of binder viscosity by the addition of cutter oil
Designed Spray Rate	The spray rate of bituminous binder as calculated by the Seal Designer in accordance with Clause 6
Designed Spread Rate	The aggregate spread rate as calculated by the Seal Designer in accordance with Clause 6
Double/double seal	Two applications of binder, each followed by an application of aggregate
Estimated Spray Rate	The estimated spray rate of bituminous binder stated in Clause 2 of Annexure MRTS11.1. It is not to be used as an actual designed spray rate.
Estimated Spread Rate	The estimated spread rate for cover aggregate or prime cover material stated in Clause 2 of Annexure MRTS11.1. It is not to be used as an actual designed spread rate.
Geotextile reinforced seal (GRS)	An application of a bituminous binder into which both aggregate and geotextile are incorporated to provide a durable wearing surface. A layer of binder is applied first, followed by a layer of geotextile fabric, then a single/single or double/double seal is applied.
Homogeneous section	A continuous section of carriageway in one direction where: • the Adjusted Designed Spray Rate, when designed in accordance with the design procedure stated in Clause 6.1.1, does not vary by more than 0.2 L/m2 in the longitudinal section, and • the underlying surface type does not change within the longitudinal section. For the purpose of testing for determining seal design inputs, the maximum size of each homogeneous section is one lot.
Initial seal	An application of a sprayed seal to a prepared base course, which has not been primed. It is intended to adhere to the base, whilst providing a temporary wearing course for traffic and consists of either a single/single seal, a single/single seal with a scatter coat or a double/double seal. Cutback bitumen binders (AMC4, AMC5, AMC6 or AMC7) or emulsion bitumen binders are typically used for initial seals.

Term	Definition
Initial treatment	An application of a prime (prime coat) or initial seal to a prepared base course
Lot	A spray run or series of spray runs applied on any calendar day
Parts of additive	The number of parts by volume of additive to be added to 100 parts by volume of binder measured at 15°C
Pavement temperature	The temperature measured at the surface of the pavement to be sprayed
Prime	An application of a primer to a prepared base, with or without cover aggregate, to provide penetration of the surface, temporary waterproofing and to obtain a bond between the pavement and the subsequent seal or asphalt. It is a preliminary treatment to a more permanent bituminous treatment.
Reseal	A seal applied to an existing seal or asphalt surface
Retreatment	An application of a sprayed bituminous treatment on an existing bituminous surfacing
Roller Pass	One pass of both axles of a roller over a specific point in one direction
Scatter coat	A light application of small size aggregate to temporarily ‘lock in’ a larger size aggregate seal to reduce aggregate movement during rolling and initial trafficking
Seal	A thin layer of sprayed bituminous material into which aggregate is incorporated
Seal Designer	A competent, trained designer who shall complete the seal design and shall determine the Designed Spray Rate and the Designed Spread Rate. The Seal Designer shall have successfully attained the Australian Asphalt Pavement Association (AAPA) *Statement of Successful Completion of Written Assignment* (or equivalent) for the course titled *Sprayed Sealing Selection and Design*.
Seal Designer’s Delegate	A competent, trained nominee of the seal designer who may modify, on behalf of the Seal Designer, the Designed Spray Rate and/or the Designed Spread Rate as follows: • determine the Adjusted Designed Spray Rate • determine the Adjusted Designed Spread Rate, and • determine the parts of cutter oil to add prior to spraying. The Seal Designer’s Delegate shall have successfully attained the Australian Asphalt Pavement Association (AAPA) *Certificate of Attendance* at the course titled *Sprayed Sealing Selection and Design*.
Secondary treatment	An application of a sprayed bituminous treatment on an initial treatment
Single/single seal	One layer of binder covered with a single layer of aggregate
Spray run	The area of pavement selected for coverage with a bituminous material during one continuous operation of a sprayer
Spray sheet	Contractor’s Bituminous Material Spraying Record Sheet
Sprayed bituminous treatment	An initial treatment, surface enrichment, secondary treatment or retreatment
Strain Alleviating Membrane (SAM)	A sprayed bituminous treatment with a polymer modified binder which is used to delay the onset of reflection cracking on existing cracked surfaces or where the potential for cracking exists

Term	Definition
Strain Alleviating Membrane Interlayer (SAMI)	A sprayed bituminous treatment with a polymer modified binder which is used as an interlayer between asphalt and the underlying pavement. A SAMI is used to delay the onset of reflection cracking on existing cracked surfaces or where the potential for cracking exists.
Crumb Rubber Modified Binder	Bitumen blended with crumb rubber. The bitumen is generally C170 and the crumb rubber is generally obtained from the shredding and grinding of scrap rubber from vehicle tyres.

3 Referenced documents

References used in this Technical Specification include, but are not limited to the latest versions, listed in Table 3.

Table 3 – Referenced documents

Reference	Title
Advisory Note 7-	*Guide to the Heating and Storing of Binders for Sprayed Sealing and Asphalt Manufacture,* AAPA
AP-G41	*Bituminous Materials Safety Guide*
AP-T236-13	*Update of Double/Double Design for Austroads Sprayed Seal Design Methods*
AP-T68-06	*Update of the Austroads Sprayed Seal Design Method*
AS 2008	*Bitumen for Pavements*
HSE Guide 5	*Guide to the Manufacture, Storage and Handling of Polymer Modified Binders and Multigrade Bitumens,* AAPA
MRTS02	*Provision for Traffic*
MRTS17	*Bitumen*
MRTS18	*Polymer Modified Binder (including Crumb Rubber)*
MRTS57	*Geotextiles for Paving Applications*
PWT14-10	*Sprayed Seal Cutting Practice,* Austroads/AAPA
PWT24-00	*Sprayed Sealing – Rolling of Cover Aggregate,* Austroads/AAPA
PWT27-13	*Sprayed Sealing – Cutting Back of Polymer Modified Binders,* Austroads/AAPA
PWT33-14	*Sprayed Sealing – Selection of Spraying Nozzles,* Austroads/AAPA
TN175	*Selection and Design of Sprayed Bituminous Treatments***,** Transport and Main Roads

4 Standard test methods

The standard test methods given in Table 4 shall be used in this Technical Specification.

Further details of test numbers and test descriptions are given in Clause 4 of MRTS01 *Introduction to Technical Specifications*.

Table 4 – Standard test methods

Property to be Tested	Method No.
Field spread rate of cover aggregate	Q711A
Average Least Dimension	Q202
Ball Penetration	Q706 or AGPT/T251
Flakiness Index	Q201
Binder Stripping Value – Modified Plate	Q212B
Degree of Aggregate Precoating	Q216
Texture Depth (Sand Patch)	Q705 or AGPT/T250
Loose aggregate on sprayed seals	Q720
Particle Size Distribution	Q103B
Sampling of polymer modified binders	AGPT/T101
Sampling of bitumen	AS 2008 Appendix B

5 Quality system requirements

5.1 Hold Points, Witness Points and Milestones

General requirements for Hold Points, Witness Points and Milestones are specified in Clause 5.2 of MRTS01 *Introduction to Technical Specifications*.

The Hold Points, Witness Points and Milestones applicable to this Technical Specification are summarised in Table 5.1.

Table 5.1 – Hold Points, Witness Points and Milestones

Clause	Hold Point	Witness Point	Milestone
5.2	1. Permission to use construction procedures		Construction procedures submitted to the Administrator
6.1.2			Notification of binder class substitution
6.2	2. Contractor notified of Principal's seal design		Contractor provides Administrator with Ball Penetration test results
6.3.2	3. Consideration of the Contractor's seal design		Contractor seal design report submitted to the Administrator
8.2		1. Care of cover aggregate	
8.3.1		2. Binder storage temperature measured and recorded at delivery to site	
8.3.2		3. Heating of bituminous materials	
9	4. Plant to be used		

Clause	Hold Point	Witness Point	Milestone
10.1.2	5. Excessive Ball Penetration test results		
11.1	6. Cover aggregate availability		
11.2		4. Pavement temperature above minimum specified	
12.4		5. Current Queensland Sprayer Certificate to be sighted	
12.7		6. Nomination and recording of cutting requirements	
14.1		7. Loading of cover aggregate into aggregate spreader	
14.8	7. Loose aggregate/signage requirements prior to opening to traffic		

5.2 Construction procedures

The Contractor shall prepare documented procedures for all required processes as defined in Clause 5 of MRTS50 *Specific Quality System Requirements*. These shall include, but are not limited to, procedures for handling, storage, transport, heating and transfer of binder in accordance with the requirements of Clause 8 of MRTS17 *Bitumen* or Clauses 5.2 and 8 of MRTS18 *Polymer Modified Binder (including Crumb Rubber)* and this Technical Specification as appropriate.

The Contractor shall establish an Inspection and Test Plan (ITP) for supply and delivery of binder. The Inspection and Test Plan shall address at least:

a) traceability

b) conformance of binder supplied to the Site, and

c) sampling and testing at the Site.

The Contractor shall submit the documented procedures and the ITP to the Administrator not less than seven days prior to their proposed use. **Milestone**

Documented procedures and the ITP shall not be implemented until permission to use has been granted by the Administrator. **Hold Point 1**

5.3 Conformance requirements

The conformance requirements which apply to lots of work covered by this Technical Specification are detailed in Clauses 7.2, 8, 10, 11, 12, 13 and 14. Materials shall conform to the requirements of Table 7.1. The conformance records for all lots of work shall be compiled on a spraying record sheet as specified in Clause 16.

6 Seal design

6.1 General

6.1.1 Scope

Sprayed bituminous treatments shall be designed in accordance with the requirements of the department's Technical Note TN175 *Selection and Design of Sprayed Bituminous Treatments* and any additional requirements stated in Clause 3.1 and Clause 3.2 of Annexure MRTS11.1.

The specific treatments for work under this Contract shall be as set out in Clause 2 of Annexure MRTS11.1 and the Drawings. Acceptable binder classes that may be used for each treatment type are defined in Table 6.1.1.

Table 6.1.1 – Acceptable binder classes for initial treatments, secondary treatments and retreatments

Treatment Type	Technical Specification	Acceptable Binder Class
Initial Treatments		
Prime	MRTS20	AMC00, AMC0 or AMC1 [Note 1]
I-S/S or I-D/D	MRTS20, MRTS17	AMC4, AMC5, AMC6, AMC7 or C170 [Note 2]
Secondary Treatments and Retreatments		
S/S or D/D	MRTS17	C170, C320 or M500 [Note 3]
HSS1-M	MRTS18	S10E, S35E, S45R or S15RF
HSS1-H	MRTS18	S15E, S45R or S15RF
HSS2-M	MRTS18	S10E, S35E, S45R or S15RF
HSS2-H	MRTS18	S15E, S45R or S15RF
XSS	MRTS18	S20E, S45R, S15RF
SAM-S	MRTS18	S10E, S35E, S45R or S15RF
SAM-R	MRTS18	S15E, S45R or S15RF
SAMI	MRTS18	S25E or S18RF
WP-A	MRTS18	S20E, S25E, S45R, S15RF or S18RF
GRS-S/S or GRS-D/D	MRTS17	C170, C320 or M500 [Note 3]
SE	MRTS20	AMC4

[Note 1] Where no indication is given in Clause 2 of Annexure MRTS11.1 or on the Drawings, AMC0 shall be used.

[Note 2] Where no indication is given in Clause 2 of Annexure MRTS11.1 or on the Drawings, AMC6 shall be used.

[Note 3] Where no indication is given in Clause 2 of Annexure MRTS11.1 or on the Drawings, C170 shall be used.

For all treatments to be incorporated into the Works, the treatment type, binder class, cover aggregate nominal size(s) and estimated application rates are specified in Clause 2 of Annexure MRTS11.1.

6.1.2 Use of an alternative binder class

Where a particular polymer modified binder class has been specified for a sprayed bituminous treatment, the Contractor may use an equivalent alternative binder class provided:

a) it complies with the requirements of Table 6.1.2(a)

b) the sprayed bituminous treatment conforms with all the requirements of this Technical Specification (including uniformity of binder application and limits for cutter oil content)

c) its use does not impact on the construction program, and

d) its use does not increase the cost of the sprayed bituminous treatment.

> The equivalent alternative binder classes listed in Table 6.1.2(a) can be used as an alternative to the binder class specified without the need for Administrator approval for the following reasons:
>
> a) they will provide equivalent long term performance as the binder class specified, and
>
> b) they can be applied at the same spray rate as the binder class specified as the same 'polymer factor' is used for the seal design.

Table 6.1.2(a) – Acceptable alternative binder classes

Treatment Type	Binder Class Specified	Equivalent Alternative Binder Class
HSS1-M, HSS2-M	S10E	S35E
	S45R	S15RF
	S15RF	S45R
HSS1-H, HSS2-H, SAM-R	S45R	S15RF
	S15RF	S45R
XSS	S20E	S45R or S15RF
	S45R	S20E or S15RF
	S15RF	S20E or S45R
SAM-S	S10E	S35E
	S45R	S15RF
	S15RF	S45R
SAMI	S25E	S18RF
	S18RF	S25E
WP-A	S20E	S45R or S15RF
	S45R	S20E or S15RF
	S15RF	S20E or S45R
	S25E	S18RF
	S18RF	S25E

The Contractor shall notify the Administrator of the binder class substitution not less than 14 days prior to the commencement of spraying. **Milestone**

Approval to use alternative polymer modified binder classes not listed in Table 6.1.2(a)

The alternative binder classes listed in Table 6.1.2(b) are typically considered to be acceptable alternatives to the binder class specified. However, as the use of these alternative binder classes will result in a change to the binder application rate, such a change would constitute a variation to the contract and Administrator approval is required prior to use.

The Administrator would typically use the following criteria to evaluate these proposals:

- compliance with Clause 6.1.2 requirements,
- no increase in the cost of the treatment ($/m²), and
- no increase in the unit rate for the binder ($/L).

The Administrator should refer to the department's Technical Note TN175 for appropriate 'polymer factors' when evaluating the cost implications of these proposals.

Table 6.1.2(b) – Acceptable alternative binder classes requiring the Administrator's approval prior to use

Treatment Type	Binder Class Specified	Acceptable Alternative Binder Class
HSS1-M, HSS2-M, SAM-S	S10E	S45R or S15RF
	S35E	S45R or S15RF
	S45R	S35E
	S15RF	S35E
HSS1-H, HSS2-H, SAM-R	S15E	S45R or S15RF
	S45R	S15E
	S15RF	S15E

6.1.3 Seal Designer and Seal Designer's delegate

The seal design shall be undertaken by the Seal Designer. Prior to undertaking any seal design, the Seal Designer shall inspect each site in order to identify site-specific conditions for inclusion in the design.

The Seal Designer's delegate shall have facilities to be in communication with the Seal Designer at all times and shall be supervised by the Seal Designer.

The Seal Designer's delegate shall be on site during spraying to check designed rates and shall adjust the Designed Spray Rate and Designed Spread Rate where this is required for the existing field conditions including, but not limited to, adjustments for test results from the ball penetration tests. These adjusted rates shall be called the Adjusted Designed Spray Rate and the Adjusted Designed Spread Rate.

6.2 Seal design by the Principal

Where the Principal is nominated to undertake the seal design, unless otherwise stated in Clause 3.1 of Annexure MRTS11.1, testing shall be undertaken by the Contractor at the test locations and minimum test frequencies detailed in Table 6.2 for the following properties:

a) Particle Size Distribution, Flakiness Index and Average Least Dimension of the cover aggregate (where cover aggregate is supplied by the Contractor)

b) Texture Depth (Sand Patch), and

c) Ball Penetration.

Test results for the cover aggregate and texture depth shall be submitted to the Administrator with sufficient lead time to allow a period of seven days following submission of the test results for the Principal to carry out the seal design. **Milestone**

The Contractor shall test and report the Ball Penetration in accordance with the requirements of Table 6.2 and Clause 10.1.2. Ball Penetration test results shall be forwarded to the Administrator on the day of testing. **Milestone**

Spraying operations shall not commence until the Contractor has been notified by the Administrator of the Designed Spray Rate and Designed Spread Rate. **Hold Point 2**

Table 6.2 – Testing for determining seal design inputs

Property to be Tested	Test Location(s)	Minimum Test Frequency
Particle Size Distribution Flakiness Index Average Least Dimension (ALD)	The test samples shall be sourced from the stockpiles to be directly used for the works.	Test frequency shall be: • one test for each aggregate type, nominal size and source, and • repeat tests at every 1000 tonnes.
Texture Depth	In and between the wheelpaths – that is, 3 tests at each test chainage per direction	Test frequency shall be the lesser of: • every 400 m, or • 3 test chainages per homogeneous section where the test sites selected are representative of the homogeneous section.
Ball Penetration	In the inner and outer wheelpaths – that is, 2 tests at each test chainage per direction Testing is required only for: • pavements in accordance with Clause 10.1.2 • primed or initial sealed surfaces, and • asphalt or slurry surfacing less than 6 months old.	Test frequency shall be 5 test chainages per homogeneous section where the test sites selected are representative of the homogeneous section. Testing shall be completed between 24 to 48 hours prior to spraying.

6.3 Seal design by the Contractor

6.3.1 Seal design inputs

Where the Contractor is nominated to undertake the seal design, the Contractor shall inspect each site and select inputs and associated design factors to be used in the seal design procedure. These inputs and factors shall be determined from:

a) the traffic stated in Clause 3.2 of Annexure MRTS11.1

b) project site conditions, and

c) sampling and testing by the Contractor in accordance with the requirements of Table 6.2 noting that:

   i. testing shall be sufficient to comply with the design procedure requirements, and

   ii. aggregate samples shall be taken from the material that is to be used on the project.

As part of the seal design, the Contractor shall review the selections of treatment types, binder classes, and aggregate nominal sizes nominated in Clause 2 of Annexure MRTS11.1 and, prior to commencing the design, shall notify the Administrator if the Contractor does not agree with any of the selections.

> Where the Principal intends to apply aggregate size combinations not recommended by Austroads Design Method '*AP-T68-06 - Update of the Austroads Sprayed Seal Design Method*' and '*AP-T236-13 - Update of Double/Double Design for Austroads Sprayed Seal Design Methods*' based on local experience (such as using 14/10 or 16/10 mm combinations of aggregates for D/D seal), the seal design then should be conducted by the Principal.
>
> Surface Enrichment treatment should always be designed by the Principal.

6.3.2 Seal design report

The Contractor shall submit the seal design report to the Administrator at least seven days prior to the commencement of bituminous spraying operations. **Milestone**

The seal design report shall detail:

a) separate seal designs for variations in any and each of:

   i. test results for seal design inputs stated in Table 6.2

   ii. binder class

   iii. cover aggregate size and source

   iv. homogeneity of sections of carriageway impacting on design in accordance with the design procedure, and

   v. underlying pavement type on which sprayed bituminous surfacing is to be applied

b) test results, assumptions, inputs, the design method and calculations that were used to determine the Designed Spray Rate and the Designed Spread Rate

c) for each unique combination of treatment type, binder class, aggregate size and location, the following in a tabular form:

   i. binder class, aggregate types, reference location, and

   ii. Designed Spray Rate of bituminous material and the Designed Spread Rate of cover aggregate

d) for seals involving multiple layers of binder and/or aggregate (e.g. double/double seals), the minimum and maximum period between bituminous treatments

e) documentary evidence of the Seal Designer's successful attainment of the AAPA *Statement of Successful Completion of Written Assignment* (or equivalent) for the course titled *Sprayed Sealing Selection and Design*, and

f) nomination of the Seal Designer's Delegate and documentary evidence of this delegate's successful attainment of AAPA's C*ertificate of Attendance* for the course titled *Sprayed Sealing Selection and Design*.

The seal design report shall include a statement signed by the Seal Designer that the seal design complies with the seal design method for the test results, assumptions and inputs used.

The Administrator will have three days to consider the seal design report and spraying operations shall not commence prior to the Administrator releasing a hold point for this consideration. **Hold Point 3**

For each lot or homogeneous section, at the time before spraying commences, the Seal Designer's Delegate shall determine the adjustments to be made to arrive at the Adjusted Designed Spray Rates and any addition of additives including cutter and the Adjusted Designed Spread Rates. The Seal Designer's Delegate shall record these adjustments and modifications on the Contractor's spray sheet. If no adjustments or modifications are made to the designed rates, the spray sheet record shall record the non-adjusted rates accordingly. The Contractor shall certify with a signature that the Seal Designer's Delegate has approved the spray sheet record of the adjustments and modifications.

7 Materials

7.1 Specifications

Contractor-supplied materials shall comply with the requirements of the relevant Technical Specifications stated in Table 7.1.

Table 7.1 – Material Technical Specifications

Material	Specification
Bitumen	MRTS17
Multigrade bitumen	Project specific technical specifications to be issued by the Principal
Polymer modified binder (including crumb rubber)	MRTS18
Bitumen cutter oils and flux oils	MRTS19
Cutback bitumen	MRTS20
Adhesion agent	As specified in Clause 4.1 of Annexure MRTS11.1

Material	Specification
Prime cover material and cover aggregate	MRTS22
Geotextiles for paving applications	MRTS57

7.2 *Supply of material*

The Principal will supply the materials stated in the Principal Supplied Material List (Form C7827). All other materials shall be supplied by the Contractor.

7.3 *Transport of material*

The responsibility for transport to the Site of materials supplied by the Principal will be as stated in the Principal Supplied Material List (Form C7827). Transport to the Site of all other materials shall be the responsibility of the Contractor.

8 Care of materials

8.1 *Bitumen cutter oil*

Bitumen cutter oil shall be handled and stored in a way which prevents any ingress of water. Water detection paste shall be available at all times and used if water contamination of the cutter oil is suspected.

Bitumen cutter oil which is suspected as being water contaminated shall be investigated and, if found to be water contaminated, shall not be used.

8.2 *Cover aggregate*

Cover aggregate shall not be exposed to contaminating agents, particularly dust, and shall be handled so as to avoid contamination and any other deleterious effects. Unless otherwise stated in Clause 4.2 of Annexure MRTS11.1, cover aggregate shall be protected with a light plastic or similar material to prevent the ingress of moisture and other contaminants. The protective material shall be sufficiently anchored to ensure the optimal fixture that can be achieved consistent with the protective material properties. **Witness Point 1**

8.3 *Bituminous materials*

8.3.1 Delivery (Storage and transport)

Binder shall be delivered to the Works in accordance with Clause 8 of MRTS17 *Bitumen* or Clause 8 of MRTS18 *Polymer Modified Binder (including Crumb Rubber)* as appropriate.

The temperature at delivery to site shall be measured and recorded. **Witness Point 2**

8.3.2 Heating

The Contractor shall ensure that strict controls are applied to heating of bituminous materials in accordance with the requirement of Austroads AP-G41 *Bituminous Materials Safety Guide*, Section 7: Heating, and the Contractor's Safety Plan and Clause 8.3 of MRTS18 *Polymer Modified Binder (including Crumb Rubber)*.

Heating requirements shall be strictly observed. **Witness Point 3**

8.3.3 Incorporation of additives

Volatile additives, e.g. cutter and flux oils, shall not be heated and shall be introduced into the sprayer tank through the sprayer's pumping system. Volatile additives shall not be added to the top of hot bitumen.

Non-volatile additives, e.g. adhesion agent, shall be introduced into the sprayer tank through the sprayer's pumping system in accordance with any relevant standards and/or manufacturer's instructions.

Where additive is used:

a) the additive shall be dissolved in hot binder, and

b) the hot binder and additive shall be circulated, after the addition of the last component, at a rate of at least 1000 litres per minute for a period until the sprayer contents have been circulated twice.

Where adhesion agent is to be used, the binder shall then be sprayed as promptly as field circumstances allow and within three hours. If the binder and adhesion agent has not been sprayed within three hours, additional adhesion agent may be added to the remaining binder at a dosage concentration then equivalent to one third of the original adhesion agent dosage.

9 Plant

The Contractor shall have on the Site and in use as required the plant necessary for the performance of the particular operation. The respective minimum requirements for the plant listed in Table 9 shall apply. Additional minimum requirements for plant shall apply if such are specified in Clause 5 of Annexure MRTS11.1.

Not less than three days prior to sealing operations, the Contractor shall submit details of all plant to be used in the operations. **Hold Point 4**

Table 9 – Minimum requirements for plant

Plant Item	Minimum Requirements
Aggregate spreader	A mechanical spreader capable of accurately spreading a uniform layer of aggregate and, on the day of spreading, satisfactorily meets the requirements of the field spread rate of cover aggregate test (Q711A). Additional requirements are detailed in Clause 14.4.
Bitumen tank	A tank suitable for the storage and/or transport of bitumen
Road broom	A drawn rotary broom or self-propelled rotary broom suitable for sweeping or cleaning road surfaces. Where suitable, a vacuum system may be used.
Rubber-tyred roller	A dual axle, multi-wheeled roller with a minimum load of one tonne per tyre. Tyres shall be smooth and be able to operate at a pressure of at least 550 kPa.
Sprayer	A bitumen sprayer which has a current Queensland Sprayer Certificate issued by Department of Transport and Main Roads, Queensland. The spray bar width of the bitumen sprayer shall not operate beyond the width range for which the spray bar has been certified.
Field production of Crumb Rubber Modified Binder	For field produced crumb rubber modified binders, mobile plant consisting of a crumb rubber modified binder blending mill and agitated digestion and storage tanks

10 Preparation prior to spraying

10.1 Surface preparation

10.1.1 General

The surface to be prepared shall include the surface to be sprayed plus either an area which is a minimum of 250 mm beyond the surface to be sprayed, or one which extends to the edge of the formation, whichever is the lesser.

The preparation work shall be carried out in a manner which will promote the adhesion of the bituminous material to the surface of the pavement. Such preparation work shall include that set out in Clauses 10.1.2 to 10.1.4 inclusive.

10.1.2 Initial treatments

All foreign and loose material, including lenses of pavement material, shall be removed from the surface. The surface shall be swept with a road broom until the larger particles in the surface of the pavement are slightly exposed but ensuring excessive erosion of the surrounding finer material does not occur.

A light watering shall be carried out on dry or dusty surfaces just prior to spraying.

For initial seals on new granular, stabilised or lightly bound pavement layers, Ball Penetration testing shall be completed in accordance with the requirements of Table 6.2 on the following surfaces:

a) after priming, or

b) before application of an initial seal.

Where a Ball Penetration test result exceeds 4.0 mm, the surface shall not be sprayed unless otherwise approved by the Administrator. **Hold Point 5**

10.1.3 Secondary treatments and retreatments

All foreign and loose material shall be removed from the surface using a road broom.

On surfaces where a prime coat has been covered by a cover material, all loose cover material shall be removed without damage to the prime coat.

10.1.4 Disposal of foreign and/or loose material

All foreign and/or loose material shall be removed from the road formation and utilised/disposed of in accordance with the requirements of Clause 10 of MRTS01 *Introduction to Technical Specifications*.

10.2 Protection of road furniture and roadside facilities

The Contractor shall take all necessary precautions to prevent any bituminous or other material used on the work from entering or adhering to any road furniture or roadside facility.

If any bituminous material does adhere to any road furniture or roadside facility, the Contractor shall remove all such bituminous material so that the road furniture or roadside facility is left in an as-found condition.

Any damage or defacement shall be made good by the Contractor at no cost to the Principal immediately after surfacing work on a section has been completed.

10.3 Limit of work and setting out

The Contractor shall set out sufficient marks on the pavement surface to permit the spraying of bituminous material on the sections of pavement described in the Contract and in accordance with the requirements of this Technical Specification.

The Contractor shall set out the work so that longitudinal joints coincide with lane lines, unless shown otherwise in the Contract. Tapers may be sprayed separately.

The start and finish point of each spray run shall be marked.

Unless otherwise specified, the Works shall include all existing traffic lanes, sealed shoulders, pavement widenings (turn lanes), tapers, and bell mouths at intersecting roads.

10.4 Programming spray runs

The Contractor shall program the operations to ensure that:

a) sufficient loaded aggregate trucks are ready to follow the sprayer to cover the spray run immediately (refer to Clause 14.3), and

b) not less than the minimum specified rolling is achieved (refer to Clause 14.5).

Additional requirements, if any, relating to programming of spray runs are given in Clause 6.1 of Annexure MRTS11.1.

11 Restrictions to spraying

11.1 Availability of cover aggregate

Prior to commencement of bitumen spraying operations on any day, the Contractor shall provide the Administrator with evidence that sufficient uncontaminated, precoated cover aggregate of the relevant category, nominal size and specified properties is available for the extent of bitumen spraying work to be undertaken on that day. **Hold Point 6**

11.2 Pavement surface temperature

Unless otherwise approved by the Administrator, spraying shall not commence until the temperature of the pavement surface is above the temperature given in Clause 6.2 of Annexure MRTS11.1 or, if not so given, the pavement surface temperature shall be rising or stable and shall be above:

i. 10°C for primes

ii. 15°C for initial seals containing cutback bitumen (i.e. AMC4 to AMC7) s, or

iii. 20°C for treatments containing bitumen and polymer modified binders. **Witness Point 4**

These limits do not apply to WP-A and SAMI treatments that are:

a) placed over an existing seal or asphalt, and

b) overlaid with asphalt prior to trafficking.

The minimum pavement temperatures given in Clause 11.2 represent good practice. However, the adoption of a lower temperature requires the implementation of enhanced construction practices to mitigate the increased risk of stripping of the cover aggregate and/or poor bond to the underlying pavement. Any request by the Contractor to vary the minimum pavement temperature requirement should detail the additional measures they will implement to mitigate these risks.

A relaxation of up to 5°C may be applied to treatments containing bitumen and S35E binders where enhanced construction practices are implemented. Relaxations are not typically accepted for treatments containing other binder classes.

Enhanced construction practices include:

- using cover aggregate that is in an ideal condition (i.e. clean, dry, precoated and achieves a stripping value of < 10% when tested in accordance with Q212B) at the time of intended use, and
- spreading and rolling the cover aggregate immediately after the binder is sprayed on the pavement surface.

11.3 Weather conditions

Spraying shall not take place during rain or if rain is likely to fall prior to the spreading of cover aggregate and the completion of rolling.

The Contractor shall stop sealing immediately if rainfall occurs during sealing operations. Any seal sprayed during rainfall or on a wet surface shall be rejected.

Spraying shall not take place during winds of greater than 30 km/hr or during dust storms.

11.4 Minimum period between bituminous treatments

Unless otherwise stated in Clause 6.3 and 6.4 of Annexure MRTS11.1, the minimum periods of time between bituminous treatments shall be:

a) a prime shall not be covered with a secondary treatment and/or asphalt until both of the following conditions are satisfied:

   i. the prime shall be completely dry and trafficable by light construction traffic (< 20 vehicles per day), and

   ii. the prime has been placed for a minimum period of three days.

   All traffic shall be kept off the primed surface unless prime cover material has been applied.

b) between an initial seal, secondary treatment or retreatment containing > 2% by volume cutter oil and subsequent bituminous treatment (such as a secondary treatment, retreatment or asphalt) at the same location, the minimum period is:

   i. three months in warm weather (minimum nightly temperatures > 10°C), and

   ii. at least six months in cooler conditions (minimum nightly temperatures ≤ 10°C).

> The minimum curing periods to be adopted should be based on local experience and must consider the environmental conditions and traffic loading during the curing period as well as the binder class/category, amount of cutter oil, and nominal size(s) of aggregate used. The default minimum periods between an initial seal and a secondary treatment typically results in adequate curing of the initial seal binder to avoid performance related issues associated with insufficient curing.
>
> Adoption of shorter curing periods (than the default minimums) may require an adjustment (i.e. a reduction in the binder application rate) to the seal design based on local experience.
>
> Insufficient curing may lead to bleeding of the overlying treatment during the next period of significant hot weather.
>
> Delaying the application of a secondary treatment to an initial seal excessively may lead to deterioration of the initial seal by the action of traffic, particularly during periods of hot weather, where the initial seal is subject to heavy traffic and/or high shear stresses (such as intersections or sharp curves).

c) prior to asphalt overlay, SAMI treatments shall not be left exposed for more than two days when subject to traffic other than construction vehicles. Where SAMI treatments are trafficked by only construction traffic, aggregate removed from the SAMI binder by construction traffic shall be replaced prior to asphalt overlay

d) for single/single seals with a scatter coat, the scatter coat aggregate shall be applied on the same day, and

e) for seals with multiple layers of binder and/or aggregate (e.g. double/double seals), the period shall not exceed one day.

12 Spraying

12.1 General

The Contractor shall spray the bituminous material in a uniform manner and in a way which promotes adhesion of the material to the pavement surface and to the cover aggregate, in accordance with Clauses 12.2 to 12.9 inclusive.

The sprayer shall maintain a constant road speed throughout the length of each sprayer run (except where permitted by an approved Construction Procedure for achieving a specified variable application rate).

12.2 Method of application

Bituminous materials shall be applied by a certified bitumen sprayer. Hand spraying is only permitted for areas where the bitumen sprayer cannot access.

12.3 Joints between spray runs

All joints, transverse and longitudinal, shall abut in a manner to ensure that the Adjusted Designed Spray Rate is applied uniformly across the joint.

Spraying on each spray run shall start on a protective strip of heavy paper, with a minimum mass of 120 g/m² and a minimum width of 500 mm. The paper shall be laid across the pavement surface for the full width of the spray run and shall be held securely in place.

The sprayer shall commence moving at a sufficient distance in advance of the protective strip to ensure that the road speed for correct application is attained prior to the commencement of spraying.

The spraying for each spray run shall terminate on a protective strip of paper as specified above.

After spraying, the protective strips of paper shall be removed ensuring no excess bituminous material is deposited on the pavement surface. The Contractor shall dispose of the strips of paper at the end of each day's operation in accordance with the waste management requirements of MRS51 *Environmental Management*.

12.4 Spraybar nozzles

The spraybar nozzles used shall be appropriate for each spray run and shall comply with the Queensland Sprayer Certificate for the sprayer. **Witness Point 5**

Any nozzles that are damaged or become unduly worn or defective shall be replaced by new nozzles of the same type and size. A sufficient number of nozzles for this purpose shall be available on site at all times.

The type and positioning of spray nozzles to be used on the spray bar of the sprayer shall be compatible with the nature of the binder to be sprayed and its application rate.

> Austroads/AAPA PWT33-14 – *Sprayed Sealing – Selection of Spraying Nozzles* provides guidance on the appropriate selection of nozzles for sprayed sealing.

Where either blockages or partial blockages of nozzle/s occur, spraying shall cease immediately. If the blockage is due to the condition of the binder being sprayed, the condition shall be rectified sufficiently to avoid future blockages.

12.5 Spraying temperature

The acceptable temperature range for spraying bituminous material is listed in Table 12.5. Spraying of bituminous material shall not occur below the relevant minimum temperature nor heated on site above the relevant maximum temperature in Table 12.5. However, when cutback bitumen is delivered to the Works above the maximum temperature indicated in Table 12.5, spraying is permitted within the temperature range of the minimum given in Table 12.5 and the delivered temperature provided no further heating occurs. Any binder delivered to site at a temperature above 200°C shall be rejected.

Table 12.5 – Spraying temperature range

Material	Grade	Spraying Temperature Range (°C)	
		Minimum	Maximum
Cutback Bitumen	AMC00	Ambient	Ambient
	AMC0	35	55
	AMC1	60	80
	AMC2	75	100
	AMC3	95	115
	AMC4	110	135
	AMC5	120	150
	AMC6	135	160
	AMC7	150	175
Bitumen	Class 170 Class 320	160 170	190 195
Multigrade Bitumen	Class M500	175	200
Crumb Rubber Modified Binder	S45R, S15RF and S18RF	190	200
Polymer Modified Binder (other than Crumb Rubber Modified Binder)	†	†	†

† Refer to AAPA Advisory Note 7 or manufacturer's recommendations

12.6 Faults during spraying

Spraying shall cease immediately if any fault develops in the spraying equipment or operation and shall not recommence until the fault has been rectified.

12.7 Cutting back binder

The first application of binder in a geotextile reinforced seal or any secondary treatments or retreatments placed immediately below a layer of asphalt shall not be cut back unless otherwise specified in Clause 6.5 of Annexure MRTS11.1 or approved by the Administrator. Notwithstanding the requirements of Clause 6.5 of Annexure MRTS11.1, secondary treatments or retreatments placed immediately below asphalt shall not be cut by more than the addition of 2.0 parts of cutter by volume.

Assessment of pavement temperatures shall take into account the cooler condition inherent in shaded areas of pavement.

Where the road pavement and/or surface temperature is such that a temporary reduction in binder viscosity is necessary to enhance initial adhesion between the binder and the cover aggregate, cutter oil shall be added to the binder for initial seals, secondary treatments and retreatments. The amount of cutter oil to be used shall be determined by the Seal Designer's Delegate and be appropriate to:

a) achieve a strong bond between the binder and the cover aggregate, and

b) avoid stripping or flushing/bleeding of the seal or overlying asphalt during the first year of operation, or the defects liability period, whichever is the longer.

The binder must have a sufficiently low viscosity at the time of sealing to achieve adequate initial wetting of aggregate. Where the pavement and/or surface temperature is too low to achieve the necessary viscosity for the particular binder, cutting of the binder may be required to achieve this viscosity.

Austroads/AAPA PWT14-10 – *Sprayed Seal Cutting Practice* and Austroads/AAPA PWT27-13 – *Sprayed Sealing – Cutting Back of Polymer Modified Binders* provides guidance on appropriate cutter rates for bitumen and polymer modified binders for applications other than SAMI seals.

The amount of cutter typically used for double/double seals with bitumen and polymer modified binders (other than crumb rubber modified binder) is 0 – 2 parts. The amount of cutter typically used for double/double seals using crumb rubber modified binder is 2 – 4 parts.

Use of excessive cutter oil can lead to poor cohesive strength of the binder and flushing and/or bleeding of the treatment during subsequent warm/hot weather.

Use of insufficient cutter oil can lead to poor wetting of the aggregate and aggregate loss (stripping) during initial trafficking of the seal.

In addition, use of insufficient cutter oil in initial seals and/or poor pavement surface preparation can lead to poor bonding of the initial seal and the underlying pavement.

Incorporation of cutter oil into the binder shall be carried out in accordance with Clause 8.3.3. The cutter oil, without previously being heated, shall be sucked into the hot bitumen in the sprayer. Before spraying, after the addition of the last component, the Contractor shall circulate the full sprayer load of cutback bitumen at a rate of at least 1000 litres per minute for a period until the sprayer contents have been circulated twice.

Prior to each operation, the Seal Designer's Delegate shall nominate the cutter oil adjustments, which shall be recorded. **Witness Point 6**

12.8 Spray rate

For all applications other than primes, initial seals and surface enrichments using cutback bitumen, the Estimated Spray Rate, Designed Spray Rate, Adjusted Designed Spray Rate and Actual Spray Rate referred to in this Technical Specification shall be the quantities, at 15°C, of the bitumen or polymer modified binder as appropriate.

For primes, initial seals and surface enrichments using cutback bitumen, the Estimated Spray Rate, Designed Spray Rate, Adjusted Designed Spray Rate and Actual Spray Rate referred to in this Technical Specification shall be the quantity, at 15°C, of cutback bitumen.

Any spray rates given in Clause 2 of Annexure MRTS11.1 are Estimated Spray Rates.

The Actual Spray Rate shall be within ± 5% of the Adjusted Designed Spray Rate defined in the nominated seal design as determined in accordance with Clause 6.

To comply with the above requirements, the Contractor shall make adjustments to the operation of the sprayer to account for the following:

a) the increased volume of the material to be sprayed where the temperature of the material is higher than 15°C (Refer to Table 16(a)), and

b) the increased volume of the material to be sprayed where there are other materials to be added to the binder for the relevant operation (e.g. cutter oil and/or adhesion agent in a sealing operation).

12.9 Quantities retained in sprayer tank

To ensure a uniform spray rate, each sprayer run shall be programmed so that the bituminous material retained in the tank at the completion of the spray run shall be the greater of 250 litres and the manufacturer's recommended minimum limit.

12.10 Tolerances

The sprayed binder edges shall not deviate from the specified edge by more than – 0 mm and + 150 mm.

13 Spreading prime cover material

13.1 General

The Contractor shall spread the prime cover material, where specified, so as to produce a complete and even distribution. Wet cover material containing free surface water shall not be used.

13.2 Spread rate

The spread rates stated in Clause 2 of Annexure MRTS11.1 are Estimated Spread Rates.

The Designed Spread Rate shall be that nominated in the seal design determined in accordance with Clause 6. The Designed Spread Rate may be adjusted by the Seal Designer's Delegate during the spreading operation to ensure a complete and even distribution. The adjusted rate shall then be the Adjusted Designed Spread Rate.

13.3 Time limit

To permit penetration of the prime, at least two hours shall elapse between priming and the application of the cover material unless traffic requirements dictate otherwise, and approval is granted by the Administrator.

13.4 Spreading

Bare or insufficiently covered areas shall be re-treated as soon as possible with a further light application or by hand spreading.

The Actual Spread Rate shall not vary outside the range of plus or minus 10% of the Adjusted Designed Spread Rate.

13.5 Removal of excess cover material

Unless otherwise stated in Clause 7.1 of Annexure MRTS11.1, all excess cover material shall be lightly swept and/or vacuumed from the pavement surface with a road broom and/or vacuum truck and completely removed from the road formation. All excess material shall be utilised/disposed of in accordance with the requirements of Clause 10 of MRTS01 *Introduction to Technical Specifications*.

14 Spreading cover aggregate

14.1 General

Wet cover aggregate containing free surface water shall not be loaded into the aggregate spreader. **Witness Point 7**

The Administrator may order that wet aggregate be tested using the Binder Stripping Value – Modified Plate test (Q212B). Test results shall be reported to the Administrator.

During spreading and rolling, the Contractor shall ensure that the aggregate effectively adheres to the binder without breaking down or crushing the aggregate particles.

The Contractor shall spread the cover aggregate in a uniform manner, which after rolling and initial trafficking shall:

a) produce a generally dense tight mat, and

b) form a single layer on the pavement surface, the aggregate being partly interlocked.

14.2 Spread rate

The spread rates stated in Clause 2 of Annexure MRTS11.1 are Estimated Spread Rates. The Designed Spread Rate shall be that nominated in the seal design determined in accordance with Clause 6.

In order to achieve the requirements of Clause 14.4, the Seal Designer’s Delegate may adjust the Designed Spread Rate during the spreading operation. This Adjusted Designed Spread Rate shall be recorded on the spray sheet.

14.3 Time limit

The spreading of cover aggregate shall commence as soon as possible after the spraying of the binder. Under no circumstances shall any portion of the binder be left without cover aggregate after spraying for longer than the following:

a) 10 minutes for treatments containing cutback bitumen, bitumen and multigrade bitumen binders, or

b) 5 minutes for treatments containing polymer modified binders.

In the event that cover aggregate is not applied to any one spray run within this time limit, the Contractor shall demonstrate to the Administrator that arrangements have been made to prevent a recurrence of the nonconformance before bitumen spraying may continue. **Nonconformance**

14.4 Spreading

Spreading of cover aggregate shall be carried out with suitable mechanical aggregate spreaders. Minimum requirements for aggregate spreaders shall be as stated in Clause 7.2 of Annexure MRTS11.1. If no indication is given a Type A or Type B spreader, as defined in Clause 7.2 of Annexure MRTS11.1, shall be used.

On each day of spreading, each spreader shall be tested in accordance with the Field Spread Rate of Cover Aggregate test (Q711A) and shall comply with the spread rate tolerance requirements of this clause. The test frequency shall be one test per spreader per day.

Every attempt shall be made to achieve the required spread pattern on the first spreading pass. Bare or insufficiently covered areas shall be re-treated as soon as possible with a further light spreading run or by hand spreading. Over spreading or under spreading of the aggregate shall be avoided.

If there is an uneven distribution of cover aggregate, it shall be broomed until it is evenly distributed with minimum dislodgment of any embedded cover aggregate. Areas of under-spread aggregate shall be filled in immediately behind the normal spreading operation and these areas shall receive additional rolling.

Any initial under spreading shall be rectified by a further light spreading of aggregate and brooming until it is evenly distributed with minimum dislodgement of any embedded cover aggregate.

The amount of aggregate spread shall be calculated from either:

a) the volume used as recorded on the spray sheets, or

b) by using Test Method Q711A.

The Actual Spread Rate shall not vary outside the range of plus or minus 10% of the Adjusted Designed Spread Rate.

14.5 Rolling

14.5.1 General

Steel-wheeled or rubber coated steel wheel rollers shall not be used unless approved by the Administrator.

For treatments with multiple layers of binder and/or aggregate (e.g. double/double seals), the rolling shall comply with the requirements of this clause for each application of aggregate. Any damage to the first coat shall be repaired by the Contractor at no cost to the Principal prior to spraying the binder for the second and subsequent coats.

14.5.2 Minimum number of rollers

The minimum number of rubber-tyred rollers to be available and in use on the Site shall be the greater of:

a) two, and

b) the number required to complete the minimum amount of rolling required for the average coverage rate per hour as a continuous operation with successive spray runs in accordance with Clause 14.5.3 and Clause 14.5.4.

Additionally, for polymer modified binders, there shall be enough rollers to cover the full width of the spray run with one pass.

14.5.3 Rolling speed

The initial passes shall be done at a low speed (5 – 10 km/h) to achieve the aim of pressing the aggregate into the binder. After that, the rolling speed shall be increased to between 15 – 25 km/h to move and reorientate the aggregate particles to their correct position.

14.5.4 Roller coverage

For bitumen and multigrade binders, Table 14.5.4 specifies the maximum sprayed area (m^2) that can be effectively rolled, taking into account the effect of traffic and aggregate size.

Table 14.5.4 – Area that can be effectively rolled per hour with each self-propelled multi-wheeled roller for cutback bitumen, bitumen and multigrade bitumen binders

Aggregate size (mm)	**Traffic Volume (vehicles per lane per day)**		
	< 300	**300 – 1200**	**> 1200**
	Area – m² per roller hour (Note 1)		
7 or smaller	4000 – 4500	5000 – 5500	6000 – 6500
10	3000 – 3500	3500 – 4000	4500 – 5000
14	2500 – 3000	3000 – 3500	3500 - 4000

Note 1 – 'roller hours' is defined as the product of the number of specified rollers by hours of application

Note 2 – For polymer modified binder seals the area that can be effectively rolled per hour shall be two thirds (2/3rds) of that provided in the table.

> Examples of the use of Table 14.5.4 can be found in Austroads/AAPA Pavement Work Tip No. 24.

14.5.5 Number of roller passes

After spreading, the cover aggregate shall be rolled with multi-tyred rollers with a sufficient number of roller passes to ensure adhesion of the cover aggregate to the binder.

The minimum number of roller passes shall be as stated in Clause 7.3 of Annexure MRTS11.1, or if not so stated:

a) six passes for cutback bitumen, bitumen and multigrade bitumen binders, and

b) nine passes for polymer modified binders.

14.6 Removal of loose aggregate after rolling

Loose aggregate shall be lightly swept and/or vacuumed from the pavement surface without dislodgment of the embedded aggregate. A rotary broom is permitted to remove loose aggregate from the pavement surface. Loose aggregate shall not be removed until the aggregate is properly embedded into the binder by either trafficking or additional rolling.

Areas of aggregate that have been overspread (generally at joins, turnouts and overlaps) shall be broomed off on the same day with hand brooms or mechanical sweepers.

For seals of nominal size greater than or equal to 10 mm, the number of loose aggregate particles (in any square metre of pavement) after sweeping and before opening to traffic shall not exceed the values shown in Clause 7.4 of Annexure MRTS11.1. If values are not specified in Clause 7.4 of Annexure MRTS11.1, the values shown in Table 14.6 shall apply. The number of loose particles shall be determined in accordance with Test Method Q720 at locations that are representative of each homogeneous section and as agreed by the Administrator. Testing for loose aggregate particles is exempt from the requirement for NATA registration.

Table 14.6 – Maximum allowable loose aggregate particles by area prior to opening to traffic

Location	Maximum Allowable Loose Aggregate Particles
Urban Area	20 particles/m²
Other medium to high traffic (greater than or equal to 250 vehicles/lane/day)	30 particles/m²
Other low traffic (less than 250 vehicles/lane/day)	40 particles/m²

Loose aggregate in excess of the maximum allowable loose aggregate particle requirement shall be removed and transported from the job site as follows:

a) from trafficked lanes and sealed shoulders within a time period that ensures compliance with the requirements of Clause 14.8 and MRTS02 *Provision for Traffic*

b) from concrete channels, traffic islands, open drains, footpaths, nature strips or verges within 24 hours, and

c) all other areas within five days.

Loose aggregate shall be utilised/disposed of in accordance with the requirements of Clause 10 of MRTS01 *Introduction to Technical Specifications*.

Any damage to the seal resulting from removal of loose aggregate shall be repaired by the Contractor at no cost to the Principal.

During the Defects Liability Period up to the issue of the Final Certificate, where the Contractor is the nominated Seal Designer, the Contractor is required, at no cost to the Principal, to ensure that the maximum allowable loose aggregate particles requirement given in Table 14.6 is met.

14.7 Protection of fresh seals from traffic

The Contractor shall take precautions to protect the work from damage until such time as the prime or seal (including initial seals, secondary treatments and retreatments) has developed sufficient strength to carry normal traffic without dislodgement of the cover aggregate or cover material, as applicable.

Special attention is required at intersections.

14.8 Early trafficking minimum requirements

Unless otherwise stated in Clause 8 of Annexure MRTS11.1, the Contractor shall complete the following early trafficking minimum requirements in order to address both loose stone considerations in accordance with Clause 14.6 and the protection of the fresh seal from traffic in accordance with the requirements of Clause 14.7:

a) in areas where the posted speed limit is equal to or less than 60 km/h and which are opened to traffic prior to final sweeping, the Contractor shall install temporary 'loose stones' and 'slippery' warning signs and temporary 40 km/h speed signs until the maximum allowable loose aggregate requirements of Clause 14.6 are met

b) in areas where the posted speed limit exceeds 60 km/h and which are opened to traffic prior to final sweeping, the Contractor shall install temporary 'loose stones' and 'slippery' warning signs and temporary speed signs not exceeding 60 km/h until the maximum allowable loose aggregate requirements of Clause 14.6 are met, and

c) for a period of between 24 hours and 48 hours after the maximum allowable loose aggregate requirements of Clause 14.6 have been met, the temporary speed limit shall be not greater than 80 km/h and the posted speed limit, and the Contractor shall install signs accordingly.

For primes, traffic including construction traffic shall not be permitted on the surface where the traffic exceeds 50 v/l/d. Where the traffic is less than 50 v/l/d, traffic including construction traffic shall not be permitted on the surface:

a) within 24 hours of spraying or until the prime has dried sufficiently so as not to be damaged by vehicles, and

b) until prime cover material is applied.

All signage shall comply with the requirements of MRTS02 *Provision for Traffic*.

The requirements of Clause 14.8 are **Hold Point 7** and the road shall not be opened to traffic until the release of this Hold Point by the Administrator.

15 Geotextile reinforced seals

The geotextile used in a GRS shall be supplied and constructed in accordance with the requirements of MRTS57 *Geotextiles for Paving Applications*.

16 Measurement and recording

The volume of bituminous material sprayed of each run shall be determined by dipping the tank after each run and recording the volume of bituminous material in the tank to the nearest 50 L. The sprayer shall be dipped whilst parked on level ground. Sprayers with electronic process control and data recording may, with the approval of the Administrator, be exempt from this requirement.

For each spray run, the Contractor shall record all details of the sealing operations on an appropriate spray sheet, which shall include details of at least the following:

a) Job Number

b) The Queensland Sprayer Certificate number and its expiry date

c) Date, start time and end time of the spray run

d) Description of the weather throughout the spray run

e) Name and signature of the Spray Seal Designer’s Delegate determining the Adjusted Designed Spray Rate and Adjusted Designed Spread Rate

f) Pavement temperature at the start and end of the spray run, and when there is significant change in temperature (record time/ temperature degrees Celsius)

g) Gazettal chainages for start and finish of the spray run

h) Area of the spray run (m^2)

i) Hot volume of binder prior to addition of cutter and additives (L)

j) Binder type/s used on the spray run

k) Additive (including adhesion agent and cutter) types used, if any

l) Design cutter oil proportions (parts per 100 parts of binder) used, if any (refer Clause 12.7)

m) Actual cutter oil proportions (parts per 100 parts of binder) used, if any

n) Quantity of adhesion agent (parts per 100 parts of binder)) used, if any

o) Temperature of mixture at start of the spray run

p) Adjusted Designed Spray Rate/s and Actual Spray Rate/s for each run (at 15°C)

q) Nominal aggregate size used for the spray run

r) Quantity of aggregate spread for the spray run

s) Adjusted Designed Spread Rate/s and Actual Spread Rate/s

t) Number of and type of rollers used, and

u) A statement of whether the spray rate complied with the tolerance requirements detailed in Clause 12.8, and whether the aggregate spread rate complied with the tolerance requirements detailed in Clause 13.4 and Clause 14.4.

The bituminous materials spraying record sheet shall be made available to the Administrator for verification, within one day of the sealing operations applicable to the run.

All records shall be such that the actual spray rate for each spray run shall be calculated at 15°C prior to the next spray run.

All volume conversions, in relation to changes in temperature of bituminous materials, shall be carried out in accordance with the relevant factors listed in Table 16(a) and Table 16(b).

Table 16(a) – Equivalent volumes at higher temperatures of 1 Litre of bituminous material measured at 15ºC

Temp (°C)	Factor	Temp (°C)	Factor	Temp (°C)	Factor
15	1.0000	80	1.0420	145	1.0861
20	1.0031	85	1.0453	150	1.0897
25	1.0062	90	1.0487	155	1.0932
30	1.0094	95	1.0520	160	1.0967
35	1.0126	100	1.0553	165	1.1003
40	1.0158	105	1.0587	170	1.1038
45	1.0191	110	1.0620	175	1.1074
50	1.0223	115	1.0655	180	1.1109
55	1.0255	120	1.0689	185	1.1145
60	1.0288	125	1.0723	190	1.1180
65	1.0321	130	1.0757	195	1.1216
70	1.0354	135	1.0792	200	1.1252
75	1.0387	140	1.0827	205	1.1287

Table 16(b) – Equivalent volumes at 15°C of 1 Litre of bituminous material measured at higher temperatures

Temp (°C)	Factor	Temp (°C)	Factor	Temp (°C)	Factor
15	1.0000	80	0.9597	145	0.9207
20	0.9969	85	0.9566	150	0.9177
25	0.9938	90	0.9536	155	0.9148
30	0.9907	95	0.9506	160	0.9118
35	0.9876	100	0.9476	165	0.9089
40	0.9844	105	0.9446	170	0.9060
45	0.9813	110	0.9416	175	0.9031
50	0.9782	115	0.9385	180	0.9002
55	0.9751	120	0.9355	185	0.8973
60	0.9720	125	0.9326	190	0.8945
65	0.9689	130	0.9296	195	0.8916
70	0.9658	135	0.9266	200	0.8888
75	0.9627	140	0.9236	205	0.8860

17 Construction compliance

17.1 General

Material compliance shall be tested and checked in accordance with the requirements of the material technical specifications detailed in Table 7.1.

The process requirements shall be checked for compliance with the specified requirements during and after construction for each lot.

In the event of any fuel or oil leaks or spillages by the Contractor onto the newly sealed surface, or any other damage to the newly sealed surface, the Contractor shall reinstate the surface and the underlying base course to its pre-damage condition at no cost to the Principal.

The Contractor and Administrator shall jointly investigate and provide the Principal with a written report on the causes where any of the following occurs on more than 10% of any wheel path length of any run at any time to the end of the Defects Liability Period:

a) stripping which is defined as areas where more than 10% cover aggregate has been lost from the seal's aggregate matrix

b) flushing which is defined as where surface texture depth is < 0.5 mm when tested by AGPT/T250, and/or

c) debonding which is defined as separation of the seal from the underlying layer.

17.2 Surface texture

Where the seal is the final surfacing or shall be opened to public traffic, surface texture shall be tested, recorded and reported to the Administrator as follows:

a) Surface texture shall be assessed by the Modified Surface Texture Depth (Pestle Method)

b) Testing shall be carried out:

  i. At sections of through pavement that have a homogeneous visual appearance, and

  ii. At each of the following locations:

    - pedestrian crossings, railway level crossings, roundabouts, intersections including the maximum 50 m approaches and departures to these
    - curves with radius ≤ 250 m
    - gradients ≥ 5% and ≥ 50 m long
    - on/off ramps, including merge and diverge areas, and/or
    - merge and diverge areas of overtaking lanes and intersections

c) Testing shall be completed after the loose aggregate requirements of Clause 14.6 are met.

All surface texture depths shall achieve the requirements stated in Clause 9 of Annexure MRTS11.1.

18 Supplementary requirements

The requirements of MRTS11 *Sprayed Bituminous Treatments (Excluding Emulsion)* are varied by the supplementary requirements given in Clause 10 of Annexure MRTS11.1.

APPENDIX B UPDATED MRTS18 *POLYMER, INCLUDING CRUMB RUBBER, MODIFIED BINDER*

Technical Specification

Transport and Main Roads Specifications MRTS18 Polymer Modified Binder (including Crumb Rubber)

July 2017

Queensland Government

Feedback: Please send your feedback regarding this document to: tmr.techdocs@tmr.qld.gov.au

Contents

1 Introduction

This Technical Specification applies to the material requirements for polymer modified binder (PMB), including binders incorporating crumb rubber, for use in both sprayed sealing and asphalt applications for road construction, resurfacing, rehabilitation and maintenance.

This Technical Specification shall be read in conjunction with MRTS01 *Introduction to Technical Specifications,* MRTS50 *Specific Quality System Requirements* and other Technical Specifications as appropriate.

This Technical Specification forms part of the Transport and Main Roads Specifications Manual.

2 Definition of terms

The terms used in this Technical Specification shall be defined in Clause 2 of MRTS01 *Introduction to Technical Specifications.* Additional terms used in this Technical Specification shall be as defined in Table 2.

Table 2 – Definition of terms

Term	Definition
Bitumen	Bituminous material obtained by processing the material obtained from the refining of naturally occurring crude petroleum
Crumb rubber (scrap rubber)	Rubber particles manufactured from waste or reclaimed rubber products such as vehicle tyres and graded to conform to a specified size range.
Compliance testing sample	The sample of binder taken by the Contractor for compliance testing
Manufacturer	An organisation which has the necessary plant and equipment to manufacture polymer modified binder to this Technical Specification. For supply only contracts, the manufacturer shall be the Contractor.
Polymer	A predominantly organic substance comprising a very large number of chemical entities. These chemical entities may comprise identical segments (producing a homopolymer) or a combination of two or more different segments (producing a copolymer).
Polymer modified binder (PMB)	A binder consisting of polymeric material (including crumb rubber) dispersed in bitumen with enhanced binder performance for particular applications
Polymer modified binder class	A type of polymer modified binder which is classified according to its torsional recovery at 25ºC, softening point and consistency at 60ºC as defined in AGPT/T190 *Specification Framework for Polymer Modified Binders*
Point of delivery	The point in the delivery process where the polymer modified binder is: a) transferred to the sprayer for sprayed sealing work, or b) located in the storage tank at the asphalt plant immediately prior to asphalt production
Site	Where the polymer modified binder is used (includes the asphalt manufacturing plant)

3 Referenced documents

Table 3 lists documents referenced in this Technical Specification.

Table 3 – Referenced documents

Reference	Title
AP-G41	*Bituminous Materials Safety Guide,* Austroads
AGPT/T101	*Method of Sampling Polymer Modified Binders, Polymers and Crumb Rubber,* Austroads
AGPT/T190	*Specification Framework for Polymer Modified Binders,* Austroads
AP-T235-13	*Guide to the Selection and Use of Polymer Modified Binders and Multigrade Bitumens,* Austroads
Advisory Note 7	*Guide to the Heating and Storage of Binders for Sprayed Sealing and Asphalt Manufacture,* Australian Asphalt Pavement Association (AAPA)
HSE Guide 5	*Guide to the Manufacture, Storage and Handling of Polymer Modified Binders,* Australian Asphalt Pavement Association (AAPA)
ISO 9001	*Quality Management Systems: Requirements,* International Organisation for Standardisation
AS/NZS ISO 9001	*Quality Management Systems: Requirements,* Standards Australia
EN07	*Conformance of Polymer Modified Binders*
MRTS01	*Introduction to Technical Specifications*
MRTS11	*Sprayed Bituminous Treatment*
MRTS30	*Asphalt Pavements*
MRTS50	*Specific Quality System Requirements*

4 Standard test methods

The test methods applicable to this Technical Specification are those listed in the latest version of the Austroads document AGPT/T190 *Specification Framework for Polymer Modified Binders*.

5 Quality system requirements

5.1 Hold Points, Witness Points and Milestones

General requirements for Hold Points, Witness Points and Milestones are specified in Clause 5.2 of MRTS01 *Introduction to Technical Specifications*.

The Witness Point applicable to this Technical Specification is shown in Table 5.1. There are no Hold Points or Milestones defined.

Table 5.1 – Hold Points, Witness Points and Milestones

Clause	Hold Point	Witness Point	Milestone
9.3.1		1. Sampling at the point of delivery	

5.2 Binder handling procedures

The Contractor shall prepare documented procedures for all required processes as defined in Clause 6 of MRTS50 *Specific Quality System Requirements* and be consistent with the requirements of this Technical Specification, MRTS30 *Asphalt Pavements* and MRTS11 *Sprayed Bituminous Treatments*, as appropriate. These procedures shall be included in the respective asphalt quality plan or construction procedure specified in MRTS30 *Asphalt Pavements* or MRTS11 *Sprayed Bituminous Treatments*.

For field blended or plant blended crumb rubber modified binders, the construction procedures shall address the following specific issues:

- method for achieving a homogeneous product that can be sprayed to achieve a uniform application of binder across the pavement during sealing operations, free of streaking
- the management of crumb rubber blending, digestion, and storage times and temperatures
- the maximum time / temperature conditions that field produced / plant blended product can be stored and / or transported without loss of properties
- the maximum distance that the product can be transported from a blending site without degradation of properties
- circulation of the product during transportation and storage, and
- requirements for spraying plant and spraying practices including adjustments to nozzles (if required).

5.3 Conformance requirements

Materials supplied to this Technical Specification shall be sampled and tested in accordance with Clause 9.

The conformance requirements which apply to this Technical Specification are summarised in Clause 6.

6 Material

6.1 General

Polymer modified binders shall comply with the property requirements and associated notes listed in the latest version of AGPT/T190 *Specifications Framework for Polymer Modified Binders*.

The crumb rubber used to produce S15RF and S18RF binders shall meet the requirements for a size 16 crumb rubber in accordance with Table 5.4 of AGPT/T190.

Transport and Main Roads has adopted the Austroads classification system for polymer modified binders. AGPT/T190 can be downloaded for free from the Austroads publications website.

https://www.onlinepublications.austroads.com.au

The nearest equivalent Austroads PMB class (AGPT/T190) to the previous MRTS18 (November 2011) PMB class is listed in the table below.

Austroads PMB Class (AGPT/T190)	Previous PMB Class (MRTS18 – November 2011)
Sprayed Sealing Applications	
S10E	S0.25S
S15E	S0.7S
S20E	–
S25E	S4.5S
S35E	S0.3B
S45R	S1.8R
S15RF	S15RF
S18RF	S18RF
Asphalt Applications	
A10E	A10S
A15E	A5S
A20E	A0.6S
A25E	A0.6B
A35P	A2V

6.2 Polymer types

Polymer modified binders shall be manufactured using the polymer types listed in Table 6.2.

Table 6.2 – Polymer type to be used in binder

Polymer Type	Polymer Modified Binder Class
Styrene-butadiene-styrene (SBS)	S10E, S15E, S20E, S25E, A10E, A15E, A20E
Polybutadiene (PBD)	S35E, A25E
Ethylene vinyl acetate (EVA)	A35P
Crumb rubber (CR)	S45R, S15RF, S18RF

6.3 Foaming

Polymer modified binder shall not foam at any time when heated up to a temperature of 180°C. The formation of a thin layer of bubbles on the surface of the binder is not regarded as foaming.

7 Manufacture

The polymer modified binder manufacturer shall:

a) Operate a quality management system certified to AS/NZS ISO 9001 for material manufactured in Australia.

b) Operate a quality system certified to ISO 9001 or equivalent for material manufactured outside Australia.

c) Operate to an inspection and test plan acceptable to Transport and Main Roads for manufacturing and supplying polymer modified binder which demonstrates compliance with this Technical Specification. The inspection and test plan shall include testing of polymer modified binder, analysis of results (including control charts) and a requirement for a copy of the results to be forwarded promptly to Transport and Main Roads.

d) Ensure all polymer modified material supplied can be traced to the production batch and associated test report.

8 Delivery of polymer modified binder

8.1 General

The handling, storage, transport, heating and transfer of polymer modified binder shall comply with the requirements and practices outlined in the latest versions of the following documents:

a) Austroads – *Bituminous Materials Safety Guide*, AP-G41

b) Austroads – *Guide to the Selection and Use of Polymer Modified Binders and Multigrade Bitumens*, AP-T235-13

c) AAPA – *Guide to the Heating and Storage of Binders for Sprayed Sealing and Asphalt Manufacture*, Advisory Note 7, and

d) AAPA – *Guide to the Manufacture, Storage and Handling of Polymer Modified Binders*, HSE Guide 5.

8.2 Binder contamination

Polymer modified binder shall be heated, stored and transported in purpose-built containers and transferred between containers in such a way that contamination does not occur, the resultant product complies with this Technical Specification and the performance of the product is not adversely affected.

As necessary, storage and delivery vessels, sprayers and hoses shall be flushed or cleaned with appropriate solvents before transfer of binder has commenced. Residues from flushing and cleaning shall be removed before transfer.

If contamination of the binder is suspected, additional sampling and testing may be ordered by the Administrator to confirm compliance of the binder with the requirements of this Technical Specification.

8.3 Heating

Polymer modified binder shall not be heated to temperatures greater than the maximum values listed in the latest version of AAPA Advisory Note 7 – *Guide to the Heating and Storage of Binders for Sprayed Sealing and Asphalt Manufacture*. The rate of increase in temperature shall not exceed 15°C per hour.

8.4 Records

Records shall be kept for the handling, storage, transport, heating and transfer of binder from the date/time of sampling at the point of release from the manufacturer until such time as the binder is incorporated into the works.

These records shall include the binder's class and history, including (as relevant):

a) dates, times, production batch numbers, polymer modified binder classes and volumes of transfers in to and out of the storage container

b) date, time and amount of any additives (e.g. cutter oil and/or adhesion agent) incorporated into the binder, and

c) duration of storage, temperature over time, and degree of agitation during any period of storage.

8.5 Delivery dockets

Delivery of polymer modified binder to the Site shall be accompanied by a delivery docket giving at least the following information:

a) name and address of the manufacturer

b) location and date of manufacture

c) polymer modified binder class

d) production batch number

e) storage and heating information (i.e. location, date, time, temperature), and

f) certification that the polymer modified binder has been sampled prior to release from the manufacturer, tested as stated in Clause 9 and its properties comply with Clause 6.

Delivery dockets shall be made available for inspection by the Administrator and shall be included in the quality records for each relevant construction lot.

9 Compliance sampling and testing

9.1 General

Sufficient sampling and testing shall be carried out to ensure that the polymer modified binder complies with the property requirements of Clause 6. Sampling of polymer modified binder shall be undertaken in accordance with the procedures defined in AGPT/T101 *Method of Sampling Polymer Modified Binders, Polymers and Crumb Rubber*.

Sampling and testing shall take place at the point of release from the manufacturer and at the point of delivery. The minimum requirements are as follows:

a) Sampling and testing at the point of release from the manufacturer shall be in accordance with Clause 9.2.

b) Sampling and testing at the point of delivery to the sprayer or from the asphalt binder storage tank shall be in accordance with Clause 9.3.

9.2 Sampling and testing at the point of release from the manufacturer

Sampling and testing of polymer modified binder at the point of release from the manufacturer shall be undertaken by the manufacturer.

A batch shall be defined as the quantity of polymer modified binder stored in a single tank by the manufacturer at any particular time. The binder in the storage tank shall be considered a new batch whenever new material is added to the storage tank.

The minimum frequency of sampling and testing performed by the manufacturer shall be in accordance with the testing frequency requirements and associated notes listed in the latest version of AGPT/T190 *Specification Framework for Polymer Modified Binders*.

All test results obtained from each batch shall be included in the relevant construction lot record.

9.3 Sampling and testing at the point of delivery

9.3.1 Sampling

Polymer modified binder shall be sampled by the Contractor at the point of delivery.

For sprayed sealing work, a compliance testing sample and a sample for the Administrator shall be taken from the tanker/storage tank immediately prior to transfer or during each transfer of binder from the tanker/storage tank to the sprayer **Witness Point 1** Unless otherwise directed by the Administrator, where a single tanker/storage tank load of binder is being transferred multiple times to the sprayer during the same work shift, only one pair of samples needs to be obtained.

For asphalt works, a compliance testing sample and a sample for the administrator shall be taken from the binder storage tank immediately prior to the commencement of asphalt production for each work shift.

Each sample shall be one litre (1 L) of polymer modified binder. The Contractor shall retain the compliance testing samples and forward the samples taken for the Administrator to the Administrator, unless otherwise directed by the Administrator.

Samples shall be labelled at the time of sampling and appropriately stored to avoid contamination or deterioration for a minimum of 12 months, or for the duration of the project’s defect liability / correction period, whichever is greater.

Sample labels would typically contain the following information:

- designation or classification of the binder
- name of supplier / manufacturer
- batch or identification number
- date and time of sampling
- sampling location
- type and identifying number of the container or vehicle where the sample was taken
- name of sampler
- identification mark or sample number
- project name or number
- sampling temperature

9.3.2 Testing

9.3.2.1 Testing frequencies

The minimum testing frequencies for point of delivery testing are provided in Table 9.3.2.1.

Where the Contractor is able to provide suitable, traceable and auditable records to the Administrator that demonstrate the binder has been handled, stored, transported, heated and transferred in accordance with this Technical Specification and the latest version of AAPA Advisory Note 7 – *Guide to the Heating and Storage of Binders for Sprayed Sealing and Asphalt Manufacture*, the frequency of compliance testing for each class of polymer modified binder from each manufacturer shall be at the 'normal frequency'. If the Contractor is unable to demonstrate compliance with the above requirements, an 'increased frequency' shall be adopted.

A 'normal frequency' shall immediately change to an 'increased frequency' if a nonconforming sample has been detected. The frequency may return to the 'normal frequency' after no nonconformances have occurred in four consecutive compliance testing samples.

Where the binder has not been stored in accordance with the latest version of AAPA Advisory Note 7 – *Guide to the Heating and Storage of Binders for Sprayed Sealing and Asphalt Manufacture*, the 'increased frequency' shall apply.

In addition to the requirements of MRTS50 *Specific Quality System Requirements*, and unless otherwise specified or agreed with the Administrator, the extents of conforming and nonconforming works shall be determined based on the midpoint between adjacent binder tests.

Table 9.3.2.1 – Minimum testing frequencies

Frequency	Normal Frequency	Increased Frequency
Testing of samples required:	The first compliance testing sample and then every 10th compliance testing sample thereafter for a particular binder class (that is compliance testing sample 1, 11, 21 and so on)	Each compliance testing sample

9.3.2.2 Testing requirements

Samples shall be tested for torsional recovery at 25°C and softening point, and assessed for conformance with the requirements of Table 9.3.2.2. In the event of a nonconformance being detected, additional tests shall be performed on the same sample so that the one sample is tested for the following additional properties:

a) consistency

b) segregation

c) viscosity, and

d) rubber content (where applicable).

For the purpose of undertaking these tests, reheating of binder samples shall be minimised as much as possible.

Table 9.3.2.2 – Binder properties

Binder Class	Softening Point (ºC)		Torsional Recovery at 25ºC (%)	
	Point of Release from the Manufacturer [1]	Point of Delivery	Point of Release from the Manufacturer [1]	Point of Delivery
A35P	62 – 74	62 – 74	6 – 21	6 – 21
A25E	52 – 62	52 – 62	17 – 30	16 – 30
A20E	65 – 95	59 – 95	38 – 70	25 – 70
A15E	82 – 105	76 – 105	55 – 80	45 – 80
A10E	88 – 110	81 – 110	60 – 86	49 – 86
S10E	48 – 64	48 – 64	22 – 50	14 – 50
S15E	55 – 75	52 – 75	32 – 62	20 – 62
S20E	62 – 88	56 – 88	45 – 74	30 – 74
S25E	82 – 100	75 – 100	54 – 85	44 – 85
S35E	48 – 56	48 – 56	16 – 32	15 – 32
S45R	55 – 65	53 – 65	25 – 55	23 – 55
S15RF	–	≥ 55	–	≥ 25
S18RF	–	≥ 62	–	≥ 30

[1] Requirements for softening point and torsional recovery at the point of release from the manufacturer are given in Tables 5.1 and 5.2 of AGPT/T190, and are repeated in this table for information purposes.

Variation of binder property between the point of release from the manufacturer and the point of delivery

A reduction in torsional recovery and softening point can occur with some binder grades over time due to ageing, particularly for moderately to heavily modified SBS binder grades. Such changes do not have a significant detrimental effect on the performance of the binder and have been accounted for in the lower point of delivery requirements. However, reductions in torsional recovery and softening point caused by other means (such as nonconforming binder properties at the point of release from the manufacturer, contamination or mishandling) can have a detrimental effect on the performance of the binder.

All properties, other than softening point, torsional recovery and consistency should not vary between the point of release from the manufacturer and the point of delivery.

Acceptance of nonconforming binder

For binder that does not conform to the point of delivery requirements but has been assessed by the Administrator as being suitable to remain in the Works, the reduction in value of the binder would typically be determined in accordance with Technical Note EN07 *Conformance of Polymer Modified Binders*. Additionally, the project’s defect liability / correction period for sprayed seals and asphalt containing nonconforming binder would typically be extended to a period of at least 24 months after the date of installation, as the performance implications associated with the nonconformance cannot be fully evaluated until it has been subject to a period of sustained hot weather.

Audit testing undertaken by the Administrator

When audit testing is undertaken by the Administrator, samples are typically tested for the following properties:

- softening point
- torsional recovery
- consistency, and
- segregation.

APPENDIX C SUPPLEMENTARY SPECIFICATION PSTS112 *CRUMB RUBBER MODIFIED OPEN GRADED ASPHALT SURFACING*

Supplementary Specification

Transport and Main Roads Specifications
PSTS112 Crumb Rubber Modified Open Graded Asphalt Surfacing

June 2016 Version 3 for Trial Purposes

Queensland
Government

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Contents

1 Introduction

This Supplementary Specification sets out the requirements for crumb rubber modified open graded asphalt. The requirements for open graded asphalt in MRS30 *Asphalt Pavements* and MRTS30 *Asphalt Pavements* shall apply unless they are specifically amended by this Supplementary Specification.

This Supplementary Specification shall be read in conjunction with MRS01 *Introduction to Specifications*, MRTS01 *Introduction to Technical Specifications*, MRTS50 *Specific Quality System Requirements* and other Specifications and Technical Specifications as appropriate.

2 Measurement of Work

2.1 Work Items

The Supplementary work items covered by this specification are listed in Table 1.

Table 1 – Supplementary Work Items

Item No.	Description	Unit of Measurement
9001	Asphalt mix design testing, OG [nominal size] mix	Item
9002P	Supply of crumb rubber modified binder (Provisional Quantity)	tonnes
9003P	Supply and incorporation of warm mix asphalt additive into crumb rubber modified binder (Provisional Quantity, if ordered)	tonnes
9165	Crumb rubber modified open graded asphalt in surfacing course, OG [nominal size] mix (excluding binder supply)	tonnes

For tendering purposes, a binder content of 6.0% by mass of the mix is typically assumed for crumb rubber modified open graded asphalt.

2.2 Work Operations

Item 9001 Asphalt mix design testing, OG [nominal size] mix

Work Operations incorporated in the above item include:

a) Work Operations listed in Clause 2.1.5 of MRS01 *Introduction to Specifications*
b) being a prequalified asphalt contractor or engaging a subcontractor who is a prequalified asphalt contractor
c) undertaking asphalt mix design testing, to obtain a registered mix design in accordance with Clause 8.2
d) supply and handling of all materials required to undertake mix design testing
e) provision of laboratory and compliance testing facilities
f) sampling, testing and quality assurance requirements, and

g) delivery of the results for all tests, inspections and reports to the Asphalt Mix Design Registrar by the nominated time.

Item 9002P Supply of crumb rubber modified binder (Provisional Quantity)

Work Operations incorporated in the above item include:

a) Work Operations listed in Clause 2.1.5 of MRS01 *Introduction to Specifications*
b) supply of binder required to meet the mix design requirements nominated by the Asphalt Mix Design Registrar in accordance with Clause 8.2, and
c) transport and handling of binder necessary for incorporation into the asphalt mix

Item 9003P Supply and incorporation of warm mix asphalt additive into crumb rubber modified binder (Provisional Quantity, if ordered)

Work Operations incorporated in the above item include:

d) Work Operations listed in Clause 2.1.5 of MRS01 *Introduction to Specifications*, and
e) supply and incorporation of warm mix asphalt additive into crumb rubber modified binder.

Item 9165 Crumb rubber modified open graded asphalt in surfacing course, OG [nominal size] mix (excluding binder and warm mix asphalt additive supply)

Work Operations incorporated in the above item include:

a) Work Operations listed in Clause 2.1.5 of MRS01 *Introduction to Specifications*
b) being a prequalified asphalt contractor or engaging a subcontractor who is a prequalified asphalt contractor
c) maintaining (and updating as required) a registered mix design for the duration of the works for the binder content nominated by the Asphalt Mix Design Registrar in accordance with Clause 8.2
d) manufacture of asphalt in accordance with the registered mix design(s), including incorporation of the required binder content into the mix
e) delivery of asphalt to the Works
f) laying, compacting and finishing the asphalt, including use of a material transfer vehicle as specified
g) providing an allowance for asphalt used in temporary ramps and asphalt lost from cut-offs from joints
h) provision of laboratory and compliance testing facilities
i) sampling, testing and quality assurance requirements, including binder supplied in accordance with Item 9002
j) delivery of the results for all tests and inspections to the Administrator by the nominated time, and
k) removal and disposal of any nonconforming material or product, or any material or product not utilised for a reduced level of service, and replacement with conforming material or product.

2.3 Calculation of Quantities

2.3.1 Binder

The quantity of binder (in tonnes) used in the production of asphalt shall be determined from the nominated percentage of binder (by mass of the asphalt mix) and the quantity of asphalt incorporated in the works.

2.3.2 Warm mix asphalt additive

The quantity of warm mix asphalt additive (in tonnes) used in the production of asphalt shall be determined from the nominated percentage of warm mix asphalt additive (by mass of binder), the nominated percentage of binder (by mass of the asphalt mix) and the quantity of asphalt incorporated in the works.

2.3.3 Asphalt

The quantity of asphalt incorporated in the woks shall be determined in accordance with MRS30 *Asphalt Pavements.*

3 Reference documents

Table 3 lists the documents referenced in this Supplementary Specification.

Table 3 – Reference documents

Reference	Documents
Australian Standards	
AS 2341.12	Methods of testing bitumen and related roadmaking products – Determination of penetration
Austroads	
AG:PT/T103	Pre-treatment and loss on heating of bitumen, multigrade and polymer modified binders (rolling thin film oven (RTFO) test)
AG:PT/T108	Segregation of polymer modified binders
AG:PT/T112	Flash point of polymer modified binders
AG:PT/T122	Torsional recovery of polymer modified binders
AG:PT/T131	Softening point of polymer modified binders
AG:PT/T142	Rubber content of digested crumb rubber binders – trichlor bath method
AG:PT/T143	Particle size and properties of crumb rubber
AG:PT/T144	Morphology of crumb rubber – Bulk density test
ASTM International	
D2007	Standard test method for characteristic groups in rubber extender and processing points and other petroleum-derived oils by clay-gel absorption chromatographic method
D2196	Standard test methods for rheological properties of non-newtonian materials by rotational viscometer
D5329	Standard test methods for sealants and fillers, hot-applied, for joints and cracks in asphaltic and Portland cement concrete pavements
D7741/D7741M	Standard test method for measurement of apparent viscosity of asphalt-rubber or other asphalt binders by using a rotational hand held viscometer

4 Test methods

The test methods given in Table 4 of MRTS30 *Asphalt Pavements*, Table 4 of MRTS18 *Polymer Modified Binder* and Table 4 shall be used in this Supplementary Specification.

Further details of test numbers and test descriptions are given in Clause 4 of MRTS01 *Introduction to Technical Specifications*.

Table 4 – Test methods

Property to be Tested	Test Method Number
Crumb rubber modified binder	
Flash point	AG:PT/T112
Penetration	AS 2341.12
Resilience	ASTM D5329
Rubber content	AG:PT/T142
Segregation	AG:PT/T108
Softening point	AG:PT/T131
Torsional recovery	AG:PT/T122
Viscosity	ASTM D2196 and ASTM D7741/D7741M
Crumb rubber	
Bulk density	AG:PT/T144
Foreign materials	AG:PT/T143
Grading	AG:PT/T143
Particle length	AG:PT/T143
Water content	AG:PT/T143
Asphalt	
Binder film index	AS/NZS 2891.8, AG:PT/T237 or Q317
Compaction of asphalt test specimens (using a Marshall compactor)	Q305[1]
Compacted density	AS/NZS 2891.9.3 or Q306D
Asphalt binder drain-off	AG:PT/T235
Asphalt particle loss	AG:PT/T236
Maximum density	AS/NZS 2891.7.1 or Q307A
Voids calculations for compacted asphalt	AS/NZS 2891.8 or Q311
Equivalent compaction temperature for warm mix asphalt	Q323

[1] Where a temperature less than the standard laboratory conditioning and compaction temperature is used for mixes containing a warm mix asphalt additive, the temperature shall be determined in accordance with Q323.

5 Binder

The binder for crumb rubber modified open graded asphalt shall comply with:

- the requirements MRTS18 *Polymer Modified Binder*
- the property requirements specified in Table 5-A (CR1) or Table 5-B (CR2), and
- contain a minimum of 17% of crumb rubber by mass of total binder.

The binder shall be classified as CR1 (i.e. Type 1 crumb rubber modified binder) or CR2 (i.e. Type 2 crumb rubber modified binder) on the asphalt mix design certificate.

The crumb rubber used to manufacture the binder shall comply with the requirements of clause 6.

Crumb rubber modification of asphalt mixes is accomplished by two methods: the wet process and the dry process. The Wet Process can produce a wide variety of crumb rubber modified binders from high viscosity (sometimes called ‘field blend’) to no agitation (sometimes referred to as ‘terminal blend’) types. Note that regardless of naming conventions, high viscosity binder may be produced in either the field, or at a refinery/terminal

The high viscosity wet process requires thorough mixing of the crumb rubber into the bituminous material and holding the resulting blend at elevated temperatures for a designated period of time to permit an interaction between the crumb rubber and the bituminous material.

This specification uses the Wet Process – High Viscosity process. Characteristics of this type of binder are:

- Typically contains around 20% crumb rubber
- Maximum crumb rubber particle size ≤ 2.36 mm
- The crumb rubber (and other constituents) must be thoroughly mixed with hot bitumen
- The crumb rubber must interact with hot bitumen (and other constituents) for a designated minimum period (typically 60 minutes)
- Crumb rubber particles swell and exchange oils with bitumen, and
- Rotational viscosity of the binder must be between 1.5 – 4.0 Pa.s at 175°C at the time of use.

The temperature of the bitumen shall be between 175 and 205°C at the time of addition of the crumb rubber. No agglomerations of crumb rubber particles in excess of 50 mm shall be allowed into the mixing chamber. The temperature of the crumb rubber modified binder immediately after the initial dispersion of the crumb rubber into the bitumen shall be between 163 and 190°C. The Contractor shall ensure that the crumb rubber and bitumen are thoroughly mixed prior to the beginning of the reaction period. The reaction period shall be a minimum of 60 minutes, during which time the crumb rubber modified binder is continued to be mixed while the temperature between 163 and 190°C is maintained. The reaction period shall be completed before the crumb rubber modified binder is used. The Contractor shall ensure the crumb rubber particles have been uniformly incorporated into the mixture and that they have been “wetted”. The occurrence of the crumb rubber floating on the surface or agglomerations of crumb rubber particles is evidence of insufficient mixing.

The crumb rubber modified binder shall not contain any constituent materials that are not safe for incorporation into the binder at the specified incorporation, dispersion and mixing temperatures.

Table 5-A – Type 1 crumb rubber modified binder (CR1)

Property	**Test method**	**Reaction time (since incorporation of rubber into the binder)**							**Minimum testing frequency**
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hours	TBN[1]	
Penetration @ 4°C, 200 g, 60 sec, 0.10 mm, minimum	AS 2341.12	10	-	-	10	-	10	10	AMDS[2]
Resilience @ 25°C, percent rebound, minimum	ASTM D5329	25	-	-	25	-	25	25	AMDS[2]
		25	-	-	-	-	-	-	Each batch
Torsional recovery at 25°C 30 s, %	AG:PT/ T122	TBR[3]	-	-	TBR[3]	-	TBR[3]	TBR[3]	AMDS[2]
		TBR[3]	-	-	-	-	-	-	Each batch
Softening point, °C, minimum	AG:PT/ T131	57	-	-	57	-	57	57	AMDS[2]
		57	-	-	-	-	-	-	Each batch
Viscosity at 175°C, Pa.s	ASTM D2196	TBR[3,4]							AMDS[2]
	ASTM D7741/ D7741M	1.5-4.0[5]							Refer Clause 8
Flash Point, °C, minimum	AG:PT/ T112	250[6]							AMDS[2] and as nominated by the Contractor during production
Loss on Heating, %, maximum	AG:PT/ T103	0.6[6]							

1. TBN denotes to be nominated by the Contractor. Where the contractor desires to store the crumb rubber modified binder in excess of 10 hours (after the 60 minute reaction period) but not more than 4 days (96 hours after the 60 minute reaction period) prior to usage, testing should be completed to confirm compliance with specification requirements.
2. Asphalt mix design submission.
3. TBR denotes to be reported.
4. The test results are used to demonstrate the minimum and maximum reaction (and storage) time for the crumb rubber modified binder.
5. The Viscosity at 175°C of the crumb rubber modified binder at the time of use shall be 1.5 – 4.0 Pa.s.
6. Reaction time does not apply to this property.

Table 5-B – Type 2 crumb rubber modified binder (CR2)

Property	**Test method**	**Reaction time (since incorporation of rubber into the binder)**							**Minimum testing frequency**
		60 mins	90 mins	120 mins	240 mins	360 mins	11 hours	TBN[1]	
Penetration @ 4°C, 200 g, 60 sec, 0.10 mm, minimum	AS 2341.12	15	-	-	15	-	15	15	AMDS[2]
Resilience @ 25°C, percent rebound, minimum	ASTM D5329	20	-	-	20	-	20	20	AMDS[2]
		20	-	-	-	-	-	-	Each batch
Torsional recovery at 25°C 30 s, %	AG:PT/ T122	TBR[3]	-	-	TBR[3]	-	TBR[3]	TBR[3]	AMDS[2]
		TBR[3]	-	-	-	-	-	-	Each batch
Softening point, °C, minimum	AG:PT/ T131	55	-	-	55	-	55	55	AMDS[2]
		55	-	-	-	-	-	-	Each batch
Viscosity at 175°C, Pa.s	ASTM D2196	TBR[3,4]							AMDS[2]
	ASTM D7741/ D7741M	1.5-4.0[5]							Refer Clause 8
Flash Point, °C, minimum	AG:PT/ T112	250[6]							AMDS[2] and as nominated by the Contractor during production
Loss on Heating, %, maximum	AG:PT/ T103	0.6[6]							

1. TBN denotes to be nominated by the Contractor. Where the contractor desires to store the crumb rubber modified binder in excess of 10 hours (after the 60 minute reaction period) but not more than 4 days (96 hours after the 60 minute reaction period) prior to usage, testing should be completed to confirm compliance with specification requirements.
2. Asphalt mix design submission.
3. TBR denotes to be reported.
4. The test results are used to demonstrate the minimum and maximum reaction (and storage) time for the crumb rubber modified binder.
5. The Viscosity at 175ºC of the crumb rubber modified binder at the time of usage shall be 1.5 – 4.0 Pa.s.
6. Reaction time does not apply to this property.

Minimum compliance testing requirements nominated in Table 5-A and Table 5-B apply to crumb rubber modified binder and take precedence over those stated in MRTS18 *Polymer Modified Binder*.

Two litre samples of binder shall also be supplied to the Administrator for each batch. Samples shall be taken as follows:

- 60 minutes after the incorporation of the rubber into the binder, and
- Immediately prior to incorporation of the binder into the asphalt.

The Contractor need not have NATA accreditation for the ASTM tests in Table 5-A and Table 5-B.

6 Crumb Rubber (scrap rubber)

Crumb rubber must be processed from tyre waste obtained from a Tyre Stewardship Australia Accredited Tyre Recycler.

The use of uncured or devulcanized rubber is not permitted. The crumb rubber must be dry, free-flowing particles that do not stick together. The crumb rubber must not cause foaming when combined with the bituminous binder. The crumb rubber shall be an essentially uniform material and meet the requirements of Table 6.

Table 6 – Crumb Rubber Properties

Test	Method	Requirement
Grading	AGPT/T143	
passing 2.36 mm		100
passing 1.18 mm		#
passing 600 µm		#
passing 300 µm		#
passing 150 µm		#
passing 75 µm		#
Particle length (mm) max.	AGPT/T143	3
Bulk density (kg/m^3)	AGPT/T144	Report
Water content (%) max.	AGPT/T143	1
Foreign materials – other than iron (%) max.	AGPT/T143	0.1
Foreign materials – metallic iron (%) max.	AGPT/T143	0.1

[#] target grading and production tolerances to be nominated by the Contractor as part of the asphalt mix design submission.

The Contractor need not have NATA accreditation for the tests listed in Table 6.

A certificate of compliance shall be provided by the Contractor confirming that all of the crumb rubber requirements have been met.

7 Additives

Additives shall comply with the requirements in MRTS 30 except that the use of water as a warm mix asphalt additive is not permitted.

A warm mix asphalt additive must be incorporated into the asphalt at locations nominated on the Drawings (or as directed by the Administrator).

8 Requirements for Asphalt

8.1 Particle size distribution of combined aggregate and filler

The particle size distribution of the asphalt aggregate and filler for open graded asphalt must conform to Table 7.2.1.1-B of MRTS30 *Asphalt Pavements*.

8.2 Mix design

Crumb rubber modified open graded asphalt need not comply with the requirements of Clauses 7.2.2, 7.2.9 and 7.2.10 of MRTS30 *Asphalt Pavements*.

However, the contractor shall provide test results for the following properties as part of the asphalt mix design submission:

- Air voids in laboratory compacted specimens,
- Asphalt binder drain-off, and
- Asphalt particle loss.

Asphalt mix design testing shall be completed using binder contents of 5.0%, 6.0%, 7.0% and 8.0% by mass of the asphalt mix. These test results will be used by the Asphalt Mix Design Registrar to determine the nominated binder content for the mix design.

The nominated binder content will be selected based on an evaluation of:

- laboratory air void content (18% minimum),
- binder film index (18 minimum when determined in accordance with AS2891.8 or AG:PT/T237, or 17 minimum when determined in accordance with Q317)
- asphalt particle loss (20% maximum), and
- asphalt binder drain-off (0.3% maximum) results.

The Asphalt Mix Design Registrar will advise the Prequalified Asphalt Contractor of the nominated binder content for the mix within fourteen days of the receipt of a conforming mix design submission.

Asphalt mix design testing shall then be completed at the binder content nominated by the Asphalt Mix Design Registrar and the test results submitted to the Asphalt Mix Design Registrar and the Administrator at least 7 days before the mix is incorporated into the Works. Testing for equivalent compaction temperature for warm mix asphalt (Test Method Q323), asphalt particle loss (Test Method AG:PT/T236 and asphalt binder drain-off (Test Method AG:PT/T235) shall also be completed with the Contractor's nominated warm mix asphalt additive incorporated into the mix.

A production trial need not be completed as part of the asphalt mix design submission.

The binder grade (CR1 or CR2) to be used in the mix design shall be nominated on the asphalt mix design certificate e.g. OG14 (CR1).

Air voids in laboratory compacted specimens shall be reported for each lot of the Works.

9 Binder Storage and handling

Once the crumb rubber modified binder has been mixed, it shall be kept thoroughly agitated to prevent settling of the crumb rubber particles. The temperature of the crumb rubber modified binder shall be maintained between 165 and 190ºC.

If in the first ten hours after the completion of the reaction period the temperature of the crumb rubber modified binder drops below 165ºC, it may be reheated to a temperature between 165 and 190ºC.

In no case shall the crumb rubber modified binder be held at a temperature between 165 to 190ºC for more than ten hours after the completion of the reaction period. Crumb rubber modified binder that is to be held for more than ten hours shall be allowed to cool and gradually reheated to a temperature between 165 and 190ºC before use.

The reheating of crumb rubber modified binder that has cooled below 165ºC shall not be allowed more than one time unless otherwise approved by the Administrator.

Crumb rubber modified binder shall not be held at temperature above 120ºC for more than four days after the completion of the reaction period unless otherwise approved by the Administrator.

For each load or batch of crumb rubber modified binder, the Contractor shall provide to the Administrator with the following documentation:

- The temperature of the bitumen prior to the addition of crumb rubber
- The crumb rubber content expressed as percent by the weight of total binder
- Times and dates of the crumb rubber additions and resultant binder viscosity.
- A record of the temperature, with time and date reference for each load or batch. The record shall begin at the time of the addition of crumb rubber and continue until the load or batch is completely used. Readings and recordings shall be made at every temperature change in excess of 11ºC, and as needed to document other events which are significant to batch use and quality.

Immediately prior to use, the viscosity of the crumb rubber modified binder shall be tested by the Contractor with a rotational viscometer (ASTM D7741/D7741M). The binder shall have a viscosity at 175ºC of 1.5 – 4.0 Pa.s.

If the binder is found to no longer satisfy the requirements of Table 5, the Contractor may propose to add up to 10% crumb rubber to the binder in order to bring its properties back within the specified limits. The additional crumb rubber would need to be thoroughly mixed through the binder, the 60 minute reaction period observed and compliance of the binder conformed prior to use.

10 Asphalt manufacturing temperatures

Unless otherwise approved by the Administrator (e.g. where a warm mix asphalt additive in used in the mix), the temperature of the crumb rubber modified binder must be between 165 and 190°C when mixed with aggregate. The temperature of the crumb rubber modified open graded asphalt shall not exceed 190ºC at any time during the asphalt manufacturing process.

11 Pavement temperature and weather conditions

Unless otherwise accepted by the Administrator, placement of crumb rubber modified open graded asphalt shall not commence or continue, unless the pavement surface temperature complies with the requirements of Table 10. Table 10 replaces the minimum pavement surface temperature requirements for asphalt placement provided in Table 8.7 of MRTS30 *Asphalt Pavements*.

Table 10 – Minimum pavement surface temperature for asphalt placement

Asphalt Type	**Nominal Size of Asphalt (Asphalt Designation)**	**Minimum Surface Temperature for Asphalt Placement (°C)**
Crumb rubber modified open graded asphalt	10 mm (OG10)	20
	14 mm (OG14)	20

12 Material transfer vehicle

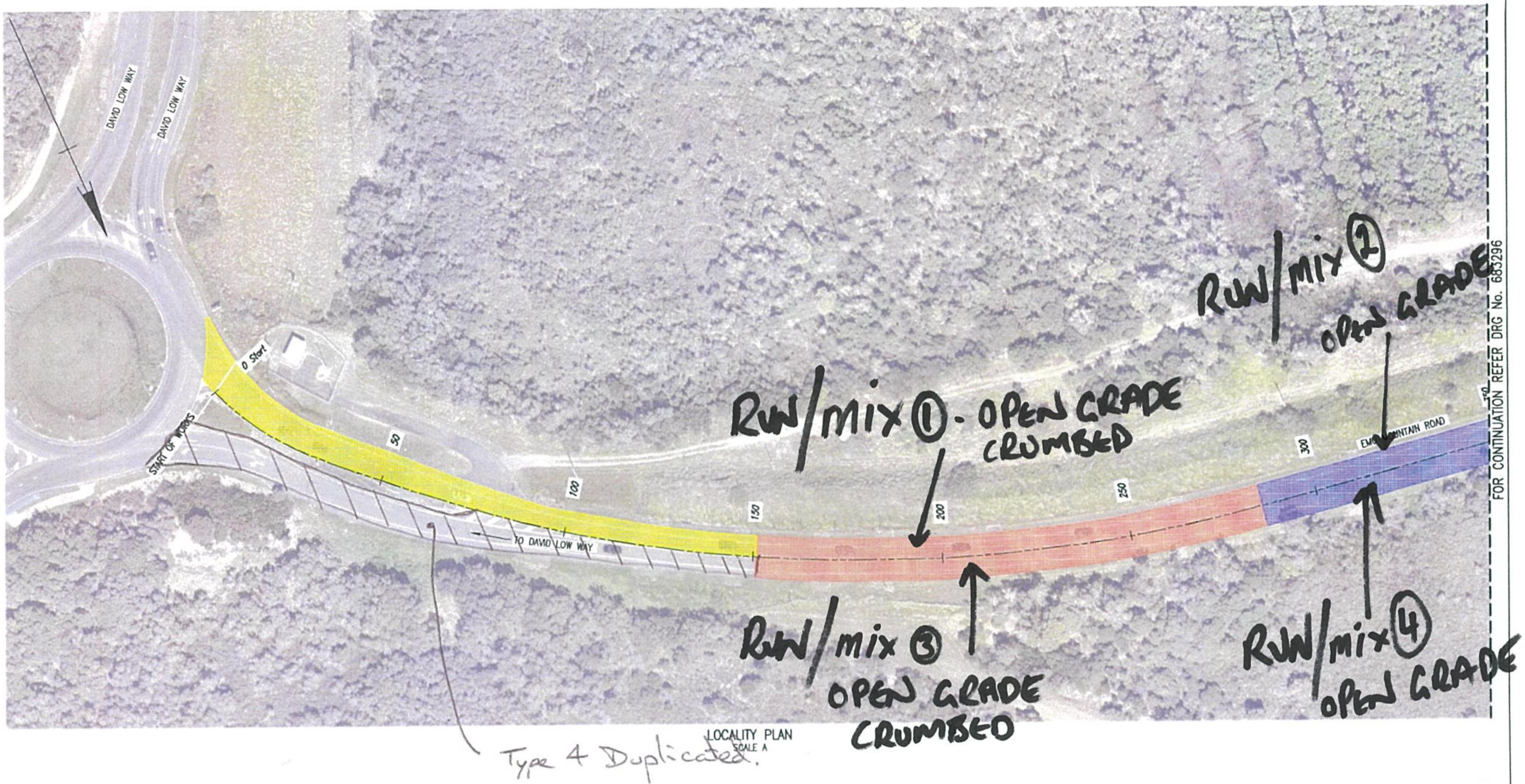
A material transfer vehicle must be used in the paving process for crumb rubber modified open graded asphalt except for areas to be paved at tapers, turning lanes less than 100 m in length, roundabouts of radius less than 50 m, and other areas approved to be excluded by the Administrator.

13 Compaction requirements

For crumb rubber modified open graded asphalt, unless otherwise approved by the Administrator (e.g. where a warm mix asphalt additive in used in the mix), the following minimum compaction requirements shall apply:

- steel wheeled rollers used to compact the asphalt mat shall have a minimum mass of 6 tonnes
- the temperature of the asphalt at the time of commencement of rolling shall be ≥ 135°C, and
- at least 5 passes of the steel wheel roller(s) shall be completed within 20 minutes of discharge of the asphalt into the paver receiving hopper.

APPENDIX D DEMONSTRATION PROJECT CHAINAGE LOCATIONS



LOCALITY PLAN
SCALE A

FOR PAVEMENT MATERIAL NOTES, SPECIFICATIONS AND DETAILS REFER DRG NO. 683297

	Revisions/Descriptions	Certification	Date	Microfiled
G				
F				
E				
D				
C				
B	Works Extended	NBG	17.10.16	
A	Issued For Construction			

Associated Job Nos

Auxiliary Drg Nos

Survey Data	
Datum	
Horiz. Grid	
Height Origin	
Survey Books	

Scales

A 0 5 10 15 20m

Dimensions shown in metres except where shown otherwise

SUNSHINE COAST REGIONAL COUNCIL

EMU MOUNTAIN ROAD (144) C1

CTL CHGE CH:0.00km – CH:0.97km

Reference Points

Preceding RP	Dist. to start of job (km)	From start to end of job	From end to Following RP	Following RP

Through Chainage from

PAVEMENT DETAILS
SHEET 1 OF 2

Drawn AD
Designed NBG

ENGINEERING CERTIFICATION (RPEQ)

ENG. AREA	NAME	SIGNATURE	NO.	DATE
CIVIL	N. Bosman – Gertenbach		17072	10/16

Queensland Government

Job No.	R07/R002/706
Contract. No.	NCHD-2702
Drawing No.	683295 1B
Series Number	PD-01 of 04

MRR_Detail (08/13)

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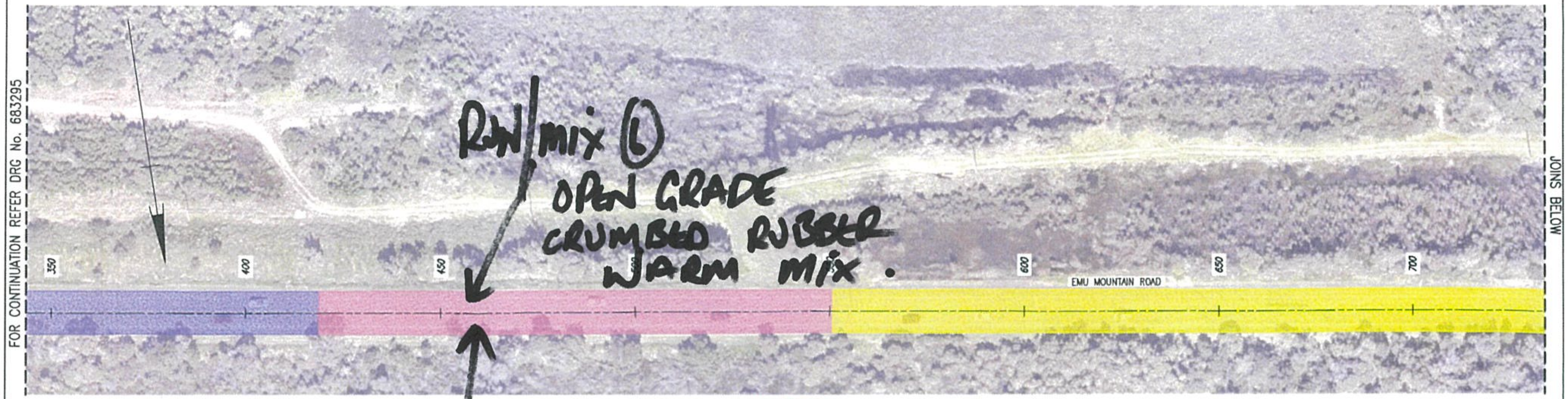
Last Modified :- Oct 17, 2016 – 3:00pm XREFS :- X_MG_0.20km – 0.80km.dwg ; X_CLINE.dwg ; X_PAVE.dwg



RUN/mix ⑥
OPEN GRADE
CRUMBED RUBBER
WARM MIX.

LOCALITY PLAN
SCALE A

RUN/mix ⑤
OPEN GRADE
CRUMBED RUBBER
WARM MIX

LOCALITY PLAN
SCALE A

FOR PAVEMENT MATERIAL NOTES, SPECIFICATIONS AND DETAILS REFER DRG NO. 683297

Last Modified :- Oct 17, 2016 - 3:00pm XREFS :- X_IMG_0.20km - 0.50km.dwg ; X_CLINE.dwg ; X_PAVE.dwg

	Revisions/Descriptions	Certification	Date	Microfiled
G				
F				
E				
D				
C				
B	Works Extended	NBG	17.10.16	
A	Issued For Construction			

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Associated Job Nos

Auxiliary Drg Nos

Survey Data	
Datum	
Horiz. Grid	
Height Origin	
Survey Books	

Scales
A 0 5 10 15 20m

Dimensions shown in metres except where shown otherwise

SUNSHINE COAST REGIONAL COUNCIL
EMU MOUNTAIN ROAD (144) C1
CTL CHGE CH:0.00km – CH:0.97km

Reference Points

Preceding RP	Dist. to start of job (km)	From start to end of job	From end to Following RP	Following RP

Through Chainage from

PAVEMENT DETAILS
SHEET 2 OF 2

Drawn AD
Designed NBG

ENGINEERING CERTIFICATION (RPEQ)

ENG. AREA	NAME	SIGNATURE	NO.	DATE
CIVIL	N. Bosman – Gertenbach		17072	10/16

Queensland Government

Job No.	R07/R002/706
Contract. No.	NCHD-2702
Drawing No.	683296 1B
Series Number	PD-02 of 04

MRR_Detail (06/13)

APPENDIX E QAEHS EMISSIONS MONITORING REPORT

THE UNIVERSITY OF QUEENSLAND AUSTRALIA | Queensland Alliance for Environmental Health Sciences

Monitoring of emissions from standard and crumb rubber modified asphalt

Xianyu Wang, Meng Xiu, Li Yan, David Pass, Jochen Mueller, Phong Thai

April 2017

Report compiled by
Phong Thai

Project Team
Xianyu Wang, Meng Xiu, Li Yan, David Pass, Jochen Mueller, Phong Thai

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Table of Contents

Abbreviations

BaP	Benzo[a]pyrene
CRM	Crumb rubber modified
GFF	Glass fibre filter
PAHs	Polycyclic aromatic hydrocarbons
TMR	Transport and Main Roads, Queensland
TSP	Total suspended particles
PM_{10}; $PM_{2.5}$	Particulate matter with aerodynamic diameter less than 10, 2.5 μm.
VOCs	Volatile organic compounds
LOR	Limit of Report

Introduction

The introduction of crumb rubber in bitumen and asphalt used in road construction can be a potentially valuable way to recycle the vast amount of used tyres in Australia. However, there have been environmental and occupational health and safety concerns surrounding the use of crumb rubber modified (CRM) binder/asphalt, especially regarding the emission of harmful organic chemicals during road construction (i.e. high temperature condition).

Previously we have reported the level of volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) as well as the total suspended particles (TSP) emitted from mixes containing CRM binder and conventional Polymer Modified Binder (PMB) during a pavement sprayed seal trial held in South East Queensland. This study suggested that future trials include the personal monitoring of particulate matter emitted during the pavement works.

In this study, we continued with the monitoring of VOC, PAH, and TSP emissions from crumb rubber and standard asphalt mixes. Additionally, we conducted personal monitoring for different types of particulate matter (TSP, PM_{10}, $PM_{2.5}$) during the pavement work.

The objectives of the project were to:
a) Measure the emission concentrations of VOCs and PAHs from different asphalt mixes;
b) Measure the levels of different PM types that key workers are exposed to during paving operations;
c) Evaluate if there is any difference in pollutant emissions between different asphalt mixes.

Methodology

		Measuring parameters
Paving date:	Wednesday 22nd February, 2017	
Paving location:	Emu Mountain Road, Peregian Beach	Personal PM measurement
Manufacturing plant:	Downer EDI Works Asphalt Plant, Cooney Road, Bli Bli	Emission chamber testing

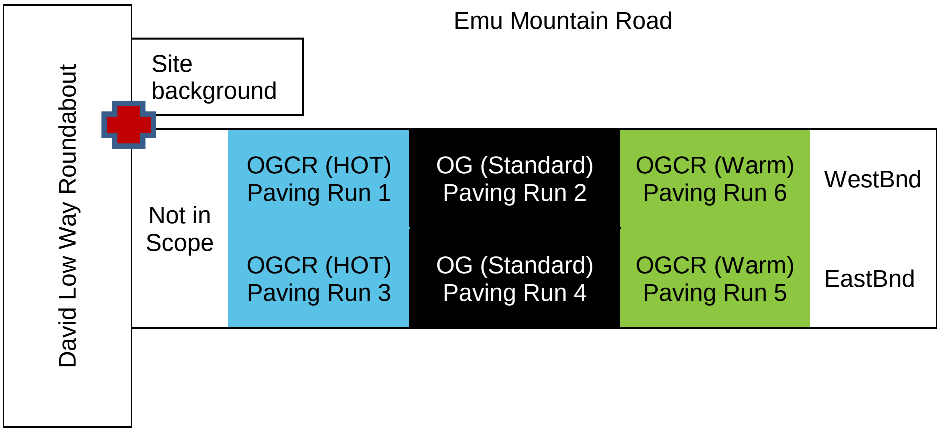


Figure 1. Pavement site layout with allocations of different asphalt runs

Figure 2. Personal monitoring for particulate matter (PM) during pavement work (red circle)

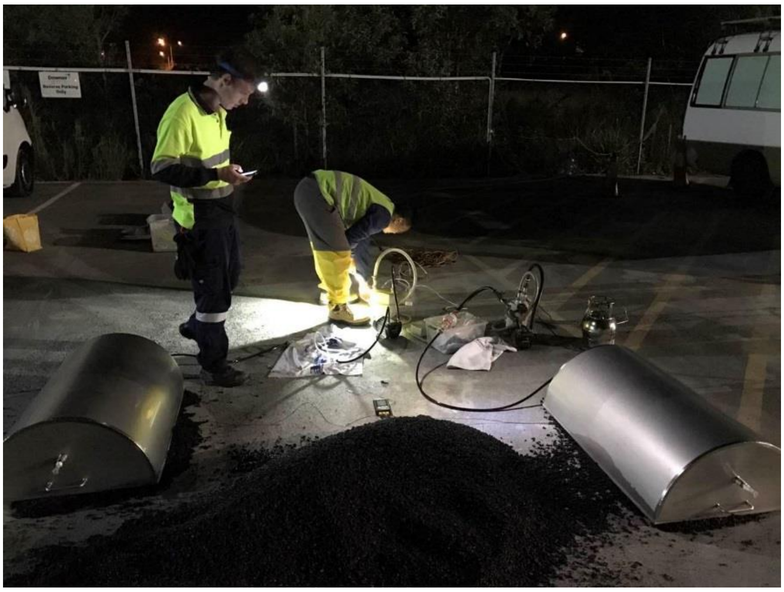


Figure 3. Setup of emission chamber testing

Air sampling

a) Personal sampling for PM.

The levels of PM in the field were monitored by the DustMate device (Turnkey Instruments, UK), which is a lightweight portable light scattering particulate monitor that is capable of measuring total suspended particles (TSP), PM_{10} and $PM_{2.5}$ with a resolution of 0.1 $\mu g\ m^{-3}$. Air is drawn into the instrument at a rate of 0.6 $L\ min^{-1}$, and the flow is configured so that only one particle is illuminated by the laser light beam (670 nm) at any particular moment in time. The signal obtained from the diffraction of these individual particles is then converted to an equivalent mass concentration. The sampling frequency was set at every 1 minute. DustMate has good correlation with reference method but will probably underestimate the fine particulate fractions due to the higher proportion of volatile organics (Deary et al., 2016).

Background sampling was conducted in an urban setting (Brisbane) and on site before paving and during the break between different runs. During the paving work, the DustMate was worn by the worker (paver driver or screed operator) as shown in Fig. 2.

b) Sampling for VOCs and TSP from emission chamber #1.

For VOC analysis, an air sample was collected using a pre-evacuated vacuum canister equipped with a vacuum gauge and a critical orifice controller. Sampling canisters were cleaned by repeated evacuating and filling of humidified zero air for 4–5 cycles.

During the test, the canisters were connected to the chamber and were filled within 30-60 seconds. Due to time constraint, only two samples were collected for each chamber test (i.e. each asphalt mix).

Once the VOC sampling was completed the chamber was connected to a low volume sampler (LVS) operating at a flow rate at ~67 L min^{-1} to collect TSP sample. The air from the chamber was drawn through a glass fibre filter (GFF) where the solid particles were trapped and measured. Each sample was collected during one hour as shown in Table 1.

c) Sampling for PAHs from emission chamber #2.

Another LVS was used to collect emitted PAHs. Air was drawn through a polyurethane foam (PUF) plug and subsequent XAD resin to collect PAHs. After sampling, the cartridges were stored at -20 ℃ until analysis.

Background samples for VOCs, TSP, and PAHs were collected at the site right before the application.

Details about the sample collection are shown in Table 1.

Table 1. Chamber sampling information

	Chamber #1 – TSP and VOC	**Chamber #2 –PAHs**
Background sampling	0-1 hour	0-1 hour
Then switch to:		
Rubber (hot mix)	0-1 hour	0-1 hour
Rubber (hot mix)	1-2 hour	1-2 hour
Then switch to:		
Polymer (control mix)	0-1 hour	0-1 hour
Polymer (control mix)	n.a.	n.a.
Then switch to:		
Rubber + warm mix	0-1 hour	0-1 hour
Rubber + warm mix	1-2 hour	1-2 hour

n.a.: due to time constraints and delays in receiving additional mix to test from the plant

Chemical Analysis

a) VOCs analysis

Analysis of VOCs was performed using established protocol (USEPA Method TO-15). Air samples from the canisters were analysed using gas chromatography-mass spectrometry (GC-MS).

b) TSP measurement

The mass of TSP collected on the GFF samples were dried in a desiccator for 7 days before being weighed by an analytical balance.

c) PAHs analysis

PAHs were extracted from the PUF-XAD sampling trains using an Accelerated Solvent Extractor after being spiked with a solution containing 8 deuterated PAHs at different levels as the internal standards. Extracts were concentrated to 1 mL in hexane before cleaned up by neutral alumina and silica. After cleanup, the samples were carefully blown down to 25 µL and a recovery standard was added before instrument analysis.

Samples were analysed using a Thermo DFS high resolution mass spectrometer (HRMS) coupled to a Thermo TRACE 1310 gas chromatograph (GC). 1.6 µL of each sample was injected in splitless mode and a DB-5MS column (J&W Scientific) was used to separate the compounds. The HRMS was operated in electron impact (EI) mode applying an electron energy of 70eV. Resolution was set to ≥10,000 (10% valley). The instrument was operated in multiple ion detection (MID) mode and a total of 13 PAHs were screened and quantified: phenanthrene (Phe), anthracene (Ant), fluoranthene (Flu), pyrene (Pyr), benzo[a]anthrancene (BaA), chrysene (Chr), benzo[b]fluoranthene (BbF), benzo[k]fluoranthene (BkF), benzo[e]pyrene (BeP), benzo[a]pyrene (BaP), indeno[1,2,3-c,d]pyrene (IcdP), dibenzo[a,h]anthracene (DahA) and benzo[g,h,i]perylene (BghiP). These PAH compounds are among the priority PAHs listed by the US EPA and some are known to be carcinogenic to humans such as BaP, probably carcinogenic to humans such as DahA and possibly carcinogenic to humans such as BaA, Chr, BbF, BkF and IcdP (WHO).

Results and Discussion

Particulate matter

Background:

The TSP, PM_{10} and $PM_{2.5}$ at an urban site in Brisbane is well within the Air Quality Objective of Queensland Government (State of Queensland, 2012).

At work site

Compared to background levels in the urban area, the levels of TSP and PM in the area around the paving site (during preparation and paving) were higher, as expected. Site background #1 and #2 were higher than the urban background but because they were monitored when the paving activities were underway on site, such levels were not unexpected. Site background #1 was higher than #2 because it was closer to the paving activities.

Concentrations of TSP, PM_{10} and $PM_{2.5}$ measured during Run#1, #4, #5 were not significantly different ($p>0.05$). These results suggested that there is no significant difference in emission of TSP, PM_{10} and $PM_{2.5}$ among asphalt mixes. The high concentration of TSP, PM_{10} and $PM_{2.5}$ could be seen during the dumping of asphalt from trucks to the paver. It can be seen from the large range of PM concentrations in the scatter plots (Fig. 4).

Run #6 was significantly lower than other runs, which probably indicated the impact of temperature of the actual mix on site to emission rather than the manufacturing temperature of the mix at manufacturing plant.

Table 2. Descriptive statistics of PM data (μg/m^3)

		Urban	#1 Site background	Run #1	Run #4	Run #5	#2 Site background	Run #6
TSP	*Median*	*44.4*	*228.8*	*260.2*	*241.8*	*126.1*	*133.6*	*125*
	Mean	48.52	228.2	622.6	665.6	1017	144.9	167.6
PM_{10}	*Median*	*25.9*	*142.9*	*154.7*	*191.5*	*77.1*	*84.7*	*77.6*
	Mean	30.44	138.1	547.9	630.9	961.3	88.54	125.9
$PM_{2.5}$	*Median*	*5.82*	*24.09*	*62.9*	*78.92*	*28.44*	*13.51*	*21.1*
	Mean	7.193	24.41	125.6	117.5	133.7	14.31	41.64

The data measured in different Runs are personal exposure data (see Fig. 1)

Exposure compared to legal limit

At the moment, there is NO legal limit for occupational exposure to asphalt fumes in Australia. Only the US National Institute for Occupational Safety and Health (NIOSH), the US Occupational Safety and Health Administration (OSHA), and American Conference of Governmental Industrial Hygienists (ACGIH) have proposed the limits for exposure to particulate during pavement works.

In Table 3, the limits for two approximate forms of dust to asphalt fume are presented. And in Table 4, the proposed limits for asphalt fumes in the US are presented.

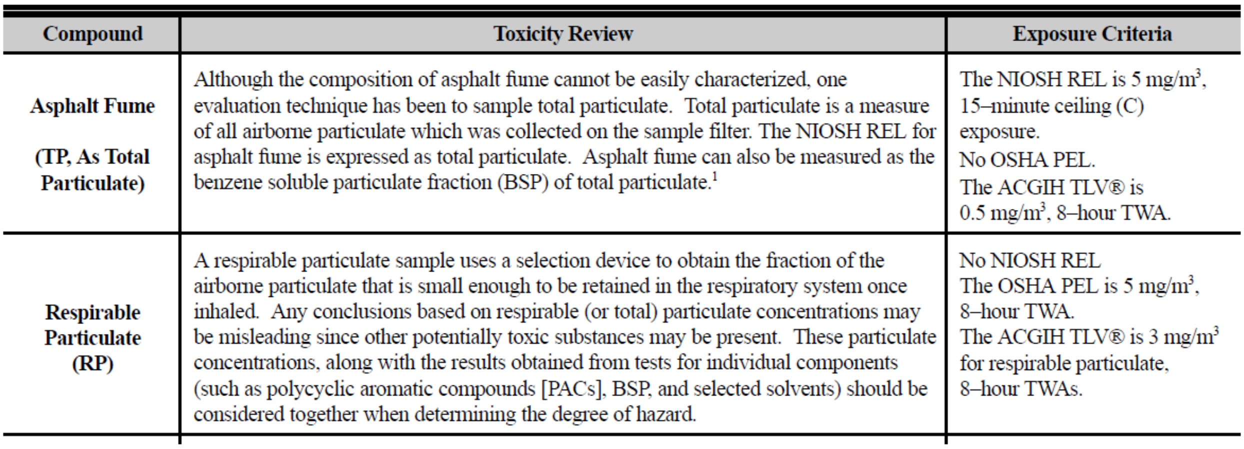
It can be seen from Tables 2, 3, and 4 that the levels of personal exposure recorded in all runs of this study are under the limits.

Table 3. Excerpt from workplace exposure standards for airborne contaminants (Safe Work Australia)

	8-hour TWA ($\mu g/m^3$)
Coal dust (containing < 5% quartz) (respirable dust)	3,000
Fumed silica (respirable dust)	2,000

8-hour Time-weighted average (TWA) means the maximum average airborne concentration of a substance when calculated over an eight-hour working day, for a five-day working week.

Table 4. Occupational limit to PM from US National Institute for Occupational Safety and Health (NIOSH), Occupational Safety and Health Administration (OSHA), and American Conference of Governmental Industrial Hygienists (ACGIH)



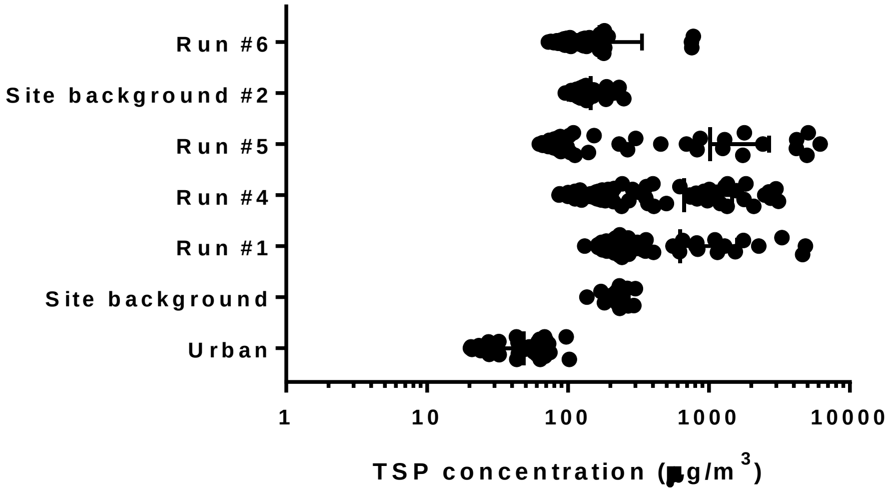
Compound	Toxicity Review	Exposure Criteria
Asphalt Fume **(TP, As Total Particulate)**	Although the composition of asphalt fume cannot be easily characterized, one evaluation technique has been to sample total particulate. Total particulate is a measure of all airborne particulate which was collected on the sample filter. The NIOSH REL for asphalt fume is expressed as total particulate. Asphalt fume can also be measured as the benzene soluble particulate fraction (BSP) of total particulate.[1]	The NIOSH REL is 5 mg/m^3, 15–minute ceiling (C) exposure. No OSHA PEL. The ACGIH TLV® is 0.5 mg/m^3, 8–hour TWA.
Respirable Particulate (RP)	A respirable particulate sample uses a selection device to obtain the fraction of the airborne particulate that is small enough to be retained in the respiratory system once inhaled. Any conclusions based on respirable (or total) particulate concentrations may be misleading since other potentially toxic substances may be present. These particulate concentrations, along with the results obtained from tests for individual components (such as polycyclic aromatic compounds [PACs], BSP, and selected solvents) should be considered together when determining the degree of hazard.	No NIOSH REL The OSHA PEL is 5 mg/m^3, 8–hour TWA. The ACGIH TLV® is 3 mg/m^3 for respirable particulate, 8–hour TWAs.

PEL Permissible exposure limit (OSHA exposure criteria)

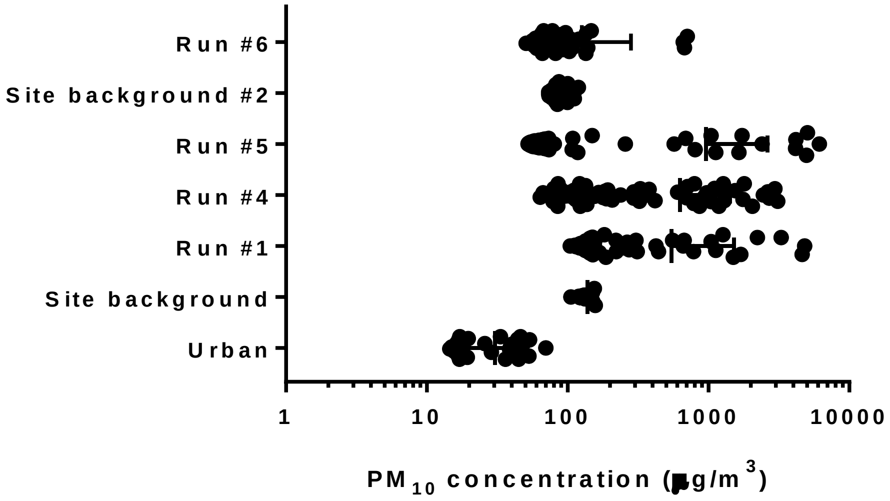
REL Recommended exposure limit (NIOSH exposure criteria)

TLV Threshold limit value (ACGIH exposure criteria)

TSP concentration in different runs



PM10 concentration in different runs



PM2.5 concentration in different runs

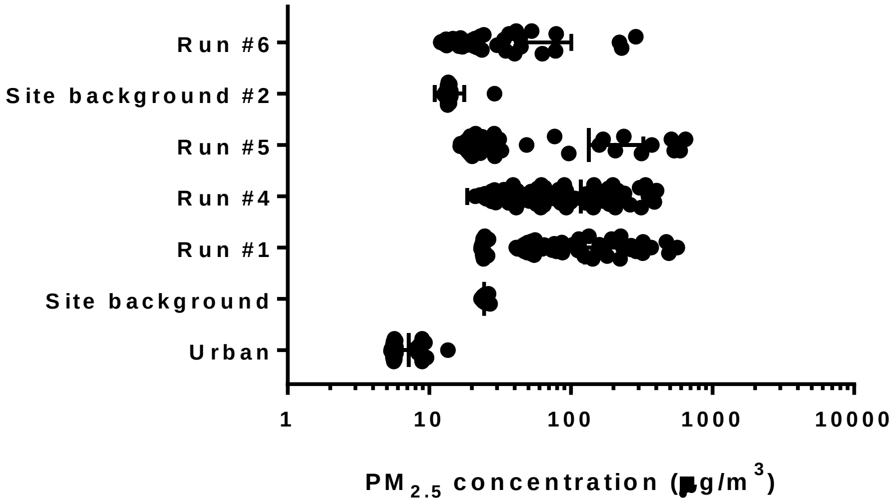


Figure 4. Scatter plots of PM data across different runs

(Note the logarithmic scale; the bars indicate the mean value ± standard deviation; some lower error bars are missing because they would go to negative values)

VOCs

Background:

The levels of VOCs were low in background sample except for some compounds with low molecular weight (butane, isobutane, pentane, 2-methyl butane) whose concentrations were higher than those from asphalt mixes. That is probably because of the use of LPG at the site and there was not competition from other VOCs from the asphalt.

From asphalt mixes:

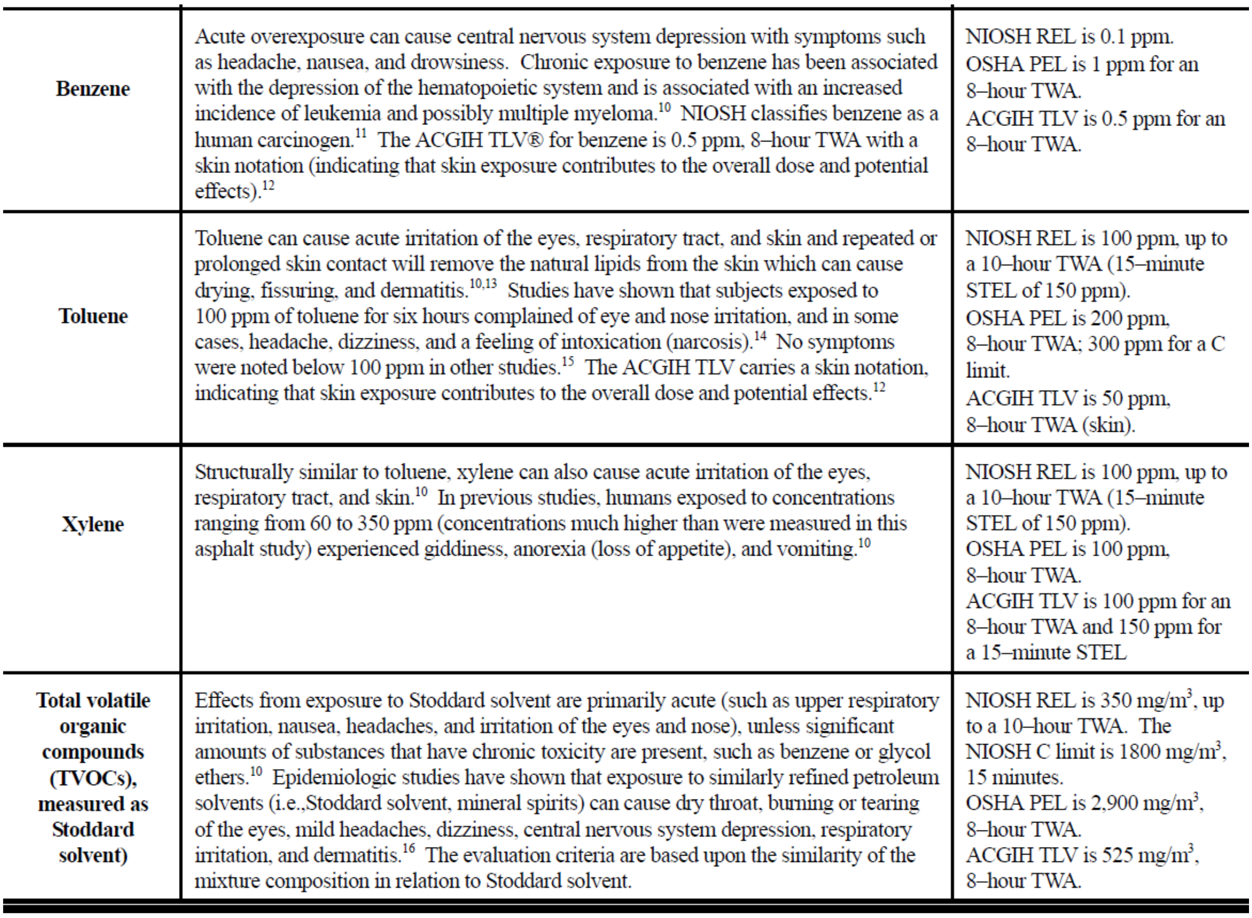
There were no detection of halogenated VOCs from the mixes apart from chloromethane and methylene chloride, whose levels were low and not much different from the background (for chloromethane) or between polymer and background (for methylene chloride).

Regarding the emissions of other VOCs, the measured concentrations varied from compound to compound and it is not possible to conclusively compare the emissions between OGCR mixes and the polymer mix. Meanwhile, qualitatively, OGCR (hot mix) could be seen to produce higher concentrations of VOCs than OGCR (warm mix). Detailed results are showed in Table 6.

Exposure compared to legal limit

At the moment, there is NO legal limit for occupational exposure to asphalt fumes in Australia. Compared to the occupational limits proposed in the US, the exposure concentrations of total VOCs and individual VOCs (BTEX) measured in this study are lower, except that the concentrations of benzene in CRM could surpass the US limit if no dilution factor is considered. If there is a source of benzene to CRM, that should be considered to be replaced to reduce the risk to workers.

Table 5. Proposed limits for VOCs from different American Institutions



Benzene	Acute overexposure can cause central nervous system depression with symptoms such as headache, nausea, and drowsiness. Chronic exposure to benzene has been associated with the depression of the hematopoietic system and is associated with an increased incidence of leukemia and possibly multiple myeloma.[10] NIOSH classifies benzene as a human carcinogen.[11] The ACGIH TLV® for benzene is 0.5 ppm, 8–hour TWA with a skin notation (indicating that skin exposure contributes to the overall dose and potential effects).[12]	NIOSH REL is 0.1 ppm. OSHA PEL is 1 ppm for an 8–hour TWA. ACGIH TLV is 0.5 ppm for an 8–hour TWA.
Toluene	Toluene can cause acute irritation of the eyes, respiratory tract, and skin and repeated or prolonged skin contact will remove the natural lipids from the skin which can cause drying, fissuring, and dermatitis.[10,13] Studies have shown that subjects exposed to 100 ppm of toluene for six hours complained of eye and nose irritation, and in some cases, headache, dizziness, and a feeling of intoxication (narcosis).[14] No symptoms were noted below 100 ppm in other studies.[15] The ACGIH TLV carries a skin notation, indicating that skin exposure contributes to the overall dose and potential effects.[12]	NIOSH REL is 100 ppm, up to a 10–hour TWA (15–minute STEL of 150 ppm). OSHA PEL is 200 ppm, 8–hour TWA; 300 ppm for a C limit. ACGIH TLV is 50 ppm, 8–hour TWA (skin).
Xylene	Structurally similar to toluene, xylene can also cause acute irritation of the eyes, respiratory tract, and skin.[10] In previous studies, humans exposed to concentrations ranging from 60 to 350 ppm (concentrations much higher than were measured in this asphalt study) experienced giddiness, anorexia (loss of appetite), and vomiting.[10]	NIOSH REL is 100 ppm, up to a 10–hour TWA (15–minute STEL of 150 ppm). OSHA PEL is 100 ppm, 8–hour TWA. ACGIH TLV is 100 ppm for an 8–hour TWA and 150 ppm for a 15–minute STEL
Total volatile organic compounds (TVOCs), measured as Stoddard solvent)	Effects from exposure to Stoddard solvent are primarily acute (such as upper respiratory irritation, nausea, headaches, and irritation of the eyes and nose), unless significant amounts of substances that have chronic toxicity are present, such as benzene or glycol ethers.[10] Epidemiologic studies have shown that exposure to similarly refined petroleum solvents (i.e.,Stoddard solvent, mineral spirits) can cause dry throat, burning or tearing of the eyes, mild headaches, dizziness, central nervous system depression, respiratory irritation, and dermatitis.[16] The evaluation criteria are based upon the similarity of the mixture composition in relation to Stoddard solvent.	NIOSH REL is 350 mg/m^3, up to a 10–hour TWA. The NIOSH C limit is 1800 mg/m^3, 15 minutes. OSHA PEL is 2,900 mg/m^3, 8–hour TWA. ACGIH TLV is 525 mg/m^3, 8–hour TWA.

Table 6. Emission concentrations of VOCs from different asphalt mixes and background measurement

Emission concentration – VOCs (mg/kg or ppm)								
Sample code		#1 VOC	#2 VOC	#5 VOC	#6 VOC	#3 VOC	BA VOC	LOR
Sample type		OGCR (hot mix)		OGCR (warm mix)		OG Polymer	Background	
Asphalt mass load (kg)		56.08		49.326		43.032	NA	
Sampling duration		0 h	1 h	0 h	1 h	0 h	0 h	ppbv
Temp range (°C)		150.8 – 98.6 °C	95.3 – 77.0 °C	132.3 – 88.2 °C	85.9 – 67.5 °C	154.5 – 98.6 °C	NA	
Alkanes	Butane	**0.39**	**0.13**	**0.53**	**0.08**	**0.30**	**1.10**	13
	Pentane	**0.61**	**0.21**	**0.68**	**0.11**	**0.31**	**0.49**	13
	Hexane	**1.28**	**0.11**	**0.54**	**0.09**	**0.19**	**0.10**	13
	Heptane	**1.85**	**0.11**	**0.40**	**0.14**	**0.12**	< LOR	13
	Octane	**2.38**	**0.22**	**1.67**	**0.37**	**0.39**	< LOR	13
	Nonane	**2.61**	**0.34**	**0.66**	**0.44**	**0.13**	< LOR	13
	Decane	**2.96**	**1.00**	**0.77**	**1.36**	**0.34**	< LOR	13
	Undecane	**3.64**	**4.33**	**1.82**	**3.29**	**4.59**	**0.54**	13
Branched alkanes	Isobutane	**0.12**	**0.04**	**0.23**	**0.03**	**0.09**	**0.55**	13
	2-Methyl butane	**0.19**	**0.19**	**0.33**	**0.10**	**0.32**	**1.78**	13
	2,2,4-Trimethylpentane	< LOR	< LOR	< LOR	< LOR	**0.07**	< LOR	13
Cycloalkanes	Cyclohexane	**2.46**	**0.11**	**1.58**	**0.23**	**0.09**	**0.09**	13
Alkenes	Propylene	**0.63**	**0.10**	**0.65**	**0.08**	**0.29**	**0.02**	13
	1,3-Butadiene	< LOR	< LOR	**0.03**	< LOR	< LOR	< LOR	13
Aromatics	Benzene	2.17	0.11	1.04	0.16	0.08	0.04	13
	Toluene	0.46	0.10	0.48	0.13	6.24	0.41	13
	Ethylbenzene	**0.92**	**0.14**	**0.38**	**0.19**	**0.41**	< LOR	13
	m- & p-Xylene	12.67	5.13	7.65	5.67	2.60	0.22	13
	o-Xylene	0.80	0.11	0.33	0.15	0.82	0.05	13
	Styrene	**1.49**	**0.12**	**1.03**	**0.18**	< LOR	< LOR	13
	4-Ethyltoluene	**2.84**	**0.53**	**1.03**	**0.75**	**2.90**	**0.09**	13

	1,3,5-Trimethylbenzene	**1.22**	**0.15**	**0.37**	**0.22**	**2.21**	< LOR	13
	1,2,4-Trimethylbenzene	**2.46**	**0.74**	**0.82**	**1.03**	**3.83**	**0.09**	13
	p-Diethylbenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Naphthalene	**7.32**	**9.43**	**3.24**	**7.18**	**11.44**	**1.23**	13
Sulphur	Carbon disulfide	**0.03**	< LOR	< LOR	< LOR	< LOR	< LOR	13
Oxygenated hydrocarbons	Ethanol	**3.15**	**0.58**	**1.63**	**2.91**	**0.98**	**0.54**	13
	Acetone	**1.22**	**2.83**	**0.57**	**1.45**	**4.48**	**0.38**	13
	Methyl tert-butyl ether	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Methyl ethyl ketone	**0.27**	**0.64**	**0.11**	**0.89**	**0.06**	**0.05**	13
	Ethyl acetate	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Vinyl acetate	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Tetrahydrofuran	< LOR	< LOR	**0.09**	< LOR	< LOR	< LOR	13
	Methyl isobutyl ketone	**8.30**	**4.47**	**4.11**	**3.04**	**0.63**	**0.07**	13
	Methyl butyl ketone	< LOR	< LOR	**1.57**	**0.40**	**1.45**	< LOR	13
	Acrolein	2.00	0.30	**1.63**	**0.24**	**0.54**	< LOR	13
	1,4-Dioxane	< LOR	< LOR	**0.17**	< LOR	< LOR	< LOR	13
	Methyl methacrylate	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Nitriles	2-Propene nitrile	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Fluorinated alkanes	Dichlorodifluoromethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Dichlorotetrafluoroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Trichlorofluoromethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,1,2-Trichloro-1,2,2-trifluoroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Brominated alkanes	Bromomethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Bromodichloromethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Dibromochloromethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,2-Dibromoethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Bromoform	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Chlorinated alkanes	Chloromethane	**0.02**	**0.03**	**0.05**	**0.03**	**0.03**	0.03	13
	Chloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13

	1,1-Dichloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,2-Dichloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,1,1-Trichloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,2-Dichloropropane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,1,2-Trichloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,1,2,2-Tetrachloroethane	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Hexachlorobutadiene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Methylene Chloride	**0.08**	**0.30**	**0.10**	**0.04**	**0.05**	**0.04**	13
	Chloroform	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Carbon tetrachloride	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Brominated alkenes	Vinyl bromide	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Chlorinated alkenes	Vinyl chloride	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Allyl chloride	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,1-Dichloroethylene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	trans-1,2-Dichloroethylene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	cis-1,2-Dichloroethylene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Trichloroethylene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	cis-1,3-dichloropropene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	trans-1,3-dichloropropene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Tetrachloroethylene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
Chlorinated aromatics	Chlorobenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	Benzyl chloride	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,3-Dichlorobenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,4-Dichlorobenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,2-Dichlorobenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
	1,2,4-Trichlorobenzene	< LOR	< LOR	< LOR	< LOR	< LOR	< LOR	13
TOTAL VOC	**mg/m^3**	**86.50**	**42.41**	**59.77**	**10.26**	**47.16**	**40.24**	

LOR*: limit of report

TSP & PAHs from the chamber test

Background:
The levels of TSP and PAHs in background samples were all <LOR.

Between different mixes:
Significant increase in TSP and PAH concentrations were detected.

Table 7. Concentrations of TSP emitted from different asphalt mixes and background measurement

Emission concentration - TSP (μg m^{-3})							
Sample code	#1 TSP	#2 TSP	#5 TSP	#6 TSP	#3 TSP	BA TSP	LOR*
Sample type	OGCR (hot mix)		OGCR (warm mix)		OG Polymer	Background	
Asphalt mass load (kg)	56.08		49.326		43.032	NA	
Sampling duration	0 -1 h	1 - 2 h	0 -1 h	1 - 2 h	0 -1 h	0 -1 h	
Temp range (°C)	150.8 - 98.6 °C	95.3 - 77.0 °C	132.3 - 88.2 °C	85.9 - 67.5 °C	154.5 - 98.6 °C	NA	
TSP	**360**	**1,100**	**1,400**	**1,400**	**1,800**	<LOR	23

The TSP measured from chambers returned the highest level from OG Polymer. But one should note that this measurement was from a single measurement due to time constraint.

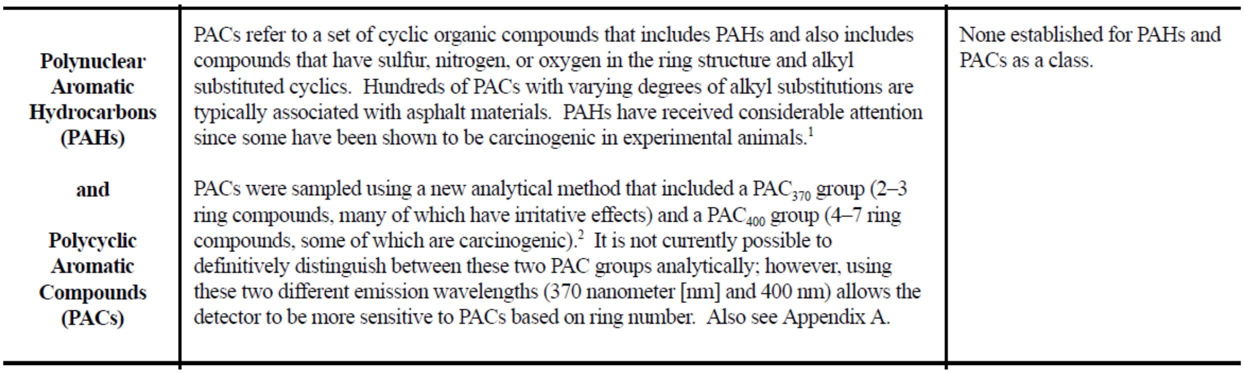
Concentrations of $\sum_{13}$ PAHs were higher from the OGCR (hot mix) emissions compared to OG Polymer and OGCR (warm mix). The concentration profile was dominated by lighter PAHs (3- and 4-ring compounds).

Table 8. Concentrations of PAHs emitted from different asphalt mixes and background measurement

Emission concentration - PAHs (μg m^{-3})							
Sample code	#1 PAHs	#2 PAHs	#5 PAHs	#6 PAHs	#3 PAHs	BA PAHs	LOR
Sample type	OGCR (hot mix)		OGCR (warm mix)		OG Polymer	Background	
Asphalt mass load (kg)	60.663		39.733		36.768	NA	
Sampling duration	0 -1 h	1 - 2 h	0 -1 h	1 - 2 h	0 -1 h	0 -1 h	
Temp range (°C)	147.3 - 97.6 °C	93.7 - 73.9 °C	131.9 - 89.9 °C	87.5 - 68.5 °C	146.7 - 93.4 °C	NA	
Phe	**54**	**10**	**25**	**7.2**	**24**	<LOR	0.38
Ant	**19**	**3.2**	**7.6**	**2.1**	**7.6**	<LOR	0.093
Flu	**9.5**	**4.0**	**2.7**	**1.0**	**17**	<LOR	0.23
Pyr	**7.9**	**3.0**	**1.8**	**0.67**	**15**	<LOR	0.17
BaA	**0.50**	**0.16**	**0.100**	**0.068**	**0.23**	<LOR	0.0010
Chr	**0.32**	**0.10**	**0.059**	**0.041**	**0.14**	<LOR	0.0011
BbF	**0.0068**	**0.0027**	**0.0017**	**0.0010**	**0.014**	<LOR	0.00084
BkF	**0.0018**	<LOR	<LOR	<LOR	**0.0049**	<LOR	0.0012
BeP	**0.0026**	<LOR	<LOR	<LOR	**0.0066**	<LOR	0.00098
BaP	**0.0021**	<LOR	<LOR	<LOR	**0.0067**	<LOR	0.00082
I123cdP	<LOR	<LOR	<LOR	<LOR	**0.0015**	<LOR	0.00022
DahA	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	0.00010
BghiP	<LOR	<LOR	<LOR	<LOR	**0.0012**	<LOR	0.00011
$\sum_{13}$ PAHs	**92**	**20**	**37**	**11**	**64**		

Exposure compared to legal limit

At the moment, there is NO legal limit for occupational exposure to asphalt fumes in Australia and anywhere else. Therefore, it is not feasible to conduct the comparison.



Polynuclear Aromatic Hydrocarbons (PAHs) **and** **Polycyclic Aromatic Compounds (PACs)**	PACs refer to a set of cyclic organic compounds that includes PAHs and also includes compounds that have sulfur, nitrogen, or oxygen in the ring structure and alkyl substituted cyclics. Hundreds of PACs with varying degrees of alkyl substitutions are typically associated with asphalt materials. PAHs have received considerable attention since some have been shown to be carcinogenic in experimental animals.[1] PACs were sampled using a new analytical method that included a PAC_{370} group (2–3 ring compounds, many of which have irritative effects) and a PAC_{400} group (4–7 ring compounds, some of which are carcinogenic).[2] It is not currently possible to definitively distinguish between these two PAC groups analytically; however, using these two different emission wavelengths (370 nanometer [nm] and 400 nm) allows the detector to be more sensitive to PACs based on ring number. Also see Appendix A.	None established for PAHs and PACs as a class.

Potential health impact

The measured levels of exposure to PM and most of VOCs except benzene to paving workers in this study are lower than the corresponding occupational limits. There would be no extra risk of adverse health impact in addition to the normal occupational risk.

In the case of benzene, the concentrations emitted from CRM mixes could be higher than the exposure limit proposed by American institutions. If the source of benzene can be traced, it should be considered to be mitigated/replaced to reduce relevant risk. It should be noted that the violation of threshold limit is probably the worst case scenario when we assume no dilution condition, which is not realistic in the field.

In the case where no difference in emissions observed between CRM and standard materials it would mean that the risk of exposure to air pollutants are not significantly different between the two materials.

It should be noted that the workers should follow their health and safety requirements concerning protective gear to minimise the risk of exposure.